

APPLICATION FOR AMENDMENT

TO

SOURCE MATERIAL LICENSE  
NO. SUA-551, DOCKET NO. 40-6659

FOR THE PURPOSE OF

MODIFYING THE PRESENT

PETROTOMICS COMPANY TAILINGS DAM

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## INTRODUCTION

The intent of this application for an amendment to Source Material License No. SUA-551 Docket No. 40-6659 is to obtain permission to modify the present dam to facilitate disposal of wastes from the Petrotomics Mill during operation under the forementioned license.

The scope of this application is kept to a minimum in time, manpower, and costs because in the future, another method or location for tailings disposal may be introduced or required.

The information provided in this application follows Regulatory Guide<sup>1</sup> procedures and has been derived from past licenses, publications, investigative soils tests, neighboring property (Utah International) analyses, texts on the subject, and private communication with personnel at the job site.

The office of Inspection and Enforcement, NRC, Arlington, Texas has periodically inspected the Petrotomics Company facilities since its inception, and has found either no items of non-compliances or relatively few non-compliances which were satisfactorily corrected.

Copies of the compliance proceedings are on file at the Petrotomics operation, as well as with the NRC.

1. Several Regulatory Guides were used - see references.

## PART I - GENERAL SUMMARY FOR EXISTING TAILINGS DAM

### A. SITE INFORMATION

1. Geology
2. Topography
3. Hydrology
  - a. General Hydrology of the Area
  - b. Domestic Water Use
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4. Proximity of Wells, Streams, and Springs
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6. Construction Data for Existing Dam
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### B. TYPE OF WASTE MATERIALS IMPOUNDED

1. Solid Waste
2. Liquid Waste
3. Concomitant Material

### C. SEEPAGE CONTROL

### D. MONITORING OF EXISTING DAM EMBANKMENT



## A. SITE INFORMATION

### 1. Geology

The Eocene Wind River formation underlies the tailings dam and pond area. It is about 350 feet thick in this area and is represented largely by sandstone and shales resulting from deposition from an aggrading, meandering stream environment. Eight generally correlatable rock units have been recognized in the Petrotomics mining areas east of the tailings area. A generalized stratigraphic section (Figure 4) shows these units. The cross section (Figure 5) through the tailings area includes the lower portion of these units. The thick basal sand unit is the Little Medicine Bow sand, with consecutive overlying units terminating with the Upper Ring Tail Shale. Locally discontinuous, thin (usually  $\frac{1}{2}$  to 2 feet thick) cemented, limey sandstone beds occur in the sandstone units. These are shown on Figure 5. The Little Medicine Bow sand is the principal aquifer in this area and is the source of mine and mill water for the Petrotomics operations.

### 2. Topography

The general relief of the area in which the tailings have been retained for fourteen and one-half years (April 5, 1962 to present) is low, ranging in elevation from 7000 feet to 7125 feet above sea level. From the topographic map in Part IV of this proposal, approximately 75 feet vertical in 2600 feet horizontal is the typical relief ( $= 3\% = -1^{\circ}39'$ ).

### 3. Hydrology

#### a. General Hydrology of the Area

The ground water tests by the USGS<sup>1</sup> have determined that the main water table slopes southward at gradients of 20-30 feet per mile, and at rates up to 1000 meinzer units.

The depth to the water table in the area of the Petrotomics Company mill site and tailings dam is 150+ feet.<sup>1</sup>

#### b. Domestic Water Use

There are two wells to the principal aquifer within a two-mile radius of the Petrotomics Company tailings dam as shown on Map 8 in Part IV. The first (known internally as No. 1) is 375 feet deep, cased to 332 feet with perforated section from 332 feet to 352 feet, with the pump setting at 348 feet.

The second, known as KGS #3 and drilled under Wyoming Permit No. U. W. 31943, was drilled to 480 feet with the pump setting at 390 feet. This well is for the mine maintenance shop and is one-half mile in a general northerly direction from the tailings dam.

1. E. N. Harshman, USGS Professional Paper 745, Geology and Uranium Deposits, Shirley Basin Area, Wyoming; pp 37-39.

### c. Domestic Water for the Mill Site

The water from Well No. 1 goes into the fresh water pond (stocked with trout) shown on the topographic map (see Part IV). Water samples are taken from this pond and analyzed for natural uranium, radium 226, and thorium 230. From the pond, the water is pumped to the water tower for mill make-up water and domestic use. The portion of water for potable use is treated by a standard chlorination treatment process.

Specific sampling procedures and analysis are documented in the Source Material License No. SUA-551, Docket No. 40-6659, issued May 5, 1976, and therefore are not discussed in detail in this proposed amendment.

### 4. Proximity of Wells, Streams, and Springs

The fresh water wells are discussed in the preceding section on hydrology, under Domestic Water Use. There are no known springs in the area. The downstream distance from the tailings dam via a small, usually dry, uninhabited draw (Sand Creek) to the Little Medicine Bow River is approximately 5 miles.<sup>1</sup> Sand Creek is an ephemeral stream carrying snow run-off water in the spring, and occasional run-off from spring and summer rains. It is dry most of the year.

The only non-domestic wells in the two-mile radius of the tailings dam are the three monitoring wells<sup>2</sup> for testing for possible radioactive leakage into the perched water table.

### 5. General Site Conditions

#### a. Meteorological Conditions

The general climate for the Shirley Basin area is windy and arid. Average annual precipitation is about 11 inches.<sup>3,4</sup>

The prevailing wind is out of the southwest. The 14+ years experience at the Petrotomics tailings dam has shown no problems with wave action on the face of the dam. Any wave action from the prevailing winds is directed toward the impounded tailings and not the dam.

1. Drainage Map, Part IV.
2. Seepage Control, Part I-C.
3. Dames & Moore Job No. 0961-067-06, April 15, 1975 (see references).
4. Climatological data, Part III.

b. Probable Maximum Precipitation - PMP  
Probable Maximum Flood - PMF

The proposed raising of the dam will offer a minimum freeboard distance of 15 feet.<sup>1</sup> After direct comparison with the precipitation and storm run-off analyses by Dames & Moore<sup>2</sup> for the tailings dam approximately 4 miles north of this designated area under consideration, it is not felt necessary to do the PMP and PMF analyses in the text of this application. There are no streams draining into the subject tailings pond, and run-off currently is and will be channeled away via drainage ditches and dikes.<sup>4</sup>

c. Seismic Coefficient

The seismic coefficient is 0.05 for the Shirley Basin area as determined from the S. T. Algermissen chart on page 22 of the Engineer Manual 1110-2-1902. Seismic history in detail may be found in the Dames & Moore Job No. 0961-067-06.<sup>2</sup>

6. Construction Data for Existing Dam

Note: The data for this section have been gathered from old records, correspondences, and Source Material License No. SUA-551. For any discrepancies between these data and the new data developed for this application, the new data are considered to be more reliable due to experience factor and more recent test data.

a. Foundation Material

Chen and Associates, Inc.<sup>3</sup>, consulting soils engineers, have determined by drilling (see Part III) that the foundation material is principally claystone, overlain by sandstone in varying thicknesses.

b. Embankment Material

The embankment material used was referred to as a "bentonitic clay and sand mixture," impervious as placed and compacted in thin layers by Euclid T. S. 24 Scrapers.<sup>4</sup>

1. Cross-section of proposed dam - Part IV.
2. Dames & Moore Job No. 0961-067-06, April 15, 1975 (see references).
3. Chen & Associates, Inc. - Part III.
4. Mr. G. T. Beardshear, Part III.

## B. TYPE OF WASTE MATERIALS IMPOUNDED

### 1. Solid Waste

The waste material is mill tailings in the form of a sand slurry at 35% solids. These tailings contain small amounts of natural uranium, radium 226, and thorium 230.

### 2. Liquid Waste

The liquid effluent associated with the tailings and impounded directly behind the dam is acidic ( $H_2SO_4$ ) and contains in solution natural uranium, radium 226, and thorium 230. The pH of this liquid is between 2.0 and 3.5.

### 3. Concomitant Materials

Domestic sewage effluent is also discharged into the tailings impoundment area following passage through septic tanks. No other material is discharged into the tailings impoundment area.

## C. SEEPAGE CONTROL

Some seepage occurs from the dam and is collected and pumped back to the tailings system when and as required.

Monitoring of the perched water tables by three monitoring wells substantiates the effectiveness of successful collection of seepage throughout the life of the tailings dam.

In addition to the three monitoring wells, the No. 1 well water pumped into the fresh water pond<sup>1</sup> as discussed earlier is sampled and tested for radioactive elements.

## D. MONITORING OF EXISTING DAM EMBANKMENT

The tailings dam has been continuously monitored over the life of the mill operation. There has never been a release of impounded materials which testifies to the integrity of the dam structure.

### 1. Topographic Map, Part IV.

PART II - PROPOSED DESIGN AND CONSTRUCTION SPECIFICATIONS  
FOR MODIFYING THE PRESENT DAM

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INTRODUCTION TO PART II

SUMMARY OF PART II

A. EMBANKMENT DESIGN DIMENSIONS

B. DESIGN CRITERIA

1. General Site Conditions
2. Foundation Conditions
3. Embankment Material
4. Seepage Control

C. STABILITY ANALYSIS

D. CONSTRUCTION SPECIFICATIONS

1. Bonding Between Present Dam and New Material
2. Compaction Procedures

E. MAINTENANCE AND INSPECTION AFTER CONSTRUCTION

## PART II

### INTRODUCTION

The desired and necessary result of this application and its pending approval is to design an embankment addition within reasonable, economic boundaries that will permit the start-up of the Petrotomics Company milling operation by late 1977. Therefore, the proved integrity and reliability of the established dam is of prime consideration in the design and analysis to follow. However, with the increasing concern for accountabilities and responsibilities involved in uranium processing and the related daughter products disposal and retention, a soils consultant<sup>1</sup> was contracted to perform selected soils analyses and determinations to assure the integrity of the proposed addition to the dam. Other dam design and engineering are performed by GOC engineering and operating personnel.

### SUMMARY

The investigations and analyses show that the most feasible, safe dam is a homogeneous earthfill dam incorporating the present dam as it now stands, and raising and extending the entire structure of the dam to the desired elevation.

The dimensions of the dam are given in the following sections of this application; also the specifications and considerations as suggested and outlined by appropriate NRC personnel and Regulatory Guide 1.70 as necessary for evaluation of this proposed increase in tailings storage capacity are discussed.

1. Chen & Associates, Inc., Consulting Soil Engineers.



## A. EMBANKMENT DESIGN DIMENSIONS

The proposed homogeneous dam design<sup>1</sup> incorporates the following maximum dimensions:

1. Upstream and downstream slopes at 2:1.
2. Crest width = 120 feet (includes 10 feet on either side for safety berm).
3. Height of final crest = 7100 feet (70 feet above original ground, 35 feet above existing dam).
4. Water pool to be at 7085.
5. Freeboard = 15 feet.
6. Width at base = 400 feet at the widest point, including present dam.

## B. DESIGN CRITERIA

### 1. General Site Conditions

This category is the same for the proposed modification as for the present dam. (See Part I)

### 2. Foundation Conditions

The analysis by Chen et al confirms the presence of pervious sandstone layers above the impervious claystone. The present dam is keyed and stable, but not 100% impermeable.<sup>3</sup>

### 3. Embankment

The overburden material as removed from the open pit mine has been determined by Chen et al to be of two types by the Unified Soils Classification:

- a. Very sandy clay CL-CH;
- b. Claystone CH.

Both of these soils placed at optimum moisture content and compacted to a 100% standard Proctor density are suitable as embankment materials in an homogeneous earthfill dam.<sup>2</sup>

1. Cross-section, Part IV.
2. Chen & Associates, Inc.; personal communication.
3. Mr. G. T. Beardshear, Part III.

#### 4. Seepage Control

- a. The base of the dam is generally on material of low permeability.
- b. The dam is keyed.<sup>1</sup>
- c. Seepage is collected and pumped back into the system.<sup>2</sup>
- d. Slimes from impounded tailings will continue to aid the sealing of the bottom of the impoundment area.<sup>3</sup>

#### C. STABILITY ANALYSES

1. The stability analyses are in conformance with those described in the Corps of Engineers Manual EM 1110-2-1902. The approach followed was to apply the most conservative foundation data at the maximum height section of the dam.

The stability analyses were performed by Chen and Associates, Inc. and the results are included with the data in Part III of this application.

2. The maximum settlement is estimated to be 27 inches for that portion of the dam of 70 feet in height, and 15-16 inches in the area of 40 feet. It is anticipated that 90% of the settlement will occur during construction, with the remainder requiring many years because of the large soil mass and its being placed at optimum moisture content.

#### D. CONSTRUCTION SPECIFICATIONS

##### 1. Bonding Between Existing Dam and New Embankment

The new embankment will be bonded to the existing dam by scarifying the existing dam crest and the downstream slope 18" deep, and then recompact the disturbed portion at optimum moisture content as the new embankment is brought up during construction.

##### 2. Compaction Procedures

The placement and compaction procedures will be developed at the onset of the project such that 100% standard Proctor density is achieved.<sup>4</sup> This procedure will provide:

1. Mr. G. T. Beardshear, Part III.
2. Seepage Control, Part I.
3. Sears et al, page 130 (see references).
4. For density testing, a soils consultant shall be retained until Getty Oil Co. Engineers have achieved this capability.



- a. Number of passes required by given equipment;
- b. Type of equipment;
- c. Moisture content;
- d. Lift thickness;
- e. Orientation and training of engineers and supervisory personnel on the job site. Note: For density testing, a soils consultant shall be retained until Getty Oil Company engineers have achieved this capability.

E. MAINTENANCE AND INSPECTION AFTER CONSTRUCTION

The inspection of the dam will be as specified in the Source Material License.

Additional monitoring of movement/settlement will be by quarterly checks made with a Hewlett-Packard 3810A Total Station (Distance Meter) accurate to 0.016 feet within 1000 feet.

The dam will be readily accessible for possible maintenance via the wide crest used as a haul road and the near proximity of the pit overburden removal operation.

PART III - DATA/SOURCES

A. GENERAL INFORMATION DOCUMENTATION

B. SOILS ANALYSIS DATA BY CONSULTANT

C. STABILITY ANALYSIS DATA

D. LIST OF REFERENCES

PART III - DATA/SOURCES

- A. GENERAL INFORMATION DOCUMENTATION
- B. SOILS ANALYSIS DATA BY CONSULTANT
- C. STABILITY ANALYSIS DATA
- D. LIST OF REFERENCES

A. GENERAL INFORMATION DOCUMENTATION

1. Climatological Data for Casper, Wyoming (4 pages)
2. Evaporation Rate Data for Pathfinder Reservoir as determined by the Bureau of Reclamation. (1 page)
3. Correspondence Between Mr. G. T. Beardshear and Mr. N. A. Grant, 1-12-62 (6 pages, 4 pages designated "Item 5").

Note: Referenced Cross-Section is in Part IV.

4. Mr. R. D. Odell to Mr. R. O. Cypert, Jr., 3-30-62 Memorandum with data for RTH wells. (1 page)

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REVIEW OF TRACER SURVEYS

by

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For presentation at the  
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(The statements and opinions expressed herein are those of the authors and should not be construed as an official action or opinion of the Institute.)

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INTRODUCTION

Gamma ray detectors for use in oil wells were developed in the late 1930's. Since then radioactive isotopes have been applied in various manners in the attempt to chart fluid movements within the well bore. A variety of materials, tools and techniques have been used in tracer logging and most of the logging tools were satisfactory for their specific purpose. However, failure in understanding the limitations of and the improper use of isotopes has resulted in a great volume of erroneous and misleading information. These errors have implanted a deep mistrust of all "tracer" logging operations in the minds of many people.

The emphasis on secondary recovery operations, of which water injection constitutes the major portion, has increased the need and demand for valid tracer logging information. This validity is a direct function of the knowledge and application of isotopes and detector tools. Therefore, every individual concerned with obtaining valid data should thoroughly analyze the problems and become as familiar as possible with radioactive materials and detection tools before attempting to use them.

First, who can run these surveys? Many service companies, both large and small, offer these services in many and varied forms. The personnel doing the logging and handling of the isotopes must be operating under a current and valid Atomic Energy Commission license. This means the logging operator must have been schooled and tested in the basic concepts of nuclear and atomic structure, types of radioactive decay, reaction of matter, health physics, radiation tolerances, preventive safeguards, and first aid for overexposure. In addition to Federal regulations an operator must comply with State regulations. Failure to comply with these regulations can result in legal action and possible loss of life.

In addition to the preceding, a logging engineer must have a thorough knowledge of well completion, well equipment, production and injection procedures and how these affect the logging operations. Otherwise, the data obtained will be just so much blue ink on white paper. In order to obtain a meaningful log, it is necessary for the logging engineer to be able to calculate and interpret on the job.

RADIOACTIVE MATERIAL

Isotopes to be used for surveys should be chosen with consideration as to their properties and limitations. There is no "universal" tracer material that can be used in all instances. For example I-131 in benzene or xylene carrier will not disperse in water. Potassium iodide I-131 in water solution will not perform properly in oil. The conditions under which the isotope is to be used should be considered and made known to the service company when the job is planned. Some factors to be considered are temperature, type of fluid in the well, acids, and various oxidizing agents.

The yardstick for computing the length of time the isotope will continue to emit radiation of measurable intensity is its "half life". For example, I-192 has a half life of 74 days which means that the radiation intensity decreases by 50 percent every 74 days. Wells in which one expects to run a series of surveys should not be subjected to materials of long life. This is particularly true of particle type or plate out materials. Radiation from these isotopes interferes with future survey operations for the life of the material. The following tabulation describes the more commonly used isotopes.

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\*Cardinal Chemical, Inc., Midland, Texas

+Cardinal Surveys Co., Midland, Texas

# INSOLUBLES

ISOTOPE	FORM	PROPERTIES	REMARKS
Cobalt Co-60	Solid-spherical particles 25 - 1000 microns in diameter	5.3 years half life. Temperature tolerance 900° F. Gamma emitter oxidizes to radioactive sulphide residue. Half life long enough to interfere with radioactivity logging operations for 21 to 26 years.	Can be mixed with cement or propping agents - not recommended for oil well tracers.
Cobalt Co-60	Particle in nearly neutral Aqueous Collodial sus- pension		For placement in injection streams by surface place- ment or dump bailer for "plate out" tracer, lost circulation, filter cake evaluation, etc.
Cobalt Co-60	Solid, Nodule or button		Attached to downhole tool- tracer material produced by ionization downhole. Used in velocity deter- mination
Silver Ag-110	Particles in nearly neutral Aqueous Collodial suspension	270 day half life. Temperature tolerance 950° F. High intensity gamma emitter. Oxidizes to radioactive sulphides. Interferes with radioactivity logging operations for 3 to 4 years.	For placement in injection stream by surface place- ment or dump bailer for plate out operations. Fine particle size 5 - 20 microns allows some intrusion into more per- meable zones.
Iridium Ir-192	Varnish baked onto Ottawa Sand of selected mesh size	74 day half life. Temperature tolerance of 2454° F. Medium gamma emitter. Use in oil or water. No interference with logging after one year.	For placement in sand or propping agents for frac evaluation. Can be handled with reasonable safety.



INSOLUBLES (Continued)

ISOTOPE	FORM	PROPERTIES	REMARKS
Iridium I-192	Impregnated resin. Density 1.1. Mesh sizes 16-400	74 day half life. Temperature tolerance of 212° F. in brine carrier. Unstable in oil at 212° F.	Surface placement or downhole dump bailer for "plate out" operations, lost circulation, filter cake evaluation, etc.
Iodine I-131	Impregnated resin. Density 1.1. Mesh sizes 16-400	8.1 day half life. Temperature tolerance of 212° F. in brine. Carrier is unstable in oil at 212° F. After 45 days no logging interference.	Surface placement or downhole dump bailer for "plate out" operations, lost circulation, filter cake evaluations, etc.
Bromine Br-82	Gas tracer containing Methyl Bromide ( $\text{CH}_3\text{Br}$ ) in pressurized cylinder	<u>GAS TRACERS</u> 35.9 hours half life. High energy gamma emitter. Boiling point is 40° F. at 150 psi. No interference with future logging operations.	For surface placement or special downhole carrier. Dangerous to handle on surface without proper equipment.
Iodine I-131	Liquid Ethyl Iodide ( $\text{C}_2\text{H}_5\text{I}$ ) in sealed glass ampules	8.1 day half life. Medium energy gamma emitter. Specific gravity of carrier 1.93. Boiling point is 163° F.	For surface placement or special downhole carrier.
Iodine I-131	Liquid Methyl Iodide ( $\text{CH}_3\text{I}$ ) in sealed glass ampules.	Specific gravity of carrier 2.279, boiling point 108.5° F.	Low boiling point gas tracer for use as above.



