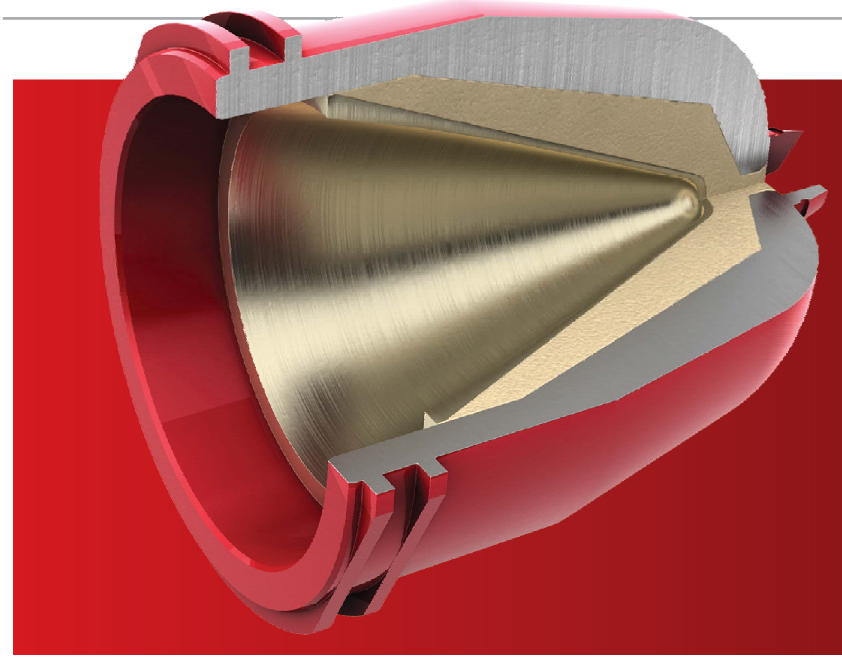

Perforating Solutions

HALLIBURTON

Wireline & Perforating

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Perforating Solutions

Halliburton Perforating Solutions encompass the industry's leading technologies, tools, and techniques for critical perforation operations. Integrated services and a collaborative attitude set Halliburton apart, allowing for more efficient teamwork, less data translation, higher accuracy, single-source accountability, reduced nonproductive time, and reduced risk, which translates to development and delivery of innovative, quality products and services. Business development groups stay in close contact with technology to help ensure clients have the latest technology available. Manufacturing methods, inspection/testing, packaging, and warehousing help ensure quality products from the point of delivery to operations. With a commitment to health, safety, environment (HSE), and flawless service quality, Halliburton offers industry-leading perforating solutions.


HAL84824

Halliburton Perforating Center of Excellence Administrative Building

Jet Research Center

The Halliburton Jet Research Center (JRC) originated and introduced jet perforating to the energy industry — forever changing how oil and gas are produced. JRC was founded in 1945 as Halliburton Well Services Company (Welex). The adaptation of bazooka technology from World War II prominently positioned JRC as the pioneer of the shaped charge. The introduction of jet perforating rapidly moved the industry away from bullet perforating and propelled the energy industry.

Located on more than 800 acres in Alvarado, Texas, JRC is a world-class, fully integrated research, design, testing, and manufacturing facility that delivers customized solutions, advanced perforating systems, and specialty explosive devices for the oil field, including shaped charge perforators, RF-safe detonators, tubing and casing cutters, and severing tools.

Research and Design

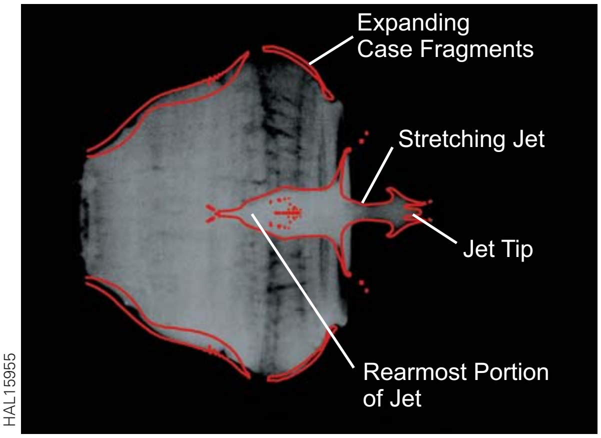
The premier technical staff at JRC includes a balance of engineers, designers, and technicians who are among the most knowledgeable experts in the perforating industry. Their backgrounds range from PhD and MS degree-level engineers and scientists to highly skilled explosive technicians.

Industry-leading techniques and equipment are employed in research and design including:

- Hydrocodes, such as LS-DYNA and CTH, that model the high-strain-rate deformations of materials subjected to explosive loading
- Analytical computer programs that predict the response of structures to explosive impulse loads
- Flash X-ray equipment that allow precise, detailed study of explosive events in nanosecond resolution, allowing improvement in the performance of new and existing shaped charge designs

To understand and design oilfield tools at high-strain rates and/or explosive loads, Halliburton uses state-of-the-art simulation methods. For explosive tools and perforation charges, CTH is used. CTH = $CSQ^{3/2}$, where CSQ is a 2D radiation-diffusion hydrodynamic code. The CTH hydrodynamic computer code (hydrocode) is simulation software designed to treat a wide variety of shockwave propagation and material phenomena in one to three spatial dimensions. This computer-aided design tool forms a strong scientific basis for Halliburton charges and explosive products in general. CTH has been used in charge design, gun dynamics, explosive tool verification and validation (V&V) with tests, drill collar severing tool design, and flow laboratory vessel design.

The image at right shows the V&V of our capabilities by comparing simulation results with a charge test imaged by flash X-rays. Note the simulation matches jet and case dynamics. The related LS-DYNA tool supports the scientific basis for Halliburton products. LS-DYNA is a finite element analysis (FEA) code with some hydrocode capability. This FEA code helps ensure our products are understood in physics subjects, such as the internal wave phenomena of our systems. This understanding leads to safer and more reliable products.



Flash X-ray and hydrocode simulation of a shaped charge during detonation sequence.

Advanced Perforating Flow Laboratory

The Advanced Perforating Flow Laboratory (APFL) at Halliburton Jet Research Center (JRC) is an industry leader in perforating system research, development, and test programs. For more than 10 years, we have conducted tests tailored specifically to our clients' needs to help them better understand actual downhole conditions and perforating system performance.

To meet our customers' developing challenges, Halliburton has expanded the APFL with leading-edge vessels and technologies. These vessels provide our customers with the most accurate information possible regarding the effects of perforations in different formations and environments. This facility provides as close to real-world conditions as one can get in a laboratory setting.

HAL37698

Advanced Perforating Flow Laboratory at Jet Research Center

Advanced Flow Vessels Raise the Bar

The APFL includes three testing vessels that do more than any other facility in the industry. Vessels include:

- 50,000-psi vessel: Tests at pressures higher than any other testing facility in the industry.
- 25,000-psi vessel: Rotates up to 180°, enabling performance of gravity-related sanding studies to better understand the effects of perforating and fracturing in horizontal wells. No other testing facility can simulate these conditions.
- 25,000-psi high-temperature vessel: Flows at temperatures reaching 400°F (204°C), enabling testing of perforating capabilities in high temperatures.

HAL37708

HAL37707

Advanced Perforating Flow Laboratory vessels give Halliburton the ability to operate beyond the most challenging environments.

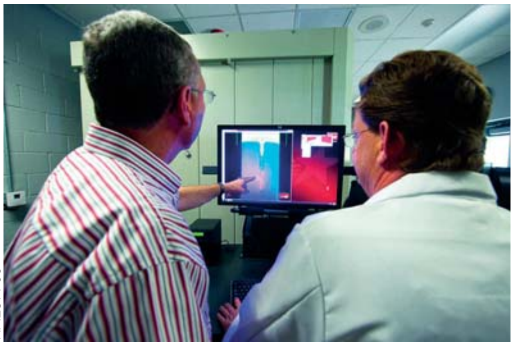
Optimizing Production

With insights gained from the tests performed at the APFL, we can find better ways to:

- Clean up perforations more effectively
- Maximize production
- Evaluate alternative perforation methods
- Assess new explosive compounds and their performance
- Use better performing metals

The APFL helps personnel understand how a perforator actually performs under extreme downhole conditions. It can provide real-world answers that account for overburden stress, reservoir pore pressure, wellbore pressure, and reservoir and wellbore response. The APFL can also help identify the optimum solution to connect the wellbore and reservoir.

Halliburton pioneered the shaped charge for oilfield use, and we are once again leading the industry in research and development. Our expanded laboratory provides insight into actual perforating system performance under the harshest reservoir conditions. With the most advanced evaluation techniques in the industry, we can now truly understand reservoir inflow from a perforation tunnel and how it can be optimized for specific well conditions.



HAL37700

Only in-house computerized tomography (CT) scanner in the industry

Our expanded facility also includes an integrated command and control center, a core preparation laboratory, and an extensive core analysis laboratory for post-test evaluation.

The Advanced Perforating Flow Laboratory (APFL) enables the most advanced perforated core analysis in the industry. We conduct these tests with the latest imaging systems adapted from the medical industry for use in oil and gas environments. The APFL is the only laboratory in the world with such dedicated equipment, allowing for reservoir inflow evaluation at the structural level.

Consequences of the Wrong Assumptions

In the oil and gas industry, the wrong assumptions can lead to billion-dollar mistakes. In some cases, pipelines are developed, roads are built, and even towns are created on the assumption that millions of barrels of oil or gas equivalent will flow from just a few wells. Therefore, an operator must know precisely how each well is going to intercept the reservoir, and how efficiently and effectively that reservoir will flow into the wellbore. The tests conducted at the APFL provide our customers precise answers on the exact depth of penetration into the formation in different types of rock and the expected crush zone and skin value of that perforation. These insights help identify or develop the best perforating system for any given well condition.

Wide Range of Applications Tailored for Specific Reservoir Conditions

Testing and research at the APFL have determined that penetration and inflow performance of a perforating system in a formation and under extreme conditions are much different than performance in cement. In fact, often the results from these tests can be misleading because the best system in cement might not be the best system in real-world conditions. Tests performed at the APFL are conducted with actual cores provided by our clients, allowing better inflow evaluations for project appraisal and the ability to identify and refine the latest equipment for an optimized well completion.

HAL37703

Cores taken from the field and analog rocks are prepared and analyzed before testing in the flow vessels.

Technology Testing Area

Ultrahigh-Temperature and Pressure Laboratory

The engineering ultrahigh-temperature and pressure laboratory is the oil and gas industry's premier perforating systems testing facility for ultrahigh-temperature and pressure. This laboratory is fully capable of complex testing scenarios to include deepwater parameters:

- 20,000-psi 400°F test vessel
  - 7.50-in. ID × 13.5-ft deep
- 30,000-psi ambient temperature test vessel
  - 6.00-in. ID × 15.0-ft deep
- 40,000-psi 500°F test vessel
  - 6.00-in. ID × 8.82-ft deep
- 50,000-psi 600°F test vessel
  - 10.00-in. ID × 25.0-ft deep

HAL84819

Shooting pond: 50-lb (22.6-kg) explosives gun survival shot

Thermal Testing Facility

The thermal testing facility provides performance evaluation, degradation studies, and longevity testing of detonators, energetic transfer components, and customer-specific system elements.

Mechanical Engineering Laboratory

At the mechanical engineering laboratory, engineers conduct mechanical engineering work assembling components and fixtures for various testing all in concert to address customer needs and develop customized mechanical solutions. The laboratory is integral to other testing activities conducted continuously at Jet Research Center (JRC), such as gun systems survival testing, heat tests, and system performance testing.

Shooting Pond

The latest addition to the JRC technology testing area is a massive pond engineered to conduct testing on up to 50 lb (22.6 kg) of explosives in a single shot. Ballistics engineers use this shooting pond to conduct underwater test shots and verify gun survival in fluid.

Products and Manufacturing

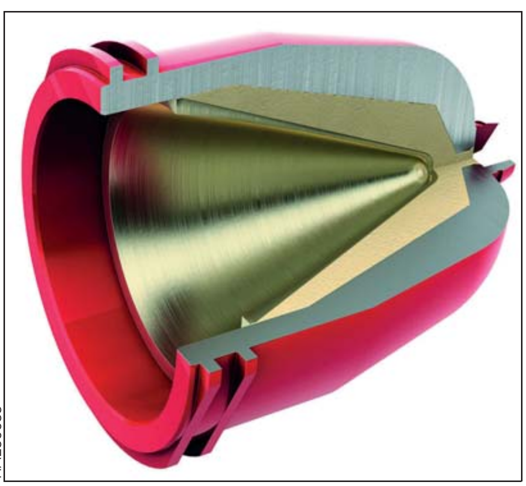
In the manufacturing process, Halliburton emphasizes quality and consistency, resulting in a continual progression toward automation. This produces a more accurate and consistent charge, while at the same time providing a more cost-effective, safer production process.

Perforating Shaped Charges

Halliburton perforating shaped charges lead the industry in quality, reliability, and performance. Jet Research Center (JRC) ballistics engineers continue to develop and manufacture perforating systems for virtually any reservoir environment or intervention technique. Halliburton also offers the expertise to develop custom charges to maximize effective penetration for your specific reservoir.

MaxForce® Family of Shaped Perforating Charges

Halliburton engineered the line of MaxForce® shaped perforating charges to help ensure perforation size performance, even if the perforating guns are lying on the low side of the completion casing string. This family of ultradeep-penetrating shaped charges delivers maximum propulsion with increased reliability and safety, even under extreme downhole conditions. The industry's deepest penetrating perforation charge relies on an improved liner geometry, proprietary liner composition, and patented case technology to help optimize uniform stimulation and accelerate production.



HAL36683

MaxForce® shaped perforating charge

Dominator® Charge

Dominator® charges were developed at the Halliburton Advanced Perforating Flow Laboratory (APFL) by firing perforating charges into actual rock under simulated downhole conditions that included rock effective stress, wellbore underbalance, and rock pore pressure. By analyzing post-shot results from the testing program, it was possible to rapidly develop a charge with favorable jet characteristics. Using the APFL in the design process also avoided the pitfalls associated with translating data from surface concrete targets to productivity estimations in downhole reservoirs.

The improvement in penetration performance is evident from the results. In one example, penetration increased by an average of 52% in the gas-filled samples and by an average of 37% in liquid-filled samples. These penetration results, along with improvement in core flow efficiency, contribute to increased flow performance. Dominator charges are available in a few variations and manufactured at JRC.

HAL84831

Assembly line of charges

The charge manufacturing process uses laser markers to etch every charge case with a unique identifier, product number, date of manufacture, and other data that provides traceability for quality control and the ability to track for compliance with federal, country, and various military governing bodies globally.

Perforating Guns

Jet Research Center (JRC) offers a comprehensive array of perforating guns to deliver its industry-leading charges safely on depth for optimal penetration and performance. JRC uses the highest quality steels to manufacture these products with rigorous quality control embedded into the manufacturing process.

Charge tubes are precision cut with a laser to help ensure accuracy of charge alignment within the guns in which they are housed. Charge alignment is crucial to the explosive jet exiting the gun body in the proper space.

RED® Rig Environment Detonators

The RED® detonator is a specially designed electro-explosive device that allows for safer wellsite explosive operations. The detonator possesses two major safety advantages over resistorized detonators used in the oil field. No primary explosives, such as lead azide, are used in its construction. Instead, the design is based on a deflagration-to-detonation technique using an insensitive pyrotechnic and secondary explosive. A semiconductor bridge (SCB) element, similar to those used in automotive airbag systems, initiates the deflagration reaction.

The RED detonator is insensitive to many common electrical hazards encountered around wellsites. This is accomplished by the combination of the 5-watt no-fire SCB and incorporation of an internal protection/firing circuit, which is similar to those used in exploding bridge wire (EBW) and exploding foil initiator (EFI) systems. However, the circuit operates at lower voltages than those required by EBW and EFI detonators. Therefore, they can be functioned using standard wireline firing panels.

During the RED system development, it was subjected to radio frequency (RF) hazard tests at various testing agencies and laboratories located in the US, including DNB Engineering, Inc., Franklin Applied Physics, and Sandia National Laboratories. A fourth testing laboratory in the UK, ERA Technology Ltd, also evaluated the RED detonator and reported it to be safe from RF hazards on North Sea oil production platforms, such as electrostatic discharge, stray voltage, and impact. The hazard levels passed by the RED detonator during these tests always met or exceeded those of resistorized detonators.

The RED detonator is available in four configurations that cover virtually any oilfield perforating situation or explosive operation. Firing is accomplished by application of 150 to 190 VDC to the device. This firing energy is usually supplied from standard wireline surface firing panels or from appropriate electronic trigger devices that are used in certain slickline operations.

RED® Capsule Detonator

RED® Top Fire Detonator

RED® Block Detonator

RED® Igniter

MaxFire® Electronic Firing System

The MaxFire® memory-based electronic firing system is specifically designed to initiate ballistic trains. Designed to fulfill the needs of challenging well projects that push the limits of today's mechanical firing systems, the forward-thinking design allows for multiple conveyance methods and applications, including tubing conveyed, slickline, and coiled tubing.

The MaxFire electronic firing system for tubing and coiled-tubing-conveyed perforating employs a distinctive user-defined sequence of pressure and time command pulses. The MaxFire electronic firing system for slickline operations adds an accelerometer command sequence combined with the mechanical pressure and temperature safety sub. It provides an entirely safe and dependable downhole solution for ballistic train initiation.

The MaxFire electronic firing system is programmable at surface with user-defined coded sequences that can address unique well completion challenges for the job. With potential unplanned wellsite operational changes in mind, additional safety and operational flexibility is designed into the MaxFire electronic firing system. This feature provides the ability to reset the operational sequence or set fail-safe parameters to adapt to wellsite requirements.

During the operation, the downhole electronics record the time, pressure, temperature, and acceleration, providing a post-job report of the downhole well environment.

MaxFire® Firing System

Jet Cutters

Jet Research Center (JRC) offers a wide variety of jet cutters that can be used in a range of applications from 1-in. coiled tubing to 9 5/8-in. casing. Each cutter is specifically designed for precision cutting of a particular pipe size and weight. This minimizes the amount of explosives needed and results in a clean cut. Jet cutters can be deployed on electric line, slickline, and coiled tubing for conveyance flexibility.

The Halliburton segmented cutter series is designed for efficient pipe recovery operations, offering reliability and ease of use. We provide a variety of sizes for a range of applications from 4 1/2 to 7 5/8-in. for all your casing recovery needs. The cutters are shipped disassembled for cost-effective transportation and storage and are easily assembled at the wellsite to save rig time.

Jet Cutters

JRC Drill Collar Severing Tool

The drill collar severing tool (DCST) is an effective last resort for severing drillpipe and drill collars. An explosive collision device creates a high-energy blast capable of shearing large, heavyweight drillstrings.

Drill Collar Severing Tool

Quality and Product Reliability—Internal Process Control

Internal process control establishes methods that help ensure all production and servicing activities are identified, planned, monitored/measured, and performed in a safe, efficient manner and under controlled conditions.

This procedure applies to all activities and operations within the program.

- Definitions
  - Capability: Ability of an organization, system, or process to realize a product that will fulfill the requirements for a product, service, and/or process.
  - Dependability: Collective term used to describe the availability performance and its influencing factors: reliability performance, maintainability performance, and maintenance support performance.
  - Design and Development: Set of processes that transform requirements into specified characteristics or into the specification of a product, process, or system.
  - Deviation Permit: Permission to depart from the originally specified requirements of a product/service prior to realization. For the purpose of this procedure, the term "Deviation Permit" has the same meaning as "Work Waiver."

Procedure

Process Integrity: Pre-Use/Startup Safety Reviews

Any new facility, equipment, process, or introduction of a new hazardous chemical substance or modification thereof requires a thorough pre-use/prestartup safety review before operation and/or use.

Pre-use/startup safety reviews confirm construction and equipment is in accordance with design specification, safety, operating, maintenance, employee training, and emergency procedures are in place and adequate. New facilities and equipment used in conjunction with a highly hazardous chemical or process require the completion of a process hazard analysis (PHA) and all recommendations implemented before production/operation/use.

Mechanical Integrity

Sites that use equipment to process, store, or handle highly hazardous chemicals must ensure equipment is designed, constructed, installed, and maintained to minimize the risk of unintentional release of such chemicals.

The mechanical integrity program includes the identification and categorization of equipment and instrumentation, development of written maintenance procedures (Level IV documents), training for process maintenance activities, inspection and testing criteria, correction of noted deficiencies in equipment outside acceptable limits, and the development of a quality assurance program (Six Star).

The mechanical integrity program includes the implementation of a total productive maintenance process to achieve the organization's objectives, goals, targets, programs, and regulatory requirements.

Management of Change

Management of change (MOC) is a process designed to help control change-related risks. The MOC process helps ensure that technical, health, safety, and environmental (HSE) aspects and impacts, procedure modifications, time allotment for process/product changes, and necessary authorizations have been considered and obtained before implementing any change.

