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Drill-Pipe Severing Tool with High-Temperature Explosive

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DRILL-PIPE SEVERING TOOL WITH HIGH-TEMPERATURE EXPLOSIVE

by

Steven P. Koczan, William W. Patterson, and Richard H. Rochester

ABSTRACT

This report describes a special-purpose borehole explosive tool designed to meet a need of the Los Alamos National Laboratory Hot Dry Rock (HDR) Geothermal Energy Development Program. This tool's particular purpose is to sever stuck drill pipe in deep (>4500 m), hot (>320°C), water-filled wellbores. No commercial severing tools are known to us that can be operated at temperatures above 260°C.

I. INTRODUCTION

The goal of the Laboratory's HDR program is to investigate and develop methods of extracting thermal energy from naturally hot granitic formations by circulating water through hydraulic fractures made in the HDR. Conventional oil field drilling techniques are used to make deep wellbores into the naturally occurring hot formations. This type of drilling places very large loads on drill strings, leading to occasional "twist-offs." To salvage the lower portion of the twisted-off and stuck drill string, an overshot tool generally is run into the hole to grapple the stuck portion. Then the sections of drill pipe below this overshot tool are explosively severed, and removed from the wellbore. At temperatures above 260°C, commercial explosive severing systems either fail or detonate prematurely. The Los Alamos severing tool has been designed to operate in the HDR wellbores at higher temperatures (>320°C). The high-temperature resistance was achieved by using a specially formulated high explosive (HE) as the high-temperature detonator, and a dewar-protected firing system, both of which are encased in a standard seamless steel tube 63.5-mm o.d.

x 50.8-mm i.d. (2.5-in. o.d. x 2.0-in. i.d.). The tool is operated through a seven-conductor, 7600-m-long, armored wireline that allows control of the downhole firing unit from the surface. The tool was designed to sever a 76-mm (3-in.) i.d. x 127-mm (5-in.) o.d. steel drill pipe. Changes in the shape of the HE lens may be adapted for other pipe sizes.