# OIL SOLUBLES

ISOTOPE	FORM	PROPERTIES	REMARKS
Cobalt Co-60	Cobalt Naphtenate in Benzene or Xylene carrier	5.3 years half life. High energy emitter. Completely oil soluble. Insoluble in water. Stable to 300° F.	Surface placement down-hole, dump bailer or ejector. "Pump-in" tracers on production wells. Erratic results if water is present in well fluids.
Antimony Sb-124	Radioantimony in benzene carrier	60 day half life. Medium energy gamma emitter. Completely oil soluble. Insoluble in water. Stable to 475° F.	Surface placement down-hole dump bailer or ejector. Pump in oil tracer for high temperature wells or where extreme chemical stability is needed, erratic results if water present in well fluids.
Iridium I-192	Radioactive iridium in benzene or xylene carrier	74 day half life. Medium energy gamma emitter. Oil soluble. Insoluble in water. Stabilized for organic solutions.	Surface placement or downhole dump bailer or ejector pump in oil tracer. Erratic results if water present in well fluids.
Iodine I-131	Solution of Elemental Iodine in Benzene	8.1 day half life. Medium energy gamma emitter. Moderately stable in oil to 250° F. Oxidizes at temperatures above 250° F. Insoluble in water.	Surface placement or downhole dump or ejector. Oil tracers where short half life is desired. Erratic results if oxidized or if water present in well fluids.

OIL SOLUBLES (Continued)

ISOTOPE	FORM	PROPERTIES	REMARKS
Iodine I-131	Liquid - pure Iodo-Benzene $C_6H_5I$	8.1 day half life. Medium energy gamma emitter. Specific gravity is 1.8. Boiling point is 400° F. Oil soluble. Insoluble in water.	Surface placement, down-hole dump or ejector. Oil tracer. Very stable at high temperatures or in organic solutions. Erratic results if water present in well fluids.
Iridium Ir-192	Iridium in water solution	<u>WATER SOLUBLES</u> 74 day half life. Medium energy gamma emitter. Stabilized and miscible in water and acid. Insoluble in oil. No interference with logging operations after one year.	Surface placement, down hole dump or ejector. Water flood injection profiles, channel location, etc.
Iodine I-131	Radioiodine in water solution	8.1 day half life. Medium energy emitter. Miscible in water. Insoluble in oil. Available in three forms. Stabilized to prevent oxidation in air, water or acid.	Surface placement, down-hole dump or ejector for water flood profiles and tracers. Cement top and squeeze locator tag. Indicate when ordering to obtain correct solution.

### DETECTORS

The detector is one of the basic factors to be considered when planning tracer work. Since downhole conditions are variable, the effectiveness of the tools will also vary.

The two most common detectors in use today are the geiger mueller tube and the scintillation crystal. The scintillation detector crystal is usually sodium iodide and is coupled optically with a light sensitive amplifier tube or photo-multiplier. Gamma rays striking the crystal will produce small light flashes that are sensed and amplified by the photo-multiplier. It has excellent efficiency (approximately 85 percent) in the detection of small amounts of radiation and produces a good quality correlation log for depth control and identification. The photo-multiplier is heat sensitive and becomes inoperative at about 185 degrees Fahrenheit and requires careful handling to avoid shock damage. The scintillation detector used in small through-tubing tools cannot be refrigerated as is possible in large diameter casing type tools. This 185 degrees Fahrenheit temperature limit is not a problem in most water injection wells. Also, it does not become a problem in producing wells until extreme depths are reached in the Permian Basin.

The geiger mueller tube which is used in most through-tubing or tracer tools is more rugged. It is heat resistant to 350 degrees Fahrenheit but has a low resolution efficiency of ten to twelve percent. This means that it produces poor quality correlation logs. The efficiency can be improved in larger diameter tools by coupling or bundling tubes together. However, the size of through-tubing tools prohibits this. Therefore, if a quality correlation log is needed, it should not be attempted with the small diameter tracer tool with a geiger tube. Also, small amounts of activity or material some distance away from the bore hole can be completely missed with this tool. This is especially true if the fluid velocity is high, as it will be in a small channel.

### TOOL TYPES

Several types of through tubing tools are available for use in radioactive tracer work. Listed below are the three common types and their general uses.

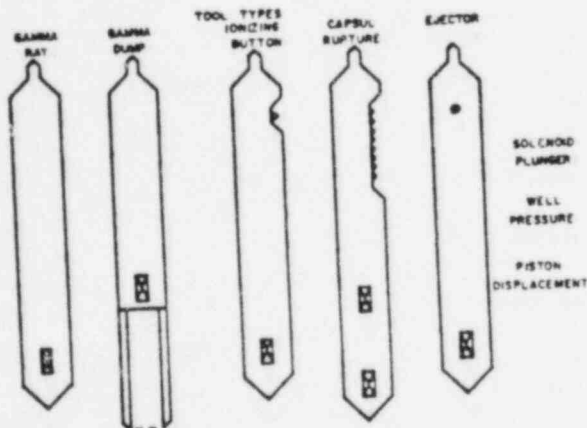


FIGURE No. 1

1. Standard Gamma Detector. This detector is used when radioactive material is introduced in the well at the surface. Logging runs are made to observe dispersal.

2. Gamma-Dump Bailer. Material is carried down hole in a dump bailer attached to the bottom of a gamma tool. The material is dumped by electrical means and after waiting, timed logging runs are made with the tool.

3. Velocity Measurements. Rate determinations are made at selected depths for injection profiles. Small slugs of radioactive material are released and the travel time over a known distance is recorded. The injection rate is then calculated. Several methods of introducing material into the fluid stream are available.

(a) Ionizing "button"

A cobalt "button" is attached to the tool above the detector. The "button" is ionized by an electrical current, thereby releasing some radioactive material into the fluid stream.

(b) Capsule rupture - single and double detector

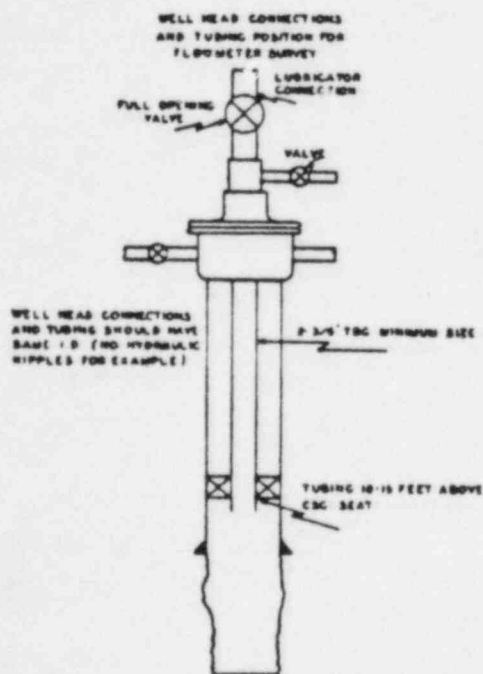
Several small ampules of radioactive material are positioned on the tool above the detector. These are ruptured at will by an electrical current and the material released into the well stream.

(c) Ejector cylinders - single and double detector

This type tool has a cylinder which can be filled with liquid radioactive material. This material can be ejected into the fluid stream by actuating an ejector.

There are three types of ejectors presently in use: (1) the solenoid plunger, (2) well pressure operated, and (3) positive piston displacement. All these types vary in the amount of fluid the cylinder will hold. They also vary in the amount of material that can be ejected at a single time. With some tools it is possible to make the ejections vary in strength and amount while it is fixed with others.

#### WELL EQUIPMENT



As with other survey work the well equipment must be considered. Injection profiles being the most common application, a typical injection well arrangement is shown in Figure 2. This ideal arrangement is satisfactory for all work except for the isotope interface survey which requires tubing to the bottom of the well and no packer. The well head should permit the tool to be run into the well without altering the injection rate or pressure in any manner. It is also very desirable to have the tubing and packer set high enough above the top perforation or casing seat so as to permit the location of at least two casing collars. In addition, locating a channel behind the casing is much more positive when working below the packer. Channel determination above a packer becomes very uncertain and confusing.

FIGURE No. 2

Prior to any injection profile survey the well head should be examined for hydraulic nipples, bent subs and other restrictions. If a full opening valve is not on the well head above the injection valve, one should be installed at least 24 hours prior to the survey. This will permit the logging operator to attach his lubricator and run the tool into the well without stopping injection.

The tubing must be open ended and free of restrictions. Also, in making velocity measurements with ejector tools the 100 percent rate measurement must not be made too close to the end of the tubing if any reasonable accuracy is to be expected as there is a considerable jetting effect and turbulence near the end of the tubing.

Some modification of the above equipment is permissible when using tracer materials while pumping into a producing well for channel detection. However, the swab valve on top of the well head is a desirable feature in case of trouble.

### STABILIZATION

Stabilization of injection is of the utmost importance in injection profile surveys and it cannot be overemphasized. Nothing should be done to the well to interrupt or alter the injection rate or pressure for at least 24 hours prior to running an injection profile survey. In most cases it is virtually impossible to detect unstable downhole injection with tracer tools.

To illustrate the point several examples of erratic downhole fluid behavior are shown. Erratic downhole conditions that have been observed during flowmeter surveys cannot be detected at the surface. Briefly, for those not familiar, the flowmeter makes positive volumetric fluid measurements downhole at any desired point and the direction of fluid movement through the tool is always known. This tool has been extremely valuable in interpreting tracer work and vice versa.

Erratic fluid behavior downhole can completely confuse the running and interpretation of a tracer log, but if one is aware of these possibilities, certain techniques can be employed to advantage.

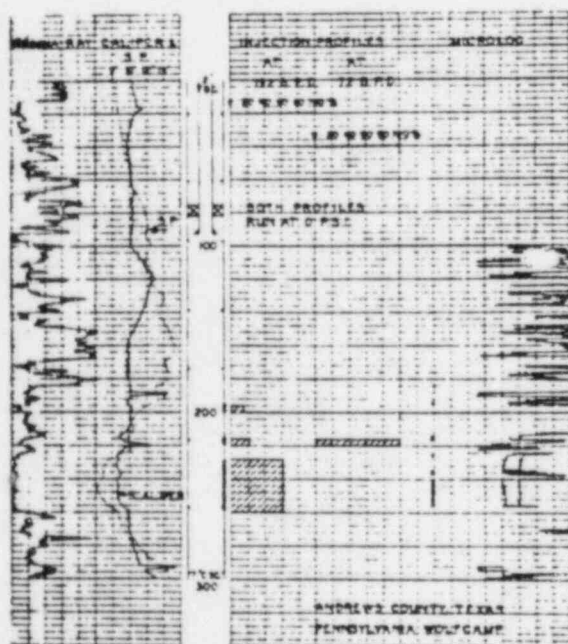


Figure No. 3 illustrates a change in profile as a result of a change in injection rate. The profile was made at 192 B.W.P.D. and zero injection pressure and water was found to be leaving the borehole in a good distribution pattern. The rate was reduced to 72 B.W.P.D. and zero injection pressure. This reduced rate profile showed the thin middle set of perforations to be taking 100 percent of the injection water. At the high rate (192 B.W.P.D.) the middle set of perforations was taking 21 percent of the fluid or 40 B.W.P.D. These perforations and the cement job were checked with a radioactive tracer and no communication was found.

FIGURE No. 3



Rate changes in this well during a tracer log would have affected the response of the tracer drastically, especially if a plate out type tracer were used and there was no opportunity to allow the well to clear up and a second survey to be run.

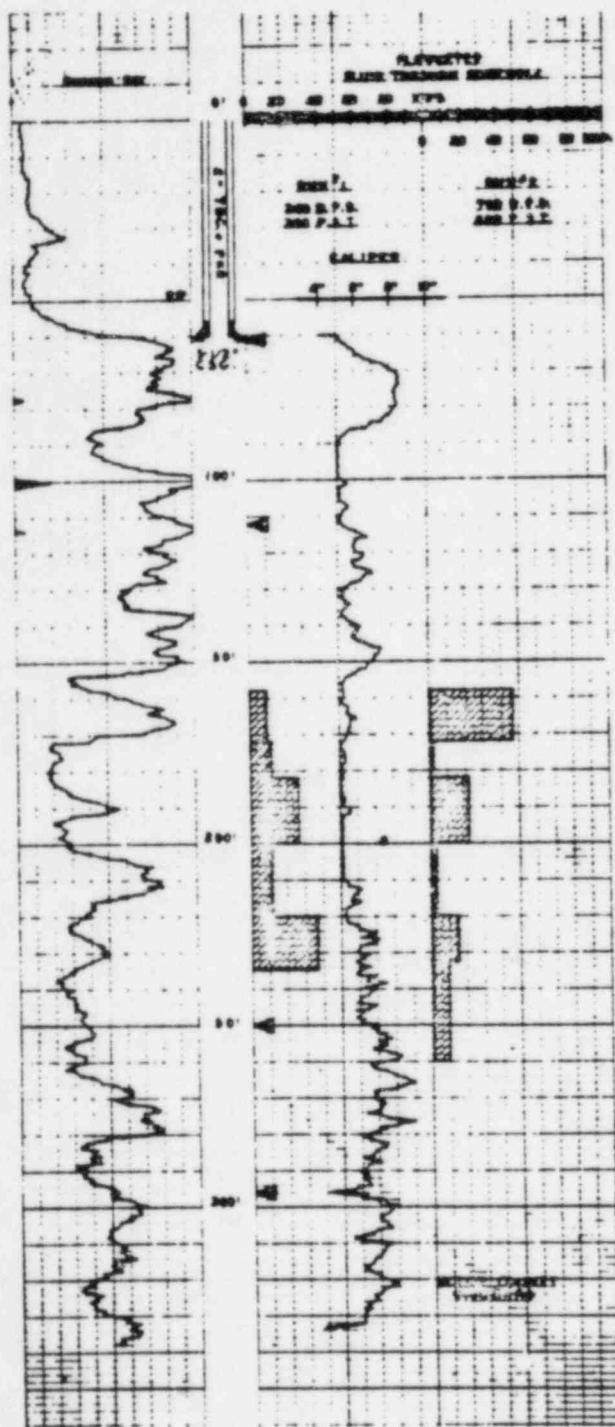


FIGURE No. 4

Figure No. 4 illustrates a change in profile by changing injection rate and pressure. The first profile was run at 340 B.W.P.D. and 300 psi injection pressure which yielded the profile on the left. The second profile was run at 785 B.W.P.D. and 400 psi. No appreciable change in profile was noted with the exception that the upper zone actually broke down and accepted 48 percent of the total injected fluid.

Figure No. 5. Injection on this well had been interrupted for about 12 hours. Two hours after injection was resumed all surface indications were that the well had stabilized. The survey indicated that all the injection fluid was entering the formation in the upper third portion of the zone. In the middle there was a back flow which divided as it entered the well, part of it moving up hole and into the zone directly above, and part moving down hole to re-enter the formation. The back flow zone was monitored for eight hours until all back flow ceased. The second profile was then obtained, and it was found that the middle section was still unstable as variations were still taking place. It is interesting to note that the injection pressure at all times was zero.

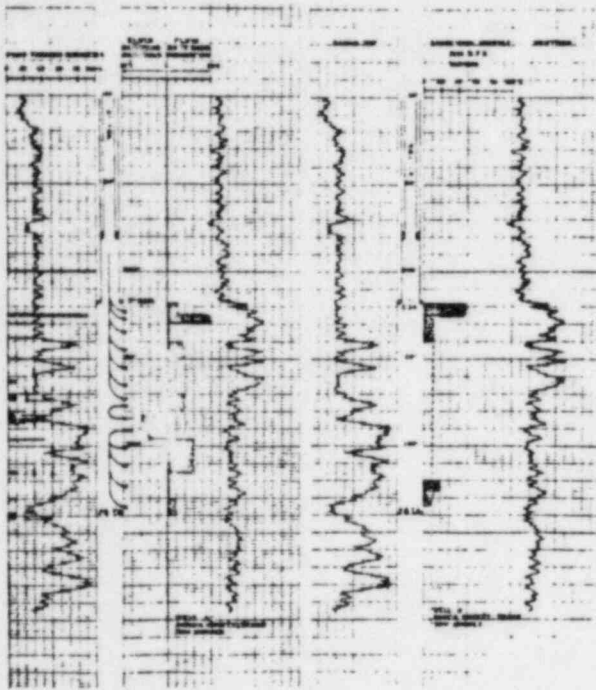


FIGURE No. 5

Many times during injection surveys the water plant will stop for 10 to 15 minutes. As a result zone swapping has occurred for two to three hours. A certain zone will be taking 10 percent of the fluid and another adjacent zone taking 40 percent, these zones will swap back and forth.

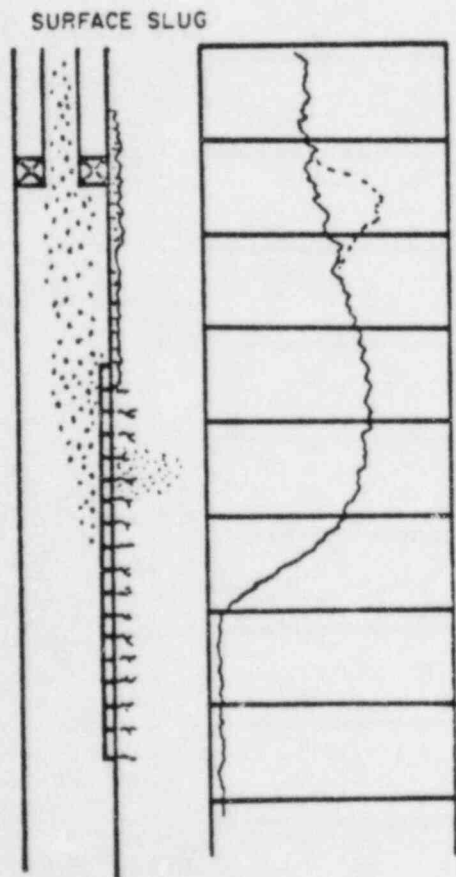


FIGURE No. 6

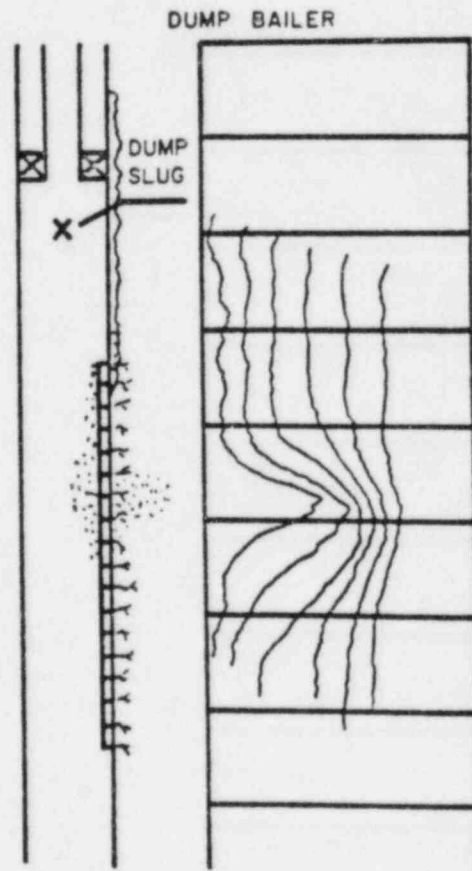


FIGURE No. 6-A

### LOGGING TECHNIQUES

The logging methods possible with the series of tools illustrated can yield a wealth of information if, as stated previously, the technique is used in the manner intended and the shortcomings and pitfalls of the methods are realized.

#### Surface Injected Slug - Figure No. 6

This is the first and oldest method of tracer logging. An insoluble material is injected into the stream, pumped downhole into the zone and logged. Interpretation is based on accumulation of material over the zone, with the "hottest" areas supposedly the zone of greatest fluid acceptance. This method is very time consuming at most normal injection rates and the slug scatters badly, with as much as 200 or 300 feet of bore hole being occupied with contaminated fluid, thus making subsequent runs for interpretations impossible. Since the slug is usually pumped and stopped intermittently, little or no true injection pattern is obtainable. Particles depositing in collars, depressions, packers, turbulence traps and channeling from perforations further confuse the interpretation. Soluble isotopes used in this manner also scatter badly, masking the true picture of fluid movement outside casing with that of the contaminated fluid inside. The one advantage of having enough material in the hole to observe profiling in subsequent runs is almost completely negated by the disadvantages. This method is practically unused today.

#### Gamma-Dump Bailer - Figure No. 6-A

This operation is performed in much the same manner as the surface slug injection with the exception that the material is carried into the well and dumped just above the zone by a dump bailer, reducing both the time consumed in pumping the slug downhole and reducing the tendency of it to scatter. Insolubles still accumulate in much the same manner as with a surface slug. The dump bailer attached to the bottom of the tool tends to scatter the particles badly on successive trips through the slug.

Soluble materials can be used by this method with some degree of success if intermittent pumping is avoided and the log is run under usual injection conditions. The controlled interval method of velocity determination can be used with this type placement if successive runs are made with enough material for observing profiling while following slug downhole. The time delay in the first stages of the operation usually results in loss of indication of channeling up from perforations or casing seat, if any exists. Any delay or waiting time can also result in dissipation of radioactive material in the zone of greatest fluid acceptance, leaving only the areas of least injection apparent on the log.