Operation and Maintenance Servicing

All equipment and machinery used to support operation processes must be maintained in a safe and efficient manner in accordance with company, regulatory, and manufacturing specifications and requirements. The company will help ensure that additional environmental controls are taken to minimize ground, air, and water contamination associated with machinery and equipment. This includes placing secondary containment, such as drip pans to contain leaks of petroleum, oil, and lubricants (POL) and hazardous products, where necessary, changing intake and output filters as required to minimize air contamination, and properly disposing of or recycling material and POL products associated with preventive maintenance activities.

The company will implement a total productive maintenance (TPM) program that includes preventive, predictive, routine, and corrective maintenance to help ensure that all machines, equipment, and fixtures are safe, efficient, available, and work consistently without unplanned interruptions. This also helps ensure the site is meeting their objectives, targets, programs, and stated policies. Maintenance, conducted under the TPM program, is performed by qualified personnel.

Equipment and machinery operators are required to conduct a pre-use visual check of the equipment to help ensure it will operate safely, efficiently, and as intended by the manufacturer. General preventive maintenance, such as grease, oil, belt retention, tightening bolts, screws, etc., is the operator’s responsibility.

If the operator notes deficiencies beyond general daily maintenance or beyond their capability, such as electrical deficiencies, pressurized fittings, etc., they shall shut the equipment down and report it to their supervisor. The supervisor is required to submit either a work order or service order for the necessary maintenance and/or repair. If the deficiency could create a hazard or cause property damage, the equipment/machinery shall be taken out of service [by using the lock out/tag out (LO/TO) system].

Process Control

All processes and activities within the program will be planned and developed, including consideration of the following:

- The center objectives, targets, programs, and safe work requirements for operation/task.
- The resources, infrastructure, and work environment needed for a safe and efficient operation.
- The required verification, validation, monitoring, inspection, maintenance, and test activities specific operation/task and the associated acceptance criteria.
- The identification of operations and tasks that could have a negative health, safety, or environmental (HSE) impact. This is accomplished through job/process/task hazard analysis and risk assessments. Before performing risk assessment or a hazard analysis, all relevant process safety information must be compiled and reviewed by all involved parties.
- Establishing and maintaining procedures for the design of workplace, processes, installations, machinery, operating procedures, and work organization, including their adaptation to human capabilities to eliminate or reduce occupational health and safety risks. The product group leader (PGL) shall ensure there are documented procedures to cover situations in which their absence could lead to deviations from the site's policy and objectives or cause unnecessary risk to people, property, and processes.

Before implementation of new facilities, equipment, and/or process, a risk assessment or hazard analysis shall be conducted. Before conducting the assessment/ analysis, all relevant safety information must be compiled to include but not limited to highly hazardous chemicals, technology and equipment information, historical data, and manufacturing guidelines/recommendations. Existing processes that fall under process safety management (PSM) that are modified or did not undergo such analysis are required to do so before any changes.

The intent of process controls is to standardize, stabilize, measure, and continually improve the work methods and management controls that will help ensure a safe and efficient operation and contractual compliance, including customer requirements and governmental regulations. It is not intended that federal, state, and other government regulations and requirements be copied into procedure/ work instruction format but rather be referenced in the appropriate documents.

Work Instructions, Process Maps, Technical Manuals, and Contract Requirements

Each site will review their customer and company obligations to include their processes and activities, and develop specific procedures and instructions to include process maps that stipulate the operating criteria and describe how they will accomplish their task in a safe and efficient manner.

Each site (subcontractor/supplier, where applicable) shall plan and perform the production and services processes under controlled conditions, which include the following considerations:

- The information that describes the characteristics of the product is available.
- Procedures and/or work instructions are available in the workplace.
- Suitable equipment is available and is correctly used.
- Monitoring and measurement of the product characteristics is performed with appropriate equipment (devices) and compared to the acceptance criteria to determine acceptability.
- Processes for the release, delivery, and post-delivery of the product are established and implemented.

The work can be conducted in a safe and efficient manner without causing undue harm to the employee, the process, and/or the environment.

Identify situations in which the absence or noncompliance to internal control could lead to deviations from the company's quality, HSE (QHSE), and responsible care policy, goals, objectives, and targets. The company site will implement necessary action to help ensure work processes are controlled in a safe, efficient manner, without causing undue harm to the environment.

Management will consult with their employees on the development, performance, and results of process hazard analysis and on the development of other elements in the Six Star Management System.

Each site will use a required checklist to produce records required by the client or company to show work is performed in accordance with specifications.

Special processes, such as welding, confined space entry operations, cranes, rigging operations, etc., are those processes that present higher hazards and risks which could have the potential to cause harm or loss to people, property, and/or negative environmental impact. Therefore, special processes are subjected to more frequent monitoring to verify compliance with documented procedures to help ensure that the work is being performed in a safe, efficient, and environmentally acceptable manner, while all work requirements are met. As a minimum, the following controls must be applied to special processes:

- Procedures: All special processes will be conducted in accordance with written procedures and specified operating criteria that have been established and qualified as required by the applicable codes, standards, and regulatory requirements. These types of procedures will include health, safety, and environmental (HSE) aspects, impacts, and targets, as well as internal controls to eliminate accidental loss.
- Personnel: Personnel performing special process activities will be trained and qualified on internal quality, HSE (QHSE) controls and requirements as required by the applicable codes, standards, and regulatory requirements.
- Equipment: Equipment used to perform special processes will be maintained as required by the applicable codes, standards, and regulatory requirements.
- Monitoring: The work area performing special processes will develop procedure(s) to monitor their implementation and assign trained employee(s) to perform the monitoring.
- Revalidation: All special processes will be revalidated (refreshed/requalified) periodically as required by the customer/client, applicable codes, standards, jurisdictional authority, company, and regulatory requirements.
- Identification and traceability: The site requires that material, products, and services are tracked through internal processes to help ensure customer and company requirements are met. Following are the requirements for identification and traceability as they pertain to internal process control.
  - Products are identified and controlled in accordance with documented procedures and/or specifications to provide control and, when required, traceability. Identification is maintained through all stages of production. Applicable raw materials, such as explosives, steel plate, bars, and tubing, upon receipt are identified and are traceable to procurement documents and supplier documentation. Manufactured products, when required by specification, are identified by means of a batch/lot number or unique serialization.

Identification of Products, Materials, and Hazardous Items

Items or lots of items are identified at receiving and/or during the manufacturing cycle by contract, purchase or production order number, and part number, including applicable unique (property) identification numbers to differentiate between the following:

- Purchased items
- Fabricated parts
- Subassemblies
- Hardware
- Customer-supplied items

Each of these items are inspected to help ensure the items, products, and/or materials are accounted for, are safe, and pose no unreasonable significant risks to employees, customers, and/or the public.

Identification of Items, Products, and Materials at Receiving

The receiving employee identifies items by means of an identification label and/or accompanying documentation, which includes the following information as a minimum:

- Date of receipt
- Item identification

Any item that appears to present a significant hazard shall be marked and segregated with specific storage and handling instructions.

Identification for Fabricated Items

The work/service/production order documents and/or drawing part numbers that accompany the items during the manufacturing process identify fabricated items/assemblies.

Identification of Items, Products, and Materials During Storage

Personnel stocking items that are fabricated or purchased identify and track the items by their storage location. Identification labels of the stocked items are also displayed at the storage location.

Hazard Identification and Traceability

Hazards can be identified by various means, including but not limited to: workplace inspections, process checks, audits, past accidents, near misses, critical task analysis (CTA), and employee identification. Identified hazards shall be documented on either a hazard observation card (HOC) or a corrective action request (CAR).

Inspection and Testing General Requirements

Monitoring, measuring, inspecting, and testing (qualitative and quantitative) can be performed any time it is considered warranted in the process but as a minimum will be performed upon receipt, in-process, and final by each site division/function. The person performing the work or another employee designated by management will perform inspections and/or required testing activities. Quality, health, safety, and environment (QHSE) coordinators and designated personnel will perform random surveillance inspection of all activities affecting QHSE and help ensure compliance to internal processes, applicable legislation, and regulatory requirements.

Receiving Product and Materials Inspection

The employee receiving items or material or the person designated by management shall perform the following activities and verifications:

- Verify pertinent documents and/or previous inspection of items that are received.
- Visually examine the received items and verify the following:
  - No damage in transit
  - General quality of workmanship
  - Compliance of shipment with the purchasing documents to help ensure they meet any quality and safety requirements specified on the purchase orders or other pertinent documents
- Verify the documents provided by the supplier to help ensure:
  - All certificates, testing data, warranty information, or other documents required by the purchase order are available.
  - If applicable, test and material certificates conform to specified quality and safety requirements. When test or verifications cannot be performed at the receiving inspection location, the receiving employee can request the appropriate department to perform them. Acceptance or rejection of the items is based on the reported results of the requested inspections, tests, or verifications.

A green inspected tag (T5FG-IN) or label (L4IG-IN) is placed on the package/item/lot/batch to authorize the items to be placed into inventory and storage and for parts passing final inspection after repair.

Items determined to be nonconforming or unsafe at receiving are documented on either a CAR or quality deficiency report (Q-Note). Nonconformance items are identified with an orange nonconforming tag (T8F0-NC) or label (L410-NC) and segregated to help prevent inadvertent use.

A copy of the CAR, Q-Note, or HOC is forwarded to the procurement department or the organization that ordered the material to disposition the unacceptable items.

For critical or sensitive items, or items that pose a significant health or safety risk to employees, customers, or the general public shall be tagged with a suspect material tag (T8Y-SM) or label (L43Y-SM) and turned over to the operational excellence (OE) department for review and disposition.

In-Process Inspection

In-process inspections are performed by operation employees and quality assurance/quality check (QA/QC) inspectors who perform technical inspection with the use of internal processes, specifications, work instructions, technical bulletins, and other relevant documentation. The acceptance of the item is noted on the work order or inspection sheet. In-process inspections include monitoring health, safety, and environmental (HSE) and operational criteria.

Manufacturing performs first article inspection per production order to help ensure the manufactured product meets stated specification. Acceptance is identified by placing the first piece approval tag (T8DG-FP) or label (L21G-FP) on the first piece per production order.

Employees shall continuously monitor their own work environments for HSE hazards. Any hazards shall be reported on a CAR in accordance with Document 2-2-6.06 or on a HOC. If the noted hazards pose any significant threat of loss or any injury to employees, the process shall be immediately shut down until appropriate corrective action can be taken.

When the servicing or product activities are such that the test and/or inspection is not possible, the inspector helps ensure the process is monitored by means of written procedures, statement of work, or by control points established on the process or assembly instruction sheet.

Items determined to be nonconforming during in-process inspection are identified by either the nonconforming/disposition tag (T8F0-NC) or the nonconforming/disposition label (L410-NC) and segregated to prevent inadvertent use.

Trained quality and safety personnel who work for the operational excellence (OE) department shall measure, inspect, and monitor the work environment for health, safety, and environment (HSE) hazards.

Final Inspection

Upon completion of all the activities of the service or production process, a final inspection will be performed in accordance with the requirements given in the inspection and test plan (ITP), customer requirements, or other applicable laws, regulations, and/or guidelines.

The "inspector" verifies that all test and inspections required by the ITP, procedure, process, or other referenced material have been completed and that documentation is complete and acceptable. Acceptance is indicated by means of a green final inspection tag (T8FI-2G) or label (L4IG-PF).

Manufacturing uses last-piece inspection per production order for final inspection. Acceptance is indicated by means of a blue "last-piece approval" tag (T8-LB-LP) or label (L21BL-LP).

Items determined to be nonconforming during final inspection are controlled and/or repaired in accordance with customer requirements or company directives.

Operations can use another means of identifying nonconformance other than the tagging system described, as long as the process is documented on a Level IV document, incorporated into the management system, and thoroughly understood by all affected employees.

Monitoring and Measurement Status Tags

Monitoring, measurement, test, and inspection status can be identified by authorized markings, stamps, routing cards, tags, labels, test hardware, physical location, inspection records, or other suitable means. When it is necessary to use tags or labels, only the employee designated as an inspector or other authorized personnel who have been granted the authority and responsibility to place or remove inspection status indicators tags or labels can perform this activity. The status of items is indicated by the use of the following tags and or labels:

- Acceptance tags and labels (green: T5FG-IN, L4IG-IN, T8DG-FP, L21G-FP; blue: T8-LB-LP, L21BL-LP) are used to indicate the item or lot of items conform to the specified requirements.
- Nonconforming and awaiting disposition (suspension) tags and labels (orange: T8F0-NC, L410-NC) are used to indicate that work on the item or lot of items indicate a nonconformance to specifications and has been temporarily suspended until a decision is made on the disposition of a nonconformance.
- Repair/rework tags and labels (nonconforming and awaiting disposition tag and/or label is used for repair/rework; orange: T8F0-NC, L410-NC) are used to indicate that an item or lot of items are to be repaired or reworked.
- Reject/return tag (nonconforming and awaiting disposition tag is used for reject/return; orange: T8F0-NC) is used to indicate that an item or lot of items are to be scrapped or returned to a supplier for failing to meet specifications.
- Suspect material tag or label (T8Y-SM, L43Y-SM) is used to tag nonconformances, which present a hazard that is immediately dangerous to life and health (IDLH).

Inspection and Test Plans

Employees perform inspections and test in accordance with technical manuals, technical bulletins, other applicable publications, or as requested by the client/customer and the quality department. Because in-process inspections and tests are conducted in accordance with work instructions and engineering specification, additional written inspection and test plans (ITP) are normally not required. However, an ITP can be mandated by the quality department for a particular division, department, task, product, or process if one or more of the following events occur:

- Validated customer complaints of quality deficiencies, which indicate a trend of marginal to poor quality workmanship.
- The organization receives an unacceptable number of validated product quality deficiency reports (PQDR), or other unsatisfactory ratings by customers, clients, or government inspectors.
- Acceptable auxiliary procedures, technical manuals, technical bulletins, or other publications that describe inspection and testing criteria, are not available for a particular process or product, which requires inspections and/or tests to help ensure acceptable quality products and service.
- OE department detects quality, health, safety, and/or environmental (QHSE) problems/risks during random in-process and final inspections/tests.
- Additional ITPs are requested in writing by the client/customer.

If ITPs are requested or required by the quality department, they shall be prepared through a joint effort of the operation and quality department. An ITP shall specify the following as a minimum:

- The frequency of inspection or test
- The characteristics to be evaluated
- References to any auxiliary procedures
- Any special measuring and test equipment required
- The acceptance criteria
- Identification of who is to perform the inspection and/or test

- The manner in which the inspection and/or test is to be performed

ITP shall be kept in the Six Star Management System. Any ITP change or modification must be approved through the quality department.

Calibration Requirements

Company test, measurement, and diagnostic equipment (TMDE) is managed by the quality department. Company-owned TMDE is calibrated either by qualified personnel or through a qualified agency. The company will maintain a listing of all company-owned TMDE and records of internal and external calibration.

Operation divisions receive TMDE from the quality, health, safety, and environment (QHSE) department, verify the calibration label is current, and store it ready for issue to employees. Handling and storage conditions shall ensure the TMDE is maintained in good working order, and their precision is not compromised. Appointed calibration attendants will verify all calibration stickers and equipment returning from the calibration laboratories for their area of responsibility, for current calibration, and store it properly until ready for use.

TMDE is either logged out by the employees on a calibration log or signed out by the appointed calibration attendants. Calibration attendants are responsible for helping ensure that all TMDE is identified on the TMDE listing and recalled for calibration.

Before each use of TMDE, the using employee verifies that the label indicates calibration is still valid. Any instrument with an expired calibration date shall not be used by the employee. Employees are required to list all calibrated tools, to include the date it was calibrated, and the date the calibration expires on their in-process inspection forms.

Any TMDE that fails to operate as required, appears to be damaged, or has drifted from its original accuracy, shall be removed from service by the employee and immediately returned to the calibration coordinator.

All TMDE shall be calibrated before the calibration due date on the calibration label.

Equipment and tools used to transfer lengths and diameters shall be inspected annually to help ensure proper working order. These tools shall be tracked in the calibration system in the same manner as other calibrated TMDE.

If TMDE has not been returned before the calibration due date, the calibration coordinator will notify the responsible department in control of the equipment. The department shall return the TMDE immediately for calibration. Departments that have not returned the calibrated equipment shall be issued a nonconformance corrective action request (CAR), and the quality manager shall be notified of the nonconformance.

If TMDE is determined to be defective, nonconforming to TMDE specification, or not returned for calibration, the calibration coordinator shall immediately notify the quality manager of the problem to include:

- TMDE equipment that is nonconforming and serial number.
- The department assigned to the TMDE during the period of the nonconformance and the supervisor who is responsible.
- Upon request, the department will provide a list of service/work orders and equipment the nonconforming TMDE was used on.

The quality department will work with the applicable operation manager and contact those customers to notify of any problems if the TMDE was required for quality assurance or for safety reasons.

If the site uses computer software for monitoring and measurement of specified calibration requirements, a person shall be named responsible to maintain and validate the accuracy of the calibration software. If the site uses computer software application(s) to perform actual calibration on TMDE, its intended application shall be confirmed before initial use and reconfirmed as often as necessary.

Employees who fail to check, do not log calibrated equipment, or who use TMDE out of calibration, place the organization at risk of passing nonconforming products to the customer. Employees who do not comply with calibration requirements will receive disciplinary action, up to and including termination of employment.

Handling, Storage, Packaging, Preservation, and Delivery

Handling Requirements

Material handling will be consistent with the type of material being handled. Handling will be in accordance with any existing company requirements. The person responsible for storage helps ensure that the handling of material conforms to written requirements. If none exist, the material is handled in a manner consistent with the type of material.

The divisions are responsible for establishing and maintaining a maintenance, qualification, and verification program for material handling equipment (MHE), products, and hazardous materials within their areas of responsibilities.

Personnel handling equipment or hazardous materials shall be qualified to the applicable requirements. All users of equipment and hazardous materials are responsible for helping ensure that they are following applicable laws and regulations, and they shall ensure that hazardous material containers are in good condition before each use to prevent damage or accidental spills of the material being handled.

Storage Requirements

Only items and material that have been inspected, identified, and labeled "accepted" are stored in the areas designated as acceptable material.

The storage areas shall be suitable for the type of item or material stored and shall conform to all company requirements. Stacking and storage shall be performed to comply with the requirements listed in Document 2-3-A.02.

Shelf life and first-in/first-out (FI/FO) items: Operation managers will establish a list of items, including items having a shelf life that must be used on a FI/FO base.

Each division/functional area is responsible for continually inspecting and maintaining the storage areas in a satisfactory condition. Damaged, defective, or items with expired shelf life are identified, reported, and treated in accordance with Section 5.9 of this procedure.

Packaging and Preservation Requirements

Preservation, packaging, and shipping of products and hazardous materials will be in accordance with all applicable government, state, company, and contract requirements. If no government or contract requirements exist, the freight specialist and quality, health, safety, and environment (QHSE) department, based on product type, destination, and method of transportation, will establish preservation, packaging, and shipping instructions.

Packaging and preservation processes are controlled by written procedures, which are prepared by the supply and transportation division and approved by the operational excellence (OE) and mechanical engineering/industrial engineering (ME/IE) departments.

Preservation requirements for products and hazardous materials shall be followed. These requirements are specified on or within:

- Purchase order for purchased items
- Technical description for customer-supplied items
- Company or contract requirements for special items
- Material safety data sheets (MSDS)
- Code of federal regulations

Delivery Requirements

Each division is responsible for the preservation, preparation, and delivery of the final items, products, and hazardous materials according to specified procedures/ instructions, rules, and regulations, which take into consideration the contractual and/or company requirements.

Supply and transportation is responsible for the preparation of the "shipping memo," the packaging, and delivery of the material.

The post-environment management division (USG) is responsible for labeling, marking, and shipping of hazardous materials leaving the post, unless otherwise stated in the contract.

Statistical Process Control

Statistical techniques consist of two broad categories:

- Monitoring and/or measuring a sample of a product or service for acceptance.
- Analysis of data to establish control, verify process and performance capability or process characteristics, and improve the QHSE processes, including the elimination of accidental losses. When planned results are not achieved, appropriate corrective action shall be taken to help ensure conformity of products and services.

Statistical techniques and data are used to determine the conformity of products and services, conformity to the management system, and continually improve the effectiveness of internal processes.

Quality sampling inspection for acceptance is typically used during in-process inspection, special process monitoring, and final inspections. Operations will identify activities that should be inspected and verified by sampling techniques or against required standards.

Selection of the appropriate sample to be inspected is based on the following considerations in conjunction with either ANSI/ASQ Z1.4-1993 or other approved internal or external statistical technique standards.

- Characteristics to be monitored and/or measured
- Criticality of the product
- Type of product to be inspected
- Type of inspection to be performed
- Work methods used (individual or by lots)

Control Charts and Graphs

There are many variations of charts and graphs used to establish control and/or verify process capability or process characteristics. Charts and graphs that can be used onsite include check sheets, control charts, data points, histogram, Pareto diagram, process capability, run charts, and scatter diagrams.

Control charts and graphs are used primarily to establish baseline performance of a process, identify opportunities to improve the management system, and measure the results of process improvement efforts. Operation management will help ensure that during the planning stage of process realization, suitable methods are developed to measure and analyze the quality of the process's output when it is implemented. The data generated from the processes shall provide information relating to customer satisfaction, product conformance to requirements, and characteristics and trends of processes, including opportunities for preventive action.

