CARDINAL SURVEYS COMPANY

Injection Profile Procedures

CARDINAL

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I. Introduction

The injection profile is an analogy of injection fluid movement down the well bore and into the formation or formations. Along with a profile of fluid losses versus depth, the injection profile log gives a good indication of the mechanical integrity of the well, including fluid channeling away from the well bore.

This paper deals with injection profiles obtained by the use of radioactive tracers. The radioactive tracer has proven to be the most reliable logging technique to give operators qualitative and quantitative evaluations of injection fluid placement and aid in evaluation of the performance of water floods. It is applicable to a wide range of fluids and fluid injection rates.

Other data normally included in an injection profile log include temperatures, calipers and casing collar locator logs. The combination of these elements, when properly interpreted, yields a complete picture of the performance of an individual injection well.

II. PREPARATION

One of the most important aspects of obtaining good tracer profiles must be done before the Service Company arrives on location. The well must be adequately prepared for conducting the profile. The operator and the service company should work together to see that both parties are prepared.

The operator should review well records and prepare a well bore diagram. This diagram should indicate the current condition of the well, including significant past factors and changes. Well bore equipment such as casing, liners, tubing, packers, plugs, casing shoes and down hole control valves (mandrels) should be indicated including the sizes, weights and depths. Packers, seating nipples, surface valves, and any other equipment with small I.D.'s should be reported to the Service Company for selection of logging tool sizes. Perforations, open hole intervals, plugged or squeezed zones, thief zones, channels, and other known areas of possible fluid loss should be indicated.

Preparation of the well:

The tubing or tail pipe should be at least fifty feet above the top perforation or casing shoe to obtain 100 percent velocity measurements, 100 percent intensity runs, channel checks, and packer checks. More than fifty feet may be required for higher rate wells. The operator should install a full opening valve above injection equipment so the injection rate will not have to be modified to enter the well. However, high rate injection should be shut off while passing through wellhead to avoid damage to the logging tools and wire line.

The operator should arrange for a slick line service company to make a sinker bar run to verify well total depth and obstruction clearances with a weight bar of same O.D. as the survey tools. Be sure that a rate meter and pressure gauge are available and working. The well should be stabilized at the desired rate and pressure to be profiled for a minimum of 48 hours prior to survey.

Information needed at the well site:

For multiple well projects, maps with locations, roads, and plants are required. A tabulation of injection rates and pressures for each well is desirable. For depth correlation and preparation for the logging operation, well diagrams, previous profiles, primary logs, gamma ray and collar logs should be available for each well to be profiled.

The Service Company should be informed of any unusual conditions, remote injection control valves, higher well head pressures (above 2000 PSI), safety hazards (hydrogen sulfide) or any restrictions or modifications to normal procedures. Policies should be discussed that would require additional equipment such as breathing apparatus, H_2S monitors, and fluid containment systems.

Service Company preparation:

From the information obtained from the operator, the Service Company will have the proper pressure control equipment for the expected well head pressure. Pressure control equipment must include a wire line blow out preventer, tool trap, a full-opening bleed off valve, pressure control head, and lubricator. All equipment must be rated and tested to the expected working pressure limit. The selection of tool size will be determined by the smallest internal diameter of the well equipment. The standard tool configuration includes a collar locator, a radioactive ejector, detector, three-arm caliper, and a temperature tool. The standard radioisotope is Iodine (I-131) in a solution compatible with the type of fluid being injected.

Documentation needed at the well site:

Company Safety Policy and Procedures manual, Material Safety Data sheets, Radiation License, and Document of Awareness. The operator must sign the Document of Awareness.

III. OBJECTIVES

SAFELY perform the operations specified in this procedure.

Make an accurate quantitative interpretation of the injection profile.

Detect down hole equipment failures (e.g., packer, casing and tubing leaks).

Detect fluid communications behind the casing (between zones as well as above and below the injection interval).

Meet the above objectives with minimum risk to the well bore, the injection equipment and the logging equipment.

IV. PROCEDURES

In all operations related to running an injection profile survey, the logging company will comply with all Nuclear Regulatory Agency regulations and all regulations of state radiological control agencies for the state in which the injection profile survey is being run.

In all operations Cardinal Surveys Company will follow the safety guidelines provided by the operator.

Cardinal Survey Company reserves the right to refuse to perform service when in violation of Cardinal Surveys Company safety policies.

All operations should be performed according to the specifications found in this procedure and found in the definitions following this procedure.