Several methods of velocity determinations are used to plot injection profiles. A brief examination of these follows:



# Controlled Interval Log - Figure No. 7

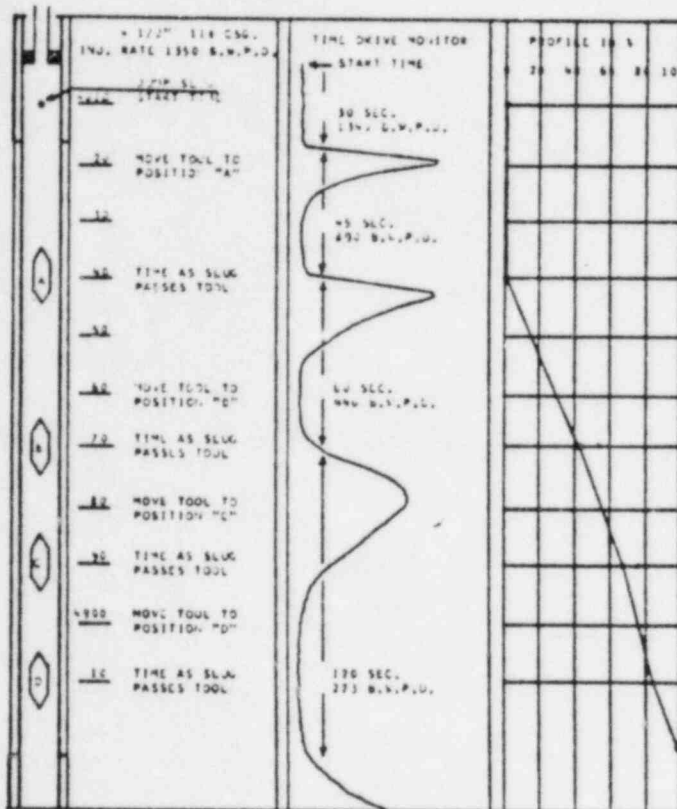


FIGURE No. 7

In this method the down hole travel time of a slug is recorded over pre-determined and uniform intervals. Soluble material is released some distance above the perforations and the gamma tool is then lowered to a point below the slug and held stationary. The arrival of the slug is recorded on time drive. Next, the tool is rapidly lowered to another point downhole, held stationary and the slug arrival recorded. This process is repeated until the formation has been surveyed. In cased holes these traverse times over uniform distances can be plotted as percentages of injection rates. In open holes which have been calipered, volumetric calculations over each zone must be made.

The accuracy of this method is good in the medium velocity ranges. However, at high velocity rates the tool cannot be lowered and observations made over short intervals due to the time available. Therefore, at high rates the inspection zones are of necessity over long intervals, which is not desirable. At low velocities the exact time of slug arrival at the detector is difficult to determine. Generally this occurs in the last 10 percent to 20 percent of the total injection volume. Since no regular logging runs are made through the formation considerable information is by-passed and thin or narrow zones of injection will be missed. Also communication between sets of perforations and channels can be missed.

## Controlled Time Log - Figure No. 8

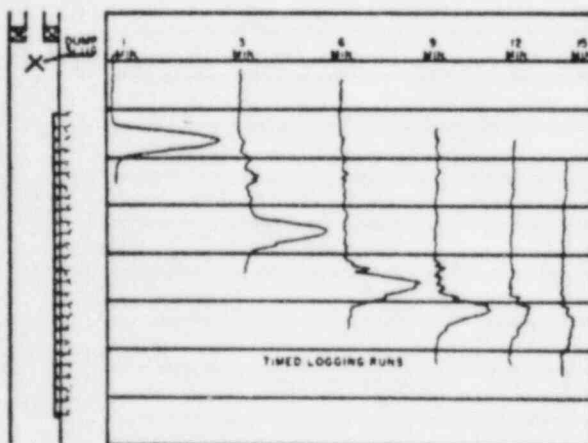


FIGURE No. 8

This method is essentially the same as the previous method; however, in this method the time is held constant and the slug travel distance permitted to vary. A slug is released some distance above the formation. The time of release and position is recorded. Then at regular and frequent

time intervals the gamma tool is pulled through the slug. In this manner the slug is logged as it moves down hole. By plotting these runs side by side and in proper chronological order considerable information is obtained. Volumetric calculations can be made and channeling or communication detected; however, the rate or volumetric calculations will not be too accurate. The material used in this method should be soluble, and the open hole must have been calipered.

#### Velocity Shot - Figure No. 9

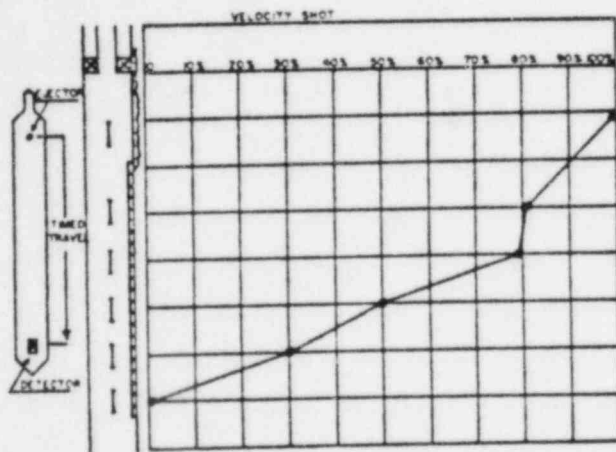


FIGURE No. 9

Rate determination is made by positioning the ejector tool at predetermined depths, ejecting material, timing it over a known tool length and then calculating volume.

This technique, when properly utilized, will yield accurate rate measurements in the high and medium injection rates. Generally during an injection survey the last 10 to 20 percent of the fluid remaining cannot be accurately broken down into small increments. This is due to the slow movement of the material making it impossible to determine just when the slug arrives at the detector.

The time recordings should not be made with a stop watch and count rate meter. This type of recording has several considerable sources of error that should be apparent. The recording should be done with a calibrated time drive on logging paper. This technique furnishes a record of each time measurement and permits one to analyze the accuracy of the measurements. This method of fluid volume measurement can give results over short intervals that are reasonably accurate. Inside casing the accuracy can be in the order of 95 percent. To do this the size and weight of the casing must be known. In open holes the accuracy can be in the order of 80 percent to 90 percent. In open holes there must be a recent and good caliper log. Obviously this accuracy cannot be obtained in ragged open holes.

The position of the tool down hole when making velocity shots is important. The 100 percent measurement will be abnormal if it is attempted within a few feet of the end of the tubing. Since the position of the tool within the bore hole greatly affects the accuracy, numerous attempts have been made to overcome these problems. Some tools have the ejector ports (3) spaced 120 degrees apart. This is to eject material into all portions of the fluid stream. Another ejector tool has two detectors and the slug is timed between them. This eliminates the problem of dispersal. The slug is well formed by the time it hits the first detector, and this arrangement results in good accuracy for straight velocity measurements.

Velocity measurements using ejector type tools have become a very important phase of tracer work. However, when used alone they do not present a complete and valid picture of fluid movement down hole. Also, velocity shots should be substantiated by other means during the survey. When velocity measurements are supported by logging runs through the tracer slug, calipers and primary logs, then and only then can a complete and valid analysis be made.

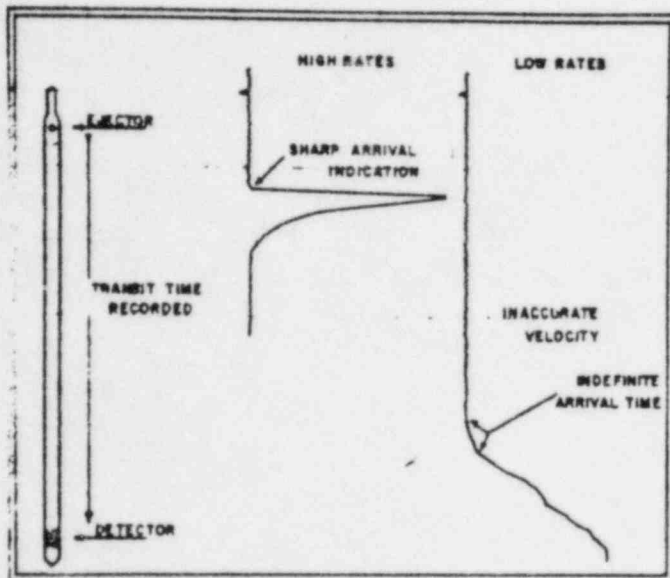


FIGURE No. 10

#### RECOMMENDED SURVEY METHODS

A number of logging techniques commonly used have been discussed. Each of these has serious shortcomings and when used alone fail to present the complete picture. However, when the good features of each is combined into a single operation, then a complete picture is much more likely.

#### Single Detector - Ejector Type - Figure 11

The example shown is a typical Permian Basin water injection well. The injection rate is 800 B.W.P.D. at 1800 psi, 5½ inch and 15½ pound casing, 2 inch tubing, packer and 4 ¾ inch open hole. The recommended procedure is as follows:

1. Run open hole caliper, gamma correlation log, collar locator, then base log for tracer operations at reduced sensitivity. The work should be done with a scintillation type gamma detector where temperature permits.
2. Position ejector port at 4895 feet and detector at 4900 feet. Put recorder on calibrated time drive. Eject a heavy slug of water soluble I-131 material and monitor for a sufficient length of time to allow material to indicate a channel behind the pipe. Generally two to four minutes are sufficient. However, once the material behind the casing passes the detector it might be flushed out in a matter of seconds. In this first step we now have the 100 percent velocity measurement and indication of a channel behind the pipe.
3. Switch recorder back to normal logging (depth correlation). Drop the tool below the slug for series of timed logging runs over interval (logging runs number one through nine). Note residual radiation in zones "A" and "B" on run number one

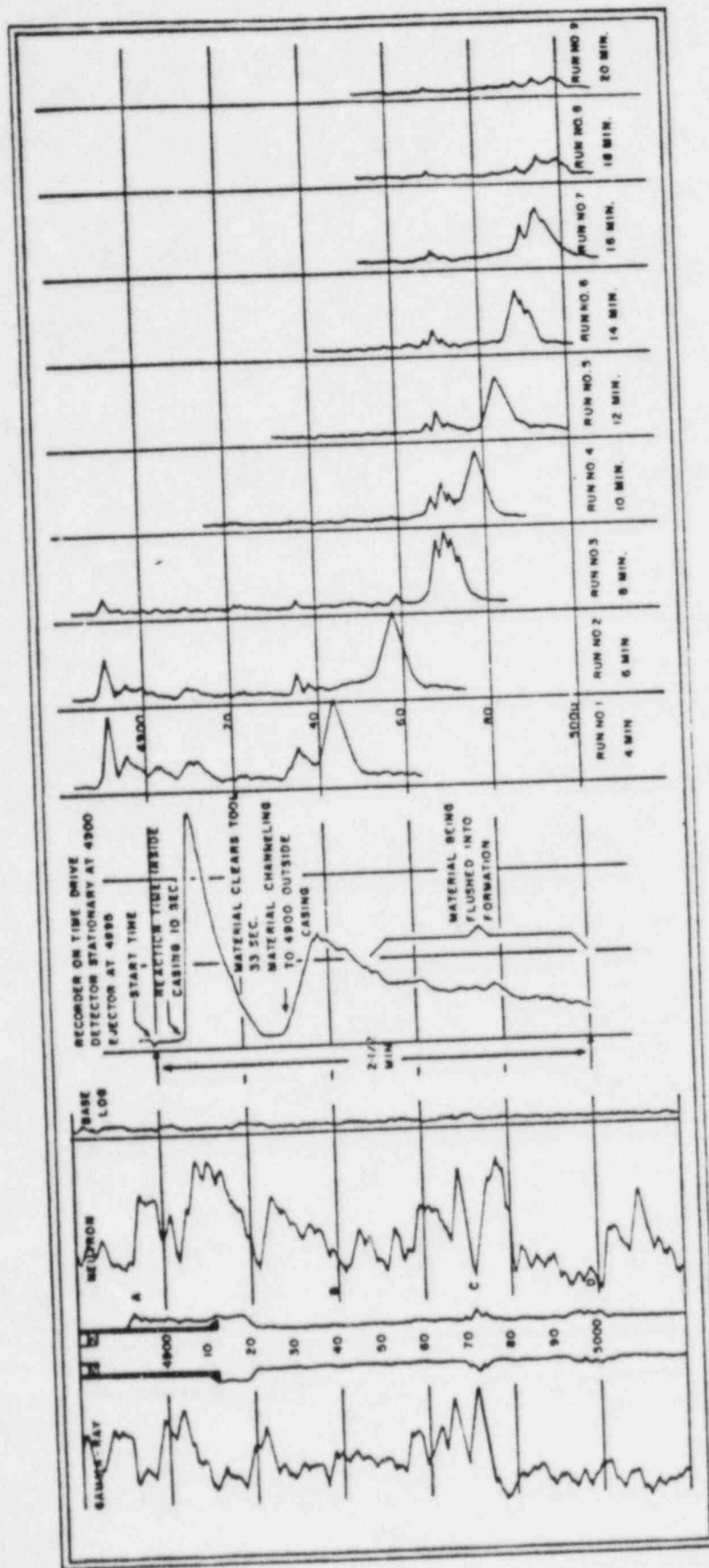


FIGURE No. 11



dissipates on subsequent runs. This indicates zones of rapid flushing. Zone "A" (4890 - 4895 feet) behind the casing first builds up radiation intensity, then flushes rapidly and within eight to ten minutes all traces of material are gone.

These logging runs are made until the slug comes to rest and the hole cleans up. At this point in the operation considerable information is available to the logging engineer. By examining these runs he can then plan the work necessary to thoroughly analyze the fluid movement.

4. The examination reveals profiling as the material moves down hole. Note log as slug moves past sections taking fluid ("B" 4930 - 4940 feet, "C" 4970 - 4980 feet, and "D" 4995 - 5002 feet). There is negligible spreading of material for two reasons, (1) the material is soluble and completely miscible in water, and (2) the tool is smooth and without traps.

The closely timed logging runs make it possible to compute approximate rate of down hole fluid movement. This is done by knowing bore hole diameter and noting the rate of down hole movement of the slug. Slug moved from 4942 - 4955 feet in two minutes; this rate is approximately 188 B.W.P.D. The next interval, 4955 - 4967 feet as shown in runs two and three calculates approximately 170 B.W.P.D. This indicates a slight fluid loss in this area. Note the slight irradiation at 4958 - 4960 feet in run number three. The slug shape at about 4970 feet (run number three) shows profile action here. Also profiling as shown on runs four, five and six show zone "C" (4970 feet) to be taking some fluid. Since runs numbers three and four are in a rate change area, a velocity check here would be unreliable. However, a check on slug movement as shown on runs four, five and six shows that about 94 - 120 B.W.P.D. are moving between 4976 - 4988 feet. Immediately below 4988 feet the final or lower most zone of injection becomes apparent at 4990 - 5000 feet (zone "D").

We now have this general information: (1) 100 percent rate measurement inside the casing, 800 B.W.P.D., (2) channel behind the casing up to 4890 feet, (3) three major fluid loss zones 4930 - 4940 feet, 4965 - 4975 feet, and 4988 - 5000 feet. About 75 percent of the injection fluid is going into the bore hole above 4940 feet and into the channel. About 10 percent is entering the formation between 4965 - 4980 feet. Also some water is entering the formation between 4995 - 5000 feet.

With this general picture in mind the gamma ray neutron log and caliper log should be examined. This examination shows definite changes in lithology and porosity at 4937 - 4940 feet, a shale break between 4968 - 4974 feet and another porosity change at 4990 feet. The caliper shows a fairly uniform hole except for the slight enlargement at 4990 - 5000 feet, shale wash out at 4968 - 4974 feet and the 7 7/8 inch drill hole just below the casing seat. Velocity shots should not be made in these enlargements or in the middle of a section where rates are changing.

This procedure is such that each step provides information to plan the next one. Also it requires that the logging engineer must be well trained and able to do more than just run a tool into the hole. The thin zones revealed by the correlation of primary logs, tracer logs and caliper information can now be closely bracketed with velocity shots and more accurate quantitative values placed on rates and injection patterns.

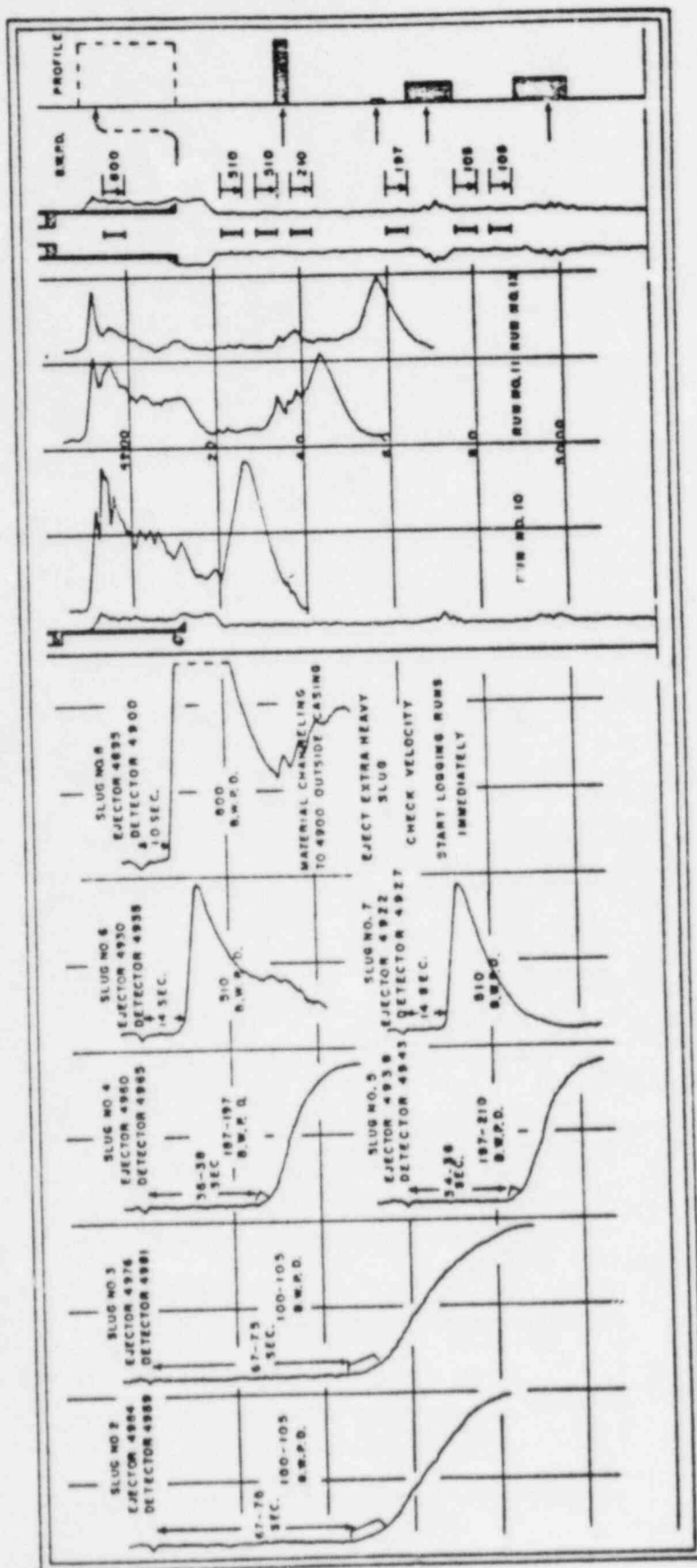


Figure No. 12. Rates determined at the points indicated by slugs two through seven correspond to the general profile derived from the logging runs, define the zones much more closely and establish the quantitative profile in the open hole. They also show the amount channeling up behind the casing by indicating the down hole rate immediately below the casing seat (slugs 6 and 7) versus the rate determined in the casing (slug 8).

Slug number eight is intentionally very heavy to more completely identify the extent of the channel behind the pipe. (Note indication of channel before the large slug clears the tool inside the casing.) Immediate logging runs through the section also catch the material behind the pipe before it dissipates and more clearly shows the single thin zone of fluid acceptance.

The overall pattern or profile of injection is shown at the right hand side of Figure No. 12 and can now be accepted as a true and accurate pattern.