II. GENERAL DESCRIPTION OF TOOL

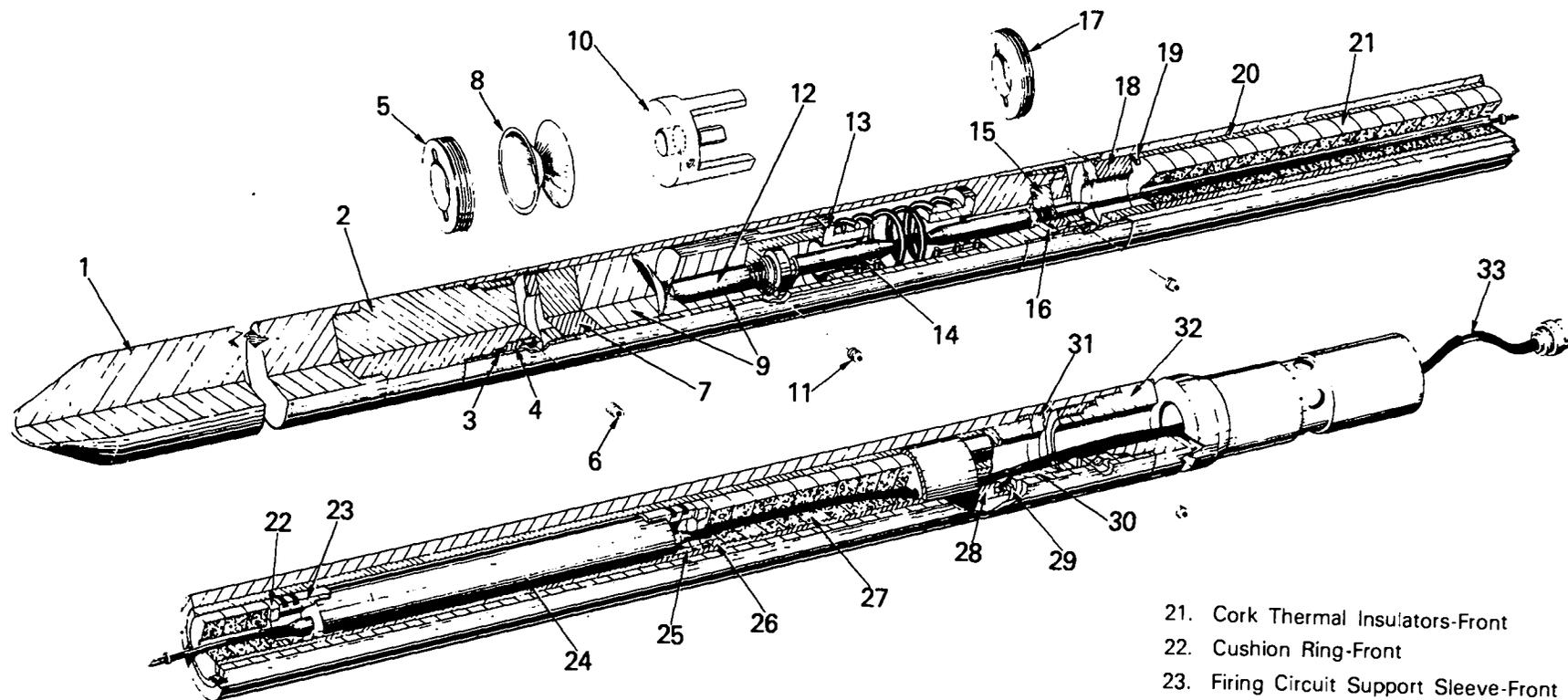
The sonde houses the shaped HE charge and the dewar that provides thermal protection for the firing system. The tool consists of a sinker bar nosepiece, a tubular section containing the explosive charge, the firing circuit, and at the tail end, a cablehead sub for attachment to the logging cablehead. Seals, capable of withstanding the wellbore fluid pressure 41 379 kPa (6000 psi) and a hole temperature of 320°C, are located at the make-up connections of the tool.

Compressive springs (wave type and helical) are used to restrain both the dewar and the explosive charge detonator; each might tend to shift while being lowered into the hole, as well as swelling from thermal expansion as the tool heats up while in the wellbore (Figs. 1 and 2).

III. HIGH-TEMPERATURE DETONATOR¹

The detonator (a Reynolds Industries modified RP-84) is a separate unit that contains only hexanitrostilbene (HNS) explosive. This relatively insensitive secondary explosive provides maximum safety from accidental detonation, as well as the stability required in a high-temperature environment. The detonator is a slapper initiator that contains ≈1 g of explosive. The high-current, high-power electrical energy pulse sent from the downhole firing module vaporizes a foil that accelerates a flyer, which in turn detonates the explosive instantaneously by impact energy. The explosive is pressed to near-crystal density and is completely separated from all conductive parts. This enhances the detonator's safety characteristics and improves its long-term stability.

The detonator is placed in a welded stainless steel housing, open at one end, with a Kemlon high-pressure feedthrough (16B-839) used to connect the high-voltage (HV) coaxial cable. Figure 3 gives the dimensions of a typical HNS detonator.



1. Nose Piece & Sinker Bar
2. Sinker Bar to Tool Adapter
3. Pressure Seal
4. Pressure Seal Retainer Sleeve
5. Threaded Sleeve H.E.(High Explosive) Retainer
6. Pressure Seal Retainer Sleeve Set Screw
7. Front Spacer
8. Copper Focusing Lens
9. H.E. Charge
10. Detonator Support

11. Detonator Set Screw
12. Detonator
13. Pressure Bushing
14. Detonator Firing Cable
15. Pressure Bulkhead Feed Thru Support
16. Bulkhead Pressure Seal
17. Threaded Sleeve-Dewar Retainer -Front
18. Spacer Sleeve-Front
19. Wave Spring-Front
20. Dewar For Firing Circuit Thermal Protection

21. Cork Thermal Insulators-Front
22. Cushion Ring-Front
23. Firing Circuit Support Sleeve-Front
24. Firing Circuit
25. Firing Circuit Support Sleeve
26. Cushion Ring Rear
27. Cork Thermal Insulators-Rear
28. Counterrotation Sleeve
29. Wave Spring-Rear
30. Spacer Sleeve-Rear
31. Threaded Sleeve-Dewar Retainer-Rear
32. Pressure Seal Retainer-Rear Sub
33. Firing Circuit Leads to Wireline Cable Head

Fig. 1.