Statistical Data for Quality Activities

Statistical techniques are useful in all aspects of the organization's operation. The following statistical methods can be used when management or the operational excellence (OE) department determines a specific need or when information is needed to improve identified deficiencies or process improvements:

- Graphical methods to help diagnose problems or improve existing processes.
- Statistical control charts to monitor and control production and measurement processes.
- Experiments to identify and quantify variables that influence product and work process performance.
- Regression analysis to provide quantitative models for work processes.
- Statistical methods for reliability specification, longevity, and durability prediction.
- Process control and process capability studies.
- Determination of quality levels and inspection plans.

Statistical Data for Health, Safety, and Security Performance

The following reactive measures of performance to monitor accidents, ill health, incidents, and near-misses, to include other applicable historical evidence of deficient health and safety performance, is calculated on a monthly basis and graphically displayed. This information is calculated by the health, safety, and environment (HSE) department and is analyzed by the HSE manager to implement corrective and/or preventive control measures to prevent future organizational losses.

- Total case incident rate (TCIR): This rate is used to calculate the percentage of injuries and illness that occur on the site. The formula used is (N/EH) × 200,000.
  - N = sum of the number of recordable injuries plus illnesses.
  - EH = total number of hours worked by all employees.
- Days away restricted or transferred (DART): This rate is used to calculate the percentage of lost work days and restricted work days that occur on the site. The formula used is the same as 5.11.8.1 except:
  - N = sum of the number of all recordable injuries plus illnesses resulting in days away from job title or restricted work activity.
- Lost time incident rate (LTIR): This rate is used to calculate the percentage of lost work days that occur on the site. The formula used is the same as 5.11.8.1 except:
  - N = sum of the number of lost work cases.
- First aid rate (FAR): This rate is used to calculate the percentage of first-aid cases that occur on the site. The formula used is the same as 5.11.8.1 except:
  - N = sum of the number of cases that resulted in first aid but did not result in lost or restricted work and did not meet the criteria for a recordable injury or illness.
- Property damage incident rate (PDIR): This rate is used to calculate the percentage of property damages that result from an unplanned incident. It excludes normal wear and tear. The formula used is the same as 5.11.8.1 except:
  - N = sum of the number of property damages.
- Site total incident rate (STIR): This rate is used to calculate the total incident rate, which includes recordable injuries and illnesses lost and/or restricted work days, first-aid cases, and property damages that did not result in personal injury. The formula used is (N+F+R+P/EH) × 200,000.
  - N = sum of the number of recordable injuries plus illnesses.
  - F = sum of the number of first-aid cases.
  - R = sum of lost and/or restricted work days.
  - P = sum of property damages that did not result in injury.
  - EH = total number of hours worked by all employees.
- Detonation incident rate (DIR): This rate is used to calculate the percentage of accidental detonations. The formula used is (N/CP) × annual man-hours for those involved in charge manufacturing.
  - N = sum of the number of detonations.
  - CP = total number of charges produced on a monthly basis.
- Subcontractors incident injury rate (S-IIR): This rate is used to calculate the percentage of injuries and illness that occur for all subcontractors whose employees worked 1,000 or more hours in any quarter at the company site. The formula used is (N/EH) × 200,000.
  - N = sum of the number of recordable injuries plus illnesses.
  - EH = total number of hours worked by all employees.

Security Incident Rates

- Total security incident rate (TSIR): This rate is used to calculate the percentage of security incidents that occur on the site. The formula used is (N/EH) × 200,000.
  - N = sum of the number of security incidents.
  - EH = total number of hours worked by all employees.
- Reportable security incident rate (): This rate is used to calculate the percentage of reportable security incidents that occur on the site. The formula used is the same as 5.11.9.1 except:
  - N = sum of the number of reportable security incidents.

RSIR is defined as a security incident that has the potential to put the public at risk, an attempted theft of explosive product, lost or missing explosives, failing to secure an explosive magazine at the end of the work shift, an intruder or unauthorized person onsite after normal working hours, or sabotage to security equipment (i.e., cut fence, attempted entry into a magazine, camera made inoperable, etc.).

Statistical Trend Analysis

The health, safety, and environment (HSE) department will provide technical direction on the use of control charts and graphs. Statistical trend data, when appropriate and applicable, will be analyzed at various levels of the site.

HSE uses relevant measures and records to analyze quality, environmental, health, safety, security, and other responsible care performance and trends. Those data are presented and reviewed by management on a monthly basis.

Each division uses trend data relating to the characteristics of processes and products to demonstrate that the planned results are being achieved and identify opportunities for improvement.

- Responsibility/accountability center manager
  - Helps ensure operation compliance to the requirements detailed within this procedure.
  - Takes corrective action for deficiencies and nonconformances reported by the HSE department
- Operational excellence (OE) department
  - Seeks authorized approval for design & development (D&D) projects and helps ensure the site has adequate D&D processes in place before accepting D&D work
  - Administrates operation documented work methods and processes and enters them into the D&D control system in accordance with Document 2-2-6.02
  - Monitors operation work methods through quality surveillance and internal audits, reports deficiencies to operation management, and tracks them through the corrective action tracking system in accordance with Document 2-2-6.06
  - Approves work methods for special processes before the execution of work
  - Provides technical training on inspection and testing for receiving, in-process, and final inspection, and can perform random inspections and tests throughout the process life cycle
  - Approves inspection and test plan (ITP) developed by operations before ITP execution
  - Monitors the site calibration processes through random surveillances and internal audits
  - Seeks disposition on nonconforming products, processes, and devices in accordance with contractual, technical, and regulatory requirements
  - Establishes effective statistical control techniques and methods to track the site quality HSE (QHSE) performance; overall responsibility to monitor, measure internal process control, and report site compliance to upper management
- Operation managers and supervisors
  - Helps ensure that operation work methods and processes are established to meet contractual, company, and ISO requirements; will submit the updated and accurate procedures and instruction to OE for recordkeeping
  - Monitors operation work methods through supervision surveillance and internal checks; will take necessary action to migrate any HSE impacts, investigate nonconformance, and take corrective action for identified deficiencies; will report critical QHSE deficiencies to OE department upon discovery and/or notification
  - Appoints personnel to perform receiving, in-process, and final inspections as required in the management system
  - Helps ensure that testing, measuring, and detection equipment that requires calibration is enrolled in the company's calibration system and that calibration requirements are complied with by employees

  - Segregates nonconforming products, materials, and devices, and shuts down nonconforming processes in accordance with contractual and regulatory requirements and will notify operational excellence (OE) department for disposition
  - Establishes effective statistical control techniques and methods to track the site's performance against company and customer requirements and will provide this information to the OE department
  - Helps ensure that handling, storing, packaging, preservation, and delivery requirements are implemented and complied with by employees
  - Helps ensure compliance to internal process control requirements as defined in this procedure are implemented through their areas of responsibility; management responsible and has the authority to manage, perform, and verify activities that have an effect on quality health, safety, and environmental (QHSE) performance
  - Helps ensure that all applicable personnel are trained in the procedures/instructions and follows all requirements listed within this procedure
- Subcontracts department
  - Helps ensure that identified subcontractor nonconformance and deficiencies are reported to the subcontractor and corrected within specified time frames in accordance with company, contractual, and federal requirements
  - Takes appropriate corrective actions as necessary, up to and including termination of subcontracts for subcontractors who consistently do not meet established QHSE performance expectations
  - Communicates pertinent and relevant procedures, processes, and HSE aspects and impacts to subcontractor and suppliers, and requires their compliance to established regulatory, contractual, and company-specified requirements
- Employees
  - Follow all procedures, processes, work methods, and management directives, and help ensure testing, measuring, and detection equipment is within calibration before use
  - Perform monitoring and inspection activities in accordance with inspection criteria, and report work stoppages, deficiencies, and nonconformances to their immediate supervisor for appropriate action
  - Perform workplace inspections and report any occupational HSE hazard or risk, and take necessary actions to minimize further loss without placing themselves or others at risk of injury

Training

Operation managers are responsible for training their employees on approved work methods, company procedures, technical manuals, and the requirements listed within this procedure. This type of training is normally performed informally through established meetings and on-the-job training.

The OE department will train managers and supervisors on the requirements listed within this procedure and will provide technical training on inspection and test plans (ITP), calibration, and disposition of nonconformances to selected employees. This type of training will be documented on internal training certificates.

Records

Copies of procedures, work methods, corrective actions, preventive actions, nonconformance reports, quality deficiency reports, internal inspections and checks, operator and equipment qualifications, or any other records produced as a result of this procedure will be retained as HSE records. Records will be maintained for 5 years in OE central files, electronic filing systems, and/or division files. Process safety management (PSM) records shall be maintained for the life of the process.

Performance Metrics

OE will monitor the requirements listed within this procedure through random surveillance and annual internal management system audits.

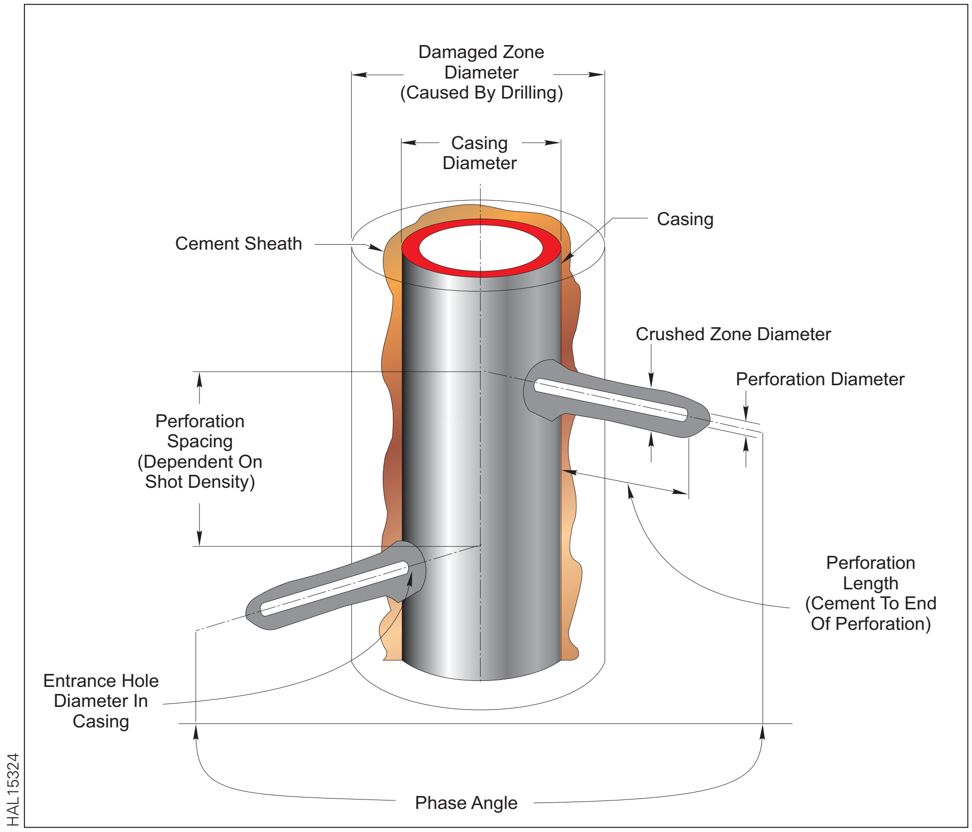
02

Perforating Optimization Design Process

Introduction

The Halliburton perforating tool kit (HPTK) takes a systematic approach to delivering engineered perforating systems. The process is based on extensive experimental work at the Halliburton Advanced Perforation Flow Laboratory (APFL) and includes perforation flow modeling and damage assessment performed with a fully 3D finite element model. To deliver the highest possible completion efficiency, the HPTK also uses experimental testing, modeling, and field validation studies to optimize perforation selection and execution.

The final step in a natural cased and perforated completion requires a way to establish communication between the reservoir and the wellbore to efficiently produce or inject fluids. The most common method involves perforating with shaped charge explosives to get through the casing and cement sheath. Numerous perforating strategies are available. These include choices of gun type, charge type, shots per foot (spf), shot phasing, gun position, and degree of under- or overbalanced pressure at the time of perforating. Because perforating is typically the sole means of establishing communication with the reservoir, it is important that this aspect of the completion receive the proper engineering focus.



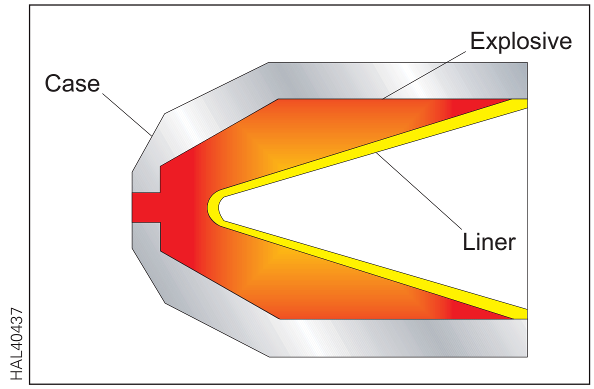
Perforated Wellbore Geometry

The Perforation Process

The shaped charge or jet perforator is the explosive component that creates the perforation and uses the same technology as armor-piercing weapons developed during World War II. These shaped charges are simple devices, containing as few as three components. However, optimizing charge performance is not an easy matter because of the physics of liner collapse and target penetration. The extreme dynamic conditions that exist during collapse and penetration involve calculation concerning elasticity, plasticity, hydrodynamics, fracture mechanics, and material characterization.

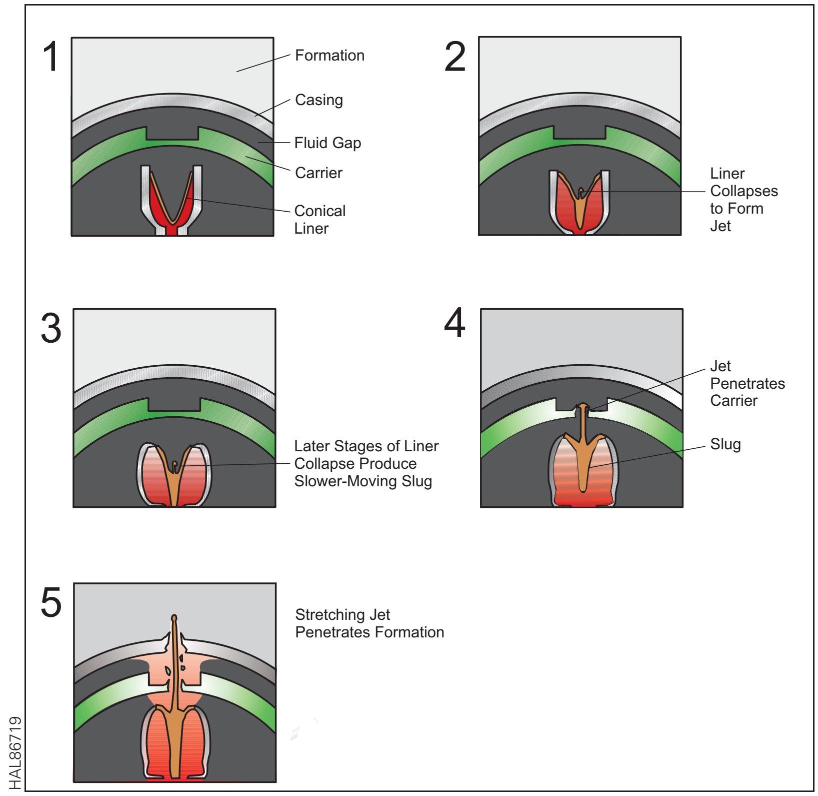
The process of liner collapse and jet formation begins with detonating the base of the charge. A detonation wave sweeps through the explosive, chemically releasing energy. High-pressure gases at the detonation front measure approximately 3 to 5 million psi and impart momentum, forcing the liner to collapse on itself along an axis of symmetry. Different collapse and penetration characteristics will result, depending on the shape and material of the liner. If the liner geometry is conical, a long, thin stretching jet will be formed. In this case, the penetration of the jet into the target is relatively deep, and the hole geometry is small.

If the liner is parabolic or hemispherical, a much more massive, slower-moving jet will be formed, creating a shallow penetration with a relatively large hole diameter. Because liner design has a tremendous influence on the penetration characteristics of a shaped charge, the shape of the liner is used to categorize jet perforators as either deep penetrating (DP) or big hole (BH). Typical DP charges create hole diameters between 0.2 and 0.5 in. with penetration depths in concrete of up to several dozen inches. DP charges are primarily used for perforating hard formations. BH charges are generally used for perforating unconsolidated formations that require some form of sand control. BH charges are designed with hole diameters of between 0.6 and 1.5 in. to facilitate placement of sand or proppants, and penetrations are normally 8 in. or less.

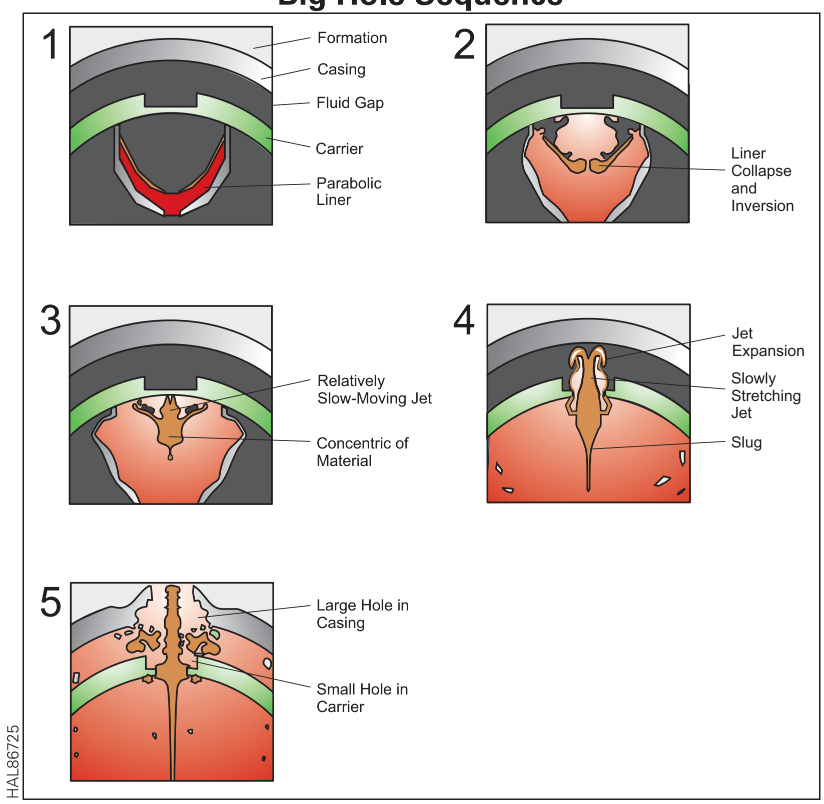


Shaped Charge Perforator

Deep-Penetrating Sequence



Big Hole Sequence



Damaged Zones

During the jet penetration process, some damage occurs to the rock matrix surrounding the perforation tunnel. The altered area, called the damaged (crushed and compacted) zone, results from high-impact pressures that occur during perforating. A damaged zone consists of crushed and compacted grains that form a layer approximately 0.25 to 0.5 in. around the perforation tunnel (Asadi and Preston 1994; Pucknell and Behrmann 1991). Later work by Halleck et al. (1992) shows that damaged zones are of nonuniform thickness and decrease down the length of the perforation tunnel. Some evidence suggests big hole charges can cause damaged zone layers that approach 1 in. around the perforation tunnel.

In addition, laboratory studies indicate that the permeability of the damaged zone can be 10 to 20% of the surrounding formation (Bell et al. 1972). Accordingly, it is important to design the perforation event to minimize this effect on well performance.

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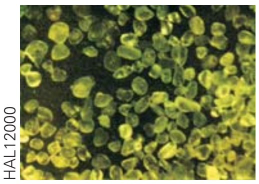

Sand Grains Before Perforating Event

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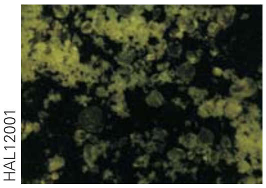

Sand Grains After Perforating Event

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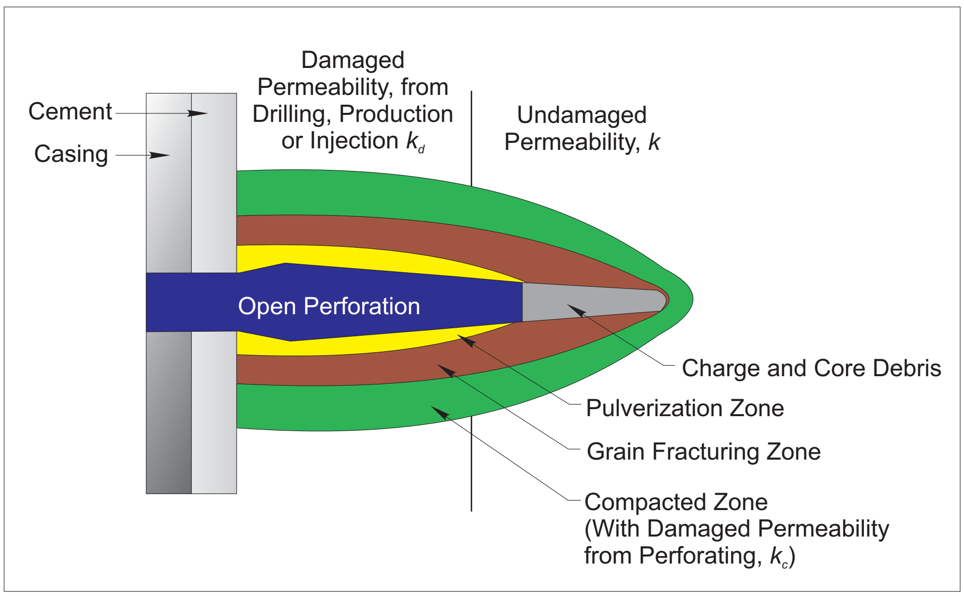


Perforation-Damaged Zone

Completion Types

The effectiveness of the communication path through the cement and casing is critical to the completion and well performance. Perforations should enhance well productivity in several ways. They should create clear channels through the portion of the formation damaged during the drilling process. They should provide uniform tunnels for hydraulic fracturing fluids and proppants and should make many large uniform holes for sand control and hydrocarbon production.