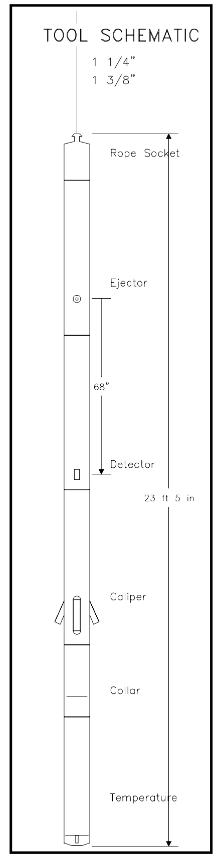
If for any reason the logger is unable to complete the following procedures as specified, then the logger should notify the operator of the problems encountered. The logging company shall provide the following information:

a. Reason for incomplete work.
b. Well name and number.
c. Observed condition of surface equipment including leaks, rates, pressures and other abnormal conditions.
d. Depth of down hole restrictions or obstructions.

A. The following well information will be obtained from the operator prior to rig up: packer depth, tubing size, casing record, elevations, injection rate and pressure, legal location, perforation and open hole depths and correlation logs with collars and gamma ray.

B. Rig up and go in hole:

1. Be careful not to damage surface equipment (i.e., meters, gauges, etc.) when rigging up. If injection control valve is remote of wellhead use LOCKOUT/TAGOUT procedures. Conduct pre and post job radiation level surveys.
2. Install mast unit and lubricator with pressure control equipment capable of handling the surface pressure of wells to be logged.
3. The tracer survey tool will consist of a collar locator, an ejector, one or two scintillation detectors and a temperature sonde. A caliper tool (minimum of 3 arms) may be required.



Tool size should be determined from smallest I.D. of down hole well equipment. (Required size should be known prior to arriving on location).

The type of radioactive material carrier should be determined based on the composition of injection fluid. Ejector tools will be loaded with radioactive material according to Cardinal Surveys Company Ejector Loading Procedures.

The temperature tool will be located at the bottom of the tool string. The detector will be located below the ejector. At higher injection rates, more spacing may be necessary, normally provided by either a sinker bar or the caliper tool. Collar locator and caliper tools will be placed in the tool string so as to facilitate the logging operation.

All tool components (ejector, detectors, etc.) run will be permanently and clearly stamped with serial numbers. No two pieces of equipment in a logging company's inventory will have the same serial number.

4. The injection stream should be shut off temporarily while the logging tools pass through the wellhead, unless proper valves are provided and the rate is not too high.
5. While going into the hole, take a temperature reading 100 feet from the surface.
6. Tools shall be run in the hole at the speeds allowed by operator. When the tools reach a depth of 100 feet above the packer, the line speed should be reduced to 50-60 feet per minute. To reduce the chance of tools being damaged by a bridge or other unknown down hole obstructions, the first trip from the packer to log total depth (L.T.D.) will be made at a line speed no greater than 50-60 feet per minute. After it is known that there are no obstructions, the tools may be moved as rapidly as necessary to perform intensity runs as long as the tools are below the packer. Wire line tools should not be moved faster than the speed allowed by operator while inside the tubing. An exception is allowed in the case of tubing drop shots.

NOTE: STEPS C-E MAY BE DONE IN WHATEVER ORDER IS MOST CONVENIENT FOR THE LOGGER.

C. Check Injection Rate.

1. Measure the instantaneous rate from the meter by taking the average of 3 different readings taken a minute apart.
2. Record average reading and meter make and model on the log heading.
3. If the well has a totalizer, record reading and time of day on the log heading (beginning and end of logging operation).

D. Run an injecting temperature survey as specified in the attached definitions.

E. Run a gamma ray and collar log and correlate to log provided. The gamma-ray log shall be run at a reduced line speed on high sensitivity. The location of casing shoes, casing collars and packers shall be indicated. The well log total depth (L.T.D.) shall be checked and recorded. Note that only scintillation detectors are to be used for gamma ray and profile runs.

F. Run gamma-ray base log at reduced sensitivity to provide a back ground recording prior to the tracer survey. Logging speed should be approximately 100 feet per minute, or at a speed equal to anticipated intensity run speed.

G. If required, run a caliper survey from L.T.D. to the packer. A minimum of three maximum-diameter-recorded arms is required to determine hole size. The caliper may be run in combination with any of the other tools. Make a repeat run to verify tool operation.