FIGURE NO. 12

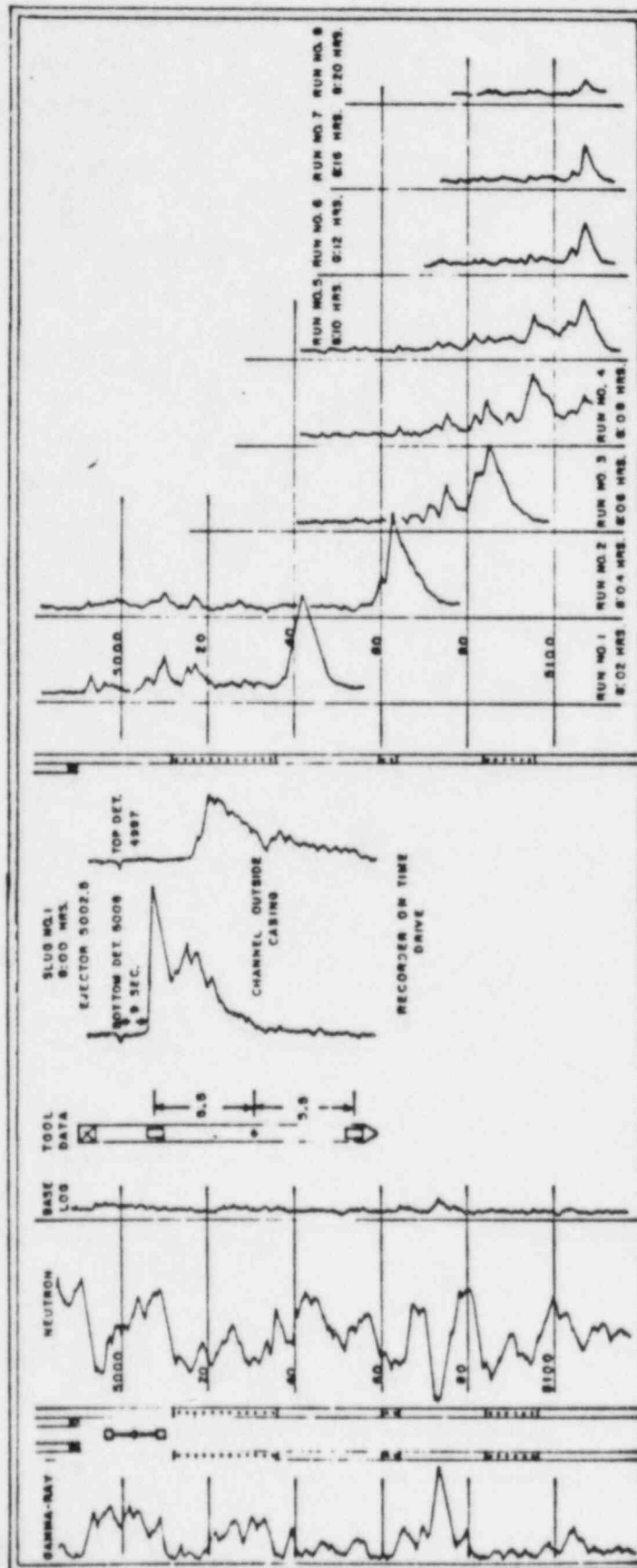


FIGURE No. 13

### Double Detector - Ejector Type

Often it is necessary to place the detector at or near the top perforation. In this situation a channel and thief zone near this point can be missed. This is because the material will be affecting the detector from inside and outside the pipe at the same time.

This problem is easily solved by using a detector above and below the ejector. Since the material is ejected into the injection stream below the top detector, a reaction on the top detector can only be from behind the casing.

Figure No. 13 represents a typical application of this type tool.

1. Run gamma correlation log, collar locator, then base log at reduced sensitivity for tracer operations. Scintillation detectors should be used.
2. Position ejector port at 5002.5 feet with detectors 5.5 feet above and below the ejector as shown in sketch. Tool is held stationary, both detectors recording simultaneously on calibrated time drive.
3. Eject heavy slug of material into the injection stream (I-131 water soluble). Monitor until material has cleared lower detector. Also, monitor for sufficient time for channel to be indicated on top detector.

Note - bottom detector shows fluid travel time of 9 seconds inside the casing (910 B.W.P.D.). The shape of this recording (ragged return to base curve) indicates possible channeling or fluid trapped at or near the top perforation. However, reaction by the top detector clearly indicates a rapid channel behind the pipe at least 4997 feet. Also, note that almost complete dissipation occurs in 90 seconds.

4. Switch recorder back to normal logging (depth correlation). Drop tool below slug and log up hole as indicated. Make several regular and frequent runs through the slug as it travels down hole.
5. Examination of slug travel as indicated by runs number one through eight reveals:
  - (a) Slight indication of activity behind the casing (at 4994 feet) which completely disappeared between run number one and two. This clean up has occurred in four minutes. At this time it is not certain if this is the top of the channel or not.
  - (b) No indication of communication between top and middle set of perforations.
  - (c) Profiling between middle and bottom set of perforations indicates communication.
  - (d) Evidence of material indicates fluid movement below the bottom set of perforations. At this time it cannot be determined whether it is a channel or not.
  - (e) Approximate rate-volume calculations based upon slug travel down hole indicates: 495 B.W.P.D. leaving the casing at or near the top perforation, 75 B.W.P.D. leaving the middle set of perforations, 170 B.W.P.D. leaving near the top of the lower set of perforations, and the remainder moving down hole to 5108 feet - probably outside the casing.



6. Check the 100 percent injection rate again (ejector at 5002.5 feet) to make certain that the rate has not changed. The first slug has indicated that a rather detailed procedure will be necessary to make a complete fluid movement analysis. This slug number two is not illustrated.

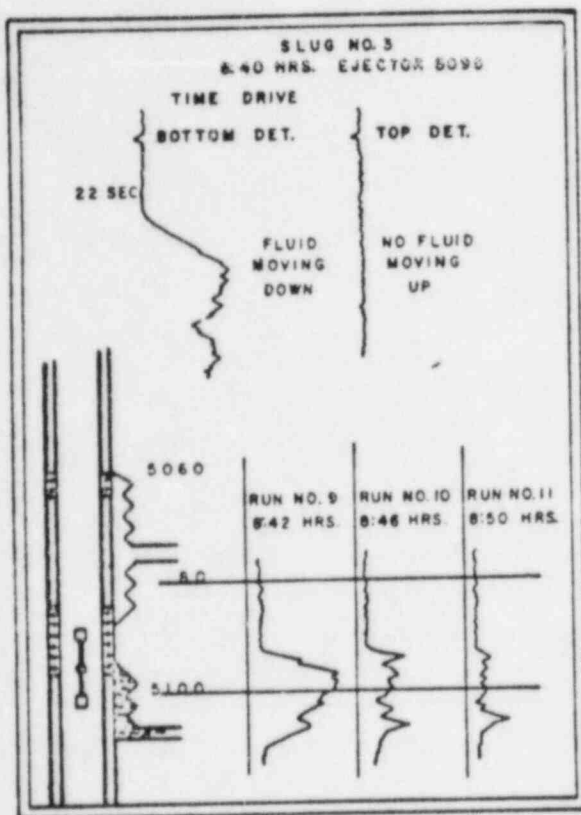


FIGURE No. 14

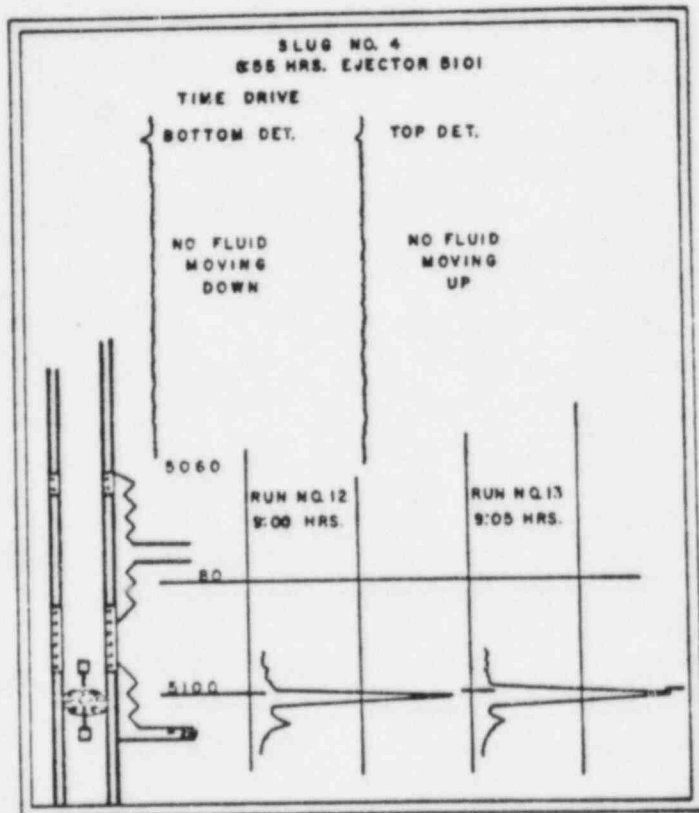


FIGURE No. 15

7. Identify channel at bottom perforations. Figure No. 14. Tool is positioned as shown with ejector at 5095 feet which is immediately above the bottom perforation. Slug number 3 is ejected and monitored on time drive. Reaction occurs on bottom detector and no reaction on the top detector. This indicates fluid moving down, probably outside the pipe. Note logging runs numbers 9 through 11 again show material as low as 5108 feet.

8. Figure No. 15. Ejector is positioned below bottom perforation. Slug number 4 is ejected and monitored on time drive. No reaction occurs on either detector. Logging runs numbers 12 and 13 at five minute intervals show slug remaining static at 5100 feet. This procedure proves that the material detected at 5108 feet is behind the casing.

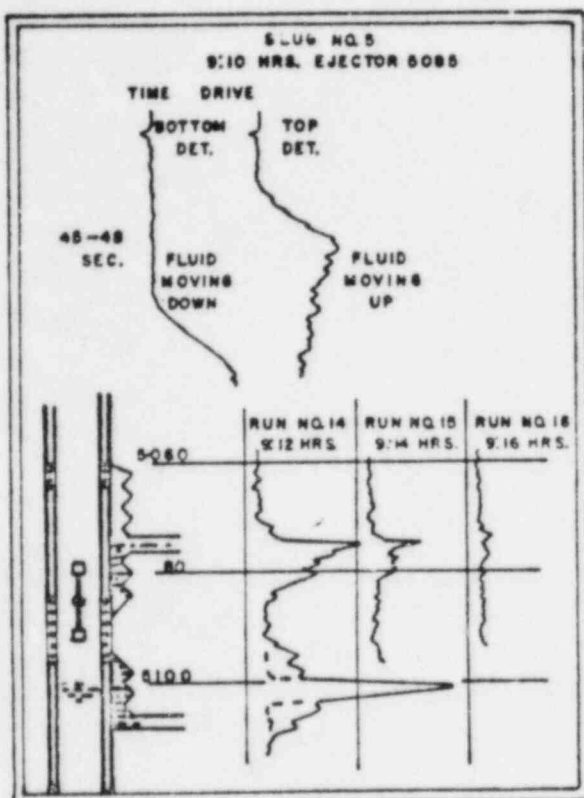


FIGURE No. 16

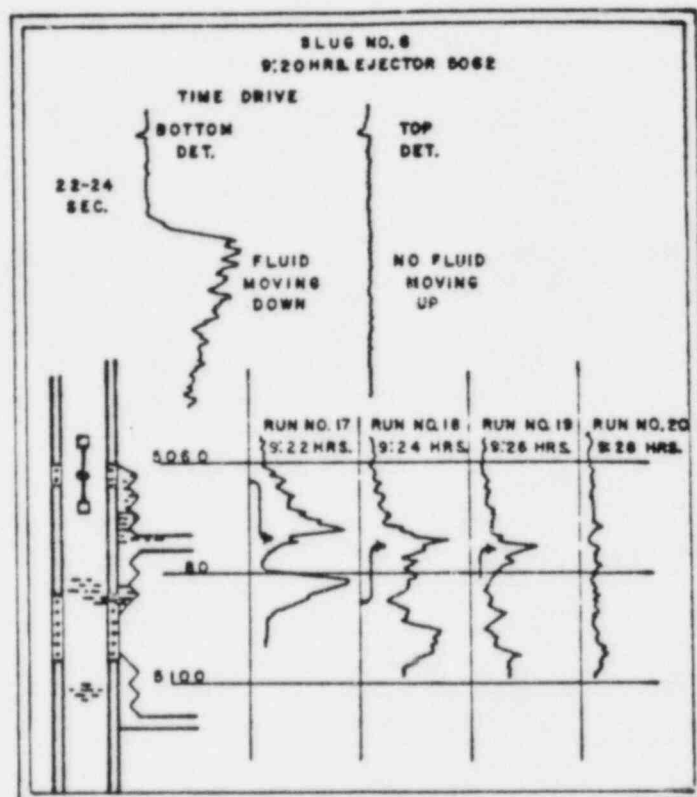


FIGURE No. 17

9. Figure No. 16. Ejector is placed immediately below the top of the lower set of perforations. Analysis of slug number one indicates a rate change across these perforations and a channel. Slug number five is ejected and both detectors are monitored on time drive. Top detector reacts in 18 to 20 seconds indicating fluid moving up outside the casing. Material reaches the lower detector in about 45 seconds which is approximately 170 B.W.P.D. rate. This checks with the amount indicated with analysis of slug number one. Several logging runs are made to define channel limits. Material is detected to 5074 feet which means water leaving top of these perforations is channeling to 5074 feet. Dissipation or clean up is rapid which indicates a zone of high permeability behind the pipe.

Analysis of slug number one, logging runs numbers 3, 4 and 5 indicated channeling between the middle and lower sets of perforations.

10. Figure No. 17. Tool is positioned across the middle set of perforations. Slug number six is ejected and monitored on time drive. Bottom detector shows fluid moving inside casing at approximately 340 B.W.P.D. (approximate because tool is in a rate change zone.) Shape of recording also indicates a channel outside casing is retaining some material. Top detector shows no channeling up behind the casing. Runs numbers 17 through 20 further substantiate water channeling down from this middle set of perforations to 5074 feet.

Run number 17 shows material channeling outside the pipe down 5074 feet. Runs number 18 and number 19 show remainder of slug inside the pipe leaving perforations at 5084 feet and moving up to 5074 feet.

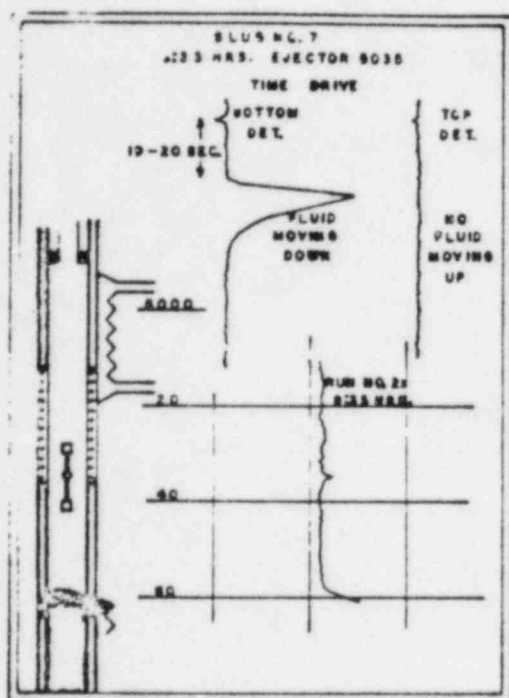


FIGURE No. 18

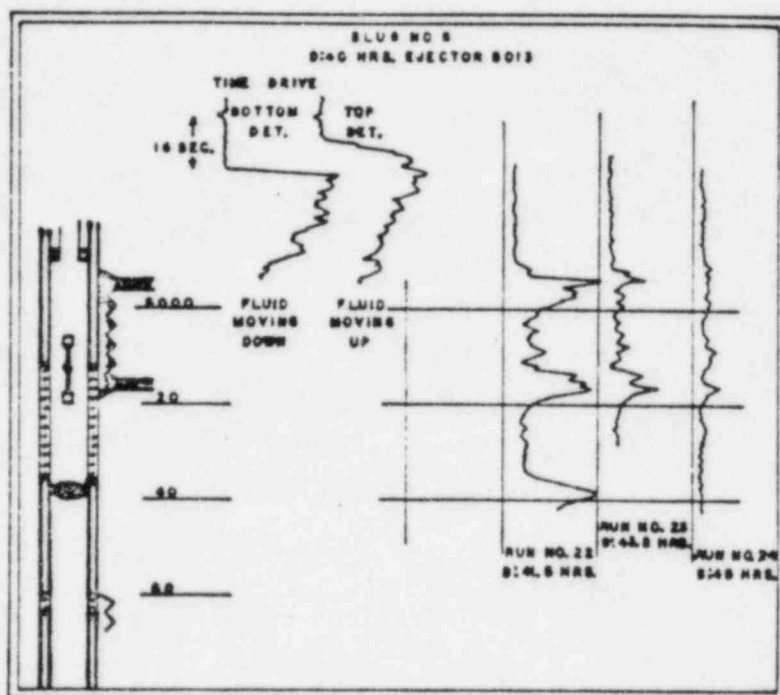


FIGURE No. 19

11. Figure No. 18. Check to determine if top set of perforations is in communication with the middle set of perforations. Tool is positioned as shown. Slug number seven is ejected and monitored on time drive. Bottom detector (19 - 20 seconds) indicates 420 - 435 B.W.P.D. moving down inside the pipe. Also, rapid return to base curve indicates no channel downward. No reaction on top detector indicates no channel upward. Logging run number 21 also indicates no channel.

12. Figure No. 19. Check for channel from top perforation. Slug number one did not clearly define the top of the channel. Tool is positioned as shown and heavy slug number eight is ejected. Note reaction times on both detectors - the material moves behind the casing at a more rapid rate up outside the pipe than downward inside the pipe.

Logging runs 22 through 24 also indicate a high velocity channel to 4994 feet. Also, an apparent zone of injection between 5014 - 5018 feet.

13. All the preceding work has defined all channels and zones of rate changes. Velocity measurements must be made above and below zones where rate changes occur. Measurements made in a zone of rate change are of little value. Five velocity shots are made and recorded as shown in Figure No. 20.

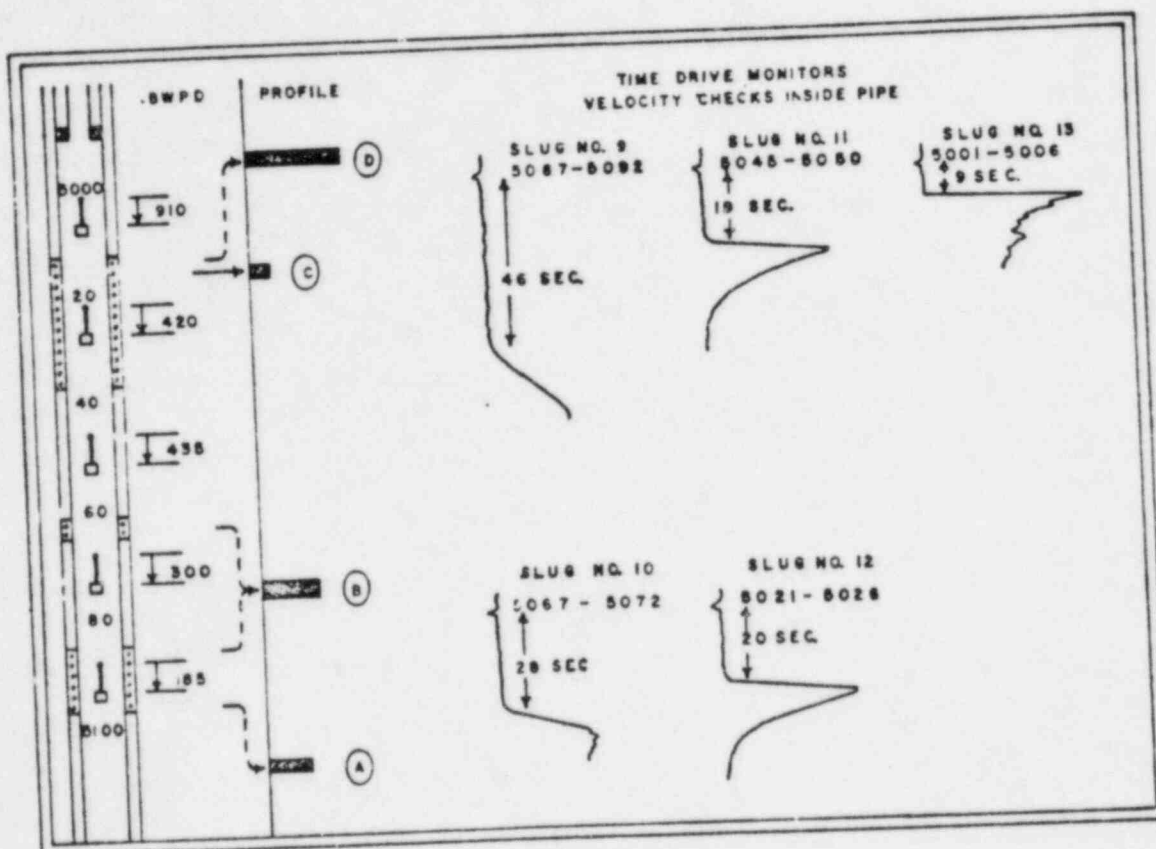


FIGURE No. 20

The injection profile is determined as follows:

- (a) 185 B.W.P.D. leaving the perforations at 5096 feet as indicated by velocity shot (slug number nine). The injection zone behind the pipe is indicated by slugs numbered three and four. This material is approximately 5106 - 5108 feet.
- (b) Velocity shot slug number 10 indicates 300 B.W.P.D. moving down inside the casing. The rate difference between slugs 9 and 10 is 115 B.W.P.D. (300 minus 185). This means that 115 B.W.P.D. is moving out at 5084 feet. Slugs numbers five and six show it to be moving up outside the pipe to 5076 feet. The difference between velocity shots, slugs number 10 and 11, show 135 B.W.P.D. to be leaving pipe at 5064 feet. Slugs numbers 5 and 6 also show this to be moving down outside the pipe to 5074 feet. Therefore, the volume into zone "B" (5074 - 5076) is 115 plus 135 or 250 B.W.P.D.
- (c) Notice that velocity shots, slugs numbers 11 and 12 do not agree by one second, probably due to turbulence in perforated area. The rate of 435 B.W.P.D. (slug number 11) is more representative. It is known that 475 B.W.P.D. is leaving the perforations between 5012 - 5021 feet. This is the difference between slug number 13 and number 11. (Refer to slug number 8.) 515 B.W.P.D. is moving down inside the pipe (5013 - 5018 feet). Therefore 515 minus 435 is 80 B.W.P.D. into zone "C" (5014 - 5017 feet), as indicated on runs numbers 22 through 24.

