Perforating Of Multiple Tubingless Completions

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ABSTRACT

The perforating of multiple tubingless completions — in which two or more strings of 2-7/8 in. outside diameter casing are installed in the same bore hole — presents two basic problems. First, good completion practices require an efficient perforator that leaves no debris to interfere with subsequent completion operations. Second, and of more complicated nature, a system is needed for controlling the direction of fire so that adjacent strings are not damaged.

Development of a two in. outside diameter steel retrievable shaped charge gun has solved the first requisite. The second was resolved through development of three different devices to provide directional perforating for the two types of completion methods being employed today. These include a mechanical orienting device and self-orienting radiation devices.

Conceivably, the latter methods could be adapted to the directional perforating (of upper zones) of conventional dual and triple completions without removing production tubing and packers.

INTRODUCTION

The problem of gun debris in slim casing completions has been well defined in the numerous 2-7/8 in. single tubingless completions which have been effected during recent years with the expendable type perforators. Failure of expendable gun debris to settle out properly, even with good gun breakup, has resulted in bridging inside these small diameter casings. This, in turn, has interfered with completion and reconditioning operations.

The past two years have clearly shown, in fact, that debris problems are not confined to this small range of casing with most designs of expendable type guns. A high incidence of bridging has even been reported in 4-1/2 in. O. D. casing.

The perforating of multiple tubingless completions has entailed, therefore, the development of a completely debris-free gun of adequate performance, as well as the necessary devices to provide positive directional perforating in the two completion methods presently being employed.

THE GUN

Design Considerations

The design of a shaped charge gun for slim casing perforating has presented a maze of interrelated problems. Since the primary specification has been leveled at efficient charge performance with complete elimination of gun debris, this necessitated the development of a retrievable steel carrier gun of tubular construction to house the charges. The carrier must be retrievable through 2.29 in. API pump seating nipples that are usually installed in 2-7/8 in. strings.

To provide for recovery of the gun from the well, swelling of the carrier on firing must be carefully controlled. Control of swelling automatically means control of explosive weight in the shaped charge which, in turn, influences charge performance.

Carrier swelling also depends upon the confinement pressure at the level being perforated, which imposes a hydrostatic pressure-depth limitation. Burr interference on the wall of the carrier, resulting from passage of the jet through the carrier wall, must be eliminated by suitable design.

Clearly then, a satisfactory shaped charge gun design for slim casing operations represents a fine balance between carrier swelling, hydrostatic pressure, explosive weight, and charge performance.

Additionally, to lend itself to directional perforating, the gun design must provide a positive locking mechanism for individual charges within the gun carrier. This fixes charge orientation within the carrier and prevents any drift of the planes of perforating. It simply means that individual charge alignment must be positive. Even with very close tolerances, excessive rotation of charges would be possible with charges of conventional linkage mechanisms.

A method must also be devised to provide positive indexing of these planes of shooting with respect to the device controlling orientation.

Design Features — Specifications

To satisfy these various requirements, a two in. O. D. hollow carrier mild steel gun was designed for operation in a pressure range of 500 psi to 15,000 psi (Fig. 1A). Reliable recovery from the well after firing is assured in this design, thus eliminating all debris. A special design, high performance shaped charge of low explosive weight maintains carrier expansion under 2.1 in. when fired at 500 psi.

Operation of the tool at pressures less than 500 psi is

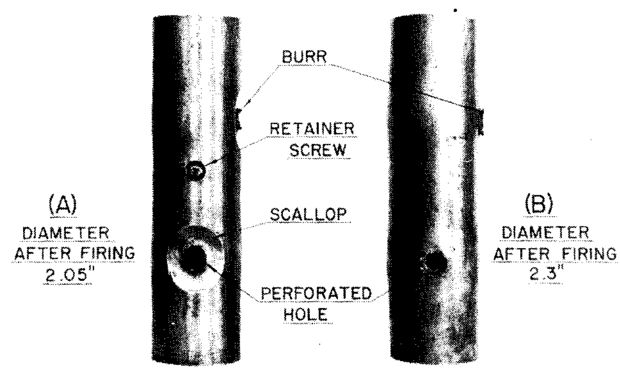


Fig. 1—(A) 2" O. Dia. Steel Retrievable Scalloped Shaped Charge Gun
(B) Conventional 2" O. Dia. Steel Retrievable Shaped Charge Gun