NOTE: STEPS H-J MAY BE DONE IN WHATEVER ORDER IS MOST CONVENIENT FOR THE LOGGER, AS LONG AS THE INTENSITY PROFILE IS RUN BEFORE THE VELOCITY PROFILE.

H. Run an intensity profile as specified in the attached definitions.
1. Locate the ejector tool at an appropriate depth above the top perforation (above the packer is permissible). Eject a slug of radioactive material and remain stationary until the slug reaches the detector. Drop to an appropriate depth and begin the logging procedure.
2. At least 3 drag runs shall be made through the radioactive material slug before the slug reaches the top perforation or open hole interval. Exceptions will be only in the case of high injection rates, small hole diameter conditions, or limited spacing between the packer and the top of the injection interval. THE EXISTENCE OF THESE CONDITIONS SHOULD BE NOTED IN THE COMMENTS SECTION.
3. In most cases, an attempt should be made to obtain as many drag runs as necessary, spread out through the injection interval, to provide adequate resolution of fluid loss. If well conditions such as high injection rates or small hole diameter cause an insufficient number of runs, then the intensity profile should be repeated with a second slug.

(These are only guidelines for determining with reasonable accuracy the different intervals taking injection. If, for example, 100% of the injection into a well is exiting the top perforation, then the number of drag runs that is required to accurately profile the well would be few.)

4. Calculations of percent loss will be based upon the area constructed from the recorded log response from pulling the detector through the radioactive slug. Base (background) readings will be used to correct area calculations. Calculation of percent loss will NOT be based on the sum of the base and height (Self's Method), or by crude triangulation.
5. The radiation slug will be logged through at the same constant velocity on every drag run (normally about 100 feet per minute).

I. Run a velocity profile as specified in the attached definitions.

Generally, the velocity profile is conducted by taking stationary velocity readings at predetermined depths (stations) starting at the deepest applicable location of the well bore. Velocity "shots" are recorded versus time, with the tool string maintained in a stationary position. The profile is assembled from the reaction times for the radioactive material to move from the ejector to the detector. The velocity profile must be run from the bottom of the well up in order to prevent radioactive contamination in the well bore.

Note: In wells with perforated intervals, if the interval is less than 10 feet, the velocity readings will be placed above and below the interval. If the section is 10 feet or more, the interval should be broken down with multiple readings. Long intervals should be logged as open hole (approximately every 10 feet).

J. Channel Checks (see attached definitions).

1. Run a downward channel check if movement below the injection interval has been determined by the profile, or if deemed necessary by injection temperature survey or other information. Use a No Flow below perforations to confirm movement outside casing in the cement annulus, or other mechanical channel. Note that the channel check must be performed prior to the ejection of a slug below the last perforation, or radioactivity will mask the channel check.

This step is not necessary if it is not possible to place the tools below the perforations to eject a No Flow. If removal of tools below detector will allow room, then trip out of hole and reconfigure the tool string.

2. In cased wells, channel checks will be made within the injection interval wherever the intensity profile indicates a possible channel, or as deemed necessary.
3. A check for an upward channel around the casing shoe will be made in all wells with open hole completions.
4. A check for a channel up at the top of the injection interval (the top being determined by the velocity profile) will be made in all wells. See attached definitions.

K. Run a packer check (see attached definitions).

G. Run tubing drop shots (see attached definitions).

Note: Tubing drop shots are required to verify metered rates. The accurate internal diameter of the tubing string must be known. This is critical for internally coated tubulars.

L. Check Injection Rate.

1. Measure the instantaneous rate from the meter by taking the average of 3 different readings taken a minute apart.
2. Record average reading and meter make and model on the log heading.
3. If the well has a totalizer, then record the reading and time of day.
4. Calculate an average injection rate from the difference between totalizer readings taken in step (C) above and the current reading along with the time interval between the readings. Record on the log heading.

M. Run shut-in temperature surveys as specified in the attached definitions.

N. Run crossflow checks as specified in the attached definitions.

O. Return the well to injection.

P. Remove tools from the well and rig down.

1. Tools should be brought through the packer and into the injection tubing at low speed. Line speed should be reduced when the tools are within 100 feet of the wellhead.
2. The injection stream should be temporarily shut off while the logging tools pass through the wellhead.