- (d) By subtraction (910 minus 515) 395 B.W.P.D. is the amount channeling to zone "D" (4094 - 4096 feet). (Refer to slug number eight, runs 22 through 24.)

### PRODUCTION PROFILES

The use of tracer ejector tools and isotopes to obtain production profiles is not recommended. The main reasons for this are: (1) the isotope presents a hazard upon returning to the surface; (2) no universal isotope is available for use in a three phase mixture of oil, gas and water. Various attempts have been made to obtain production profiles by using an isotope that is compatible with the most representative well fluid being produced, but this has not yielded valid results. In selecting an isotope that is oil soluble for use in a well producing more oil than gas or water, we encounter a mixture of the three fluids in all zones of investigation and resulting turbulence will cause the material to plate out or string out. Thus, any readings obtained will be unreliable.

### CONCLUSION

Tracer logging can be extremely reliable in diagnosing well problems when properly employed by trained personnel. Two types of problems outlined in the preceding examples are indicative of the information obtainable from tracer logs.

In planning a tracer logging operation, the company engineer has a considerably more involved task than he has in planning a primary logging operation. First, he must consider the physical equipment of the well to be certain it will accommodate the logging tools. Next he should be thoroughly familiar with the reservoir conditions, injection rates and pressures and the information on lithology, porosity and permeability as reflected by pertinent primary logs. Also, he should determine what specific information is desired from tracer logs. Then the company engineer should consult with the logging engineer and discuss the above factors before a proper isotope can be selected and correct tools and techniques be employed to adequately collect and evaluate tracer logging data.

A few basic rules for successful tracer logging can be stated as follows:

- (1) Have maximum control over fluid movement,
- (2) Reduce variables to a minimum,
- (3) Avoid use of compressible gases,
- (4) Use isotopes of short half life,
- (5) Use only miscible isotopes that are compatible with well fluids to avoid plate out or settling,
- (6) Observe the isotope in transit,
- (7) Carefully note clock times of each run or operation,
- (8) Let each logging operation set the stage for following operations, and
- (9) Double check each operation if possible.

When a trained logging engineer and a company representative confer on location as to what information is desired and what data has been obtained as the logging job progresses, a complete picture as presented by tracer logging can usually be obtained and a preliminary interpretation afforded by the time the well logging has been completed. In this manner rapid planning of any necessary remedial work on the well can be accomplished.



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## MAXIMUM USE OF WELL PROFILE INFORMATION

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### ABSTRACT

Interpretation of the information obtained from well profiles is not an exact science. Preliminary interpretation is subject to local conditions, experience, and performance data. As with all types of log interpretation, other surveys are sometimes required.

Profiles are valuable to supply information on completion and production efficiency, for control of injected water to obtain maximum flood sweep, to determine the efficiency of the mechanical conditions of the well, and to determine the causes of unpredictable behavior of a well.

Methods and tools are discussed in respect to each technique's application to the well conditions and the information desired. Typical surveys shows the capabilities and hole conditions that can contribute to interpretation errors. From this discussion, techniques on techniques can be selected to obtain the maximum information on each well.

The future of profiles will be determined by the ability to select the technique and the development of well histories to enable further interpretation of the information obtained.

References and illustrations at end of paper.

### INTRODUCTION

The knowledge of injected fluid movement in and adjacent to the borehole is an approach to determining reservoir behavior.

Interpretation of these observations is not an exact science. There are many known parameters that apply; but as with all types of surveys, many more must be assumed. Any preliminary interpretation is subject to alteration by local conditions and experience, prior or subsequent information from logs and performance data, etc.

Useful and valid information can be obtained in both primary and secondary operations, however, by utilizing the proper surveys and equipment for the information desired. Knowledge of both the response and limitations of various tools and techniques, and the effects of possible or probable downhole conditions are necessary to the correct choice.

To obtain the desired flood sweep, the injection well conditions are of the utmost importance. Assumptions as to the mechanical conditions of the well can be misleading and result in wasted effort. The nature of water-flood operations creates many problems in that the wells are not new, records are sometimes inadequate, original completions are not efficient, and equipment is worn. Injectivity profiles can provide most of the answers to questions



concerning the condition of a well.

Profiles are used to determine a wide variety of downhole conditions in both injection wells and producing wells in waterflood operations. Various tools and techniques are available to meet all well conditions. The two most commonly used are the tracejector with dual detectors and the packer spinner tool, supported by calipers and temperature tools as required [Fig. 1].

#### REASONS FOR PROFILES

1. To confirm predicted performance or determine cause of unpredictable behavior by:

- A. Initial injection [or production] pattern.
- B. Initial physical problems [thief zones, channels, parting planes, etc.].
- C. Stabilized injection patterns.
- D. Developed or induced problems.

2. To determine effective zone flooding by observing effects of:

- A. Pressure build-up.
- B. Fill-up.
- C. Flushing or top washing.
- D. Vertical sweep.
- E. Formation solubility or "weathering".
- F. Plugging.

3. To assist in determining economic feasibility by:

- A. Indicating extent of preparation and/or remedial work needed for effective operation.
- B. Determining optimum rates and pressures needed.
- C. Observing formation characteristics under actual operation.

4. To determine effectiveness of stimulation and corrective measures by comparison of performance results correlated with subsequent surveys.

#### METHODS AND TOOLS

##### Basic Tracers<sup>1</sup>

Radioactive material is introduced into fluid stream at the surface or dumped in the hole above the zone with dump bailer and its path of travel and accumulation observed by successive logging runs over the zone of interest [Fig. 2]. Qualitative evaluation is derived from the points of accumulation as indicated by gamma log. Very little control can be exerted once the material is placed, and considerable masking of true information can result from screening, spreading, and fall-out. Recommended for frac tracer [sand or resins] and zones of extremely high permea-

bility or porosity.

#### Tools Used:

- A. Simple gamma detector
- B. Gamma detector with attached dump bailer

#### Materials:

- A. Solid particles [sand-resins-flakes]
- B. Miscible carriers [water-oil-benzene]

#### Applications:

- A. In lost circulation zones
- B. In some channels
- C. In determining effectiveness of stimulation

#### Expanded or Improved Tracer

Analytical runs are made by releasing miscible material into the flow stream at selected points [above zone, bottoms and tops of zones and/or perforations, etc.]. The path and amount and rate of dissipation or flushing is observed by successive logging runs through the zone of interest [Fig. 3]. The character of these observations is interpreted to locate zones of fluid acceptance, channels, thin zones or bedding planes both in and out of zone or behind the pipe. Zones of fluid acceptance in adjacent strings and/or by specialized well equipment [sleeves, plug valves, etc.]. Only slight quantitative information is available by this method; and irregular borehole, scale, paraffin deposits, etc., can cause misleading results where no supporting information is available.

#### Tools Used:

Gamma detector with ejector capable of repeated and variable placement of radioactive materials.

#### Materials:

Miscible and compatible carriers, either liquid or gas.

#### Applications:

- A. In qualitative analysis of zones and channels accepting fluid
- B. In planning of logging techniques to obtain quantitative information from profiles
- C. In supporting information derived by other means [velocities-flowmeter-temperature]

### Quantitative Rates

Velocity determinations are made by positioning the tool at a pre-selected point in the borehole and a small amount of material released. The transitions over a known distance is recorded and the rate of fluid movement over that interval calculated by volume of interval vs transit time. Variations in indicated volume are then plotted as injection profile. There are several methods of determining rate of flow:

A. The standing velocity or multiple burst. Material is released and time measured over a given length of tool [Fig. 4]. This procedure is repeated at each station.

B. Controlled interval or single burst. Material is released and the tool lowered to a pre-selected point, transit time recorded and the tool again moved to a successively lower point, etc. [Fig. 5]. These resultant transit times are computed to a cumulative time plot and related to flow rate between intervals of inspection.

C. Controlled time plot, single burst. Material is released and the tool immediately lowered well below the material. A logging run is made at an index time interval, noting the position of the material in the hole [Fig. 6]. This process is repeated at precise time intervals and the variations of distance of slug travel per unit of time plotted as rate of flow.

[All velocity techniques are subject to error from hydraulic diameters, borehole configuration, zones of fluid egress, inaccurate calipers, channels, etc.; and when used as the sole technique, fall short of complete information. Results should be supported by one or more of the other methods for accurate determination of conditions.]

#### Tools Used:

Gamma detector with ejector or energizer capable of releasing small amounts of radioactive material to the flow stream.

#### Materials:

- A. Miscible or compatible carrier
- B. Solid or ionizing nodule or pill

#### Applications:

A. In quantitative analysis of rate of fluid movement at selected depths in the borehole to determine injection profile or pattern.

B. In lending quantitative values to the information derived by other methods.

### Volumetric Measurements

A Flowmeter Tool [Fig. 7] is lowered into

zone and stopped at a selected position. A packer or deflector is expanded against the borehole walls, diverting all, or a known increment, of the moving fluid through the metering device. This rate of flow is transmitted to the surface and recorded as volume or percentage of flow. The tool is then released and moved to another position and the process repeated. The volumes recorded at each station are plotted and the production or injection profile derived from these plots. Accuracy is excellent where good packoff or isolation can be obtained; but channels outside pipe, or vertical erosion and fracturing near the borehole allow fluid by-pass in unknown amounts. Most of these tools are limited in borehole size to seven in.; therefore, flowmeters are not recommended for shot or enlarged holes. These tools are excellent for production evaluation and for use with borehole fluid densimeter to define volumes of the various fluids moving in the borehole. Temperature is considered, since the packer elements on some tools are limited to 180F.

#### Tools Used:

A turbine or metering device capable of being lowered into the hole and recording either all, or a known portion, of the fluids moving at any given point.

#### Materials:

None, with the exception of an expandable packer or bladder used on several of the tools.

#### Applications:

- A. In quantitative determination of fluids moving at any given point [Fig. 8]
- B. In identification and isolation of thin zones and/or holes in casing
- C. In production evaluation [zones and rates of production defined]
- D. In determining optimum production rates [flowing or gas lift wells]
- E. In evaluation of stimulation treatments and remedial work

### Borehole Fluid Identification

A Borehole Fluid Densimeter is lowered to zone of inspection and a log or plot of relative densities at various depths made by two logging techniques, station settings or standing readings, and continuous logging runs. A sample of the borehole fluids is impressed across the detecting elements and the resultant changes in density or resistance are plotted as fluid identification at their respective depths [Fig. 9]. High resolution is possible with calibrated sensitivities. Interpretation is simple in two-phase flow, more complicated in three-phase systems since the densities of the total fluids

at any given point are recorded. Velocity effects in compressible fluids must be reconciled by surface calculations and downhole volumetric measurements with a flowmeter. Identification of static or moving fluids is also a flowmeter function. Log is not recommended where production is 90 per cent water, or more.

#### Tools Used:

Downhole tools capable of detecting differences in borehole fluids at any depth in the well [Fig. 10]. Several methods are used, i.e., resistance between electrodes, capacitance, sonic detectors and radiation detectors. The last is the most commonly used, since the parameters affecting the detectors are more simply recognized and controlled.

#### Materials:

None

#### Applications:

- A. In qualitative identification of borehole fluids in place
- B. In quantitative analysis of production in two- and three-phase systems
- C. In determining gas/oil/water contacts
- D. In pinpointing gas and oil entry points

#### Temperature Analysis

The temperature tool has been used, both successfully and unsuccessfully, in a wide variety of applications, and much has been written of these efforts by authors such as Boone, Bird, Dale, Ramey, Nowack, Terry and others. An outstanding study and compilation of these records was presented by Edward T. Connolly with Imperial Oil Limited of Canada.<sup>3</sup> For purposes of brevity, we shall discuss the Temperature Log as supporting information related to fluid movement analysis, or flow characteristics and evaluation.

#### Tools Used:

A downhole tool capable of detecting slight changes in borehole temperatures, either absolute or differential, and transmitting this information to the surface for recording.

#### Points for Analysis:

- A. Injection profiles
- B. Fractures and stimulation
- C. Production analysis [gas entry]
- D. Communication [producing wells]

Several tools and techniques have not been

listed here. The group discussed should provide a good cross-section for understanding, since all others in use at the present time are variations on the main theme and can be studied at length in individual articles.

#### CONDITIONS AND REQUIREMENTS FOR SURVEYS

Fluid movement analysis is subject to a great number of constantly changing conditions, some proven and some only assumed. To obtain the most information at the least expense, we must reduce these variables and unknowns as much as possible.

Pre-job preparation should include several items to assure efficient operation and valid results, i.e.:

- A. A check on the physical and mechanical conditions of the well. Numerous jobs have been cancelled or delayed because of restricted tubing, pin collars, packers set below perforations, undue fill-up, improper valving, etc.
- B. Positive control of injection or production fluids [valves, meters, chokes, etc.]
- C. Surface indication of rates and pressures for correlation to profile results
- D. Stabilization. This is of prime importance. Wells fluctuating in rates require much longer to survey, since each reading must be reconciled with the total rate at that moment. Some zones are balanced quite critically, and may take fluid at one rate and pressure and not at another.
- E. A history of the well, such as logs, lithology, completion procedures, workovers, etc., should be available for reference, as well as any unusual conditions in the project [break-through, sealing, rapid pressure changes, plugging]. A log showing some unusual results may be resolved by the first alternate technique, instead of "fishing" or eliminating possibilities by trial-and-error methods.

Special well conditions or suspected difficult logging conditions in a proposed flood can many times be alleviated somewhat by deciding the type information needed and tailoring the well set-up to fit the tools indicated. In the case of the dual injector [Fig. 11], a sliding sleeve was installed just above the packer and well below the zone of interest. Normal injection was down the annular space; but when surveys were needed, a plug was dropped on the seat. The sliding valve was opened, allowing injection into the zone from the tubing. After sufficient stabilization period the survey was run from inside the tubing by ejecting material from the tool; and a simple annular velocity log and tracer was run upward from the bottom of the zone.

#### SELECTION OF TECHNIQUES

The methods and techniques available for



fluid movement analysis are legion, each having both strong and weak points. The information obtained from these operations is overlapping; but one type may be inadequate in an area in which another is strong, i.e., a velocity profile alone may leave doubt as to a channel behind the pipe and conversely, analytical runs may show the channel with good detail but the distribution percentages may be greatly in error.

As with primary logs, complete information can be obtained by running all the surveys offered by several different companies, but the cost would be prohibitive. A combination of several of these techniques in a single presentation is available from a limited number of service companies at present, but even these must be adapted to the particular conditions of each job.

Flexibility of tool selection is governed by several aspects. One consideration, for example, is physical set-up. Small diameter tubing and/or packers [1-in. tubing — cement-lined 2-in. tubing limits the tools presently available to the tracer-type probes with single detectors and/or less sensitive components, thus limiting the amount and quality of the information received.] Dual string injectors and annular injection set-ups require special attention in tool arrangement and techniques. Material must be introduced into one stream and logged from inside the adjoining tubing to prevent hanging tools. Dual detectors at various spacings must be used if velocities are to be obtained. Miscible radioactive materials must be used in these instances to prevent masking effect in the annulus.

High injection or production rates may affect the choice of tools, since the flowmeter has definite rate limits and the rate may have to be altered to allow surveying. This can, in turn, alter the actual profile until it is no longer representative of normal conditions.

A suspected bedding plane or thin weathered and eroded zone may call for a flowmeter for pinpoint determination, but a log in an area of known channeling should definitely include tools capable of detecting and delineating a channel.

Producing wells must have both flowmeter and borehole fluid densimeter for complete analysis, but qualitative identification of gas entry zones can be accomplished with B.F.D. alone at a considerable savings in total job expense.

A quantitative breakdown of total produced fluids can be the function of flowmeter alone, with slight indication of gas breakout or entry into borehole [erratic and unstable reaction of turbine].

Thin zones or single-point perforations may be qualitatively analyzed by either a basic tracer run or analytical runs [injection wells or "pump in" production logs] where conditions prevent use of flowmeter.

Areas of known corrosion build-up resulting in decreased or erratic borehole diameters are best quantitatively surveyed by the flowmeter, unless the build-up prohibits the use of packers [sharp projections] or tends to flake off, plugging the turbine.

Extremely low rates decrease the accuracy of all radiation-type techniques and increase the time needed to obtain a survey, but a minute breakdown of low rates may cause several runs with a flowmeter to change turbines.<sup>3</sup> Rates lower than seven B/D cannot be detected with flowmeter.

High pressures limit tools to those with enough weight to overcome pressure interference or necessitate the use of special surface equipment [at extra cost].

These and many more problems or considerations affect the choice of tools and techniques. These are better suggested by one who is familiar with all the limitations of tools and methods.

The engineer in charge of the project should determine the major point of interest and discuss this and any known well or field conditions with the service company representative before positively selecting the type of service most needed. This allows tailoring the service to a particular condition and reduces the probability of inadequate information.

#### SOME TYPICAL PROBLEMS DISCLOSED BY FLUID MOVEMENT ANALYSIS

Converting fields to flood and pressure maintenance generates many problems, since old wells are normally used for injectors. Records are usually inadequate; perforations may be plugged or never have existed; some zones may be more pressure sensitive than others; liner tops may leak or channels may exist that never show during the production period.

One example of these problems is the well [Fig. 12] which was converted to injection, assuming all perforations open and open-hole porosities equal to those in the perforated intervals. Profiles run after two months injection showed only one set of perforations and a portion of the open hole accepting fluid. Later remedial work re-opened plugged perforations and adjusted profile until it was acceptable.

Not all formations accept fluids at the same pressure and rate. Profiles run at two

different rates [Fig. 13], showed that patterns altered considerably by rate increase. Better distribution of fluids at higher rates indicate that the normal rate of injection should be increased.

Wells in the same field do not react in the same manner, as shown in Fig. 14. The three wells, although completed in the same formations at approximately the same zones, show different profiles when surveyed. To obtain efficient sweep, remedial action must be taken to make these injection patterns acceptable.

Liner tops always warrant investigation. In Fig. 15, we find that all injected fluids are leaving the borehole at the top of the liner. In this instance, a simple squeeze job corrected the situation.

Casing shoes are another trouble point in many old fields. In Fig. 16, all fluids are leaving at, or just below, the shoe. When this condition is observed, a channel is immediately suspected.

Profiles alone do not determine the existence or extent of a channel. Let's follow the technique of further analysis after determining that all fluids are leaving at the casing seat. A further check is made for channeling by positioning the tool at a point above the casing seat [Fig. 17] and ejecting another burst of radioactive material. Recordings of the reaction of both detectors are run for a period of time and the secondary reactions interpreted as fluid moving up outside the casing to a point opposite or above the detector. [Note reactions detector 2 and detector 1 after the initial burst.]

For further information as to the channel, we must follow the path of the radioactive material [Fig. 18]. In this instance, several other considerations entered into the analysis. First, the 100 per cent rate indicated by the velocity in the pipe was not consistent with the indicated rate at the surface. Second, there was abnormal action of the sensitive collar locator at a point two joints above the casing shoe. A new burst of radioactive material was ejected above this point, and its movement traced by successive logging runs. Note that in runs one, two and three, immediate build-up of radioactive material, or profiling, is apparent above the casing shoe, although the main body of the slug has not yet reached the shoe. The build-up, or path, of radioactivity indicates that a portion of the material is leaving the borehole at approximately 4,900 ft and moving down outside the pipe to about 4,980 ft. The main body of the burst moves downward to the casing shoe and channels back up outside the pipe to about 4,980 ft. The sequence of build-up and dissipation of radioactive material identifies the thin zone

and bedding plane at 4,980 ft as the point accepting nearly all the fluid. In this manner, an immediate problem has been identified and a possible troublesome formation characteristic pointed out for further reference.