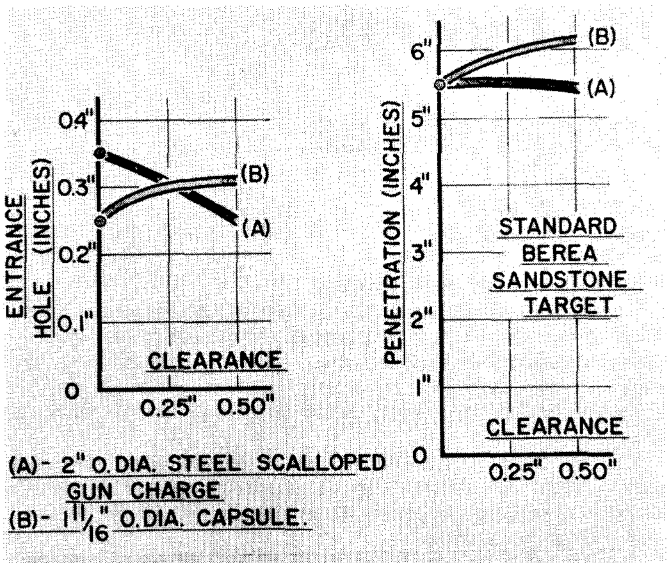


Fig. 2--Performance Variations In 2 7/8" Casing
(A) 2" O. Dia. Steel Scalloped Gun
(B) 1 11/16" O. Dia. Capsule Expendable Gun

not recommended due to increased carrier swelling and occasional splitting. Carrier wall thickness is adjusted to withstand the rated pressure and the internal gun pressures resulting from firing of the charge.

Burr interference is eliminated by means of a unique "scalloped" design. Figs. 1A and 1B contrast the streamlined nature of the scalloped carrier after firing with the conventional type gun. This feature also reduces the amount of metal in the carrier through which the jet must penetrate, thereby resulting in increased charge performance.

Charges are individually locked in the carrier by means of selfsealing retainer screws, assuring positive drift control of the two planes of perforating which are phased at 30°. When the gun is attached to the orienting device, positive indexing of the carrier, with respect to the device, is automatic.

Gun specifications covering both directional perforators and single completion models are tabulated in Chart No. 1.

Charge Performance

Performance of the charge in 2-7/8 in. casing averages 0.3 in. entrance hole size with 5.5 in. penetration in the standard Berea sandstone flow laboratory target. This compares favorably with a typical 1-11/16 in. capsule charge in the 0 to 1/2 in. clearance range as shown by Fig. 2. Well flow index, measured under conventional perforating conditions, was recorded at 0.9.

Directional Perforating Methods

To directionally perforate multiple tubingless completion set-ups, three methods have been developed and are currently in use:

1. A mechanical orienting device operating in conjunction with an auxiliary eccentric mandrel installed in the string above the zone to be perforated,
2. An interim double-line radiation method which requires no auxiliary equipment in the well,
3. A more versatile and efficient self-orienting radiation device requiring only a single line.

Mechanical Orienting Device

The mechanical orienting device was developed first to allow a study of the feasibility of completing two or three tubingless strings cemented in the same bore hole.

The device was designed to operate in conjunction with a four in. diameter eccentric pocket-type mandrel four ft. in length which is located within a few feet of the top of the zone to be perforated in the string of interest. Operation is based upon a spring-loaded arm which aligns with the eccentric axis of the above mandrel, thereby orienting the charges in the proper direction for firing. Fig. 3 shows a schematic of a triple tubingless well, while Fig. 4 shows an actual assembly of collar locator, mechanical orienting device, extension spacer, and gun.