Explosive cut-off tool, 2.5 in. o.d. x 95 in. long, pressure limit 10 000 psi, temperature limit 600°F.

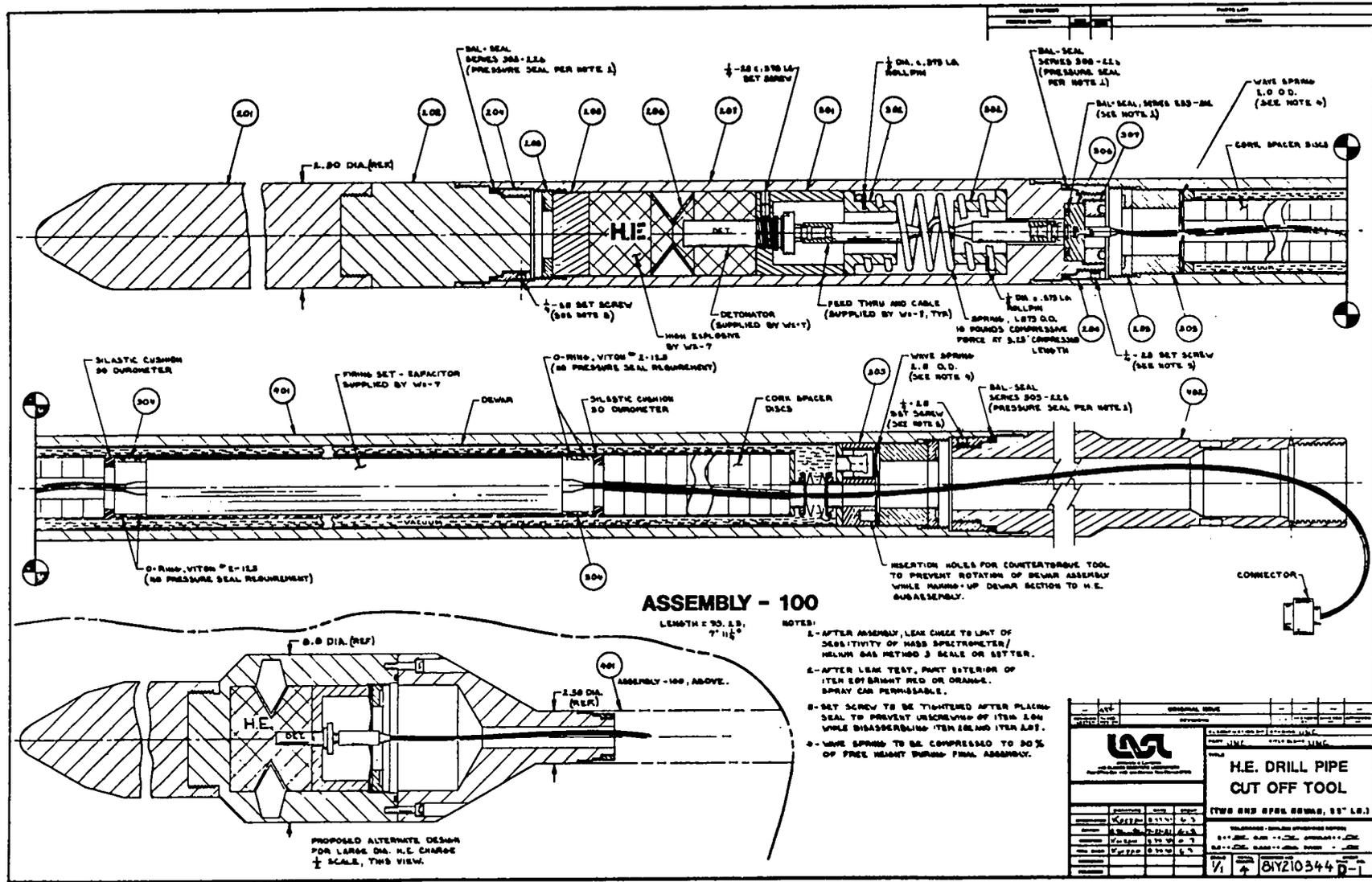


Fig. 2.
 Assembly of high-explosive drill pipe cut-off tool.

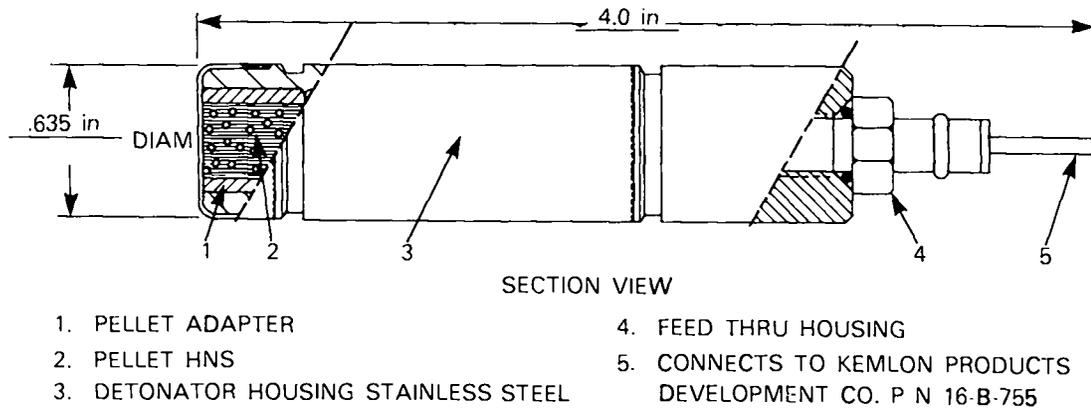


Fig. 3.
Dimensions of a typical RP-84 HP HNS detonator.

IV. DETONATOR SPECIFICATIONS

A. Performance

Threshold burst (I_{bth}) = <2200A

I_{bth} standard deviation = < 120A

All-fire burst current = >3000A

These current levels are relatively high compared with Reynolds' EBW detonators; however, if the firing system (capacitor, trigger switch, cable, and connectors) is designed for minimum inductance and resistance, and is properly matched to the slapper initiation, the total required energy is not significantly greater than a standard EBW system. For example, a reliable slapper initiation system can be designed and built with a 1- μ F capacitor, charged to 4500 V.

B. General

This initiator did not prematurely function or degrade when subjected to the following tests:

1. temperature survival of 2 h at 260°C;
2. dielectric withstanding 500 V, 1-mA leakage per MIL-1-23659 C;
3. static discharge test, 25 000 V with 500-pfd capacitor and a 500- Ω resistor per MIL-1-23659 C;
4. continuous static pressure, 34 474 kPa (5000 psi) for P/N 167-8999;
5. 28-V dc applied to the foil for at least 1 s as specified in MIL-1-23659 C;

6. maximum no-fire test, 500-V dc for 50 ms across the foil per MIL-1-23659 C;
7. explosive function time from foil burst to shock output is 4.0 μ s;
8. output characteristics that are similar to RP-1 EBW detonator (P/N 167-4314).

This initiator will not prematurely detonate, but it may degrade, deflagrate, or "dud" as a result of the following tests:

1. ac current test of 115-V ac, 60 cycles connected directly across the foil for 30 s;
2. continuous temperature 260°C.