Completions can be classified into four types: openhole, natural, stimulated, and sand control. However, in every case, the objective is to maximize production, which in turn can be modeled using the radial flow equation:

$$P_e - P_{wf} = \frac{q\mu\beta}{7.08 \times 10^{-3} kh}\left[\ln\left(\frac{r_e}{r_w}\right) + S\right]$$

The productivity index (PI), typically used to assess the performance of a well over time, is derived from the following radial flow equation:

$$PI = \frac{q}{P_e - P_{wf}} = \frac{7.08 \times 10^{-3} kh}{\mu\beta\left[\ln\left(\frac{r_e}{r_w}\right) + S\right]}$$

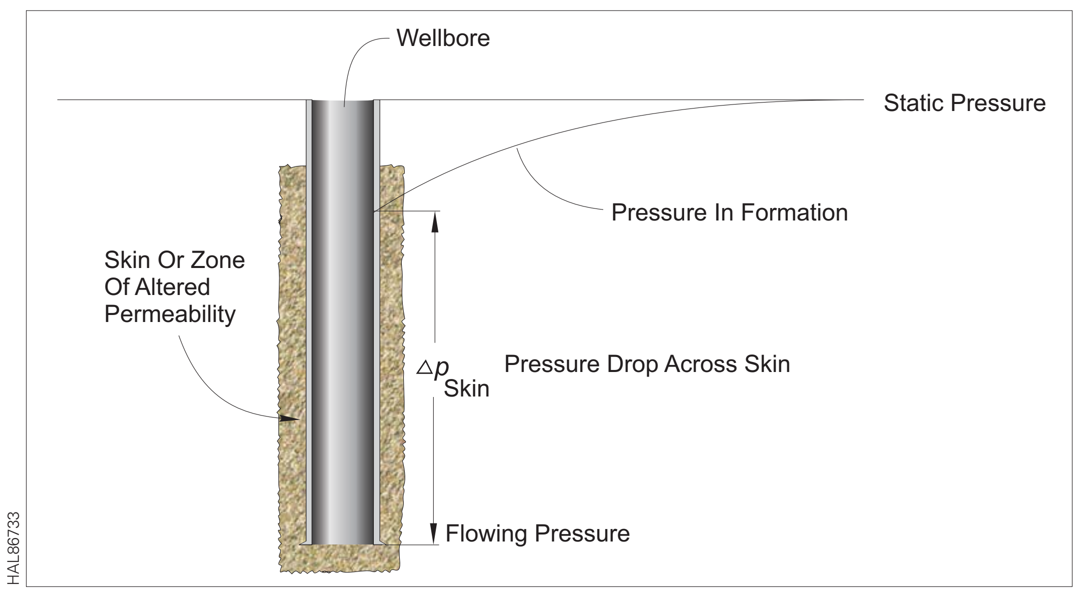
Skin Factor

The skin factor or S term is usually defined as a zone of reduced (or higher) formation permeability near the wellbore. Drilling and completing a well normally results in reduced formation permeability around the wellbore. These decreases in permeability can be caused by the invasion of drilling fluid into the formation, the dispersion of clay, and the presence of mudcake or cement. A similar effect can be produced by reductions in the area of flow exposed to the wellbore. Partial well penetration, limited perforating, or plugging of perforations would also result in a damaged formation response.

Skin factor can be used as a relative index to determine the efficiency of drilling and completion practices. The factor is positive for a damaged well, negative for a stimulated well, and zero for an unchanged well.

The total skin factor summarizes the change in radial flow geometry near the wellbore due to flow convergence, wellbore damage, perforations, partial penetration, and well deviation.

$$S_t = S_{c+\theta} + S_p + S_d + \Sigma S_i$$



Pressure Distribution in a Reservoir with a Skin

The term $S_{c+\theta}$ represents the effects caused by partial penetration and slant as described by Cinco-Ley et al. (1975). Skin effects caused by partial penetration and slant are often significant and result from operational considerations, such as drillsite location and avoidance of coning undesirable gas or water.

$$S_\theta = -\left(\frac{\theta' d}{41}\right)^{2.06} - \left(\frac{\theta' d}{56}\right)^{1.865} \log_{10}\left(\frac{h_{tD}}{100}\right)$$

$$\text{Where } h_{tD} = \left(\frac{h_t}{r_w}\right)\sqrt{\frac{K_H}{K_V}}$$

$$\theta'_d = \tan^{-1}\left(\sqrt{\frac{K_H}{K_V}}\tan\theta d\right)$$

Where h_{tD} is formation thickness dimensionless, θ_d is well deviation (sum of the deviation and the true dip — the angle that the wellbore makes with an imaginary normal to the zone), degrees, and θ'_d is adjusted well deviation, degrees.

$$S_c = 1.35\left[\left(\frac{h_t}{h_p} - 1\right)^{0.825}\left\{\ln\left(h_t\sqrt{\frac{K_H}{K_V}} + 7\right) - \left[0.49 + 0.1\ln\left(h_t\sqrt{\frac{K_H}{K_V}}\right)\right]\ln(r_{wc}) - 1.95\right\}\right]$$

Where

$$r_{wc} = (r_w)\exp\left[0.2126\left(\frac{Z_m}{h_t} + 2.753\right)\right] \text{for } y > 0$$

The term y is equal to the distance between the top of the sand and the top of the open interval, ft.

$$Z_m = y + (h_p/2)$$

The term r_{wc} is equal to the corrected wellbore radius, ft.

$$r_{wc} = r_w, y = 0$$

$$\text{When } \frac{Z_m}{h_t} > 0.5, \text{ replace } \frac{Z_m}{h_t} \text{ by } \left(1 - \frac{Z_m}{h_t}\right)$$

The term S_d represents the effects of formation damage attributed primarily to filtrate invasion during the drilling process. This filtrate invasion can reduce the productivity of an openhole completion and severely impair the performance of the perforated completion, especially when the perforation tunnels terminate inside the damaged zone. Karakas and Tariq (1988) quantified S_d for both openhole and perforated well completions. They also developed a technique to calculate skin effect resulting from perforations based on phasing and perforation length. A calculation for perforation skin effect $(S_d)_p$ can be approximated by accounting for formation damage:

$$(S_d)_p = \left(\frac{K}{K_s} - 1\right)\left[\ln\left(\frac{r_s}{r_w}\right) + S\right]$$

$$= (S_d)_o + \left(\frac{K}{K_s} - 1\right)S_p$$

This relationship is appropriate for perforations that terminate inside the damage zone ($L_p < r_d$). The term r_s represents the damaged zone radius and $(S_d)_o$ is the equivalent openhole skin effect.

$$(S_d)_o = \left(\frac{K}{K_s} - 1\right)\ln\left(\frac{r_s}{r_w}\right)$$

For perforations that extend past the damaged zone ($L_p > r_d$), the amount of damaged skin can be approximated by:

$$(S_d)_p = S_p - S_p'$$

Here, S_p' is the perforated skin evaluated at L_p', the modified perforation length, and r_w' is the modified radius. These parameters are given by:

$$L_p' = L_p - \left(1 - \frac{K_s}{K}\right)r_d$$

And

$$r_w' = r_w - \left(1 - \frac{K_s}{K}\right)r_d$$

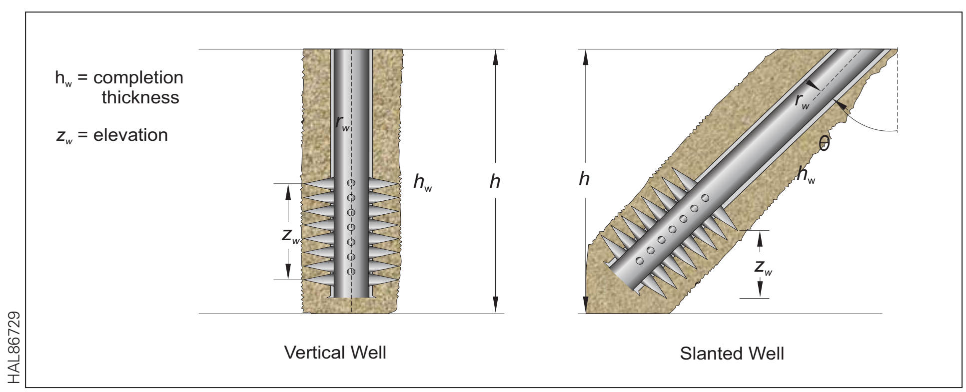
In both cases, skin caused by the perforation, S_p, is expressed by three distinct components: horizontal plane-flow effects, S_h, wellbore effects, S_{wb}, and the vertical converging effect, S_v.

$$S_p = S_h + S_{wb} + S_v$$

The term ΣS_i includes pseudoskin factors, such as phase and rate-dependent effects. This term is less important to the total skin factor. Accordingly, the focus should be on understanding and controlling the other skin factors that influence well productivity.

A complete understanding of skin and its effect on completion efficiency is vital to optimizing well productivity.

The Halliburton perforating tool kit (HPTK) was developed to assist in this effort by analyzing these effects for various gun systems.



Vertical and Deviated Well Configuration

Natural Completions

"Natural" completions are wells with sufficient reservoir permeability and formation competence to produce economical hydrocarbon rates without stimulation. With natural completions, effective communication to the undamaged formation is crucial. The primary perforation factors are depth of penetration, charge phasing, the effective shot density, percentage of the productive interval that is perforated, and degree of underbalance/ dynamic underbalance pressure. The perforation diameter is generally unimportant if it is larger than 0.25 in.

Experiments at the Halliburton Perforation Flow Laboratory highlighted the importance of optimizing the degree of underbalanced/dynamic underbalanced pressure. Perforation damage can occur from perforating with overbalance, balance, and underbalance/dynamic underbalance. All three experiments were perforated under the same test conditions with the same shaped charge, pore pressure, and effective stress condition. The only variable in the three experiments was the degree of underbalanced/dynamic underbalanced or overbalanced pressure at ±3,500 psi.

Overbalanced or balanced perforating has a significant disadvantage. Well fluids injected into the core can potentially damage the formation through fluid invasion and plugged perforations. Because there is no perforation cleanup, the results are larger positive skin values. In the underbalanced experiment, the entire perforation tunnel was effectively cleaned during the instantaneous surge and subsequent flowback period. Whereas, with the balanced and overbalanced experiments, the entire perforation tunnel was not cleaned as efficiently, resulting in much lower core flow efficiencies.

All three cores were flowed and injected at the same flow rates to simulate well cleanup during field conditions. Underbalanced/dynamic underbalanced perforating creates negative differential across the formation during the perforation, offering significant benefits. Maximum perforation cleanup can be applied to the entire perforation interval from the surge effect with no fluid invasion into the reservoir.

Deep Penetrating

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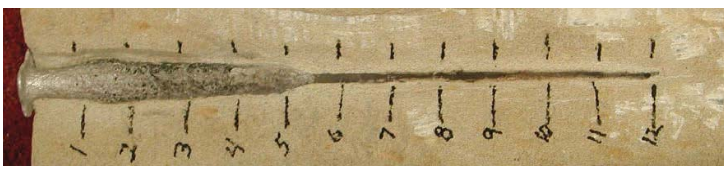

Overbalanced

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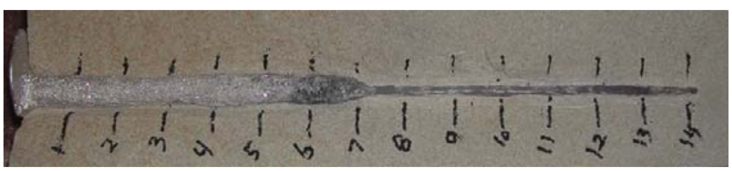
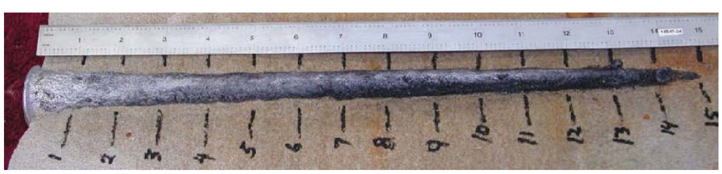


Balanced

HAL11001



Underbalanced/ Dynamic Underbalanced

Alignment of Perforation with Preferred Stress Plane

Stimulated Completion

Stimulated completions are typically either hydraulically fractured or acidized or a combination of the two. Hydraulic fracturing is performed to increase the effective wellbore radius, r_w and is usually performed in reservoirs with extremely low permeabilities (k <1 md). In hydraulic fracturing, fluids and proppants are injected at high pressure and rate (to alter the stress distribution in a formation) and create a fracture or crack in the rock. The perforation strategy can be critical to the success of a planned stimulation treatment. In long intervals or multizone treatments, the proppant or acid might cover only part of the interval or enter only one zone because of permeability variations.

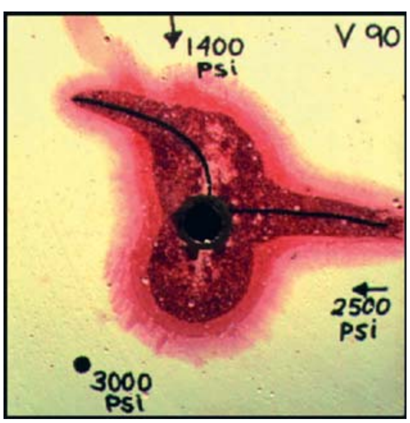
Limiting the number and diameter of perforations can increase the pressure in the casing to a point in which intervals of lower stress can be fractured. This prefracture technique is called "limited-entry" perforating. The perforation diameter and uniformity are important because they are the limiting factor in creating pressure restrictions in the well and providing a sealing surface for ball sealers if necessary.

Completion success for stimulated wells is influenced by three perforation effects: perforation erosion, perforation bridging, and perforation phasing. The success of the limited-entry technique depends on the differential pressure across the perforation. Perforation erosion leads to loss of differential pressure, improper placement of proppant or acids, and a poor stimulation treatment. Obtaining the most uniform perforation helps minimize this friction component and fluid shearing.

Perforation bridging reduces the effective shot density of the completion and potentially causes early screenout of the stimulation treatment. At proppant concentrations greater than 6 lbm/gal, the perforation diameter should be six times greater than that of the proppant diameter as suggested by Gruesbeck and Collins (1978).

Perforation phasing has been studied in great detail, and its importance to the successful placement of proppant is recognized. Fractures preferably initiate and propagate in a plane perpendicular to the minimum stress direction. If the perforations are not aligned with the preferred stress plane, fluids and proppants will travel through an annular path around the casing to initiate or propagate the fracture plane. This tortuous path can cause higher treating pressure, premature screenout, and asymmetric penetration of the fracture wings. The work by Abass (1994) shows the effects of not having the perforations aligned properly with the preferred stress plane. Studies by Warpinski (1983) and Daneshy (1973) indicate that if the perforations are not within 30° of the preferred stress plane, the fracture can initiate on a plane different than the perforation.

To help ensure success during stimulation when the preferred stress plane is unknown, a 60° phased gun should be used to minimize the perforation and stress plane offset. To fully maximize stimulation performance, it is also important to accurately define the near-wellbore stress field and orient the perforations at 180°. Proper gun orientation maximizes perforation to fracture flow communication and minimizes breakdown pressures to initiate fracturing.



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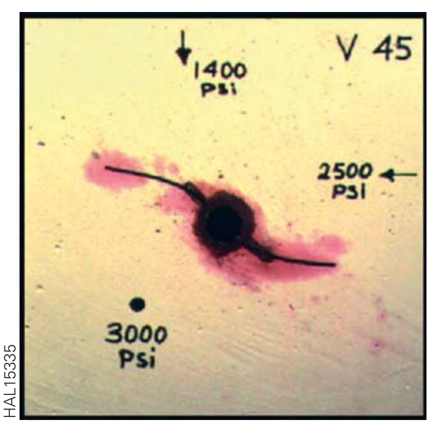
Unoriented Perforation

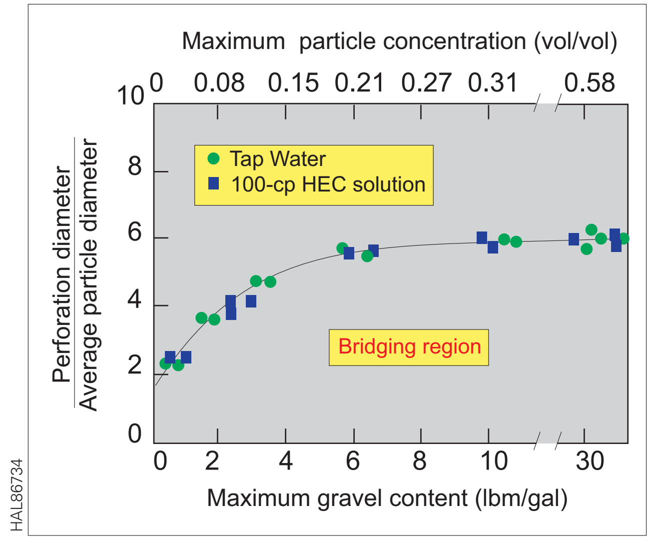


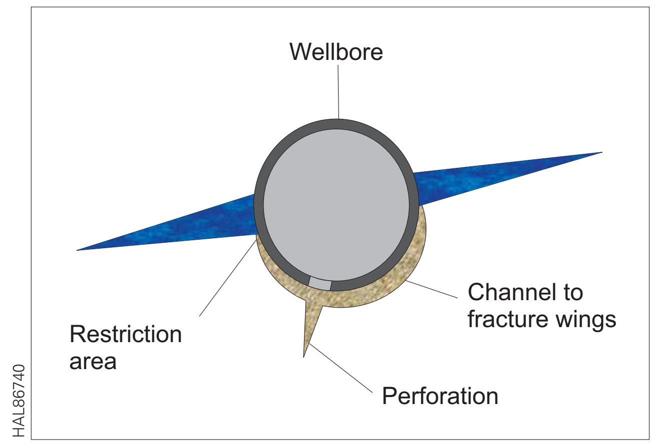
HAL15335

Oriented Perforation

Acidizing is a stimulation process used to repair formation damage caused by the drilling or perforation process. Injecting acids below fracturing rates allows the acid to dissolve any plugging in the perforations or pore throats, removing damage from the matrix rock. Perforation hole size is less important because proppants are not normally used. If a "ball-out" acid job is planned, specially designed shaped charges are desirable because they create a uniform hole size with no burr on the casing. Bullet perforators help improve the ability of the ball sealers to seal on the casing wall.

Acid fracturing is usually performed on carbonate formations to etch the surface of the hydraulically induced fracture. The etched surface significantly improves the effective wellbore radius, making the job less operationally complex because proppants are not required. The disadvantages of acid fracturing are the expense of the fluids and the nonuniform leakoff that results in "wormholes" with potentially untreated formation intervals.