Q. Draft logs meeting specifications in section called "Log Presentation".

R. Distribution list of final log prints should be provided by operator.

V. DEFINITIONS

A. CHANNEL CHECKS

1. The tool configuration consists of at least one scintillation detector located below the ejector.

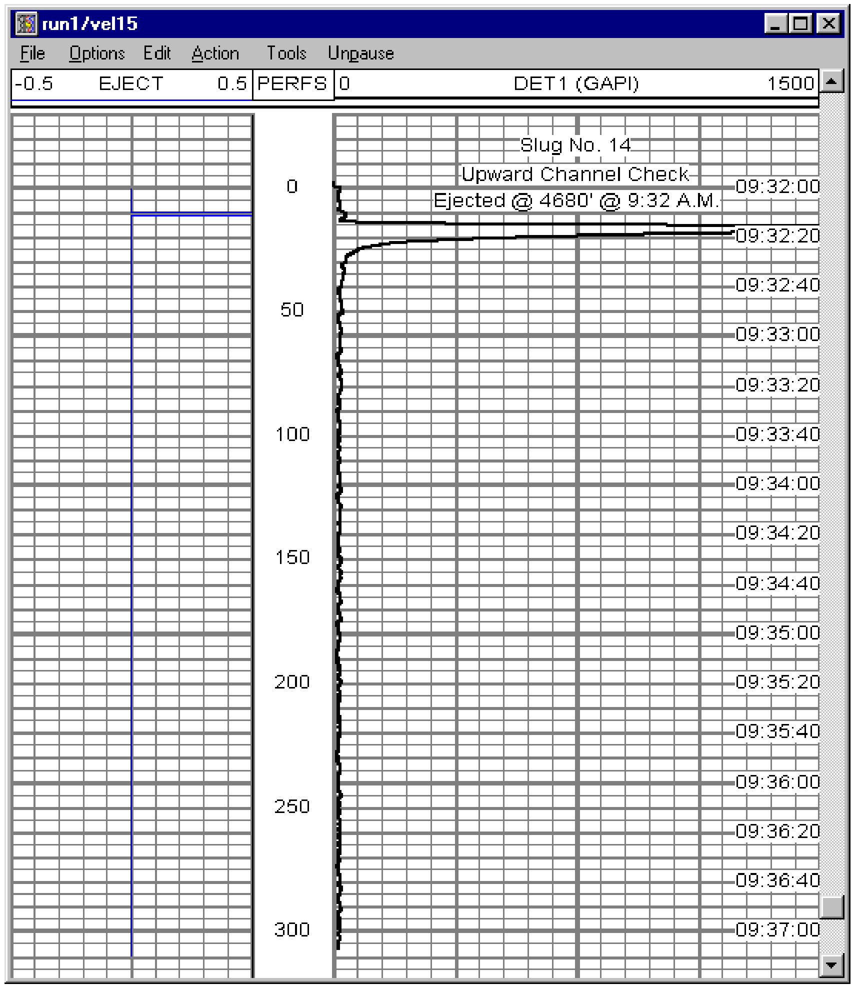
2. To follow a channel down (communication) within the injection interval:

a. Data are recorded versus well depth.

b. Radioactive material is ejected just above the point where the channel being checked is expected to originate. Material must be ejected above a known point of fluid exit.

c. The interval of the channel is logged through repeatedly (recorded versus depth) following the channeling radioactive slug until the end of the channel is located.

Note: This method can be used for liner top check.



3. To locate and follow a channel down below the injection interval:

a. Data are recorded versus time.

b. The tool is situated such that the detector is located below the bottom of the injection interval and the ejector is located above the bottom of the injected interval (lowest point of fluid exit).

c. A slug of radioactive material is ejected.

d. The tool string is held stationary waiting to detect the leading edge of the radioactive slug channeling down. Five minutes is the minimum monitoring time.

e. After the channel of radioactive material is detected, the tool is repositioned down hole approximately 5 feet and step (d) is repeated.

f. Step (e) is repeated until the channel can no longer be detected.

g. Drag detector tool through area with readings recorded versus depth.

4. To locate and follow a channel up:

a. Data are recorded versus time.

b. The detector is placed 5 feet above the suspected channel's origin.

c. A slug of RA material is ejected and seen to pass by the detector inside the well bore.