A safety circuit is incorporated in the tool to assure that the gun will not fire unless the charges are properly oriented. As the arm opens and approaches full extension, an electrical switch is actuated which closes the circuit to the blasting cap in the gun. This action is seen on an indicating panel at the surface and is recorded on film to provide a permanent record of the location of the mandrel in the string, (Fig. 5).

To provide a double safety factor, a mechanical interlock system is included. As the tool enters the mandrel and the arm approaches full extension, it automatically locks in the "out" position and cannot be compressed until either of the smaller release arms, shown in Fig. 4, enters the 2-7/8 in. casing above or below the mandrel and releases the device. This assures that once the tool has opened properly it will remain in the extended and oriented firing position — even under large torque loads emanating from cable or hole conditions.

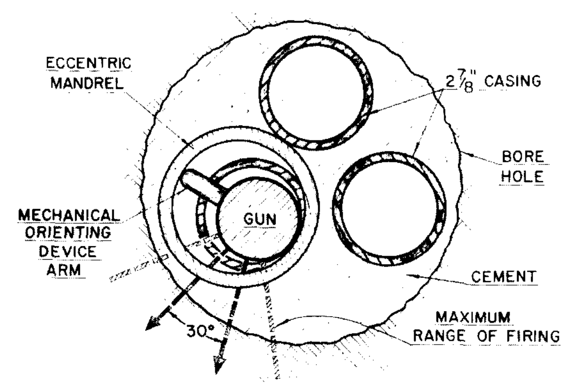


Fig. 3--Schematic Of Shot Distribution In Triple Tubingless Completion

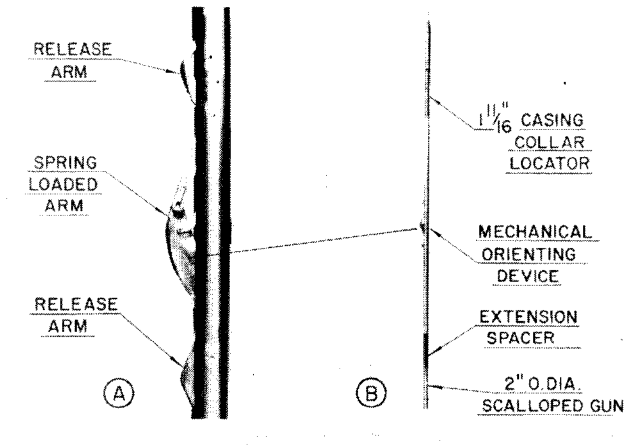


Fig. 4--(A) Mechanical Orienting Device
(B) Orienting Device--Gun Assembly

Both the electrical and mechanical safety systems are adjusted so that the maximum range of firing of the charges is controlled at 100°. This gives a minimum angular safety factor of 70° to the nearest adjacent string in a triple set-up. The safety factor would, of course, be larger in a dual well.

WELL REQUIREMENTS

Limitations

The principal limitation of the mechanical orienting device lies in lack of versatility of the completion method. Obviously, only those zones where a mandrel has been set and cemented in place can be perforated.

Use of this method naturally entails the running of two or three clamped strings into the bore hole simultaneously. Reports from the field indicate that this operation requires additional handling and is therefore more time consuming.

Moreover, the entire weight of the parasite or "piggy-back" strings is usually supported by the long string, thus imposing a definite limitation on the length to which the casings can be run.