Acid Fracturing

Sand Control Completions

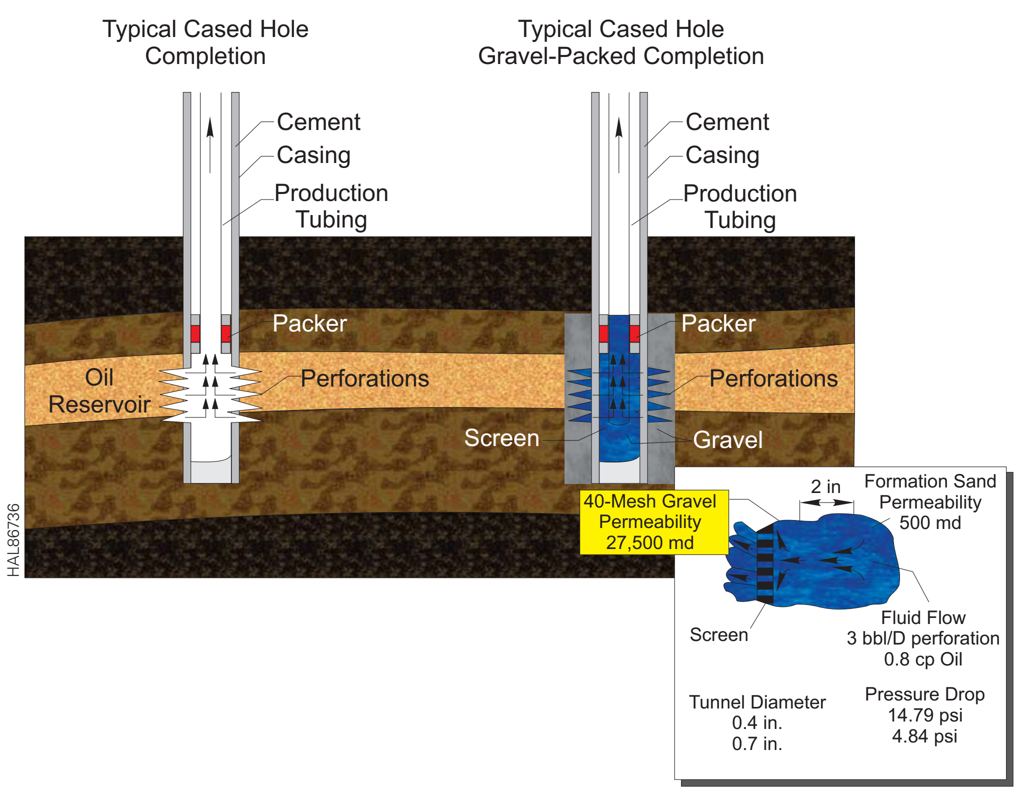
Sandstone formations that are not structurally competent often produce sand along with formation fluids. Fluid movement through the reservoir produces stress on the sand grains because of fluid pressure differential, fluid restrictions, and overburden pressure. If these stresses exceed formation cohesive strength, sand is produced and near-wellbore permeability is altered. Sand production can lead to some undesirable results. These include the plugging of perforations, casing, tubing or surface facilities; casing collapse caused by changing overburden stress; the destruction of downhole and surface equipment; and costly sand disposal.

In a natural completion, formation fluids entering the perforation tunnels can flow unimpeded into the wellbore. In the gravel-packed completion, a series of filters is created to hold back the formation sand, while producing formation fluids. Fluid flow entering the perforation tunnel of a gravel-packed well must flow linearly through the sand and gravel in the perforation tunnel and inside the annulus of the well before entering the gravel pack screen. The linear flow path is only a few inches; however, the materials inside the flow path have a tremendous impact on well productivity. Inflow performance for a cased gravel-packed completion can be expressed as follows:

$$P_{wfs} - P_{wf} = \frac{q\beta\mu 1}{1.1271 \times 10^{-3} \text{kg } A} + \frac{9.107 \times 10^{-3} \beta (q\beta)^2 \rho 1}{A^2}$$

For a specific well, this simplifies to:

$$P_{wfs} - P_{wf} = \frac{C_1 q}{Kg\ A} + \frac{C_2 q^2}{A^2}$$



Comparison of Natural Completion vs. Sand Control Completions

The two key parameters to well productivity (q) for a gravel-packed completion are the area open to flow (A) and the permeability of the gravel in the perforation tunnel (kg). The area open to flow (A) is essentially the number of perforations multiplied by their respective cross-sectional flow area. Gravel-pack sand permeability is typically many orders of magnitude higher than the formation permeability, with values up to 40,000 darcies common.

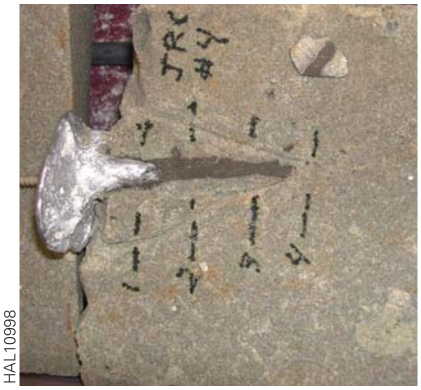
The key perforating strategy for gravel-packed completions is to help ensure high-permeability gravel-pack sand can be placed in the perforation tunnel, which means removing perforating debris and crushed formation material. Perforation damage when perforating overbalanced and underbalanced/ dynamic underbalanced with big hole charges includes crushed sand grains and liner debris that remain in place with the balanced and overbalanced test shots. Perforation impact on the sand grains surrounding the perforation tunnel includes crushed sand grains or fines that are generated. Insufficient underbalanced/dynamic underbalanced pressure leads to perforation damage that can adversely affect injectivity and sand placement.

The greater the perforation density and hole diameter, the smaller the pressure drop through each perforation and the slower the fluid velocity. This promotes the creation of a stable arch around the perforation and reduces the influx of formation fines that can lead to screen erosion or plugging of the gravel pack. Perforation phasing is important to maintain uniform flow patterns around the wellbore, resulting in lower fluid velocities and formation sand movement. High shot density guns (>12 spf) with spiral phasings provide optimum flow area and flow patterns, while maintaining casing integrity.

In some semi-consolidated formations, it might be possible to complete the well and manage sand production without traditional screens in place. High shot density perforating with deep-penetrating (DP) charges can be used to maintain the stable arch and manage sand production. DP charges provide greater depth of penetration into undamaged formation material while destroying a smaller radius around the perforation tunnel. Charge phasing is critical to maximize the vertical distance between perforations and maintain formation integrity between perforations.

Restricting the flow of fluids is another way to avoid collapse of the stable arch. Another approach to managing sand production is to orient perforations in the direction of maximum principal stress. Perforations oriented to maximum principle stress result in more stable perforation tunnels that are less susceptible to collapse or sand production. Selective perforating to avoid weaker sand members along with oriented perforating is an effective strategy to avoid gravel packing and the potential for reduced well productivity.

In field operations in unconsolidated sandstones, stable arch bridges occur at the set producing rate. When the producing rate is adjusted, sand production can occur for a short period of time until a different shaped stable arch occurs.



HAL10998

Overbalanced Perforating with Big Hole Charge

HAL11002

Underbalanced/Dynamic Underbalanced Perforating with Big Hole Charge

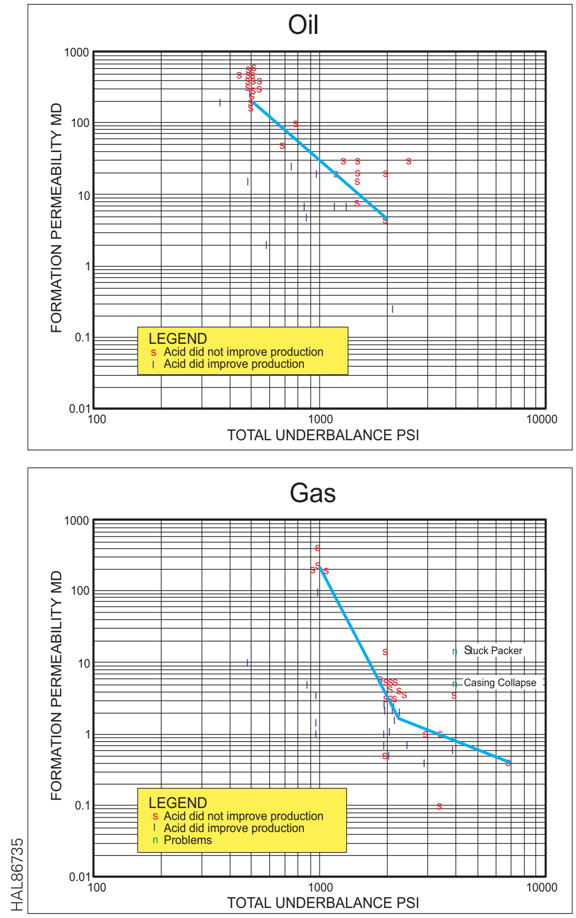
Underbalanced/Dynamic Underbalanced Perforating

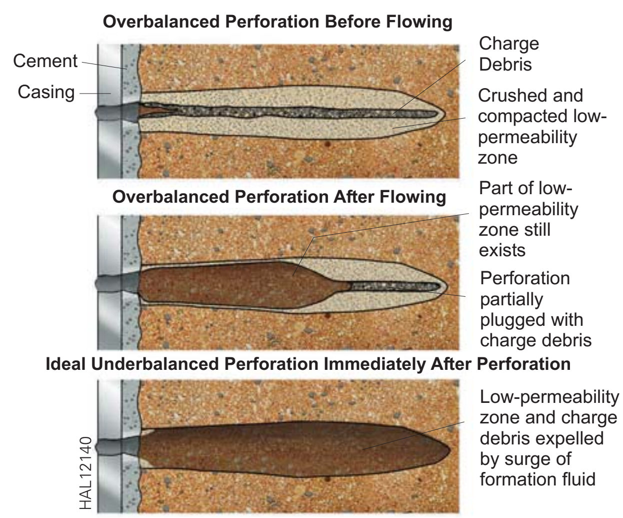
Underbalanced/dynamic underbalanced perforating occurs when the pressure in the wellbore is lower than the pressure in the formation. The level of pressure differential is important to create open, undamaged perforations and optimize well productivity. Overbalanced perforating without flow typically results in a perforation tunnel with severe tunnel plugging caused by crushed formation material and charge debris. Overbalanced perforating with cleanup flow reveals that typically most of the charge debris is removed. However, a low permeability zone due to perforation jets remains. The ideal underbalanced/dynamic underbalanced example shows that all perforation damage has been removed with the proper differential applied across the perforation.

King et al. (1985) and others have published the results of a large number of underbalanced/dynamic underbalanced perforating jobs in which initial well productivity was compared to subsequent well productivity after acidizing.

Laboratory studies performed by Halliburton suggest higher underbalanced/dynamic underbalanced pressures are required to achieve clean undamaged perforation tunnels. The work by Folse et al. (2001) shows that in addition to focusing on underbalanced pressure as it is defined in our industry, some consideration to the so-called "dynamic" underbalanced pressure is necessary.

Dynamic underbalanced pressure refers to the transient fluid gradients on the millisecond time regime that occur as a result of fluid movement or fill-up of the free gun volume or other artificial surge chambers in the downhole assembly. A perforation job pressure record from a high-speed recorder samples pressures at 100,000 samples per second. Note that even though this well was perforated with approximately 3,300-psi overbalanced pressure, the minimum surge pressure was 695 psi during the initial transient period following detonation.





Underbalanced/Dynamic Underbalanced Perforating

Experiments in the Halliburton Perforation Flow Laboratory verified that dynamic surge pressure is an actual event that can be controlled in field applications. In some actual experiments, the only variable that changed was free gun volume with a subsequent effect on perforation tunnel cleaning capability. Both cores were shot at balanced perforating conditions with an effective stress of 3,000 psi. The core shot with the higher dynamic underbalanced volume did not exhibit any perforation plugging, resulting in a much higher core flow efficiency.

The goal is to achieve the highest underbalanced/dynamic underbalanced pressure that will yield optimum productivity without compromising well integrity. The instantaneous underbalance/dynamic underbalance must be followed with continued sustained flow of several gallons per perforation to further clean the perforation and remove the crushed rock and other materials that have been loosened. This critical point is well documented in literature; however, on many jobs it is overlooked because of operational constraints. These constraints include how hydrocarbons are handled at the surface, increased completion cycle time, complexity due to well control operations, and the increased risk of sticking perforation or wireline-conveyed guns caused by debris movement.

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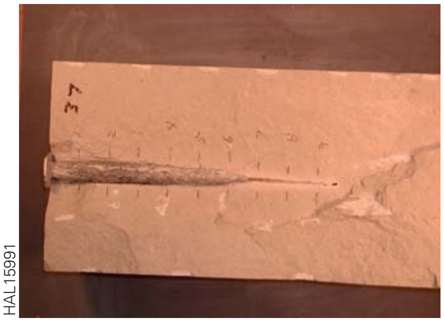

Berea test shot balanced with effective stress at 3,000 psi and dynamic volume at 308 cc.

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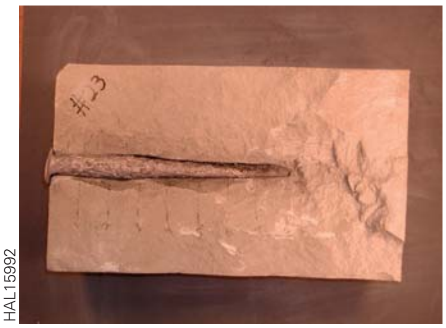
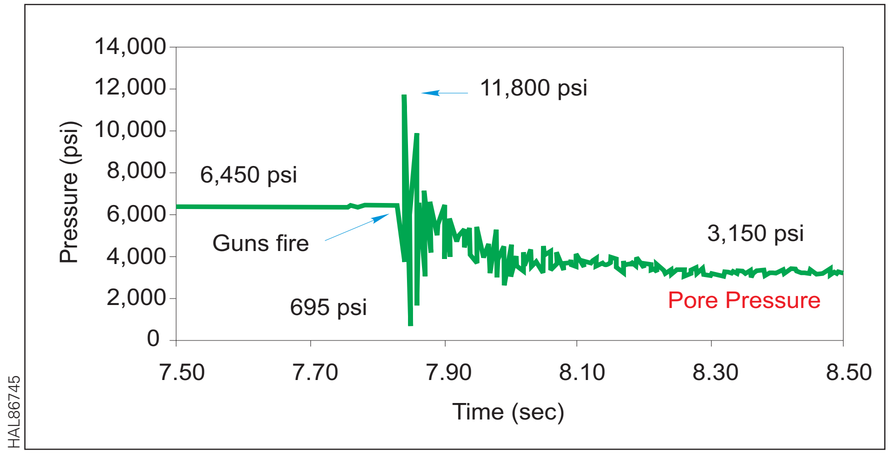
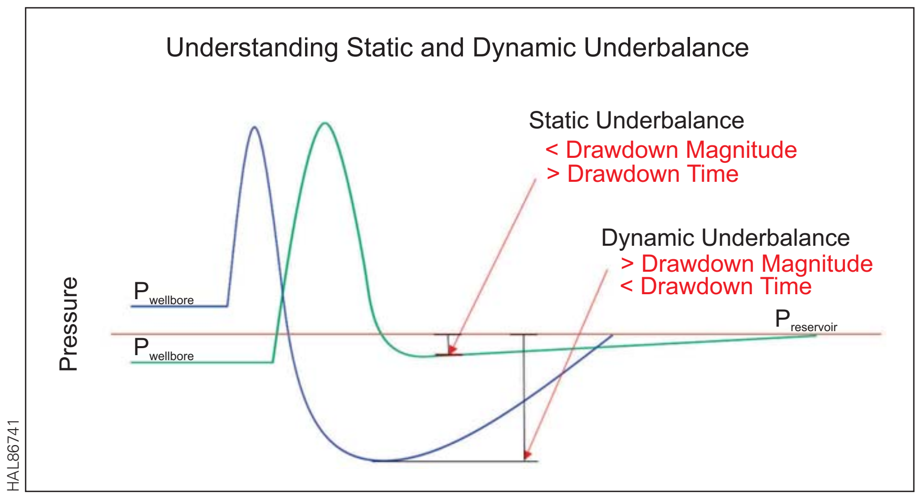


Berea test shot balanced with effective stress at 3,000 psi and dynamic volume at 1,430 cc.



High-Speed Pressure Recorder Data



Static vs. Dynamic Underbalance

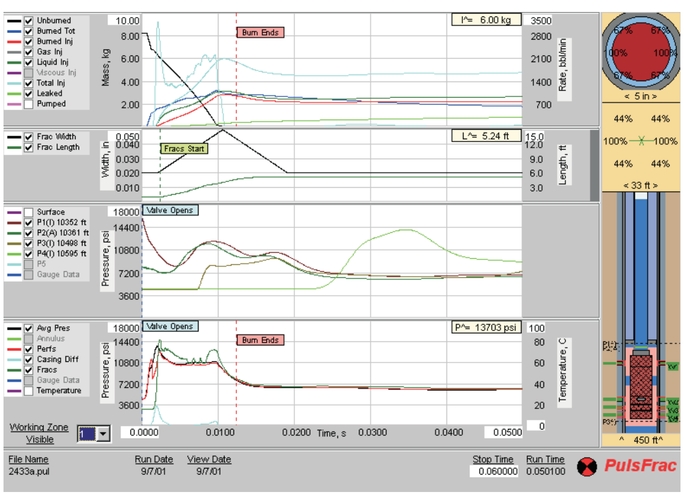
Near-Wellbore Stimulation and PulsFrac™ Software

In many formations, the remaining reservoir pressure or underbalance/dynamic underbalance is insufficient to effectively clean the perforations as suggested by King et al. (1985) and others. In other cases in which formation competence is questionable and the risk of sticking perforating assemblies is greater, sufficient underbalanced/dynamic underbalanced pressure is not possible, aid in lowering treating pressures is necessary, or bypassing near-wellbore damage is necessary, then near-wellbore stimulation could be a possible perforating solution. To address the perforation damage in these cases, some (Handren et al. 1993; Pettijohn and Couet 1994; Snider and Oriold 1996) suggested near-wellbore stimulation using extreme overbalanced (EOB) perforating and propellant-assisted perforating. Near-wellbore stimulation provides perforation breakdown in preparation for other stimulation methods and therefore eliminates the need for conventional perforation breakdown methods.

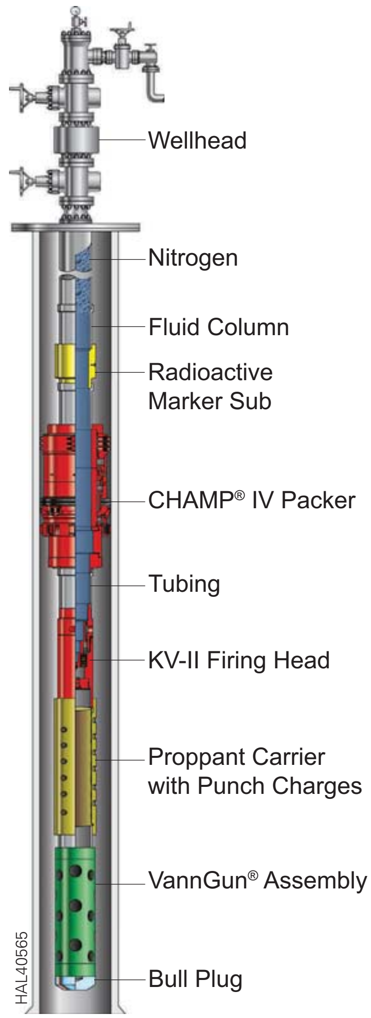
Near-wellbore stimulation can be achieved using energized fluids, propellants, or a combination of both, and all can be properly designed using PulsFrac™ dynamic pressure modeling software. PulsFrac software allows a job simulation to be performed to determine anticipated peak pressures, injection rates, injection volumes, and theoretical fracture lengths.

EOB: Energized Fluid Stimulation

EOB techniques pressure the wellbore with compressible gases above relatively small volumes of fluid. The gases have a high level of stored energy. Upon expansion at the instant of gun detonation, the gases are used to fracture the formation and divert fluids to all intervals. The high flow rate through relatively narrow fractures in the formation is believed to enhance near-well conductivity by extending the fractures past any drilling formation damage.



PulsFrac™ Analysis Report of Extreme Overbalanced (EOB) StimGun™ Job



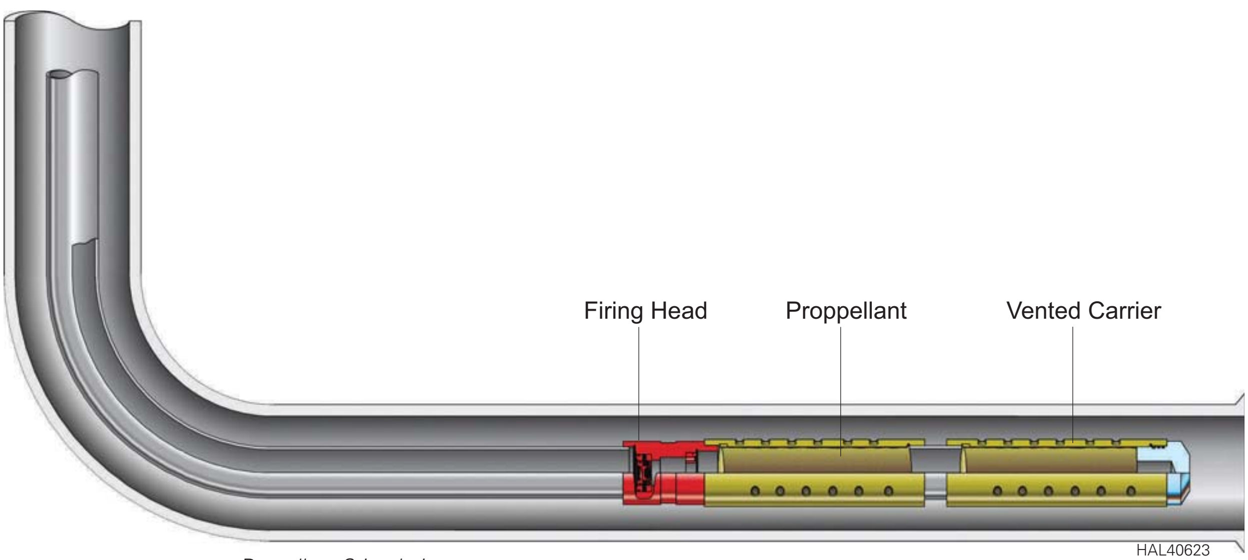
Typical Extreme Overbalanced (EOB) Perforating Assembly

PulsFrac™ is a trademark of John F. Schatz Research and Consulting, Inc.