C. High-Temperature Explosive (PYX)

During FY1979, M. D. Coburn of Los Alamos was on assignment as a visiting scientist to Eglin Air Force Base, Florida, where he initiated the development of some new thermally stable explosives. One of the materials studied, 95/5-PYX/Kel-F 800 (AFX-521),² was selected by the Air Force for interim qualification as a booster explosive. In addition to preparing the material required by the Air Force, we prepared enough of the explosive at Los Alamos for further evaluation in potential Department of Energy applications. The data obtained for this PBX, both at Los Alamos and at Eglin Air Force Base, are compared to those of two common booster explosives, Tetryl and PBX-9407, in Table I.

Evaluation of the results shown in Table I reveals that AFX-521 is a very unusual explosive. In addition to its unsurpassed thermal stability,³ it is relatively insensitive to impact, spark, and pure shock (gap tests). It is as sensitive as PBX-9404 in the minimum priming test and its wedge-failure thickness is very small. This combination of properties suggests that AFX-521 is an excellent choice for a thermally stable booster application such as the HDR downhole explosive systems.

For the HDR application, we made the main shaped charge from PYX at a density of 1.7 g/cm³ in the configurations shown in Fig. 1. One of the PYX pieces was bored to a diameter of 0.635 in. to accept the detonator. The entire charge was over designed so that we would be sure to sever the pipe. The principles of shaped charges are well known. The charge is contained in the downhole tool (illustrated in Fig. 1). The portion of the tool just above the pressure bulkhead is recoverable and can be reused. This particular type of charge severs drill pipe with a clean break (Fig. 4).

TABLE I
 PHYSICAL AND EXPLOSIVE PROPERTIES OF
 95/5-PYX/KEL-F 800 (AFX-521)

	AFX-521	Tetryl	PBX-9407
Impact Sensitivity (cm)			
Type 12	93.7	42.0	33.0
Type 12B	72.3	49.0	30.0
Spark Sensitivity (J)			
0.076-mm Foil	2.950	0.54	0.77
0.254-mm Foil	9.30	2.79	1.50
Small-Scale Gap Sensitivity (mm)	1.02 ($\rho = 1.700$)	4.04 ($\rho = 1.680$)	3.07 ($\rho = 1.780$)
Minimum Priming (mg EXTEX)	17.0 ($\rho = 1.700$)	1.50 ($\rho = 1.690$)	12.40 ($\rho = 1.760$)
Wedge Failure Thickness (mm)	0.50 ($\rho = 1.700$)	0.267 ($\rho = 1.680$)	0.305 ($\rho = 1.770$)
Vacuum Stability (cm ³ /g/48 h at 120°C)	0.02	1.0	0.5
Critical Temperature (Henkin Test, °C)	365	-----	-----
Thermal Stability (DTA, °C)	340	165	170
Plate Dent (mm) 4.13 cm diam	5.49 ($\rho = 1.700$)	8.10 ($\rho = 1.680$)	----- -----
C-J Pressure (GPa)	25.3 ($\rho = 1.700$)	26.0 ($\rho = 1.710$)	28.7 ($\rho = 1.600$)
Detonation Velocity (mm/ μ s)	7.21 ($\rho = 1.700$)	7.85 ($\rho = 1.710$)	7.91 ($\rho = 1.600$)
Cylinder Test (km/s) ² /2 (MJ/kg)			
6 mm	0.783		
19 mm	1.08		