The auxiliary mandrel or mandrels must also be correctly located within 15 ft. of the top of the zones to be perforated, otherwise excessive lengths of extension spacers would be required to bridge the gap between the

SPECIFICATIONS—
2" DIA. SCALLOPED GUN

- CARRIER: TUBULAR TYPE, MILD STEEL
- DIAMETER: BEFORE FIRING - 2.00" NOMINAL. AFTER FIRING - 2.05"
- FIRING SYSTEM: CONVENTIONAL PRIMACORD, BOTTOM-UP
- SHOT DENSITY: 4 SHOTS/FT. AT 90° PHASING } SINGLE COMPLETIONS; 2 SHOTS/FT. AT 180° PHASING } SINGLE COMPLETIONS; 2 SHOTS/FT. AT 30° (2 DIRECTIONS) } MULTIPLE COMPLETIONS
- DEBRIS: NONE
- BURR (INTERFERENCE): NONE.
- GUN LENGTHS: 20 FT. OPTIMUM.
- MAX. PRESSURE-TEMP. RATING: 15,000 P.S.I. AT 300° F.
- MIN. OPERATIONAL PRESSURE: 500 P.S.I.
- CHARGE MOUNTING: POSITIVE LOCKING WITHIN CARRIER.
- AVERAGE CHARGE PERFORMANCE IN 2½" CASING: 0.3" ENTRANCE HOLE; 5.5" PENE. (STANDARD BEREA SANDSTONE TARGET.)

Chart No. 1

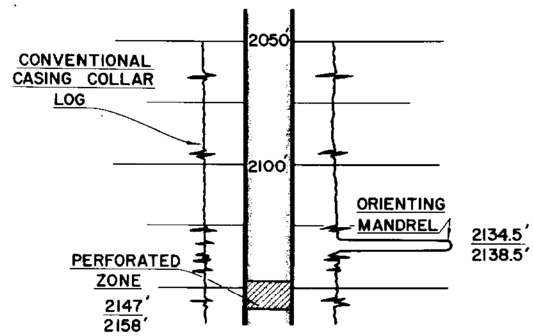


Fig. 5--Typical Recording Of Orienting Mandrel

top of the gun and the orienting device. Excessively long riser assemblies and more elaborate surface handling equipment would also be required.

Further, the mandrels must be oriented properly with respect to the adjacent strings during makeup; after all, the mechanical orienting device is only sensitive to the axis of the auxiliary mandrel, not to the adjacent string. Obviously, an improperly oriented mandrel in the well could result in damage to an adjacent string.

These are some of the factors which have spurred the development of more versatile orienting methods, which eliminate the use of mandrels and allow the casings to be run separately.

DOUBLE-LINE RADIATION DEVICE

Directional perforating without mandrels or other auxiliary well equipment in the string requires sensing apparatus to locate the adjacent string and a companion device to rotate the gun to the proper firing direction. The first of the newer orienting tools accomplishes this by means of a weak, collimated or focused radioactive source and mechanical rotating device attached to the gun, in combination with radiation detectors suspended in adjacent

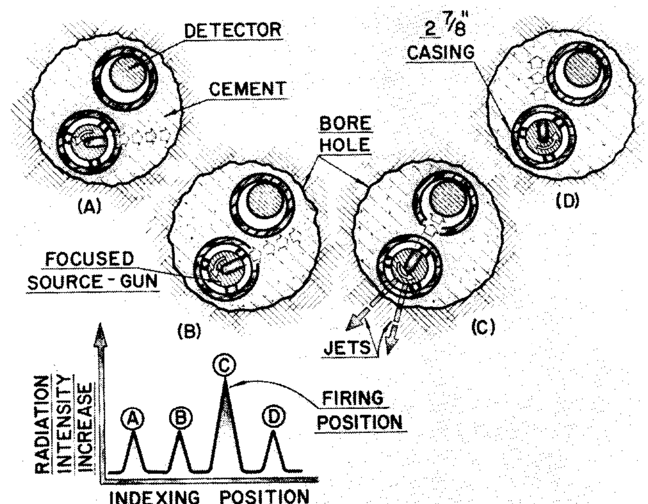
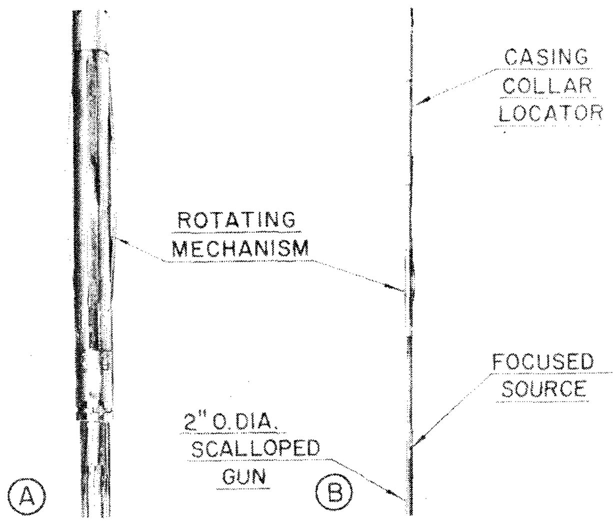