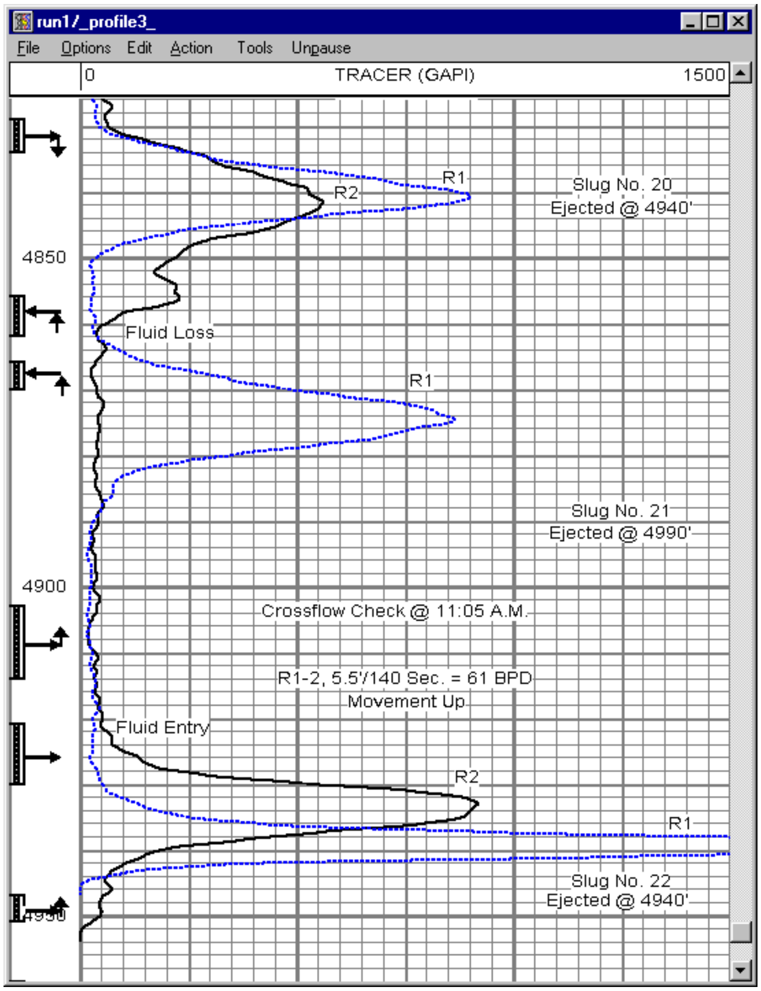
d. The tool string is held stationary waiting to detect the leading edge of the radioactive slug channeling up. Five minutes is the minimum monitoring time.

e. After the channel of radioactive material is detected, the tool is repositioned up hole approximately 5 feet and step (d) is repeated.

f. Step (e) is repeated until the channel can no longer be detected.

g. Drag detector tool through area with readings recorded versus depth.

B. CROSSFLOW CHECKS



1. The tool string consists of at least one scintillation detector located below the ejector.
2. Crossflow checks are run while the well is shut-in.
3. Data are recorded versus depth.
4. Fluid velocities throughout the well bore are determined as follows:

   a. Slugs of radioactive material are ejected across the interval (minimum 20 feet spacing) with first slug placed above the top of the injection interval. If room allows a slug should be ejected below the perforations to establish a no flow condition.

   b. Immediately after ejecting the last slug, the tool is pulled up through all the radioactive slugs noting time and depth at which each radioactive slug is encountered. Readings are recorded versus depth.

   c. The tool is lowered back down to the bottom of the well and after approximately 5 minutes (depending on rate of movement), and step (b) is repeated. (A total of 3 drags through the radioactive slugs are made).

   d. If there is fluid movement above the injection interval (the top radioactive slug moves), then crossflow checks are repeated above the injection interval to determine the top of the interval of crossflow. Note that the lubricator must be configured to effect a full seal of the well during all shut in operations.
5. Fluid velocities from step (3) are used in conjunction with a caliper log to determine volumetric flow rates throughout the well bore.

Crossflow checks on longer intervals should be broken up and surveyed in sections. (Example: A 300-foot interval would be surveyed in two parts; the bottom 150 feet first and the upper 150 feet second.) This procedure will ensure that excessive slug dissipation does not occur.

Note: This method can be used on low rate injection intervals, in leu of stationary velocities.