Fig. 19 is a chart of the incidence of some of the problems encountered in various fields.

All injection problems are not insurmountable, however. Profiles can be changed by several different methods. An undesirable profile may many times be made more acceptable by the simple expedient of changing rates and pressures. In the case of relatively new flood efforts, the adverse effect of oriented fractures, or directional permeability, can be changed by changing the position or orientation of the injection wells. [Moss Unit Flood - Ector County, Tex.]

Extreme localized conditions may dictate alterations of injection technique, such as the intermittent injection used in the Sprayberry Trend area.

Individual wells respond to remedial work in many cases and plugging agents are now receiving a lot of interest. New materials and methods are being devised and tested, one of which has been comparatively successful [Fig. 20].

The two profiles shown here are the before and after profiles illustrating the results of a chemical grout application to an unacceptable profile. Much of the injected fluid was channeling around the casing seat as well as being injected into an undesirable zone. Application of the AM-9 grouting material changed the injection pattern into one more nearly compatible with the flood endeavor.

#### CONDITIONS CONTRIBUTING TO ERROR

All surveys are either accepted as being correct, or rejected because of incomplete or irrational results. These erratic results can sometimes be rationalized or the reasons for them eliminated or accounted for by recognizing some of the conditions that produce them.

The mechanical or volumetric tools are subject to error or difficulty in operation by several conditions.

In cases of fluid by-pass, all readings are compared to the total flow or 100 per cent reading at a point that assures total fluids moving [in casing or tubing above any possible zone of fluid loss]. The packer is set and a total fluid flow is diverted through the turbine. All future readings are compared with this rate. Assuming a total seal at each setting, the readings would reflect all fluid moving at that depth

with a valid log resulting. Some formations, however, have vertical fractures or erosion extending past the perimeter of the borehole. When the packer is set total seal does not result. This allows a portion of the fluid to move outside the tool and not be measured by the turbine rotation. The resultant log reflects less than the actual fluid moving in the borehole. The error is then reflected in the profile calculated from the volumes indicated.

An example of this type of error is shown in Fig. 21. A flowmeter was run and the larger portion of fluids was lost above 4,870 ft.

Subsequent readings below 4,870 ft showed an apparent increase in volume of fluid moving in the borehole, indicating a possible zone of discharge below that point. The totals of all the readings dictated a profile as shown, with a zone in the center of the section discharging fluids to the borehole. There was no reverse flow observed, however; and this, coupled with the engineer's information as to the formation characteristics, led him to believe that fluid was by-passing the flowmeter over the upper portion of the zone.

A radioactive profile [velocity and analytical runs] was run and the resultant profile is shown in Fig. 22, compared with the incorrect results from the flowmeter. As seen, the results show almost all the water leaving near the bottom of the well.

The flowmeter results, though in error, proved a localized condition of the formation--that vertical fractures exist in the upper portion of the zone, but do not extend through the impermeable zone from 4,950 to 4,965 ft.

Paraffin or algae in small quantities can restrict the rotation of the turbine to a point that erroneous readings result. Large quantities of paraffin, as well as sand, scale and other debris, can plug turbine completely.

Sulphate or Sulphide crystals form "needles" and sharp projections that sometimes puncture a flowmeter packer or cause "pin-holes" that make complete packoff impossible.

Unstable and very low pressure or vacuum conditions usually result in erroneous logs, if the readings taken at any single interval are not reconciled with the total rate at that time. Usually these pulsations will follow a time pattern or cycle. Valid results can be obtained by monitoring the entire cycle and comparing total results at each station. "Zone swapping"<sup>2</sup> can also be a problem in interpretation, if not recognized.

The radioactivity types of surveys, when used in individual techniques, are subject to

the more insidious hazards. Consequently, a great amount of care and experience must be used in determining the results.

One of the more troublesome, but more readily identifiable errors, is that effective hydraulic diameter.

The effective velocity stream is affected by such conditions as proximity to tubing or liner top, perforations [both type and density], zones of large fluid loss, casing seats, borehole size and configurations, rates at any given point downhole, position of tool in well, and others.

Some of the problems existent in logging under these conditions can be seen in Fig. 23. Note obvious changes in velocity, and that true diameter does not necessarily mean true hydraulic diameter. Turbulence and fluid traps can retain enough material to confuse a tracer run. Velocity shots alone would be very erratic, as shown in Fig. 24 [per cent fluid remaining in borehole]. Careful use of several of the techniques available would be needed to reconcile the results and obtain a valid profile.

Some of the erratic results in cased hole can be made more consistent by centralizing the tool; but in irregular open hole, there is little to be gained. Effective slug or material dispersal in the total fluid stream is another means of minimizing this error.

Effective hydraulic diameters can also be altered by algae, soft paraffin, or scale build-up through and adjacent to the injection zone. The actual fluid stream diameter may be reduced to two in., or less. In the case of algae or other soft deposits, the caliper may not indicate this reduction since the legs protrude through it. In this instance, diameter reference for velocity determination would be completely in error. Algae, bacteria, and paraffin have other undesirable side effects, in that radioactive material has an affinity to hydrocarbons. Small deposits, or bubbles, of oil accumulate radioactive material and give the erroneous interpretation of profiling and fluid loss at that point.

Fluids channeling between perforations to a point behind the pipe can often indicate fluid loss at the top or bottom of a set of perforations. Actual zone of fluid entry into the formation can be at a point well removed from the perforated intervals. Care in observation of material dissipation can identify these zones, however.

Back-flow, high pressure discharge, zone swapping, unstable conditions, etc., also affect the results of a radioactive-type survey--as with the flowmeter. These erratic results can be



rationalized, however, by proper manipulation of other techniques.

Extremely low injection rates increase the error in profile determination, since the velocities are based upon cohesive slug travel. As rates are reduced, the material tends to spread and reactions are much less pronounced, causing time intervals to be more subject to error.<sup>2</sup>

#### TEMPERATURE LOGS

Though much study has been done on temperature logs as a waterflood monitoring device, no method of consistent quantitative evaluation using them has been discovered. The qualitative information overlaps with, and is usually much less defined than, the results of other types of surveys. The temperature log is good supporting evidence to other results, however, and adds a depth of investigation into another disputed condition--cross flow within the formation due to vertical permeability or fractures.

Special attention must be given to operating technique and run series, since the principle of interpretation is the comparison of relative rate of cooling or heating under controlled conditions. The relative heat transfer coefficients of saturated and unsaturated formations must be compared to normal thermal characteristics. Areas that do not have a large amount of controlled temperature log information usually need several runs at spaced time intervals to correctly judge the results.<sup>3</sup>

The temperature log is an extremely informative tool, if used properly; but extending it past its capabilities can produce misinformation--or at best, no comparable information.

#### FUTURE OF PROFILES

The great value of profiles in analyzing present conditions, assisting in performance predictions, and forcing new remedial developments, has caused the industry to overlook momentarily the period when they will become infinitely more valuable--the day in the future when a series of profiles is correlated to known performance of a reservoir to determine whether a project or flood has been exploited to its economic limits, or not.

Although the process of true profiling is still in its infancy, enough correlative results have been accumulated in certain areas to allow additional recovery from projects apparently depleted. Production results compared with consecutive profiles during the flooding process identified zones still unflushed and helped determine the type of remedial work needed to recover oil still remaining in strata or lenses.

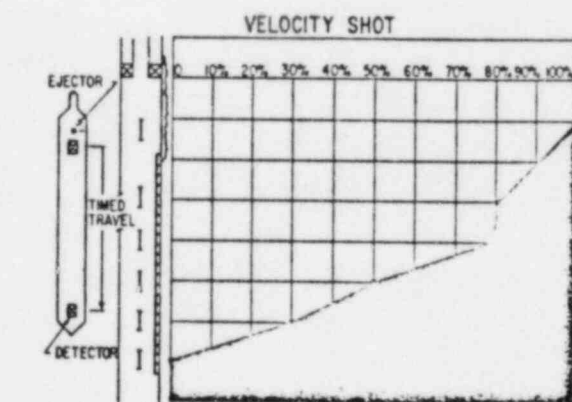
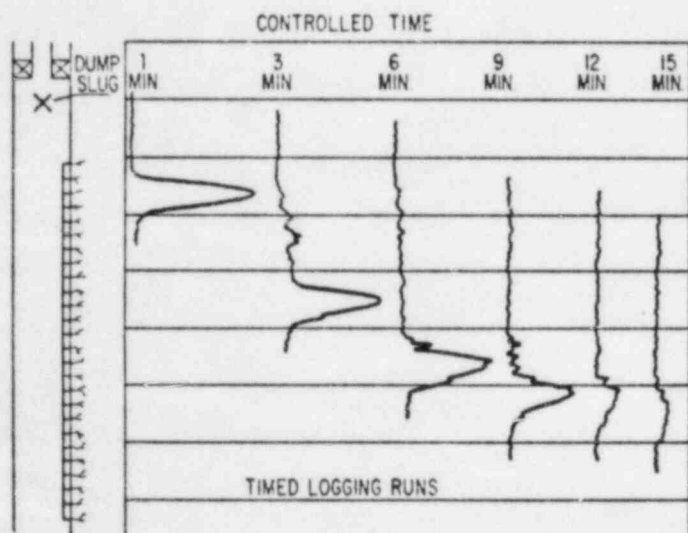
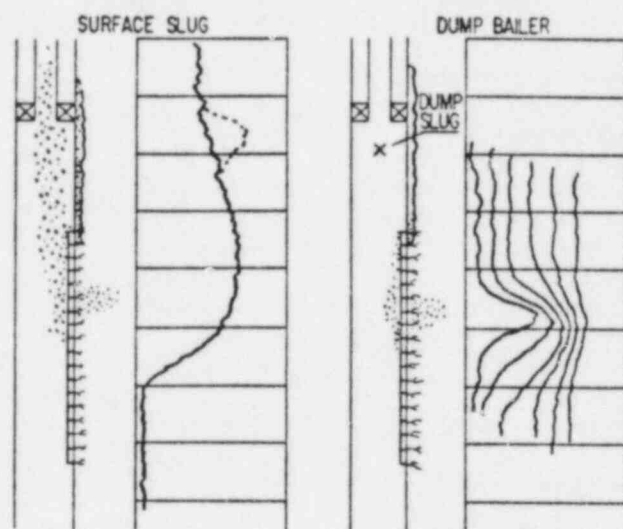
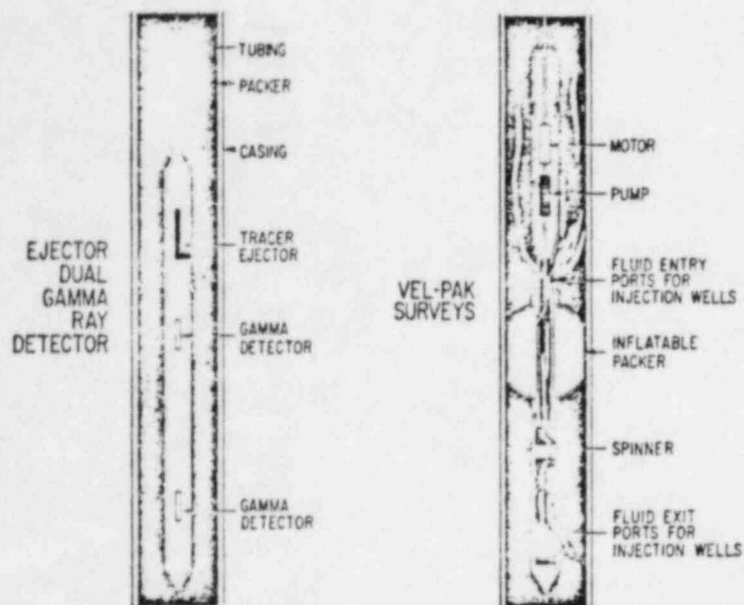
Conversely, expensive work-overs to improve injection into some zones have been curtailed when profile series indicated a zone to be flooded out.

The projection of the formations in a West Texas flood, as shown in Fig. 25, should serve to stress the complexity of the problems inherent in secondary recovery operations.

The era of fluid movement analysis as a helpful tool is just dawning. Caution should be taken in the future to prevent inadequate or erroneous profile information.

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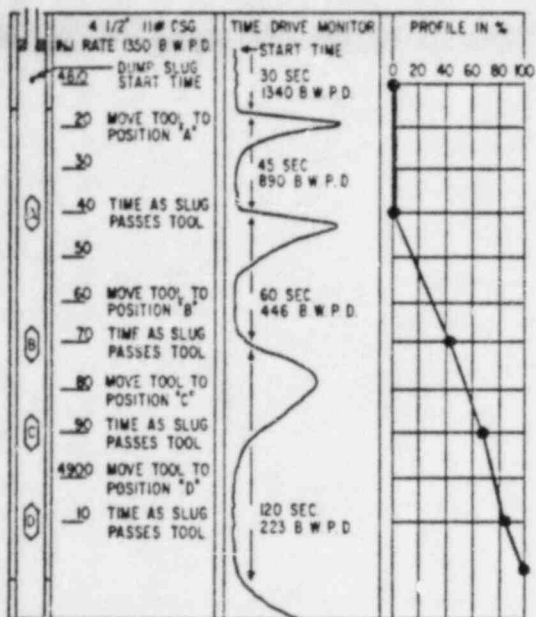


Fig. 5 - Controlled Interval Profile (Note Cumulative Time Drive Plot in Center)

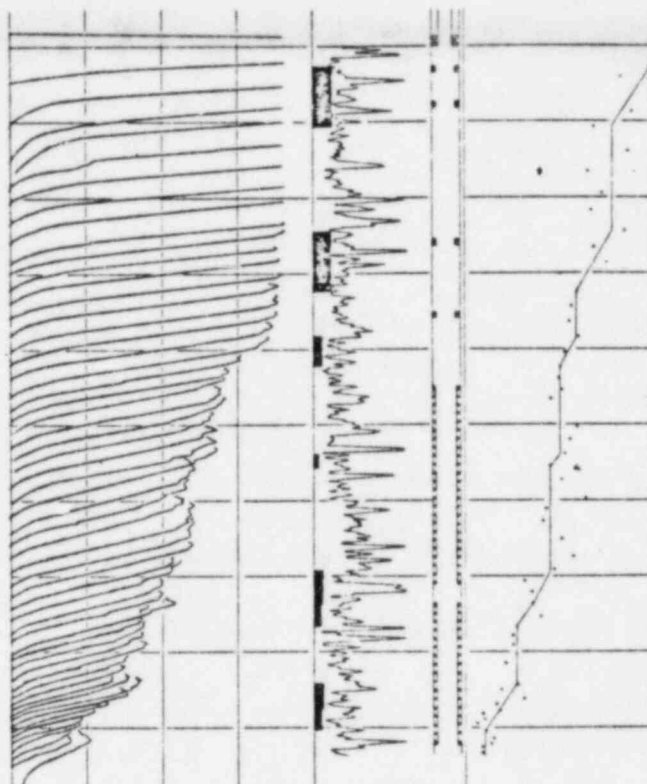


Fig. 6 - Profile as Derived by Determining Interface Movements Down Hole by Successive Logging Runs (Note Dissipation of Radioactive Material as Portions of Fluids are Lost to Formation)