Fig. 6--Principle Of Operation Of Double-Line Radiation Device



strings. This tool was developed as an interim solution to allow immediate elimination of mandrels and other auxiliary well equipment.

The principle of operation of the double-line radiation orienting tool is illustrated in Fig. 6. As the gun is rotated by steps, the detectors pinpoint precisely the direction of

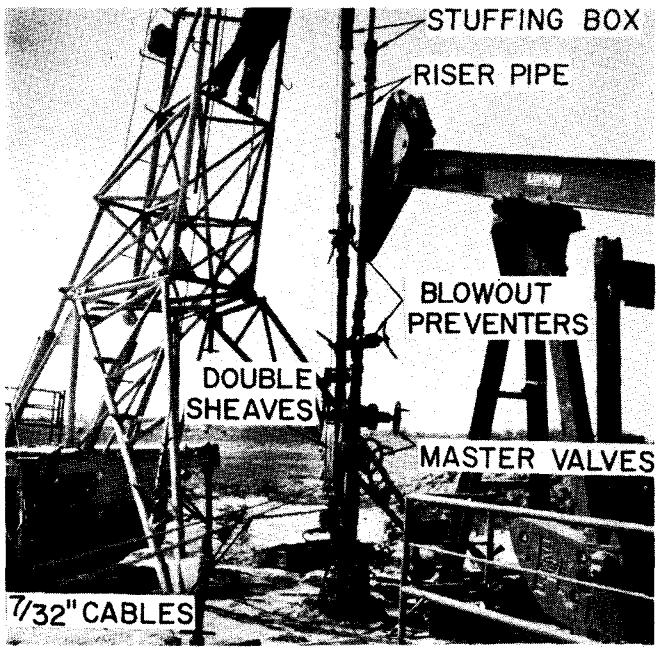


Fig. 8--Well Head Control Equipment

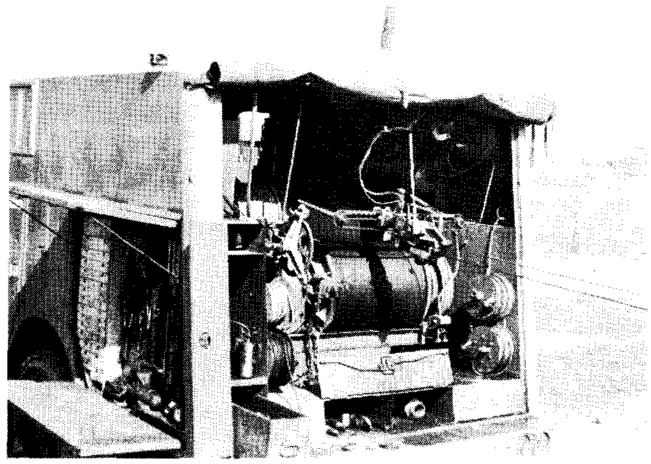
firing by locating the maximum intensity of the focused beam source. Since the charges are aligned with respect to the source, the direction of firing can be controlled.

The uniquely designed rotating device, shown in Fig. 7A, is a gated slot system and anchor spring arrangement which is actuated by moving the cable up and down through a few inches. Each time the cable is lowered one foot and then pulled back upward, the entire focused source-gun assembly rotates through 30°.