C. INJECTING TEMPERATURE SURVEY

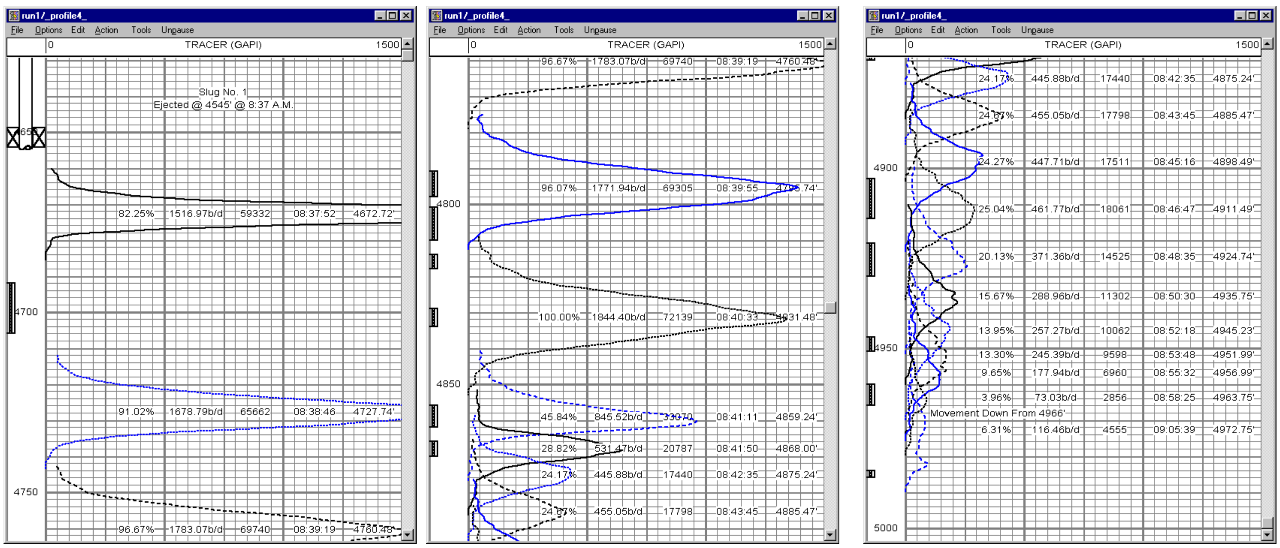
1. The logging speed is 50-60 feet per minute.
2. The well is logged once from 200 feet above the injection packer to L.T.D. while the well is injecting.

Note: Due to diurnal-nocturnal temperature variations of injection fluid, it may be advantageous to defer the injecting temperature survey until immediately prior to well shut in.

D. INTENSITY PROFILE

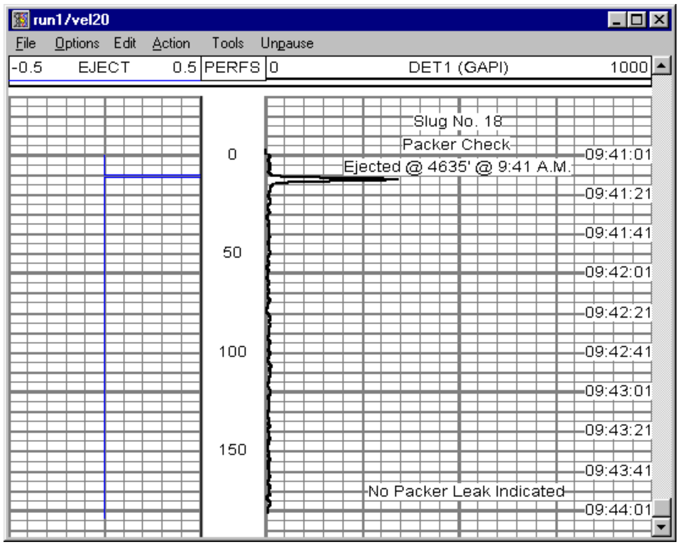
1. The tool configuration consists of at least one scintillation detector located below the ejector.
2. Readings are made versus depth.
3. A base gamma ray log is run from L.T.D. to the packer at the same attenuation that will be used for the rest of the intensity profile.
4. Radioactive material is ejected above the perforated or open hole interval.
5. The tools are moved to a point approximately 20 ft. below the radioactive slug, and pulled up the hole logging through the radioactive slug. This step is then repeated trying to catch the radioactive slug at intervals across the injection zone with a frequency adequate to determine fluid loss. The radioactive slug is logged through at the same constant velocity on every drag run (normally 100 feet per minute). The logger should be looking for channeling behind pipe in cased wells each time the position of the radioactive slug is recorded.

6. Calculations of percent loss are based upon the area constructed from the recorded log response from passing of the detector through the radioactive slug. The base of the area will coincide with the base gamma ray log response.