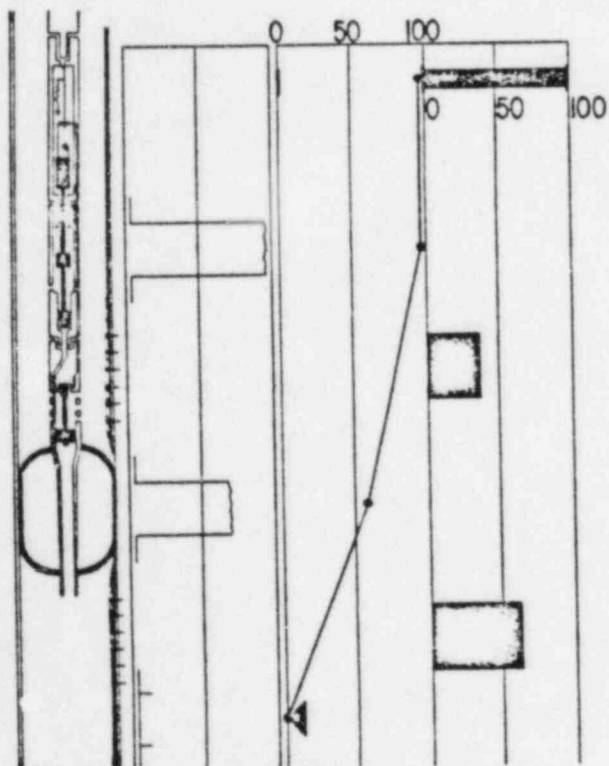


Fig. 7 - Schematic of Flowmeter Tool

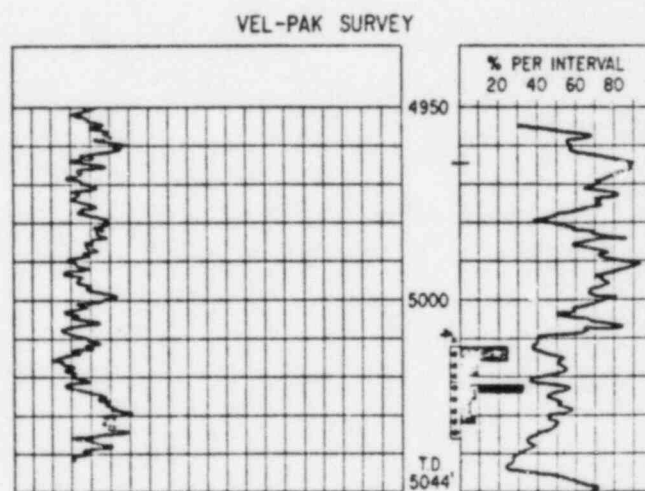


Fig. 8 - Vel-Pak Profile--Thin Zones of Fluid Acceptance Defined

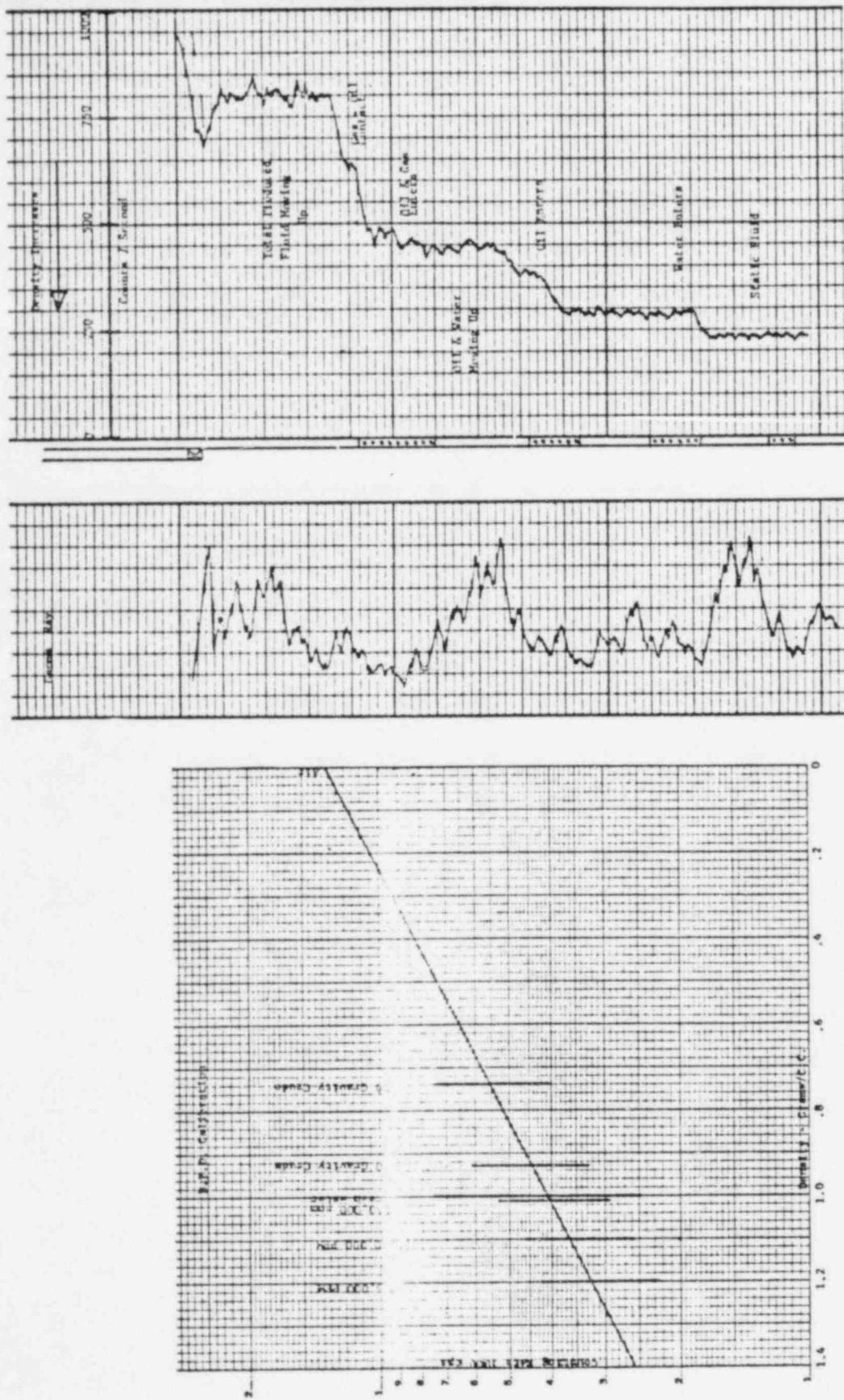


Fig. 9 - Fluid Density Log Showing Reaction as Different Fluids Enter Borehole

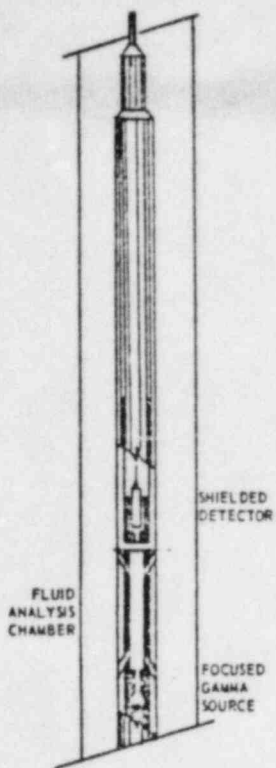


Fig. 10 - Borehole Fluid Densimeter

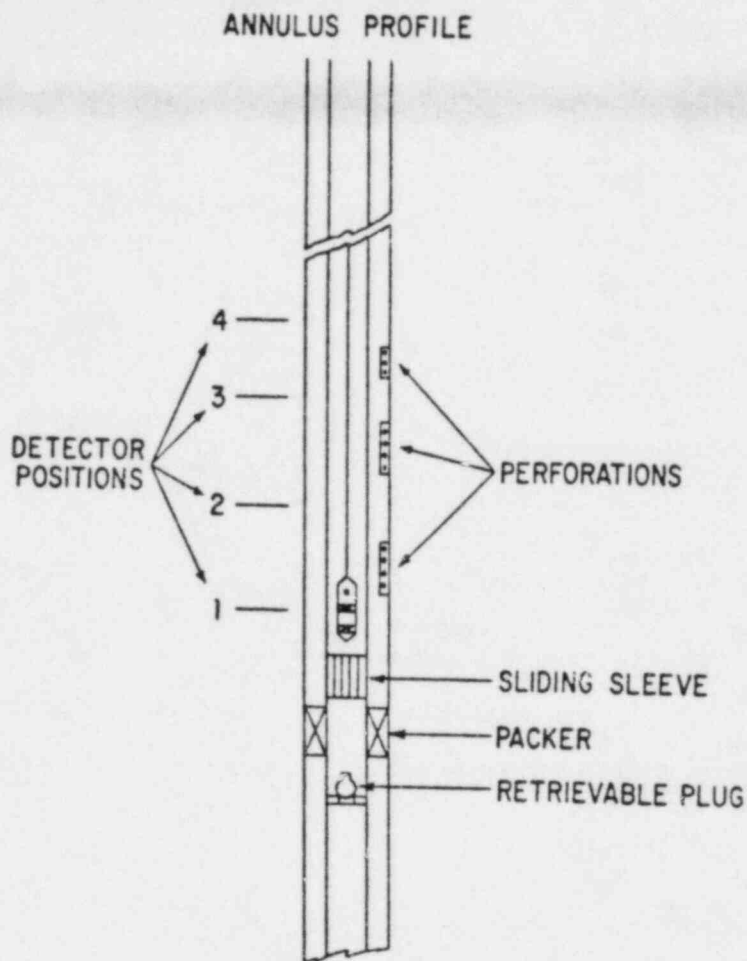


Fig. 11 Dual Injector Rigged for Annulus Profiling

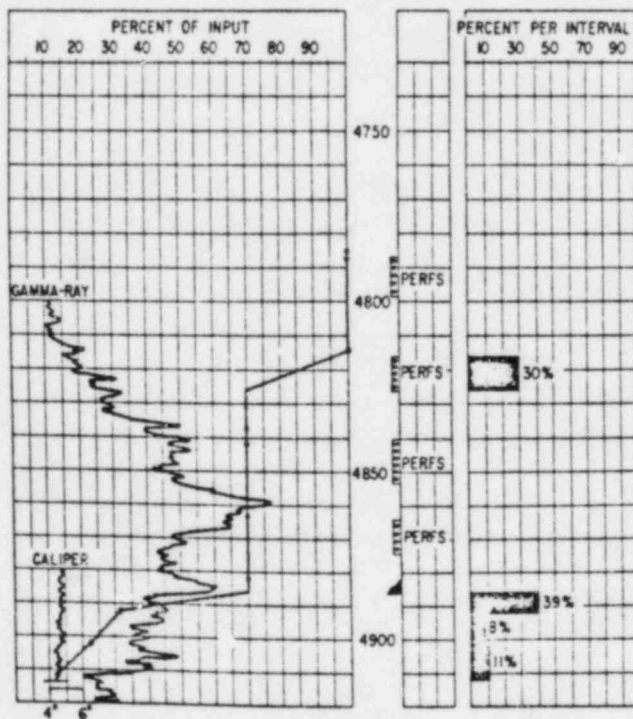


Fig. 12 - Injector Perforations Plugged



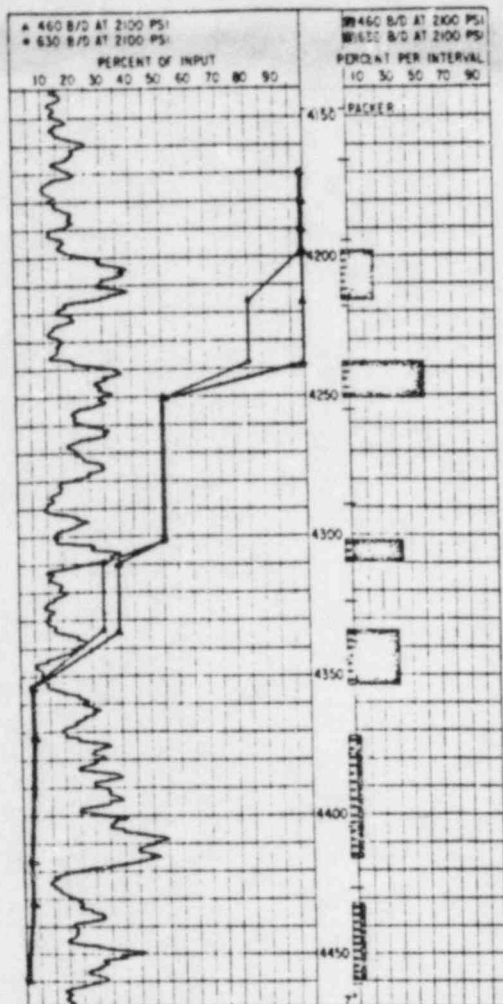


Fig. 13 - Profiles - Two Different Rates

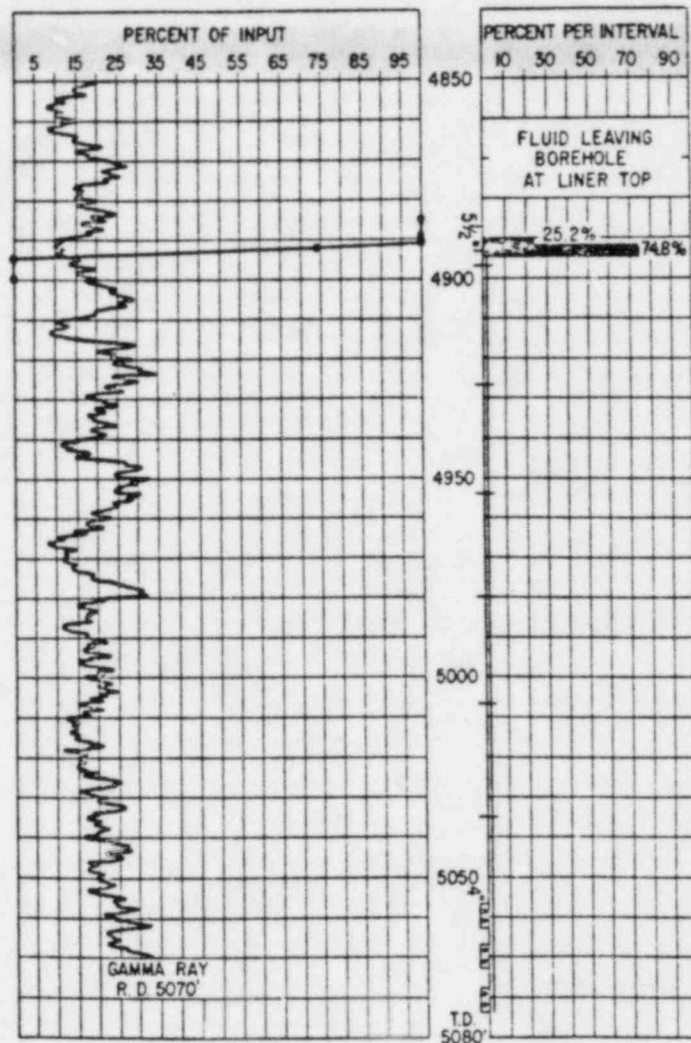


Fig. 15 - Liner Top Leaks

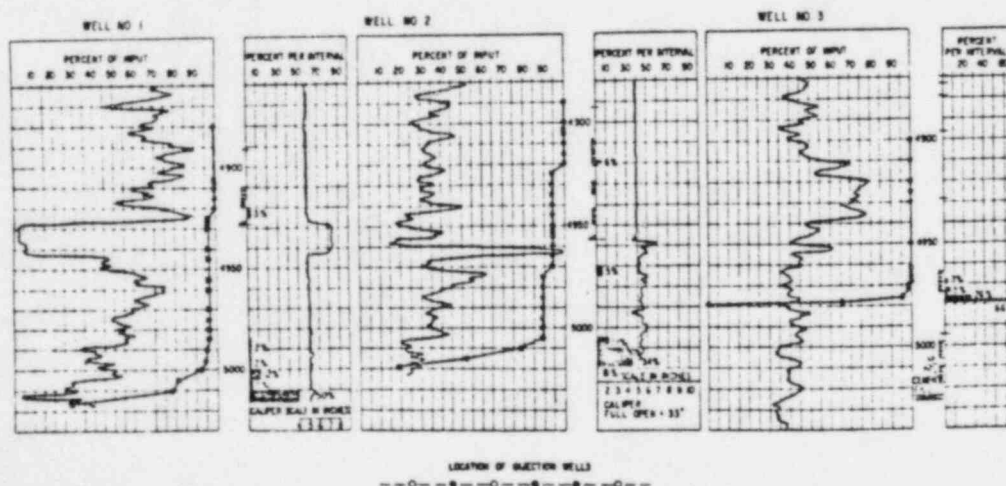


Fig. 14 - Three Wells--Same Formation, Different Profiles



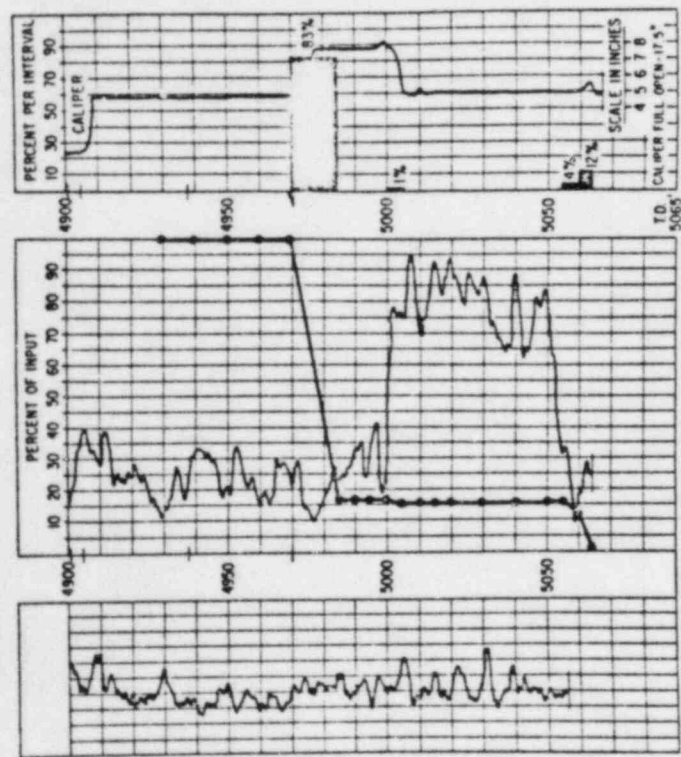


Fig. 16 - Casing Shoe Suspected Channel

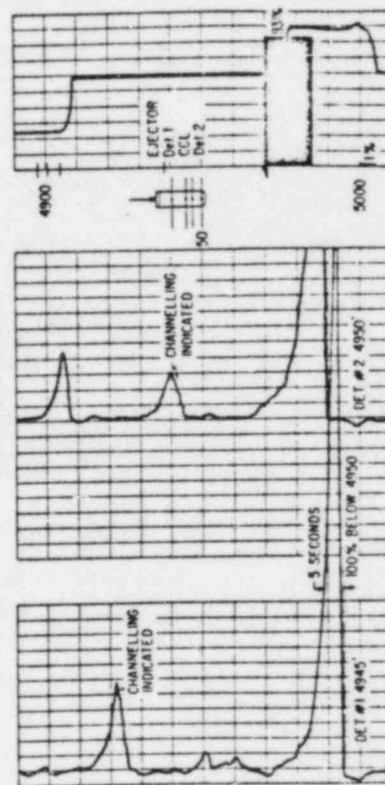


Fig. 17 - Time Drive Recording Channel Check

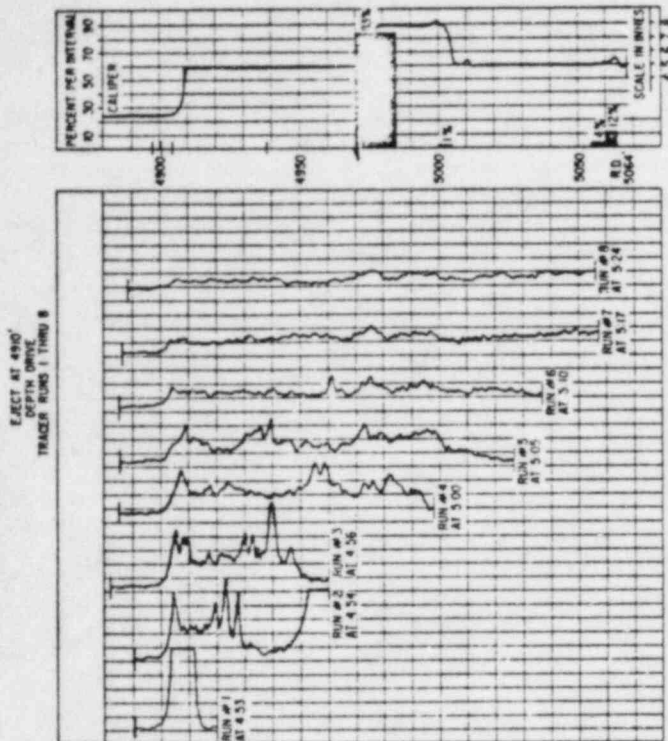


Fig. 18 - Analytical Run - Channel Definition

INJECTIVITY PROFILE  
(In Percent)

Field	No. of Wells	Desired Distribution	Actual Distribution	Thief Zones	Communication	Desired Distribution	Actual Distribution	Thief Zones	Communication	Desired Distribution	Actual Distribution
Cedar Lake	16										
Slaughter Field	69	15.9	100	4.3		18.7	26.1	20.2	25	20.2	26.1
Goldsmith	1										
West Lone Hills	8	12.5									
Mildred Farm	3	66-2/3									
Carrico Band	7	14.3	71.4	28.6	66-2/3	25	37.5	33-1/3		37.5	25
Conglomerate	5	20									
South Caprock Queen	2	50									
Scruboath	7	85.7									
Longlife Morris											

Fig. 19 - Breakdown of Problems--Various Fields

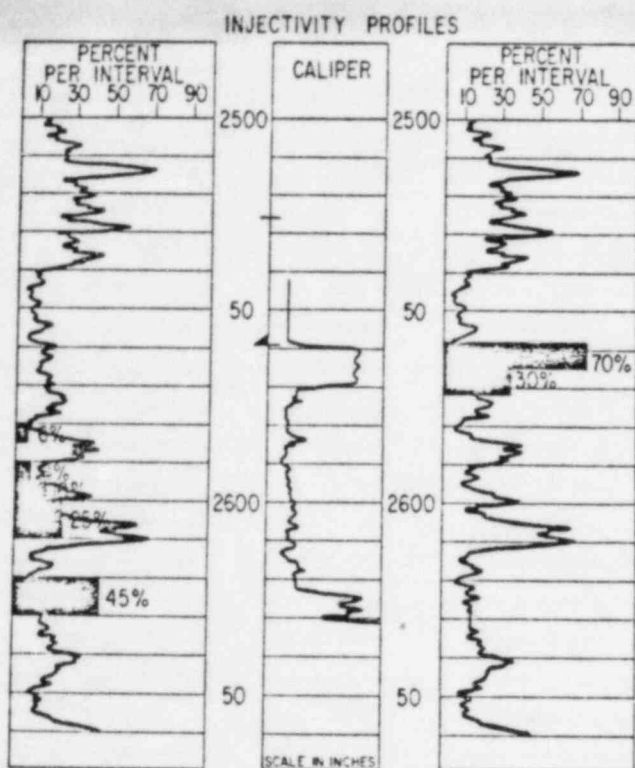


Fig. 20 - Before and After Profiles  
Chemical Grout Treatment

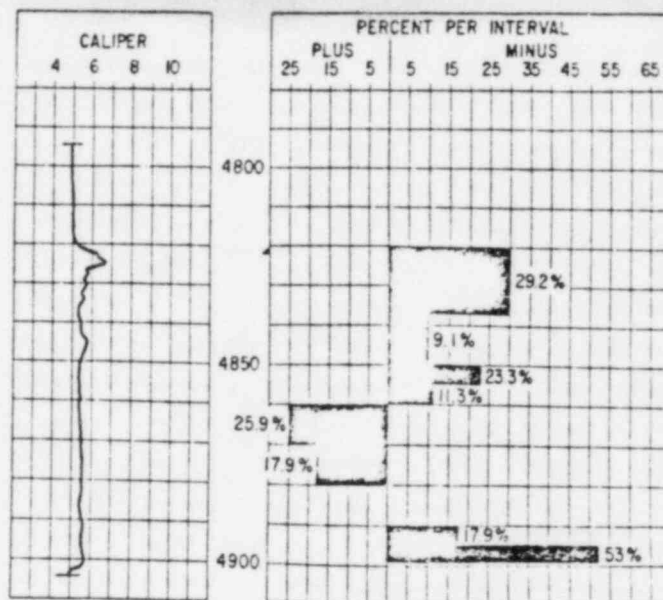


Fig. 21 - Incorrect Profile Flowmeter

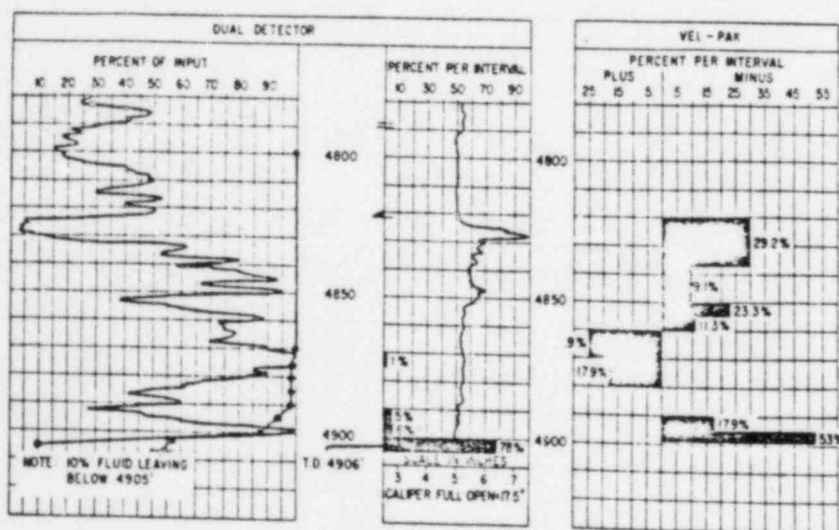


Fig. 22 - Correct Profile vs Incorrect Profile

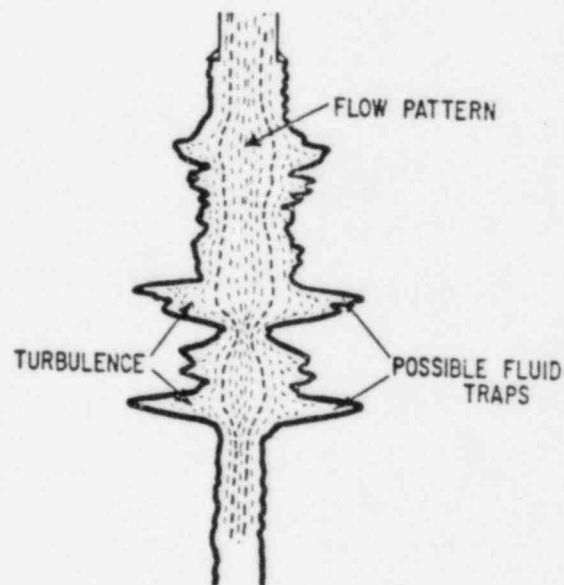


Fig. 23 - Hydraulic Diameter Effects  
Caused by Erratic Borehole Diameters

Customer Flow Rate        BPS        BPD

Western Flow Rate .0023 BPS 200 BPD

Customer Pressure 900 PSI

Western Pressure 1000 PSI

Time Drive Conversion Factor 1 = 1

Date Injection Started 11-60

Cumulative Injection 459,427 BW to 2-1-65

Distance-Ejector - Top Det. 4-1/2'