In other words, the tool makes one complete revolution in 12 steps, consistently locating the opposite string or strings one time during this cycle. The anchor spring prevents the tool from turning except when actuated from the surface. The rotating device will only turn in one direction and will not retrogress, even though opposite torque load is encountered.

A purely mechanical approach to the design of the rotating device was taken in order that the tool could be actuated without application of electrical power to the perforating tool assembly during the orienting operation.

The sequence of operation includes first placing the detector at the proper depth in the adjacent string, then running the entire gun assembly (Fig. 7B) into the string to be perforated. In the process of rotation, the tool is moved down and then back up, passing the level of the



detector each time, resulting in the peak type readings shown in Fig. 6.

A standard gamma ray neutron detector is employed to measure the intensity of the directional source. Specially modified well head control equipment and dual sheave arrangements facilitate rigging up at the surface (Fig. 8). With this equipment, wells may be shot with up to 2500 psi on the well heads. A special design two drum truck with 7/32 in. electric cables, shown in Fig. 9, is used to perforate dual tubingless completions.

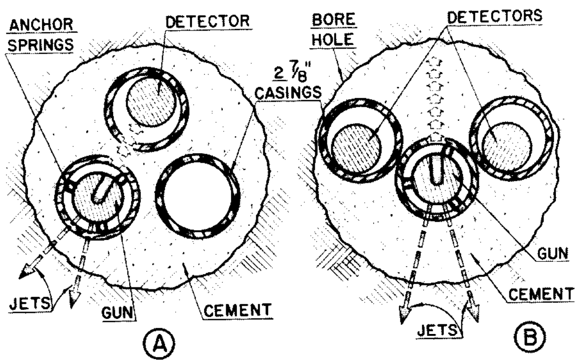
For triple completions, the relative azimuths of the three unclamped strings are not known. From Fig. 10A it will be obvious that the two drum truck would suffice for a triple completion if casing centers were located at 120°; however, in certain cases, such as washouts, it is conceivable that the three casings could tend to line up as illustrated in Fig. 10B. A second detector or third cable would then be needed to plot their relative positions and shoot the well.

Typical orientation curves of dual and triple wells completed with the double-line method are shown in Figs. 11A and 11B, respectively.

While the double-line method has eliminated the auxiliary well equipment necessary for mechanical orientation, and has proved a positive system, its inherent disadvantages lie in additional requirements in surface equipment. Extra cables and well head control equipment impose significant increases in well operating time as compared to a regular perforating system, not to mention the increased cost of equipment.

"SELF-ORIENTING" SINGLE-LINE METHOD

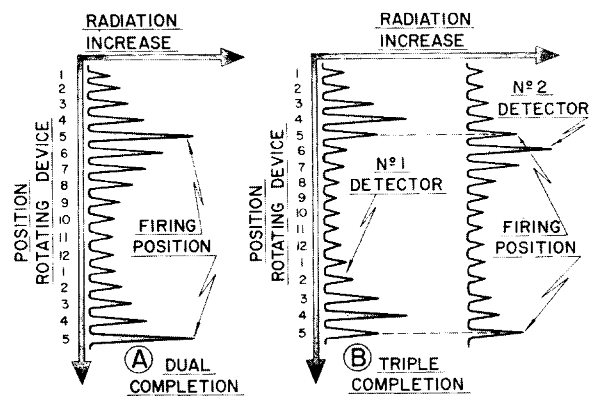
To overcome the limiting features of the double-line method, a more versatile and efficient single-line "self-orienting" radiation device was recently developed. In this method, requirements in surface equipment and operating time are substantially reduced. More significantly, adjacent strings need not be open during the operation; sucker rods or other well equipment may remain in place, undisturbed.



The device differs principally from the double-line method in that both the radioactive source and gamma ray detector are combined in the same tool assembly, thereby reducing directional perforating to a single-cable technique (Fig. 12A).