E. PACKER LEAK CHECK

1. The tool configuration consists of at least one scintillation detector located below the ejector.
2. The tool is held stationary with the detector located 5 feet above the packer.
3. Data are recorded versus time.
4. Radioactive material is ejected and flows past the detector inside the tubing. The recorded data will confirm slug ejection, demonstrating a rapid response.
5. The logger waits 3 minutes, allowing the slug of radioactive material time to leak around the packer and move up the backside (annulus) of the tubing to be detected by the detector. If a response is noted, a packer leak is confirmed and the recording is terminated. Alternately, the slug may be followed in order to determine the final point of fluid loss.



F. SHUT-IN TEMPERATURE SURVEY

1. The logging speed is 50-60 feet per minute.
2. The tool string is positioned in the tubing, 200 feet above the packer. Then the well is shut-in. An appropriate time period is allowed to elapse. While there is no general rule of thumb, at least one hour should normally be the minimum shut in time period.
3. The well is logged from 200 feet above the injection packer to logger's T.D. Between each logging run the tool will be held stationary in the tubing 200 feet above the packer.

G. TUBING DROP SHOT

1. The tool consists of at least one scintillation detector and an ejector.
2. RA material is ejected in the tubing above the packer with enough room for six stations.
3. The tool string is immediately repositioned a fixed distance below the point of ejection and held stationary until the radioactive slug peak is detected. The tool is repositioned another equal distance lower in the tubing and held stationary until the radioactive slug peak is again detected. This procedure is repeated four more times, so that a total of six drops are made.
4. The time between detection of the radioactive material arrival and the distance between the stations are used along with the known tubing diameter to calculate the injection rate for each of the drops. An average injection rate is then calculated.

Note: Station distances of 25 to 200 feet are permissible, depending upon the injection rate.

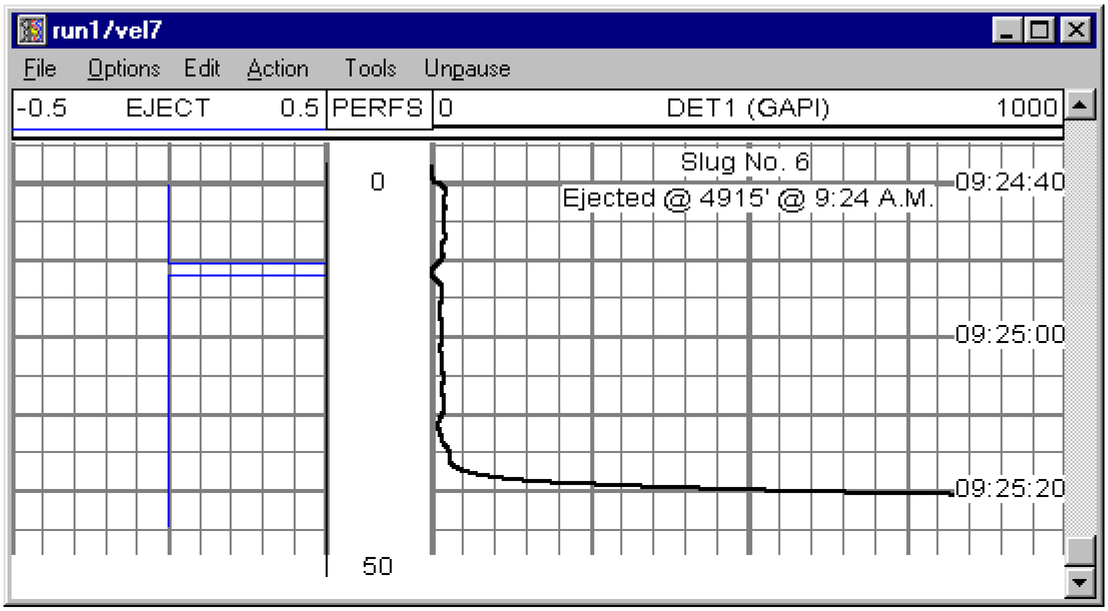
H. VELOCITY PROFILE - Velocity Shots

1. The tool configuration consists of a scintillation detector located below the ejector.
2. Data are recorded versus time. The tool string remains stationary versus depth.
3. The tools are kept stationary and a slug of radioactive material is ejected. The transit time of the slug moving from the ejector to the detector is recorded. The normal method is to use the first arrival of the radioactive slug. The recording may be continued to allow arrival of the slug peaks. If the slug does not arrive in a reasonable amount of time (at least 5 minutes), the timed recording may be terminated. The slug position should then be recorded versus depth to ensure that a slug was ejected, and to determine movement.
4. Step (3) is performed first at a depth below where the intensity survey indicates no movement (after the downward channel check is performed).
5. Moving upwards from the first shot, step (3) is repeated with the following constraints:
   a. The remaining shots are from the first shot in step (4) to the top of the injection interval.

b. Three (if possible) shots are made above the top of the injection interval as determined by the intensity profile (i.e., above the lowest drag run which indicated 100 percent of fluid inside the well bore). The 100 percent velocity shots will normally be made between the top perforation or casing shoe and the packer. The 100 percent velocity shots should be made at least 20 feet below the packer to avoid jetting from the packer and tubing.

c. The smallest allowed distance between shots is 5 feet, unless a longer than normal tool spacing is used.