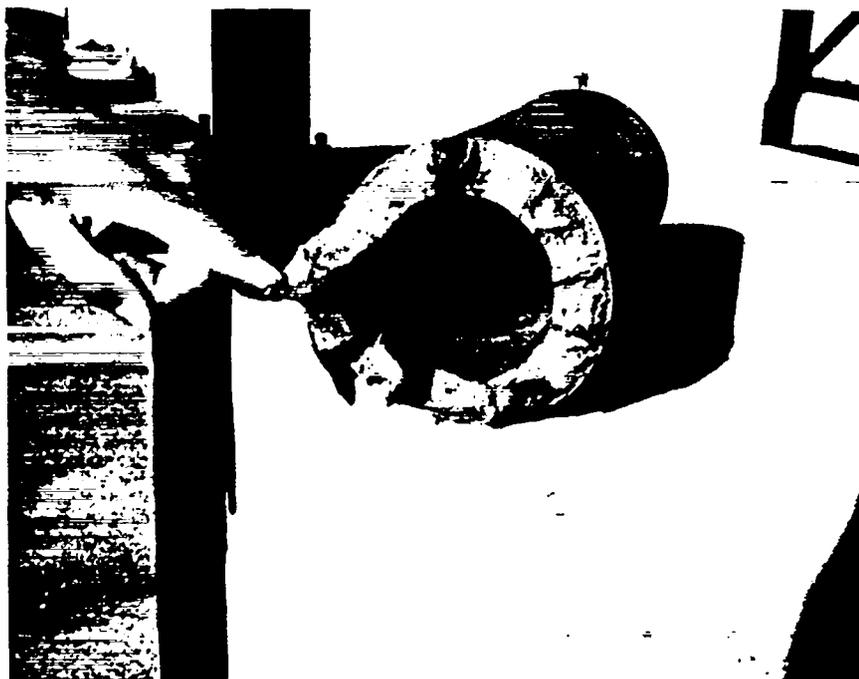


Fig. 4.
Severed drill pipe using high-explosive charge.

V. THE FIRING SYSTEM

The firing unit is a Reynolds Industries Model FS20 capacitive discharge detonator firing system. The system consists of an uphole control unit and downhole firing module. Design features are as follows:

1. an uphole control unit with a current regulator, HV monitor, and safety interlock plug;
2. a downhole firing module (Firing Circuit, Fig. 1) that operates through a logging cable up to 7600 m (25 000 ft) long.

A. The Uphole Control Unit

The 115-V ac control unit is packaged in a 9 x 5 x 6 in. moisture-sealed carrying case. On the front panel is the connector that joins the unit to the firing module, ac power outlet, and monitoring instrumentation. The unit meter monitors the HV developed in the downhole firing module and serves as an indicator that the unit has fired. Switches arm and fire the system. A safety interlock plug renders the control box inoperative when removed.

Internally, the control box contains a 120-V ac, 300-mA current-regulated power supply and associated control circuitry.

B. The Downhole Firing Module

The firing module (circuitry shown in Fig. 1) is housed in a 1-3/8-in.-diam x 10-in.-long aluminum tube that is potted to protect it from vibration and shock while the tool is lowered into the borehole.

Electrically, the firing module consists of an inverter and a voltage tripler charging a 0.5- μ F energy storage capacitor to \approx 4500-V dc. An overvoltage spark gap is provided at the output, which self triggers when the HV is approximately 4500-V dc.

Power requirements downhole are \approx 20-V dc, 300 mA to power the inverter. Power is supplied from the uphole control unit. Input voltages uphole depend on cable length, temperature, and cable resistance to ground. The logging cable now in use has seven conductors, is 7600 m (25 000 ft) long, has a resistance of \approx 250 Ω , and a minimum resistance of 1 M Ω to ground.

Operation of the downhole firing module requires three conductors. These conductors are used for a \approx 20-V ac input, HV monitor, and ground.

A dewar and pressure vessel (Figs. 1 and 2) are used to protect the firing module from the high-pressure/high-temperature downhole environment.

VI. SYSTEM OPERATION

Operation of the system is as follows.

1. Connect power plug to 110-V ac.
2. Mate shorting plug to "safety interlock" connector.
3. Depress and hold arm/fire push buttons simultaneously.
4. Continue to hold buttons until voltage on meter has stopped rising and makes an abrupt drop indicating the unit has fired.

VII. USES

This particular tool was designed for use in the high-temperature HDR holes. However, with minor adjustments in charge size, diameter, etc., the severing tool design could be applied to numerous situations where severing in harsh environments is necessary.

In Fig. 2 a proposed alternate design illustrates size variations possible for use with the basic design concept.

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