Distance-Top Det - CCL 2'

Distance-CCL - Bottom Det. 3'

Distance-Top - Bottom Det. 5'

Perforations
Open Hole

Burst No.	Depth Interval	Time Drive Units	Time Seconds	Interval Capacity (bbbls)	Hole Size	Injection Volume (bbbls)	% Fluid Remaining in Bore	Remarks
20	4795-4800		48	.1110	5	.1110	100	
19	4810-15		48	.1110	5	.1110	100	
18	4815-20		48	.1110	5	.1110	100	Cased Hole
17	4820-25		43	.1250	5-1/4	.1005	124	Open Hole
16	4825-30		64	.1960	6-1/2	.1490	132	
15	4830-35		61	.1585	5-7/8	.1420	112	
14	4835-40		55	.1445	5-5/8	.1280	113	
13	4840-45		49	.1380	5-1/2	.1140	121	
12	4845-50		55	.1515	5-3/4	.1280	118	
11	4850-55		60	.1315	5-3/8	.1400	98	
10	4855-60		54	.1250	5-1/4	.1260	99	
9	4860-65		50	.1185	5-1/8	.1170	101	
8	4865-70		54	.1250	5-1/4	.1260	99	
7	4870-75		50	.1250	5-1/4	.1170	107	
6	4875-80		54	.1250	5-1/4	.1260	99	
5	4880-85		54	.1250	5-1/4	.1260	99	
4	4885-90		51	.1185	5-1/8	.1190	99	
3	4890-95		50	.1185	5-1/8	.1260	94	
2	4895-4900		55	.1125	5	.1280	88	
1	4900-05		313	.0685	4	.7280	10	

Fig. 24 - Chart--Erratic Velocities

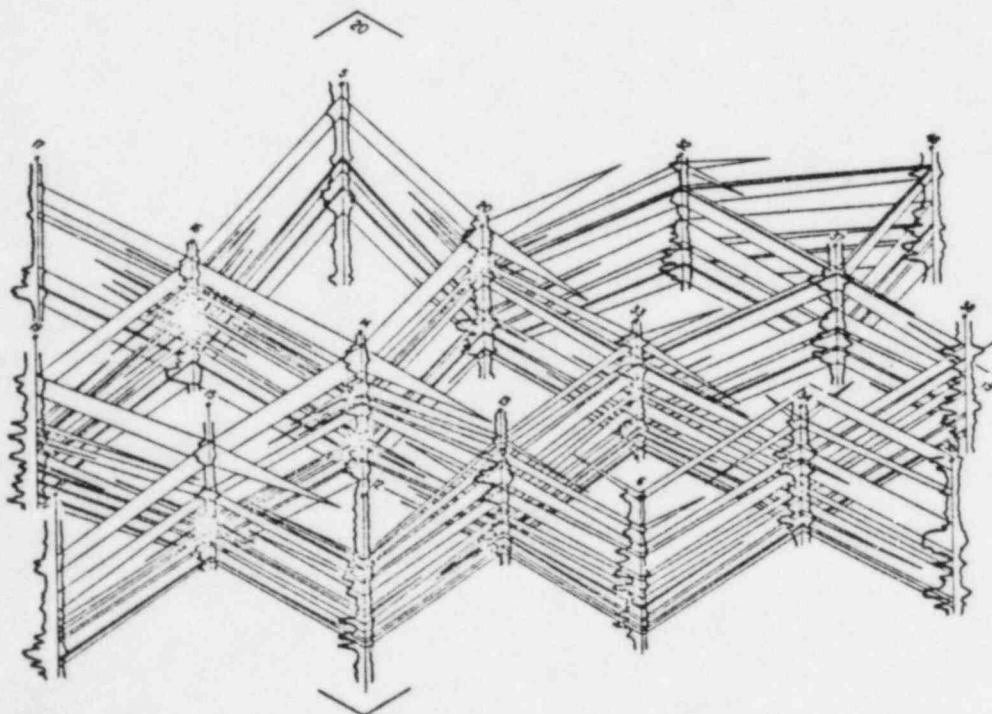


Fig. 25 - Isometric Projection--West Texas Flood

# WELL ANALYSIS COMPANY, INC.

Subsidiary SONICS INTERNATIONAL, INC.



563-0331

P. O. Box 1609

Odessa, Texas 79760

Mr. D.J. Foley, Manager  
Project Engineering  
Nuclear Operation Division  
Kerr-McGee Corporation  
Kerr-McGee Building  
Oklahoma City, Okla. 73102

Dear Mr. Foley;

RE: Reservoir Analysis, Sequoyah Facility

## Purpose

To establish feasibility of consistent storage of liquid waste materials into target reservoir without contamination of potable waters and other useable geologic horizons or endangering surrounding surface environment.

## General Conditions for Consideration

Target well is completed in the Arbuckle Limestone with 7" completion string set through a Hunt, Sytan and Simpson and cemented at 1619', approximately 260 feet below the top of the arbuckle Limestone. Injection interval completed with uniform 11" open hole extending to the top of the granite at 3102'. Location is bounded by two major faults, one five miles to the northwest and one intersected by a third fault, approximately one mile to the East southeast. Total radial exposure to the nearest fault plane approximately 120°. Formation displacement and slippage control derived from seismic data and correlation of two dry hole attempts ( the Smith #1, two miles east and the Highfield #1, approximately three miles south-southwest).

Target well is located upon Company controlled land both surface and sub-surface.

Reservoir evaluation was to be based primarily upon computer calculations and reservoir modeling utilizing high accuracy pressure, flow, time, and injection profile and inhole flow data developed during a well testing program made up of alternating periods of water injected and zero inflow. Additional evaluations of the reservoir and of the well casing and packer and near well bore formation from a leakage stand point were to be made by standard thermal profile and radioactive profile techniques.

H.J. Gruy & Associates, Inc. of Dallas, developed the testing program, evaluated the pressure, flow, time, and injection profile data, performed the computer analysis and reservoir modeling, and evaluated the proposed injection well from an overall stand point. Well Analysis Company, Inc. of Odessa, Texas, provided downhole wireline services and performed caliper measurements, all thermal measurements and all radioactive tracer measurements and calculated the injection pattern and flow characteristics from established radioactive profile techniques and provided a progressive temperature decay analysis. High accuracy downhole and surface pressure recording instruments and chart conversion were provided by Sperry-Sun Well Surveying Company of Oklahoma City, Okla. Water injection, total injection flow, time measurements and additional surface pressure measurements were made by Kerr-McGee.

Multiple dependent and unpredictable parameters dictated that the water injection and data collection be done in phases, each phase determining the details of the subsequent test phase and series of data to be collected.

This discussion is primarily concerned with the interpretation and sequence of the injection profiles and temperature data analysis.

Greater in-depth discussion of the development and application of the survey methods utilized in this study is provided in the accompanying technical articles.

A.P.I. #906-9-E Review of Tracer Surveys.

S.P.E. #1329 Maximum Use of Profile Information.

A.P.I. "Factors Considered in Interpretation".

S.P.W.L.A. "Computers to Increase Value of Temperature Logs".

S.P.E. #1752 "Fluid Flow Analysis Techniques".

S.P.E. #2255 "Computerized Temperature Decay".

S.P.E. #2685 "Interpretation of Injection Profiles".

A.P.I. #906-15-J "Practical Field Interpretation of Temperature Surveys".

Other accompanying information:

5 Panel Composite of the Survey Results for Reference during discussion. Panel 1 and 2 are representative of Phases One and Two, respectively. Panel 3 and 4 are Injection and Counterflow tests described during Phase Three. Panel 5 display the injection profiles of each of the three phases, plotted together for comparison. Panel 5 composit results are the qualified conclusion of the WACO log analyst. Quantitative results of the surveys have been modified by qualitative interpretation of both Temperature and Radioactive Surveys.



## TECHNIQUES OF PROFILE INVESTIGATION

### 1. RADIOACTIVITY PROFILES - INJECTION OR PRODUCTION

#### 1. Tools

Instruments used are two gamma sensitive detectors and a dispenser of a water solution containing Iodine-131 incorporated into a single downhole tool. The device is run in the well on a conductor line to a measured depth and a base radiation activity of the well bore recorded. A small quantity of the radioactive isotope solution is then released at a selected interval in the well and the path and rate of movement of the shot of liquid containing the radioactivity within the well bore is charted by observing the reaction of the detectors at various depths. These reactions are recorded and the data evaluated, both qualitatively and quantitatively, to define the pattern and relative volumes of injection accepted by each of the subsurface intervals.

#### 2. Calculations and Methods

Two methods of data collection are used in the investigations.

##### a. VELOCITY DETERMINATIONS

Radioactive solution is released upstream of the gamma detectors and is carried past the detectors by the moving stream of injection. The transit time over a given interval ( 5' normal spacing) is measured and corrected for parabolic flow variations and well bore diameters. The volume of fluid contained in the measured interval of well bore (5') is calculated; and utilizing this information along with the transit time, the rate of fluid movement, expressed in bbl/day, past the interval is derived. This action is repeated at selected intervals in the well and a subtraction curve developed. The results are then plotted as fluid acceptance intervals, or the injection profile.

##### b. RADIATION EQUIVALENT VOLUMES R.E.V. OR SELF METHOD

These measurements are accomplished by releasing a given amount of solution containing a radioactive isotope at a point upstream of the zone of interest and measuring its relative activity by recording the reactions of logging tools (radiation detectors) during a traverse run through the zone containing the radioactive material. The resulting curve (or graph) is triangulated and an index number assigned which represents the total amount of radioactivity in the designated interval of the well bore. As this volume of fluid moves downstream, repeated timed traverses are made through the radioactive zone, charting the position and activity level in each instance. These curves are also triangulated and their indices assigned.



Should a portion or all of the increment of fluid carrying the isotope leave the well bore and enter the formation, a proportional amount of radiation will also be diverted, since the isotope is completely soluble and mixed within the fluid stream. (The radioactive material traveling into the formation quickly becomes non-detectable to the radioactivity instruments). The variation of the assigned indices will reflect the radioactivity and hence, fluid loss at each interval and may be plotted in relative percentage to the original index. When vertical dispersal of the isotope increases to the point that accurate measurement becomes difficult, a new increment of isotope is released, and assigned the percentage represented by the last traverse through the original shot or increment. The new shot of material is then followed downstream by the same logging methods and the continued reduction of index and hence, loss of fluid into the formation is defined.

These techniques are both subject to a possible 15% error (related to 100% fluid travel), but the parameters affecting each are different than those of the other and accuracy control is effected by comparison of the two results. Additional information may be inferred by these comparisons (i.e., vertical erosion or fracturing adjacent to and connecting with the well bore). These would affect the velocity determination, but leave the radiation equivalent relatively unaffected. Thin zones of fluid acceptance may be closely defined by velocity techniques but only averaged over an extended interval by R.E.V. methods. Caliper logs are essential to velocity calculations but not needed for R.E.V. velocity calculations usually represent maximum flow rate at any given interval- R.E.V. measurements are necessarily minimal determinations.

Profiles derived from these combined methods can be expected to exceed 95% accuracy with respect to total flow.

## 11. TEMPERATURE DECAY SERIES.

### 1. Tools:

The downhole instruments consist of pulsing oscillator controlled by a calibrated temperature sensor. The downhole tool is run into the well by conductor line containing signal wire running back to surface recording equipment and the indigent temperature is monitored at each depth. The signals are sent back to the surface and recorded as temperature in degrees F°.

### 2. Methods and Techniques:

Temperature data are collected in ambient temperature only. Variations expressed as differential, or delta logs, are derived from the basic collected data. Data may be recorded by station setting, (tool held stationary at selected depths for a specific recording time) or by a continuous traverse over the entire interval of interest. Repeated runs or traverses made with the same tools and calibrations reflect the changing temperatures at all depths with respect to time, and are termed a "Temperature Decay Series".

Decay series are recorded with respect to time. A basic temperature under constant conditions is recorded by either traverse logs, or station settings. The base, or constant conditions are then altered and the resultant temperature transients during well bore recovery are recorded at timed intervals.

### 3. Interpretation:

The data recorded must be considered the temperature of the well bore only, since the information is collected at the terminal point of an equilibrium process.

The Temperatures at any point are the net results of all the surrounding thermal transfers. The temperature of the surrounding matrix is the influence for well bore temperature progression, however, and bore hole fluid attempts to assume the temperature of the adjacent dominant thermal field.

A depth of investigation may then be inferred by observation of the rates of change caused by these adjoining fields or cells.

Temperature fields generated by convection thermal transfer differ in initial recovery rates from fields caused by radiation or conduction only.

Comparison of these varying rates of recovery identifies the zone of fluid movement thru the formation by reflecting the influence of the more nearly isothermic conditions extending to a greater radius from the well bore.

Temperature influence from any matrix surrounding the well bore depends upon a completely static fluid column, else the reflected temperature will be distorted by vertical in-hole convection thermal transfer.

### 4. Information:

Properly executed, thermal decay surveys confirm fluid exit or entry intervals in the well, and define zone thickness or height beyond the limits of any in-hole rate determination method. Quantitative values cannot be applied however except under ideal conditions. They may also be useful in determining leakage from the casing or upward around the casing and thence into a higher formation.

## 111. ANALYSIS OF SURVEY RESULTS

The operating requirement of injectivity profiling and single point pressure fall off are not compatible to simultaneous surveying. A sequence of operation was scheduled to allow the most valid and efficient collection of all data.

### Preinjection Testing:

1. After setting up well head for entrance of logging tools, dummy run was made to check hole for obstruction using simulated instrument package.

2. Caliper survey of the open hole was made.
3. Pressure survey and static bottomhole measurements.

Phase One Sequence:

1. Well was placed on injection at a selected rate and allowed to reach initial relatively stabilized conditions.
2. A Radioactive profile was run using both velocity, and Radiation Equivilent Volumes for quantitative calculations. A base injection temperature run was made at this time.
3. Sperry-Sun pressure equipment and WACO Temperature Tool placed downhole @ 2900' and Well shut-in (injection stopped) for monitor of pressure.
4. Sperry-Sun instrument retrieved and well placed back on injection.
5. Injection stabilized and well shut-in for Temperature Decay Series.
6. Well placed back on injection.

Profile and Temperature Analysis of Phase One determined:  
Four gross injection intervals.

- A. 1720' to 1820' 30% of injection volume with 24% between 1755' and 1790'.
- B. 2610' to 2655' 38% of injection volume.
- C. 2760' to 2780' 12% of injection volume.
- D. 2820' to 2855' 20% of injection volume.

No injection continued below 2860' during the first injection period and no other zones were accepting fluid at the time of the Radioactive Survey. (See plots of Velocity and R.E.V. calculations on right side of 1st. panel).

Temperature Decay monitors indicated that a Fifth zone may have opened up and accepted some small portion of injection during the second injection period. This is inferred from the definite indication of after shut-in counterflow from 2700' upward into three intervals. The injection zone "B" 2610'-2655' and two new intervals, 2300'-2305' and 2360'-2365' strong counterflow exists from 2700' into zone "B" (note isothermic pattern of temperature decay curves over this interval) with only a small amount continuing upward to the two new intervals.

The influence of the additional zone of injection, and the after shut-in counterflow was observed on both the pressure monitor and the station setting temperature decay. This evidence of the net injection interval change with fill up caused phase two to be designed around both short and long term pressure decline with an injection profile to determine the current net injection pattern.

#### Phase Two Sequence:

1. Injection resumed after the decay series temperature program was completed and continued for 112 hours for stabilization.
2. Radioactive Tracer (Velocity and R.E.V.) was run to establish injection pattern.
3. Sperry-Sun pressure equipment and WACO Temperature Tool run into hole to fixed position and well shut-in (injection stopped) for testing.
4. Five hour pressure and Temperature monitor run @ 2650', Then tools removed and replaced with Sperry-Sun pressure instrument only with recorder set for 72 hour record period.
5. Pull and re-run pressure instrument with recorder set for 72 hour pressure measurement.
6. Analyze first 72 hour pressure chart then remove pressure equipment and resume injection.

#### Phase Two Profile and Temperature Analysis:

Original gross intervals of injection still exist, but with a significant change in the fluid distribution into zone "B" 2610'-2655'. The net interval decreased to 25' (2620'-2645') and the volume into zone decreased from 38% (Phase 1) to 11% of total injection. The water originally entering this zone was diverted into three thin intervals between 2710' and 2810' (see panel 5). Both zone "A" and "D" decreased in net thickness with very little change in accepted volume.

A small interval just below the small areas which the temperature profiles indicated were accepting counterflow during Phase One, now accepted approximately 8% of the diverted injection (2420'-2425').

Reference to the decay series of Phase One indicates that this zone may have been accepting injection intermittently during the first tests. (note retarded recovery of first shut-in temperature decay with respect to subsequent runs 1st. panel).

Erratic velocities between 2240' and 2370' indicate possible zone interference during injection but R.E.V. calculations show no significant fluid losses through the interval.

Phase Two pressure and temperature data again reacted to the after shut-in counterflow conditions and Phase Three was projected to chart the magnitude and full extent of fluid movement during shut-in.

#### Phase Three Sequence:

1. Injection continued for 24 hours.
2. Injection Profile run using R.E.V. methods only.
3. Well shut-in and production profile techniques used to determine counterflow extent.

### Phase Three Results:

Injection patterns again changed but the 4 original gross intervals continued to accept fluid. The lower zones show a marked tendency toward reduced volumes with continued injection, and the diverted fluids are being accepted by the top interval (increased injection into zone "A" from 30% to 46% during testing phases).

The counterflow conditions during shut-in were more extensive than first analysis indicated (see panel 4).

Shots of Radioactive Isotope, placed at indicated depths and traced, show fluid moving up from zone "D" past "C" and "B" and a portion moving to the top of the section into zone "A".

Rate of initial counterflow is approximately 240-280 bbl/day but about 60% of this volume re-enters the formation between 2280' and 2380', one of the original zones accepting counterflow. The remainder of the fluid moves up the hole and is lost to zone "A" (1750'-1800').

Zone "B" (2620'-2645') which originally accepted the major portion of the counterflow is presently receiving none, but appears to be contributing a small increment instead.

No fluid is moving at 1700' and none is entering the well bore below 2870'. (see shots #3 @ 2865' and #8 @ 1675' 4th. panel).

Lines connecting the average slope centers of each shot of material as they progress uphole show a visual reference to the relative rates of fluid movement.

Zones of fluid acceptance may also be qualified by distortion of the material distribution patterns. (See consistent distortion and intensity loss @ 2300', and runs 10 thru 22).



Conclusion:

Examination of primary open hole logs show a net probable injection zone thickness of approximately 700' over the open hole section. Of this, only 175' (approximate) is accepting injection.

Permeabilities are layered throughout the entire interval with no apparent vertical permeabilities or fractures connecting the zone. (Hence, the counterflow under shut-in conditions).

Fluid is being accepted well above total depth, (bottom of the hole) and below the casing point, and there seems to be no problem in containing injection well within the vertical limits of the formation at this point in the reservoir.

From analyzing the thermal profiles and radioactive tracer records, there are no indication of channels, leaks, holes, or other mechanical failure at the casing seat or above and no channel or leak around the packer.

Injection zone locations and extent seem rather sensitive to pressure build up and the amount of fluid injected into new zones could probably be increased by selective acidizing. The tendency for intermittent injection seems to bear this inference out.

The tendency of the lower zones to accept progressively smaller volumes points to the possibilities of relatively smaller pore volumes of permeability pinch outs or local restrictions near the well. Should the pressure data indicate the latter, selective treatment will alleviate this problem.

The opinion of WACO analysts is that net injection interval could be increased approximately 200% by proper treatment.

A program of consistent scheduled monitoring should be initiated to identify and control net volume per foot into each interval and to guard against shortening the life of injection through inefficient injection patterns.

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