6. Calculations of the percent loss are performed using transit time between the ejector and the detector.
7. The time of ejection along with the depth should be noted on each slug.



VI. LOG PRESENTATION

The final log print will include a log heading with comments section, a tool schematic, summary tables, an injection profile display, a temperature/crossflow survey display and ALL raw data gathered when logging the well.

A. The log heading will include the following information:
1. Oil Company Name
2. Lease Name
3. Well Number
4. Field
5. County and State
6. Complete well legal location
7. Elevations
8. Casing record
9. Perforation depths
10. Open hole depths
11. Packer depth and tubing size
12. Date log was run
13. Logger's total depth and well P.B.T.D.
14. Injection pressure (PSI)
15. Initial metered rate (bbls/day)
16. Final metered rate (bbls/day)
17. Average rate from totalizer (bbls/day)

18. Tubing drop shot rate (bbls/day)
19. Logging company and logger's name
20. Type of service
21. Log file number
22. Company representative's name
23. Surface injection temperature - 100 feet from surface
24. Type of injection fluid
25. A comments section with printed remarks on problems detected (e.g., channels, packer leaks, casing splits, fill, etc.) and any other pertinent comments by the logger that would enhance interpretation of the log.

If any of items 1 - 25 are not included in the logging company's normal log heading, then these items must be included in the comment section (item 25). All equations used to calculate the profile from the raw data will be included in the comment section or in the summary tables, or within the raw data section.

B. The tool schematic will include the following information:
1. A sketch showing tool configuration with each component;
2. Relative spacing between various tool components annotated;
3. Tool sizes: length and diameter.

C. Tables of data along with calculations used to interpret the profiles will be included.

D. The injection profile display will include the following:
1. Log scales for each measurement on the display.
2. An injection profile interpretation for velocity and intensity profiles, presented in bar chart form as a percent of total injection exiting the wellbore between each measured interval.
Note: The bar chart should be plotted so that the losses conform to known perforated intervals, not simply from measurement point to measurement point, as is common practice in the industry. The exception is for suspected breaches in the casing, etc., which should be clearly indicated.
3. A connected dot graph showing the location and cumulative loss for both the velocity shots and intensity drag runs. All points are to be presented, even where the readings may appear to be erratic. A dot will be connected only where the data point reading appears correct. Only the dots used to calculate the profile should be connected.
4. A schematic representation showing the location and size of packers, tubulars, casing shoes, perforations, open hole depths, squeezed perforations, etc. Channels, packer leaks, casing splits, fill, etc. will be noted.
5. The natural gamma ray log, the casing collar log and the caliper log will be displayed. Note that a separate presentation may be used to present the natural gamma ray and original collar log.
6. The injecting temperature and shut-in temperature surveys will be displayed with temperature scales. Each of the temperature curves will be identified and include the time and surface pressure at which each temperature survey was begun. The curves may be labeled as to elapsed time, such as "2 Hour Decay Temperature" as well as the absolute time of the beginning of the run.
7. The well bore flow rates and direction of flow determined by the crossflow checks will be stated on the depth tract at each depth where the flow rate was determined. Cross flow data may be presented separately from the main presentation.

E. For crossflow checks, the crossflow survey display will meet the following specifications:
1. Each slug will be identified.
2. The flow rate in the well bore and the direction of flow will be indicated on the display where the flow rate was determined.
3. The fluid entering or leaving the well bore over each measured interval will be displayed.

F. All raw data used in calculations shall be included in the log presentation and numbered to correspond to the summary table, such that any calculations can be duplicated without difficulty. Time scales will be annotated on presentations recorded versus time.

On the intensity tracer run raw data display, number all runs and indicate elapsed time, show down hole equipment and perforations, use a tick mark at each data point as used for profile.

On the velocity shot raw data display, a mark should be shown on chart paper at each interval used in the calculating the arrival times.