Building upon the success of extreme overbalanced (EOB) perforating, Marathon Oil Company incorporated proppant carriers into the perforation assembly to introduce proppants into the flow path as the gun detonates. The Powr*Perf™ process, patented by Marathon Oil Company, further enhances productivity by scouring the perforations to leave some residual conductivity on the fracture plane. Most EOB perforating operations are designed with a minimum pressure level of 1.4 psi/ft of true vertical depth. For optimum results, it is suggested to use the highest possible pressure level without compromising wellbore integrity or operation safety.

Propellant Stimulation

Propellant stimulation can be provided during the perforating event with propellant-assisted perforating. Propellant-assisted perforating using the StimGun™ assembly, patented by Marathon Oil Company, combines solid propellant technology with conventional perforating. The StimGun assembly can be used for either EOB or conventional underbalanced/dynamic underbalanced perforating. The hardware used for either system remains the same aside from added protection by using centralizer rings to protect the brittle propellant material. The propellant sleeve in the StimGun assembly simply slides over the perforation scalloped carrier and is held in position on the gun with the centralizer rings.

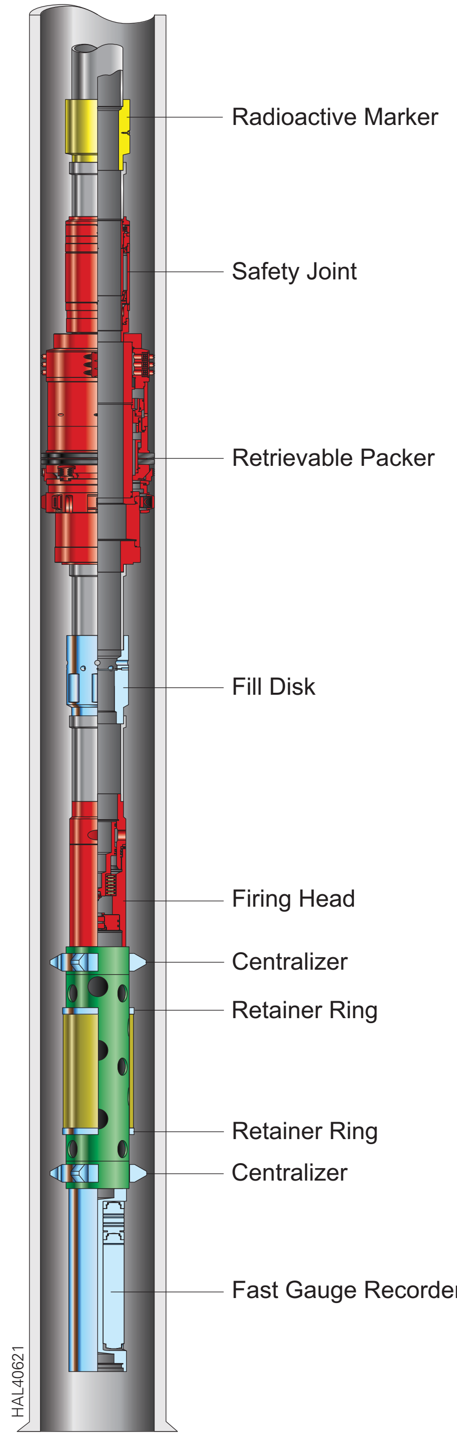


Propellant Stimulation

StimGun™ System

The propellant material is potassium perchlorate, an oxidizer that burns rapidly, creating CO_2. As the shaped charges detonate, the propellant is ignited by extreme heat from the gun system. As it burns, the propellant generates CO_2 at high peak pressures typically well above the formation fracture gradient. The StimGun™ assembly is an effective method for mild stimulation (fractures on order of 2 to 9 ft) for treating near-wellbore issues.

Propellant stimulation can also occur using solid propellant conveyed in protective carriers. This type of propellant can virtually be unlimited in length by simply interconnecting the carriers to place across existing perforations, slotted liner, or in openhole. The propellant is ignited using a sealed ignition system, and similar to the StimGun assembly once the propellant is ignited, it will generate CO_2 at high peak pressure, allowing for adequate stimulation of the desired formation interval. As with all near-wellbore stimulation techniques, PulsFrac™ software assists in proper job design and provides estimated peak pressures, injection rates, and volumes to help ensure successful propellant stimulation.



StimGun™ Assembly

SurgePro™ Service

The Halliburton SurgePro™ perforating-design software program is robust and can be used for a large variety of dynamic wellbore calculations. The submodels contained in the program are physics driven and rely on measurable or estimated actual input parameters, no curve fitting or back of the envelope calculation. As a result, the SurgePro program is ideal for predicting:

» Wellbore, perforation, and gun pressurizations
» Wave propagation — fluid injection/production
» Perforation behavior — perforation damage
» Completion integrity — burst/collapse and packer differential

Accuracy: Physics-Based Solution with Documented Validation

The SurgePro program is based on a proprietary analysis developed from:

» API Section IV perforation flow laboratory studies
» Time-marching finite-difference modeling
» High-speed pressure measurements
» Empirical field data

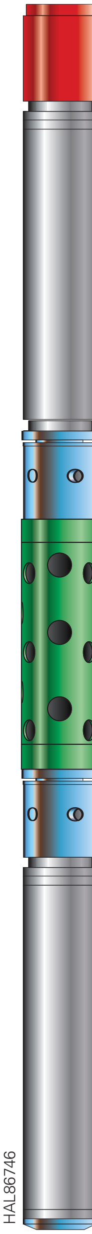
Mass, momentum, and energy are conserved for each timestep. The solution is derived by using energy release equations for the gun, simultaneous coupled finite-difference solutions of the Navier-Stokes equations for wellbore, perforation, and fracture flow, and solid rock mechanics for perforation breakdown.

Capability to Model a Wide Range of Wellbore Conditions

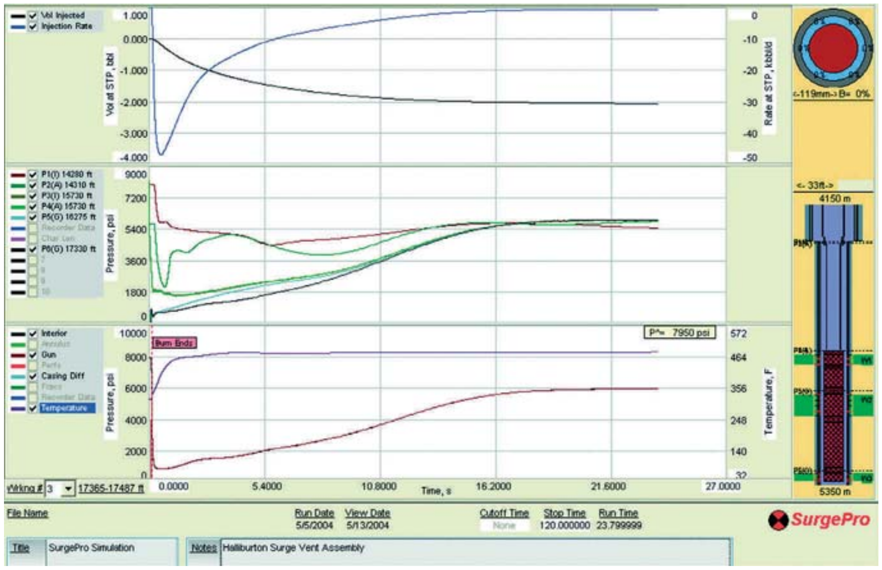
To fully represent dynamic wellbore behavior, the SurgePro program accounts for a wide variety of factors:

» Thermodynamic mixing and multiple compressible fluid types/phases
» Various energy sources, including perforating gun ignition and residual energy deposition (gun, well, and perforation tunnel)
» Valves, pumping, and orifices
» Multiple diameter effects in the well including:
  – Surface pressurization, pumping, and fluids flowback
  – Flow into and breakdown of perforation tunnels
  – Subsequent transient return flow from perforations

Full Surge Chamber



SurgePro™ Assembly



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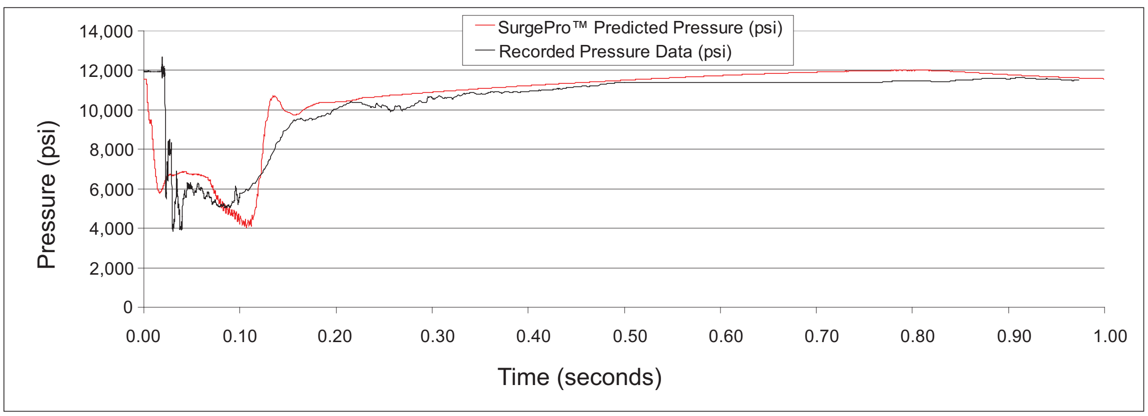
Typical screen capture from SurgePro™ software simulation: understanding and prediction of dynamic pressure behavior is paramount when conventional underbalanced/dynamic underbalanced techniques are not an option.



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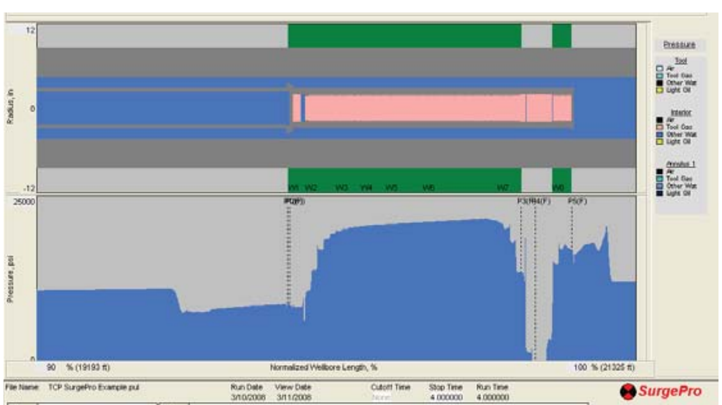
SurgePro™ software dynamic pressure prediction overlay with high-speed recorded pressure response during perforating. Clear validation of dynamic underbalance occurring and validation of the SurgePro software accuracy in simulating dynamic vents.



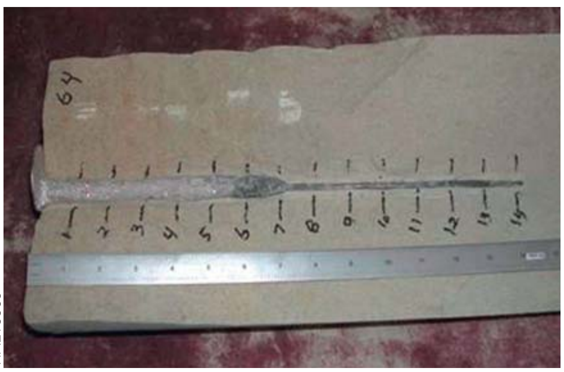
HAL86747

SurgePro™ software inhole depiction of pressure-transient propagation within the wellbore

Dynamic underbalance is created with the application of a special fast-opening surge vent assembly. Note the gauge reading atmospheric pressure in the chamber before the perforating event following a sustained minimum surge pressure across the perforated interval of ±1,000 psi for 0.5 seconds.

This minimum surge pressure across the formation results in a dynamic underbalance of 3,200 psi that can potentially improve well productivity. The high-speed gauge readings are in good agreement with the theoretical prediction from the physics-based model. Hundreds of high-speed pressure records have been collected under varying well conditions to validate the modeling results generated.

Identical sandstone targets were perforated with the same 39-g shaped charge at the same reservoir pressure and effective stress condition. The picture on the left is perforated in a balanced condition and the picture on the right is perforated ideally with 3,000-psi underbalanced/dynamic underbalanced pressure. The difference in productivity or core flow efficiency in this case is on the order of 82% by not completely cleaning up the perforation tunnel with proper underbalanced/dynamic underbalanced pressure or differential surge flow. In cases wherein conventional underbalance perforating is not applicable, SurgePro™ software can be used to create a localized dynamic underbalance pressure to overcome the perforation damage or skin factor associated with balanced or overbalanced perforating techniques, while still maintaining well control.



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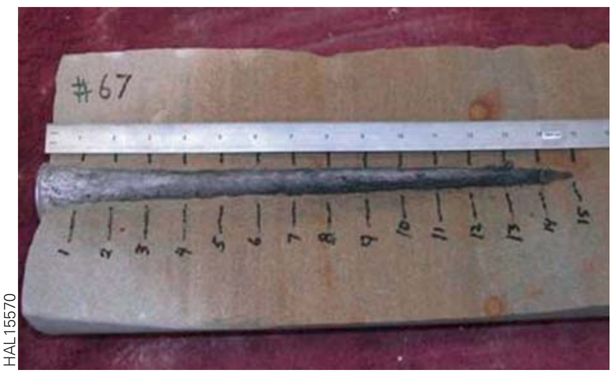
Balanced



HAL15570

Underbalanced/Dynamic Underbalanced

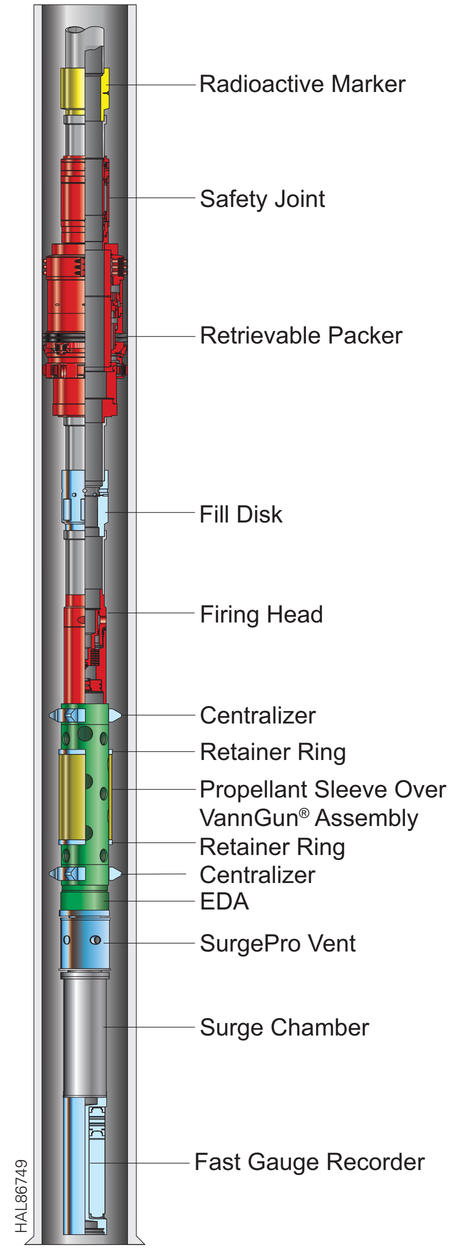
StimSurge Service

StimSurge service combines propellant-assisted extreme overbalanced (EOB) perforating and dynamic underbalance using SurgePro™ software in a single trip. The timing between these pressure-opposed perforating techniques help enable the success of this technology.

The propellant assembly comprises a conventional perforating gun surrounded by a sleeve of propellant-like oxidizers. The perforating gun is detonated in the wellbore as normal, and during the perforating process, the sleeve is initiated. The sleeve, which is a proprietary oxidizer, burns quickly and produces a burst of high-pressure gas. This high-pressure gas drives the wellbore fluid toward the perforation, creating fractures past the damaged zone and an improved flow path from the formation to the wellbore. The sleeves can be used in conjunction with all commonly available hollow steel carrier perforating gun systems from 1 9/16- through 7-in. OD. The gun assembly can be lowered into the well on wireline, jointed pipe, or with coiled tubing.

The gun detonation initiates a delay fuse, which burns for 5 minutes. It then triggers the opening of the SurgePro vents opening a flow path into the SurgePro chambers.

The StimSurge system uses a dynamic wellbore simulator to accurately model and predict the effects of pressure transients during the perforating event. This system allows the optimization of the StimGun system and the underbalance/dynamic underbalance surge for a specific reservoir condition. The technique incorporates both advanced software and hardware, such as StimGun vents and chambers. Perforating assemblies and procedures can be custom-engineered to deliver the greatest value from EOB perforating and dynamic fluid surges. This system can create a dynamic underbalance that helps vastly improve perforation cleanup and maximizes its effectiveness, regardless of initial wellbore pressure conditions after fracture creation.

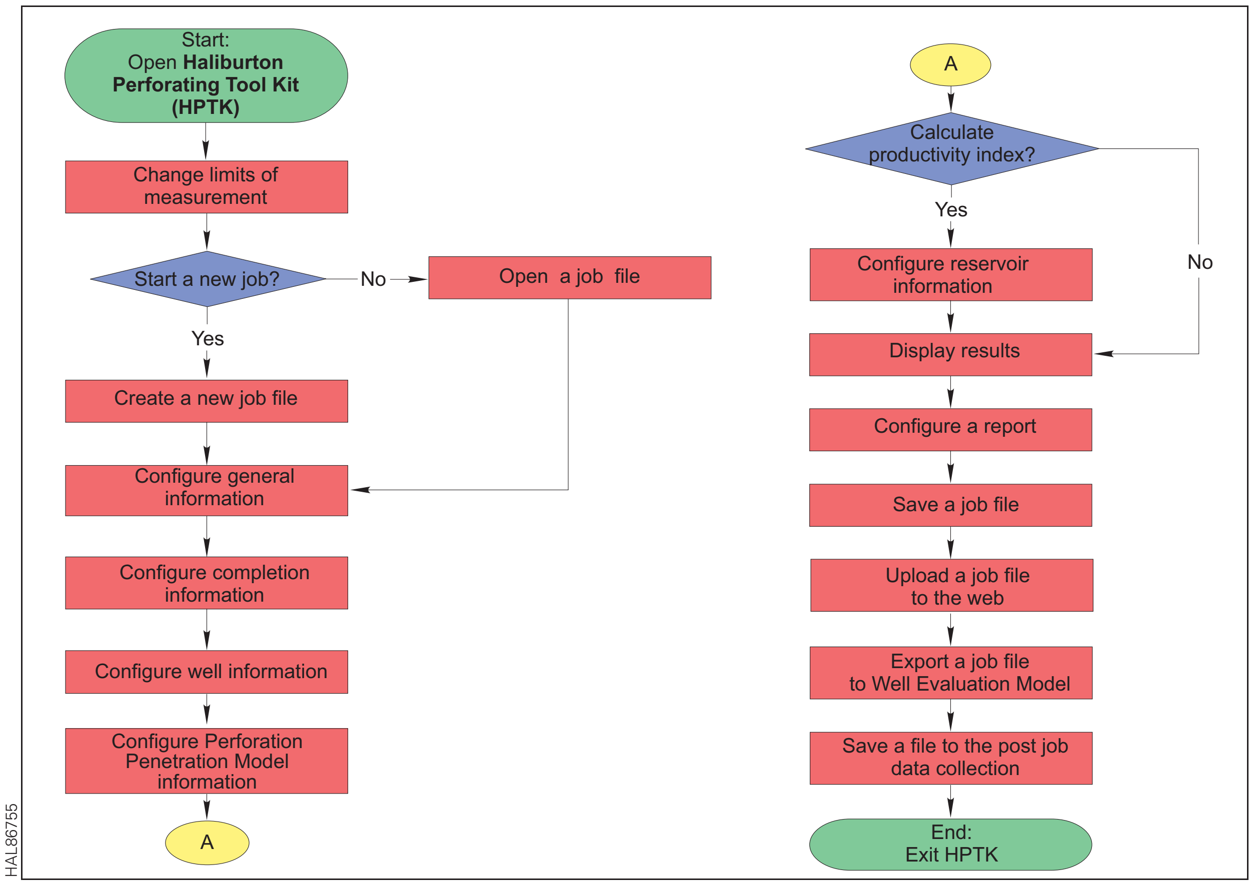


StimSurge Assembly

Modeling and Evaluation

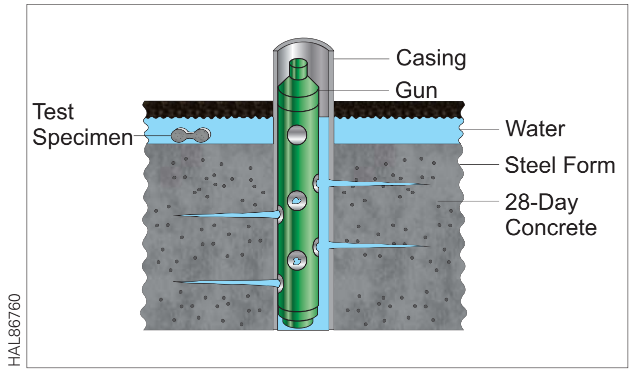
Halliburton Perforating Tool Kit

The Halliburton perforating tool kit (HPTK) provides a systematic approach to optimize well inflow performance by proper selection of the gun system, charge type, shot density, phasing, conveyance method, and well condition (overbalanced or underbalanced/dynamic underbalanced pressure). HPTK is a web-based application that analyzes the effects of downhole conditions on perforator performance and productivity. The HPTK program performs calculations for charge performance (formation penetration and perforation hole diameter) and well productivity (productivity index and total skin). The HPTK workflow is designed to provide optimum perforating conditions and prediction of gun system performance.