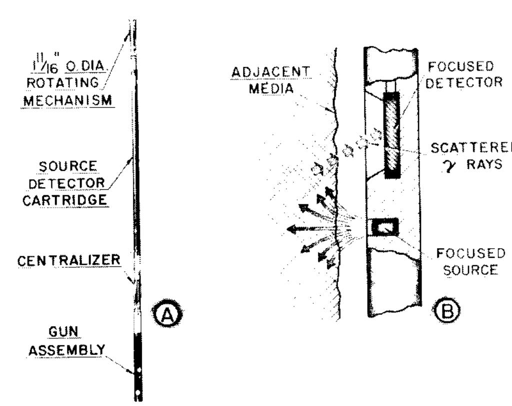
Operation is based on the gamma-gamma principle; the instrument is sensitive to changes in effective density. The rotating mechanism is basically the same as that utilized for the double-line technique. The entire assembly is designed in a diameter of 1-11/16 in. This will ultimately allow directional perforating of smaller 2-3/8 in. casings.

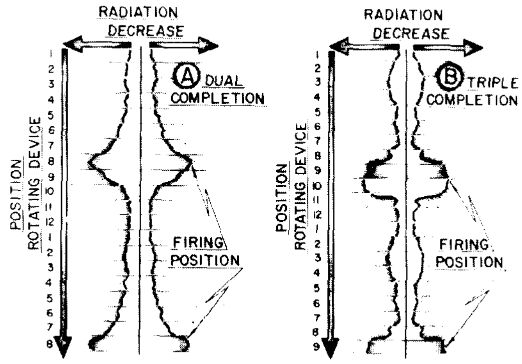
Fig. 12B illustrates that the tool is comprised of a gamma ray source and a closely spaced gamma ray detector.. These are so arranged that gamma rays are detected from principally one azimuth of orientation — both are collimated or focused in the same vertical plane.



The gamma ray source and detector apertures are arranged to maximize lateral investigation and achieve maximum signal resolution.

As gamma rays are emitted from the source, some are absorbed by the material in the path of the beam while others are scattered. Some of these scattered gamma rays eventually reach the detector where they are counted. With a given source strength and spacing between gamma ray source and detector, the number of gamma rays returning to the counter becomes an inverse function of the density of the media directly opposite the collimated windows of





the source and detector.

Steel tubing has a greater density than cement and formation. Thus, as the tool is rotated through the usual cycle, the positions of adjacent strings are indicated by reduced counting rates at the detector.

Short lateral investigation is intrinsic in the device, resulting in decreased signal resolution with increase in distance between casings. Should lack of resolution ever present a problem due to hole washout or other contingencies, an additional control measure is available. A one in. radioactive pill may be run into the adjacent strings on a standard .082 in. solid wire line. This auxiliary pill is readily seen by the detector. In this manner, casing locations may be confirmed.

Field examples of dual and triple completion orientation curves are shown in Figs. 13A and 13B. In this system, proper alignment for perforating is on the peak, as in the double-line method. Note in Fig. 13B the slight base line anomaly between peaks. This is due to differentiation between cement and formation densities and signifies that the casing to be perforated is in very close proximity to the wall of the bore hole.

Field Operations

To date, approximately 549 wells have been perforated with the debris-free Scallop Gun. Of these, 200 were single completions; 14 were perforated with the mechanical orienting device; 250 with the double-line radiation method, and 85 with the newer single-line self-orienting technique. In these cases, gun performance as based on completion data has been excellent.

Future Development

It is considered desirable to directionally perforate upper zones of conventional dual and triple completions without removing production tubing and packers. Development is continuing toward adapting the self-orienting radiation method to this end.

CONCLUSION

The perforating of multiple tubingless completions may be effected with a debris-free retrievable shaped charge gun and either of three recently developed directional perforating methods; a mechanical orienting device and auxiliary eccentric mandrel, or either of the two described radiation techniques.

The mechanical orienting device must be used in conjunction with a properly oriented eccentric mandrel installed at the proper depth in the well. This necessitates the clamping and simultaneous running of tubing strings.

The radiation methods require no downhole auxiliary well equipment and have therefore proved to be the more versatile and promising techniques.

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