Halliburton Perforating Tool Kit (HPTK) Workflow

The Halliburton perforating tool kit (HPTK) charge performance calculations for penetration are based on proprietary models derived from theoretical and experimental studies conducted at Jet Research Center (JRC). API RP-19B defines the procedure for evaluating gun system performance at surface conditions in unstressed concrete targets. A fully loaded gun system is perforated in actual casing surrounded by concrete, and the target penetration, casing entrance hole, and burr height are recorded. The HPTK program transforms API RP-19B Section I surface test data to downhole conditions by correcting for the formation compressive strength and effective stress. The associated downhole charge performance accounts for the gun positioning, casing grade, wellbore fluid density, and well condition.



API Section 1 Concrete Target

Halliburton Perforating Tool Kit (HPTK) Charge Performance Calculations

The primary objective of the Halliburton perforating tool kit (HPTK) is to optimize gun selection and job execution to deliver the highest productivity index or lowest skin factor. Therefore, after charge performance values are calculated, the HPTK program makes a productivity index and skin factor assessment. The HPTK process accounts for skin factors due to perforation, drilling damage, partial penetration, nondarcy flow, and well deviation. A fully 3D flow model is used, as described by Ansah et al. (2001), to characterize the skin component due to perforation geometry. Input well parameters and calculated charge performance values are linked to an artificial neural network, trained by the 3D finite element model, to generate the perforation skin component. The productivity index and total skin factor are corrected, using analytical calculations for well inclination, partial penetration effect, nondarcy flow, and drilling damage effects.

Zone Details

Borehole Diameter	6.125 in.
Completion Type	Natural
Completion Fluid Type	Fresh Water
Completion Fluid Density	8.34 ppg
Mid Perforation Depth (TVD)	11,460 ft
Damage Zone Thickness	12 in.
Damage Zone Permeability	250 md
Flow Direction	Production
Reservoir Net Thickness	117 ft
Perforation Total Interval (TVD)	0 ft

Reservoir Details

Lithology	Sandstone
Overburden Gradient	1 psi/ft
Temperature at Interval	215°F
Formation Fluid Type	Oil
Formation Permeability	743 md
Formation Pressure	4,900 psi
Formation Compressive Strength	5,877 psi
Formation Gross Thickness (MD)	136 ft
Reservoir Drainage Radius	700 ft
Perforation Crushed Zone Thickness	0.4 in.
Deviation at Perforations	63°
Perforation Permeability Crushed Zone Ratio	0.3
Vertical/Horizontal Permeability	0.1
Gas Gravity	0.65 sg
Fluid Gravity	19° API
Gas/Oil Ratio	25 scf/stb

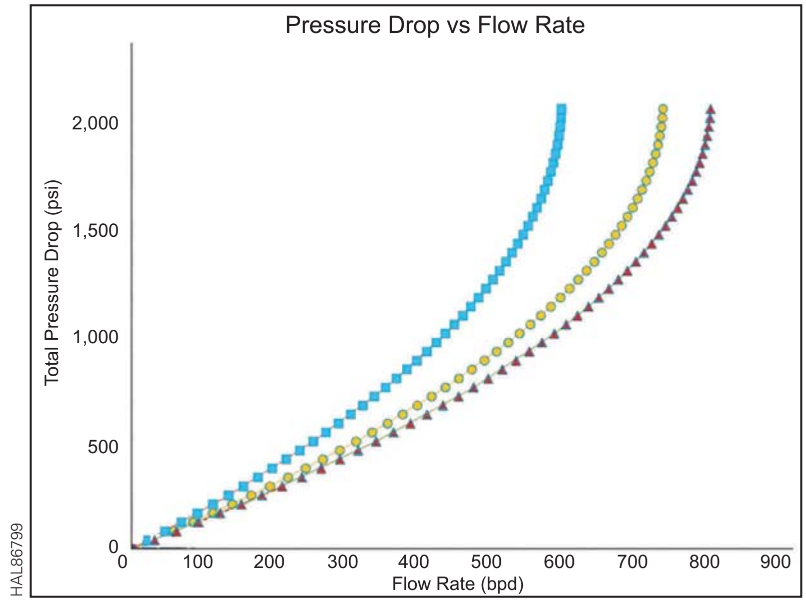
Results

Millennium™ HMX 6 spf (101233819)

Effective Perforation Tunnel	9.97 in.
Formation Penetration	13.11 in.
Total Target Penetration	14.03 in.
Thompson Weeks Formation Penetration	26.96 in.
Average Exit Hole	0.46 in.
Flow Area	1.01 in.^{2}/ft
Case Material	Steel
Total Skin	4.39
Productivity Index	3.87 bbl/D.psi
Wellbore Environment	UB 1,500 psi

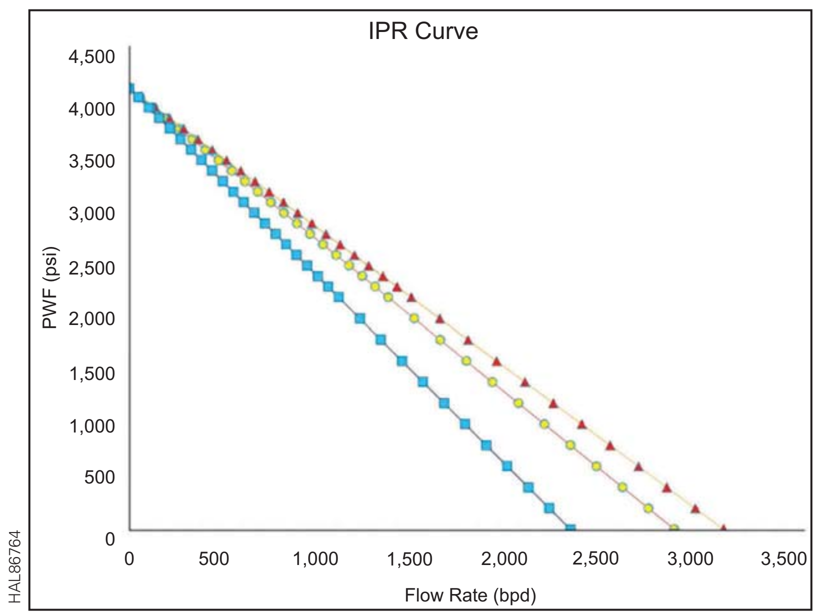
Dominator® HMX 6 spf (101309223)

Effective Perforation Tunnel	10.99 in.
Formation Penetration	14.44 in.
Total Target Penetration	15.36 in.
Thompson Weeks Formation Penetration	29.7 in.
Average Exit Hole	0.34 in.
Flow Area	0.54 in.^{2}/ft
Case Material	Steel
Total Skin	4.21
Productivity Index	3.91 bbl/D.psi
Wellbore Environment	UB 1,500 psi



Guns ☑ Millennium II HMX ☑ MaxForce HMX ☑ Dominator HMX

Halliburton Perforating Tool Kit (HPTK) Graph Example



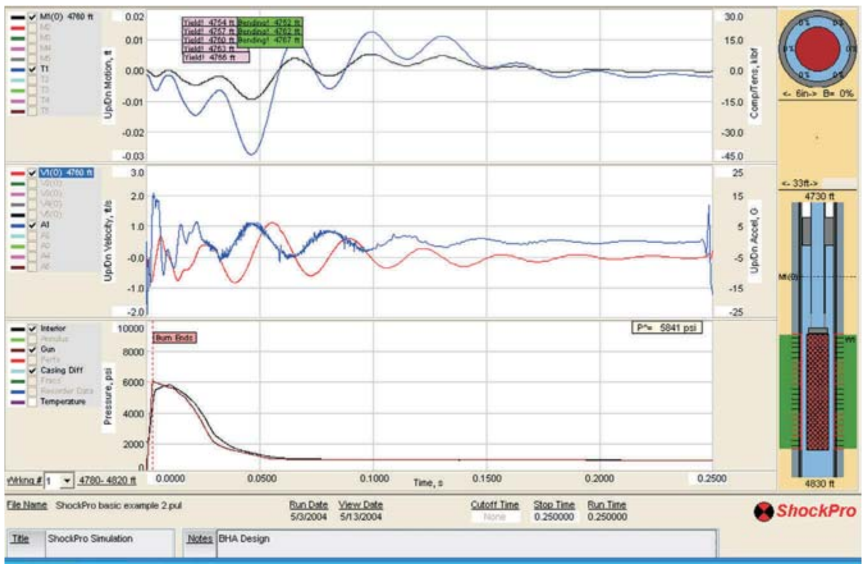
Guns ☑ Millennium II HMX ☑ MaxForce HMX ☑ Dominator HMX

Halliburton Perforating Tool Kit (HPTK) Graph Example

ShockPro™ Software Graphic Display with Error Flags for Tubing Yield and Buckling Failure

This information helps determine the peak pressure applied to a packer (i.e., the maximum tension or compression on a joint of pipe or the differential pressure applied to the packer). Once dynamic failure criteria have been established, ShockPro™ software can examine whether or not potential issues will occur with a given perforating assembly.

Steps can then be taken to correct unusually high peak loads to manage job risk factors. The physics-based model has been validated by special high-speed recorders that sense pressure, temperature, and acceleration at sampling frequency on the order of 115,000 samples per second.



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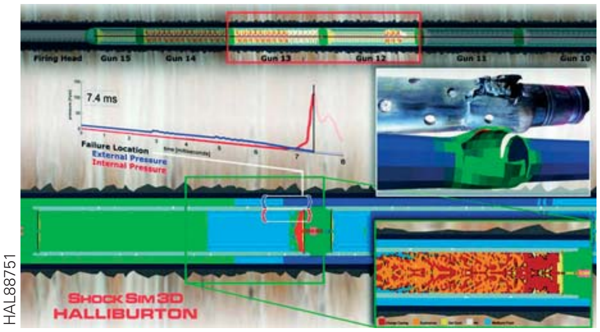
ShockPro™ Software Application

SS3D™ ShockSim 3D Model Assurance and Failure Analyses

Operators and service providers recognize wells are pushing the limits of design, and a new level of capability is necessary to truly understand and predict dynamic events. This risk of the unknown has driven the industry to determine ways to quantify dynamic effects at zones of interest during the perforation event.

Understanding the dynamic shock loading response of the completion and perforating gun strings during detonation is crucial to the development of better completion systems and optimal job designs with maximum reliability.

The SS3D™ modeling software package simulates the 3D transient shock response of the bottomhole assembly (BHA) and wellbore to perforating gun detonation. The front end of the package comprises a proprietary graphical user interface (GUI) and model preprocessor.



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SS3D™ Modeling Software

SS3D ShockSim 3D Model with HPET™ Validation

The SS3D ShockSim 3D model provides advanced downhole modeling and gun dynamic response predictions, which are fully validated with the HPET™ Halliburton perforating evaluation tool. This advanced modeling capability helps enable unique and complex failure analyses of perforating operations.

Understanding the stress/strain relationships yields a more accurate characterization of downhole events than those that only consider the pressure responses. This is accomplished with the HPET tool's unique ability to be placed directly in the perforating gun string at multiple points, whereas industry-standard fast gauges can only be placed above or below the perforated interval.

HAL88763

SS3D™ ShockSim3D Model

Benefits

- Can be run anywhere in the world because of its centralized processing facility
- Helps improve shock prediction and impact on BHAs by using a 3D model instead of a 1D model
- Provides a uniquely customized interface for efficiently defining the BHA, wellbore geometry, fluids, initial and boundary conditions, and other simulation parameters
- Provides 3D interactive visual representations during the perforation event that are an intuitive visualization of results

Features

- Combinability with the Halliburton Advanced Perforating Flow Laboratory to verify the shock loading model predictions before deployment.
- Multifaceted gun string failure investigation
- 3D structural and 2D fluid code
- Parameter sensitivity studies enabled refinement and validation of fluid model approach

SS3D™ ShockSim Failure Analyses

Halliburton developed the SS3D™ ShockSim 3D model with the ability to provide advanced downhole modeling and perforating system dynamic response understandings for failure analyses. With this advanced modeling capability, unique and complex failure analyses can be conducted for perforating operations with high confidence for success.

Benefits

- Centralized processing facility enables use of the SS3D model anywhere in the world.
- The ability to provide a 3D instead of a 1D model helps improve predictions of shock and impact on bottomhole assemblies (BHAs).
- The proprietary graphical user interface (GUI) provides a uniquely customized interface for efficiently defining the BHA, wellbore geometry, fluids, initial and boundary conditions, and other simulation parameters.
- Centrally located native post-processor helps ensure the proper expertise is applied to each model.
- The model provides intuitive 3D interactive visual representations during the perforation event.

Features

- Combinability with the Halliburton Advanced Perforating Flow Laboratory to verify the shock loading model predictions
- Multifaceted gun string failure investigation
- 3D structural and 2D fluid code
- Refinement and validation of fluid model approach through parameter sensitivity studies
- Next step in quantifying dynamic response


HAL88757

SS3D™ ShockSim3D Model

HPET™ Halliburton Perforating Evaluation Tool

By capturing actual dynamic reservoir response at multiple points throughout the perforation interval, and during and after the perforating event, the HPET™ Halliburton perforating evaluation tool provides "quick-look data" to enhance future designs and exploitation of assets.

Operators and service providers recognize wells are pushing the limits of design. The importance of predicting events during the perforating process has pushed the industry to determine ways to gather dynamic information at zones of interest during the perforation event. While perforation cleanup and flow efficiency knowledge have always been desired, now other factors are being modeled and optimized. These include shock loading, dynamic and static underbalance, dynamic trip data, "fast response" reservoir data, characteristics, and analysis.

A new level of capability is necessary to truly understand and model the perforating event. To this end, Halliburton developed HPET technology to gather data at any location within the perforation string. Understanding the stress-strain relationships yields a more accurate characterization of downhole events. The HPET can be placed directly in the perforating gun string at multiple points, whereas industry-standard fast gauges can only be placed above or below the perforated interval. This placement helps verify what is happening at a specific point in the perforated interval, rather than assuming/correlating at points within the perforated interval. HPET technology enables direct measurement and analysis across nonhomogeneous intervals with varying reservoir and wellbore parameters. The more accurate and location-specific measurement helps predict and even eliminate downhole issues caused by shock loads and dynamic pressure events. HPET technology can enhance perforating design at multiple points within an interval(s) to optimize well productivity. Gathered data can also be used to accurately test at specific modeled conditions in the Halliburton Advanced Perforating Flow Laboratory (APFL) to verify the model's predictions before deployment.

Benefits

- Can be placed anywhere in the perforating assembly
- Provides more data for job verification, post-job analysis, and model validation
  - 12 active channels for high-speed recording
  - 100,000 data samples from each channel
    - Tool string acceleration
    - Mechanical strain/stress in the tool string
    - Dynamic wellbore pressure
    - Static pressure/temperature
- Provides high-resolution characterization across nonhomogeneous intervals with varying reservoir and wellbore parameters
- Captures stress and strain, yielding a more accurate characterization of downhole events
- Enables life-of-well, time-lapsed reservoir monitoring capabilities for proactive asset management
- Operates in deviated or horizontal wells for dynamic string shock loading response

HPET™ Halliburton Perforating Evaluation Tool

Features

- Can verify the shock loading model's predictions in the APFL before deployment
- Can be placed directly in the perforating gun string at multiple points
- Helps enable direct measurement and analysis across nonhomogeneous intervals with varying reservoir and wellbore parameters
- Displays full job history

Technical Specifications	
Diameter	4 5/8 in.
Pressure Rating	20,000 psi
Tensile Rating	377,000 lb
Connections	Standard gun threads (pin × box)
Sensors	
Strain Gauges	Three axial, three hoop, one torsion
Pressure	Dynamic pressure, 100 ksi
Accelerometers	Triaxial, 60 kg
Temperature	Resistance temperature detector
Environmental	
Temperature Rating	302°F (150°C)
Logging	
Event Sampling Rate	100 kHz
Event Duration	1 second
Event Records	10
Run Duration	5 days

Technical Specifications	
Diameter	6 1/2 in.
Pressure Rating	30,000 psi
Tensile Rating	686,584 lb
Connections	Standard gun threads (pin × box)
Sensors	
Strain Gauges	Three axial, three hoop, one torsion
Pressure	Dynamic pressure, 100 ksi
Accelerometers	Triaxial, 60 kg
Temperature	Resistance temperature detector
Environmental	
Temperature Rating	302°F (150°C)
Logging	
Event Sampling Rate	100 kHz
Event Duration	1 second
Event Records	10
Run Duration	5 days

ORION Operational Reporting in an Operations eNvironment

In August 2014, the Halliburton Wireline and Perforating (WP) product service line (PSL) released ORION Operational Reporting in an Operations eNvironment software.

This global service quality (SQ) data capture software provides WP users across the globe with a software application that outperforms the legacy application with faster data processing and overall system performance. More importantly, ORION delivers a more efficient and effective platform to capture vital data across WP's varied operations and sub-PSLs.

ORION reduces manual data entry and eliminates irrelevant data capture using multisystem integration. The software's enhanced capability to process, retrieve, and send data provides WP management and leadership a conduit for intelligent business reporting. This results in an improved ability to analyze SQ metrics and deliver essential data to both internal and external customers.

Slow Surge™ Perforating Design Analysis with HPET™ Halliburton Perforating Evaluation Tool

The Halliburton Slow Surge™ process is an examination and prejob planning system used to engineer static underbalance flow post-perforation, significantly increasing the productivity index. Underbalance provides improved cleanup of the perforation tunnels created by jet perforators. Before the implementation of the Slow Surge perforating design analysis, the efficiency of removing the crush zone in the perforating tunnel was difficult to quantify. This is because of the inability to capture the required pressure drop at multiple points across the Slow Surge string. With the development of the HPET™ Halliburton perforating evaluation tool, this is no longer a concern. HPET technology captures actual dynamic pressure response at multiple points throughout the Slow Surge string after the perforating event. This provides "quick-look data" for use in the prejob Slow Surge process design analysis to enhance future designs and exploitation of the asset.

Slow Surge perforating design analysis is physics driven and relies on measurable or estimated actual input parameters — no curve-fitting or back-of-the-envelope calculations.

To fully represent wellbore behavior, Slow Surge perforating design analysis accounts for a wide variety of factors:

- Thermodynamic mixing and multiple compressible fluid types/phases
- Multiple diameter effects in the well, including:
  - Surface pressurization, pumping, and fluids flowback
  - Flow into and breakdown of perforation tunnels
  - Subsequent transient return flow from perforations

Benefits

Slow Surge perforating design analysis is ideal for predicting:

- Wellbore drawdown at a specific location within the perforated intervals
- Pressure drop across different string profiles
- Fluid injection/production
- Tunnel cleanup, enhancing shot effectiveness
- Accuracy — physics-based solution with documented validation

Understanding and prediction of dynamic and static pressure behavior becomes paramount when perforation damage cleanup and tunnel integrity are necessary.

Slow Surge perforating design analysis is based on a proprietary analysis developed from API Section IV perforation flow laboratory studies.

- Time-marching finite-difference modeling
- High-speed pressure measurements
- Empirical field data

Mini Drillstem Testing/Fast Test with HPET™ Halliburton Perforating Evaluation Tool

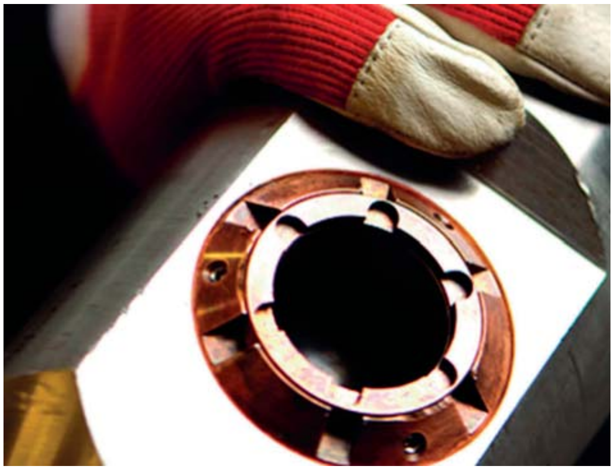
Conventional drillstem testing (DST) is a proven means of evaluating a well. However, sometimes a "quick look" at pore pressure and permeability from early-to-intermediate time pressure transients are required. Halliburton improves this technique by integrating existing technology with recent developments in the HPET™ Halliburton perforating evaluation tools and combining this with Halliburton remote open close technology (ROCT).

Before the development of HPET, when a zone of interest required evaluation, a string of DST tools was the first choice for most operators. Now, the HPET tool can be placed directly in the perforating gun string at multiple points, which helps enable mini DST/fast test analysis without the extra costs associated with long buildup time and tripping in and out of the well with a dedicated DST string.

By capturing actual reservoir response at multiple points throughout the perforation interval before, during, and after the perforating event, the mini DST/fast test can be used for production testing to obtain optimum flow rates, stabilized formation pressures, and the in-situ characteristics of the reservoir. The mini DST/fast test provides "quick-look data" that will be used to enhance future designs and exploitation of the asset.

ROCT Benefits

- No intervention or surface control lines necessary, reducing risks and saving money
- Remotely operated
- Long battery life
- Run open or closed
- Flexible deployment options and well control



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ROCT Valve Flow Port

Mini DST/Fast Test Results

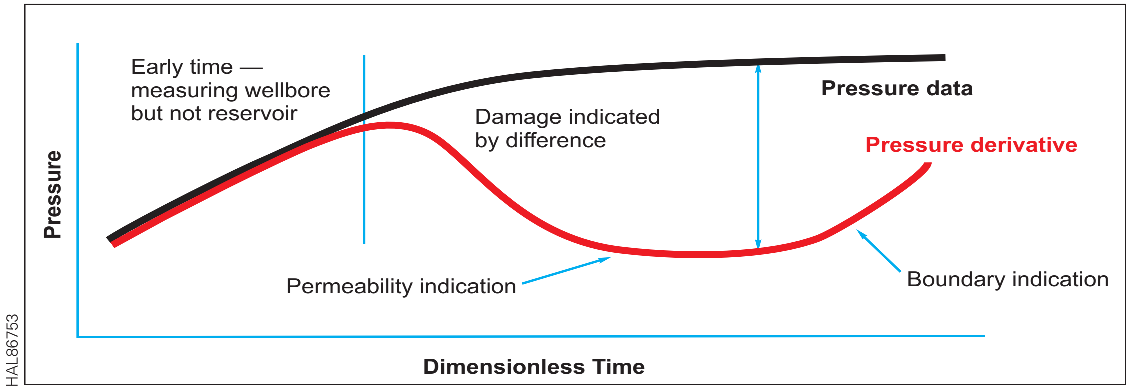
The exact solution of the spherical-flow well-test equation is valid for all time and is used to predict formation pressure and permeability from early-to-intermediate time pressure transients.

The exact-spherical flow model, derived from first principles, includes general wellbore storage effects. The model is solved in closed, analytical form. This permits convenient pressure response to theory matching using the complete time regime, including early, transitional, and late-time data.

Well test examples demonstrate accurate pore pressure and permeability predictions from the mini DST/fast test. Detailed numerical simulations over a wide range of conditions illustrate the utility and power of this technique.

To provide more accurate pressure and permeability measurements, the mini DST/fast test was designed to run capture data within the zone of interest at the sandface.

The mini DST/fast test circulates through the perforating string to help ensure differential sticking is minimized. This makes quick look for pore pressure and permeability in horizontal and extended-reach wells less expensive and safer than testing with a standard DST string.



Example of Mini DST/Fast Test Results

Features

- No need to account for pressure effect from distance of recorder from the producing zone
- Multiple flow and shut-in periods achievable
- Combinability with tubing-conveyed perforating for ease of use
- Gauges placed directly in the perforating gun string at multiple points as close to the zone of interest without having to run a second trip with DST tools
- Direct measurement and analysis across nonhomogeneous intervals with varying reservoir and wellbore parameters
- Reservoir characteristics measurement, such as pressure and temperature, captured on downhole recorders within the bottomhole assembly
- Full job history displayed visibly
- Trip in hole and out hole with all pressure cycles open to the wellbore

STIM Fracture Efficiency Analysis with HPET™ Halliburton Perforating Evaluation Tool

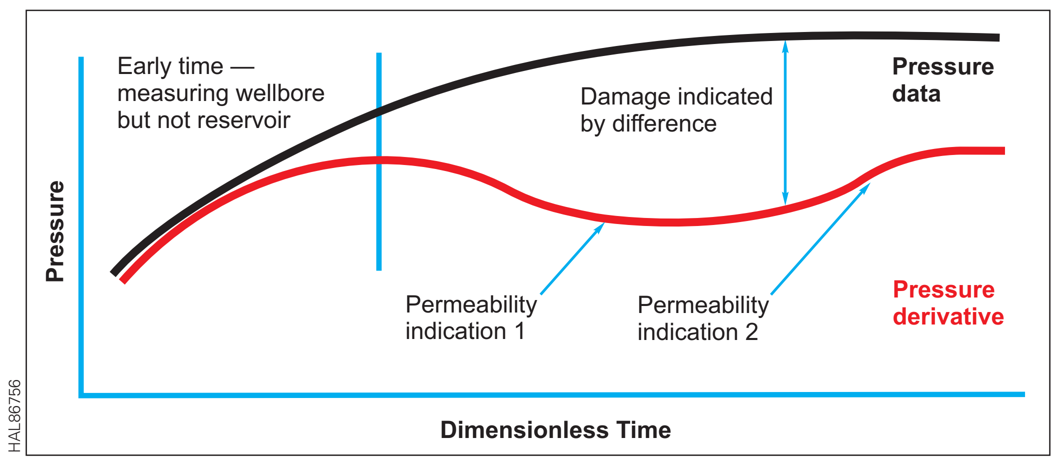
StimGun™ technology is best understood as an engineered job design process that integrates the use of products with PulsFrac™ computer modeling and data acquisition. This method of validating the results of the STIM treatment was based on the leading technology of the time. With the development of the HPET™ Halliburton perforating evaluation tool, this is no longer the only method.

In the right application and with the right tool, propellants work. However, all propellant-based products are not the same. The StimGun family of propellant-based products offers the industry the first fully integrated, technology based, and thoroughly tested tools designed to dynamically clean up and stimulate the near-wellbore area. These stimulations are not only cost effective, but in many instances, might be the only available solution for elimination of certain near-wellbore problems.

This technology is used both as a primary stimulation and in combination with other stimulation technologies, such as hydraulic fracturing. Now with the ability to provide STIM fracture efficiency analysis, this offering is complete.

Benefits

- Provide the ability to evaluate fractures created during a STIM treatment
- No more model interpretation as the evaluation is performed with imperial data collected at the sandface throughout the zone of interests
- Evaluate optimum flow rates, stabilized formation pressures, and the in-situ characteristics of the reservoir
- Wellbore drawdown at specific location within the perforated intervals



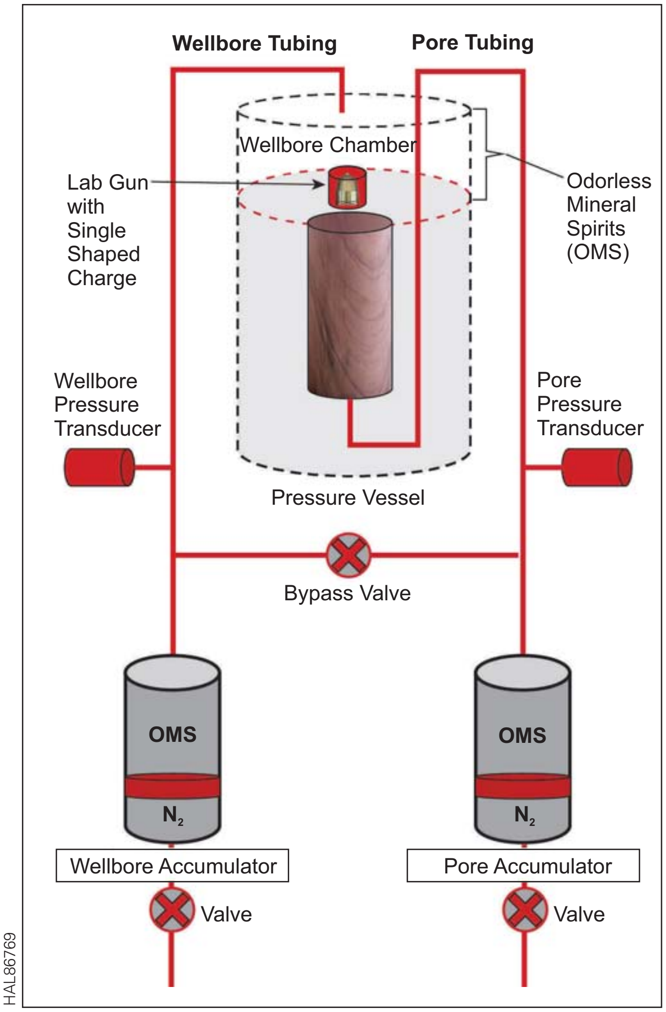
Example of STIM Fracture Efficiency Analysis Results

The Halliburton Perforation Flow Laboratory (API RP-19B Section IV)

The petroleum industry often evaluates gun systems solely on the results of an API RP-19B Section I test, choosing the gun system with the longest penetration in concrete or largest hole diameter. Unfortunately, the shaped charge manufacturers are well aware of this selection process and design and optimize their shaped charges for peak performance in unstressed concrete. Basing the perforation selection on Section I test data can lead to inefficiency in the shaped charge design process and in transforming surface data to downhole conditions.

API RP-19B has provisions for a testing setup to evaluate shaped charges at conditions as close as possible to downhole conditions with Section IV testing. In the Perforation Flow Laboratory, a formation core can be perforated with a single shaped charge at reservoir pressure, effective stress, and a given well condition (underbalanced/dynamic underbalanced or overbalanced). This special testing apparatus allows each shaped charge to be evaluated by perforating in actual formation material as opposed to unstressed concrete. The core can be injected or flowed into after perforating to characterize the degree of perforation damage and cleanup as a function of the perforating condition. Following the perforating flow study, the core can be removed and the actual perforation geometry (tunnel length, shape, and damage) measured.

Using the Halliburton Perforation Flow Laboratory puts the focus on completion efficiency as a function of the way the perforation job will be executed at field conditions. This allows a more accurate way to assess perforator efficiency than simply evaluating Section I penetration results. For example, a given charge can penetrate 2 in. deeper in a Section I target; however, if the charge cannot be shot with sufficient underbalance/dynamic underbalance to effectively clean the perforation tunnel, then the full potential of the given shaped charge might never be realized. Core samples evaluated in the Perforation Flow Laboratory under the same conditions of pore pressure, effective stress, and charge type illustrate the importance of an underbalanced/dynamic underbalanced condition. The only variable changed between the two samples is the well condition. One sample was shot balanced and shows perforation damage caused by plugging. The other sample shows that the entire perforation tunnel is completely open to flow when sufficient underbalanced/dynamic underbalanced pressure is applied.



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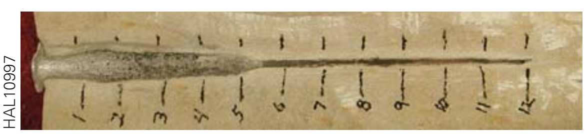
Simplified Perforation Flow Facility Schematic



HAL10997

Overbalanced

HAL11001

Underbalanced/Dynamic Underbalanced

Bibliography

1. Asadi, M. and Preston, F.W.: "Characterization of the Jet Perforation Crushed Zone by SEM and Image Analysis," SPEFE (June 1994) 135-139.

2. Pucknell, J.K., and Behrmann, L.A.: "An Investigation of the Damaged Zone Created Perforating," paper SPE 22811, 1991.

3. Halleck, P.M., Atwood, D.C., and Black, A.D.: "X-Ray CT Observations of Flow Distribution in a Shaped-Charge Perforation," paper SPE 24771, 1992.

4. Bell, W.T., Brieger, E.F., and Harrigan Jr., J.W.: "Laboratory Flow Characteristics of Gun Perforations," JPT (Sept. 1972) 1095-1103.

5. Cinco-Ley, H., Ramey Jr., H.J., and Millar, F.G.: "Pseudoskin Factors for Partially Penetrating Directionally Drilled Wells," paper SPE 5589, 1975.

6. Karakas, M., and Tariq, S.M.: "Semianalytical Productivity Models for Perforated Completions," paper SPE 18247, 1988.

7. Gruesbeck, C. and Collins, R.E.: "Particle Transport Through Perforations," paper SPE 8006, 1978.

8. Abass, H.H. et al: "Oriented Perforation - A Rock Mechanics View," paper SPE 28555, 1994.

9. Warpinski, N.R.: "Investigation of the Accuracy and Reliability of In-Situ Stress Measurements Using Hydraulic Fracturing in Perforated Cased Holes," Proceedings - Symposium on Rock Mechanics (1983) 24, 773-786.

10. Daneshy, A.A.: "Experimental Investigations of Hydraulic Fracturing Through Perforations," Journal of Petroleum Technology (October 1973) 25, 1201-1206.

11. King, G.E., Anderson, A. and Bingham, M.: "A Field Study of Underbalance Pressures Necessary to Obtain Clean Perforations Using Tubing-Conveyed Perforating," paper 14321, 1985.

12. Folse, K., Allin, M., Chow, C. and Hardesty, J.: "Perforating System Selection for Optimum Well Inflow Performance," SPE paper 73762, 2002.

13. Handren, P.J., Jupp, T.B., and Dees, J.M.: "Overbalance Perforation and Stimulation Method for Wells," paper SPE 26515, 1993.

14. Pettijohn, L., and Couet, B.: "Modeling of Fracture Propagation During Overbalanced Perforating," paper SPE 28560, 1994.

15. Snider, P.M., and Oriold, F.D.: "Extreme Overbalance Stimulations using TCP Proppant Carriers," World Oil (Nov. 1996) 41-48.

16. Ansah, J., Proett, M., and Soliman, M.Y.: "Advances in Well Completion Design: A New 3D Finite-Element Wellbore Inflow Model for Optimizing Performance of Perforated Completions," paper SPE 73760, 2002.

03

Installation Examples

Single-Zone Completions (page 63)

Single-zone completions help minimize perforating costs while maximizing potential. This section describes typical single-zone completions, perforating below a permanent packer, and how each component of the completion functions to provide quality, cost-efficient solutions.

Horizontal Completions (page 66)

Horizontal completions allow for perforating of long horizontal intervals, which maximizes the productive potential of these completions at the same cost as single-trip perforating. In addition, by combining orienting fins, swivels, and low-side VannGun® assemblies, shots can be oriented toward fracture planes or other needed areas of completions.

Automatic-Release Gun Hangers (page 68)

Automatic-release gun hangers (ARGH) allow perforating and testing of a zone without downhole restrictions. The perforating assembly can be positioned and retained adjacent to the desired interval. The drillpipe or tubing is then removed. Once surface equipment is installed, guns are automatically detonated and released in the bottom of the well.

Single-Trip Perforating and Testing (page 73)

Single-trip strings combine the benefits of tubing-conveyed perforating and advanced testing technology to save rig time. Sophisticated, accurate Halliburton data collection technology provides the information necessary to evaluate formation potential.

Multizone Perforating and Testing (page 74)

Multizone completions include dual completions and selective completions. Halliburton dual completions help maintain maximum underbalance and reduce costs while enhancing flexibility. When combining a Y-block with Halliburton sliding sleeves, multiple zones can be perforated, tested, and selectively produced through a single string.

With piggy back multizone completions, it is possible to perforate and test the lower zone, and then perforate the upper zone, commingling flow from both zones for the second test — all in a single trip.

Annulus-Fired Systems (page 77)

Annulus-fired systems are ideal for situations when nitrogen is unavailable or too costly. Tubing runs in dry or with a minimal fluid pad. Annulus-fired systems enable firing of the guns without pressuring the tubing — maintaining maximum underbalance.

Modular Gun System (page 79)

The modular gun system brings tubing-conveyed perforating advantages to monobore completions without creating flow restrictions. It also eliminates the need and cost for tubing between guns and the packer.

Enhanced Overbalanced Perforating Solutions (page 80)

These completions include Powr*Perf™, PerfStim™, StimTube™, and StimGun™ systems. Each increases productivity by incorporating different perforating techniques.

Sand Control Solutions (page 82)

Sand control techniques include shoot and pull, STTP™-GH single-trip perf/pack, screenless FracPac℠, and PerfCon℠ processes. All provide innovative, cost-efficient solutions.

Perforate and Squeeze (page 84)

The perforate and squeeze method uses single-trip block squeeze (DrillGun™ system), which cuts rig time and kill-fluid costs by using a single-trip procedure.

Select Fire™ Systems (page 85)

Select Fire™ systems use dual and multiple zone perforating and testing. These methods offer unprecedented flexibility including the ability to test two zones in one trip; isolating two zones for selective testing and perforating; and selective testing and perforating of an unlimited number of zones.

Dual Drillstem Test System (page 87)

Incorporating components of the Halliburton innovative Select Fire™ system, this string isolates each zone for perforating and testing.

Live Well Perforation (page 90)

Live well perforating uses ratchet connectors or AutoLatch™ release gun connectors. The ratchet connector is conducive to snubbing into live wells much faster without a drilling rig. The AutoLatch connector combines coiled tubing economies with perforating benefits.

The isolation subassembly is a more economical tool that can be used on wells with lower surface pressures.

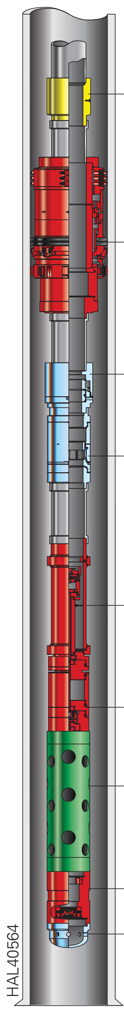
Coiled Tubing Perforating (page 95)

Coiled tubing is another method used in the industry to deploy perforating guns into a well. The firing mechanisms used to detonate the guns are hydraulically operated. The firing heads include the ball drop actuator firing head, which is also available with a swivel, and pressure-actuated firing heads, such as time-delay firer (TDF), model K, KV-II, etc.

Single-Zone Completions

Closed System

Single-zone completions help minimize perforating costs, while maximizing potential. This string runs in virtually dry to create maximum underbalance without swabbing or nitrogen blowdown costs. Redundant firing heads minimize delays caused by firing problems.

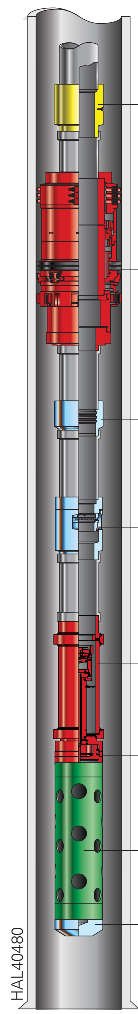


Single-Zone Closed System

Open System

Replacing a vent with the ported balanced isolation tool (BIT) provides for underbalanced perforating and replaces the fill disk and perforated sub.

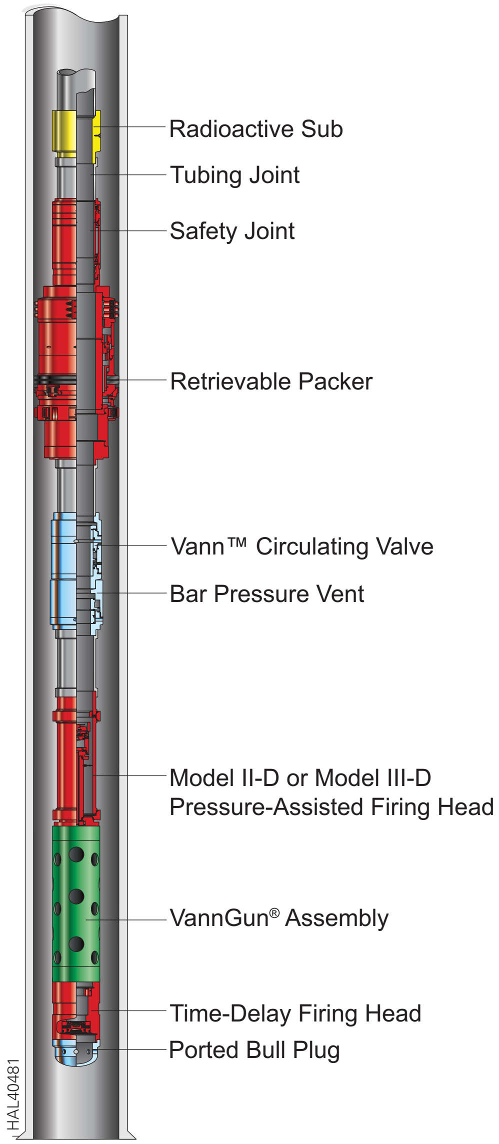
The BIT design separates the clean fluid below it from the kill fluids above it. It runs in with the ports open, allowing circulation at any point. Once the guns are positioned, circulation removes debris from the tool's glass disk. Before firing, swabbing or displacing fluids with nitrogen provides for an underbalance.



Single-Zone Open System

With Circulation Valve

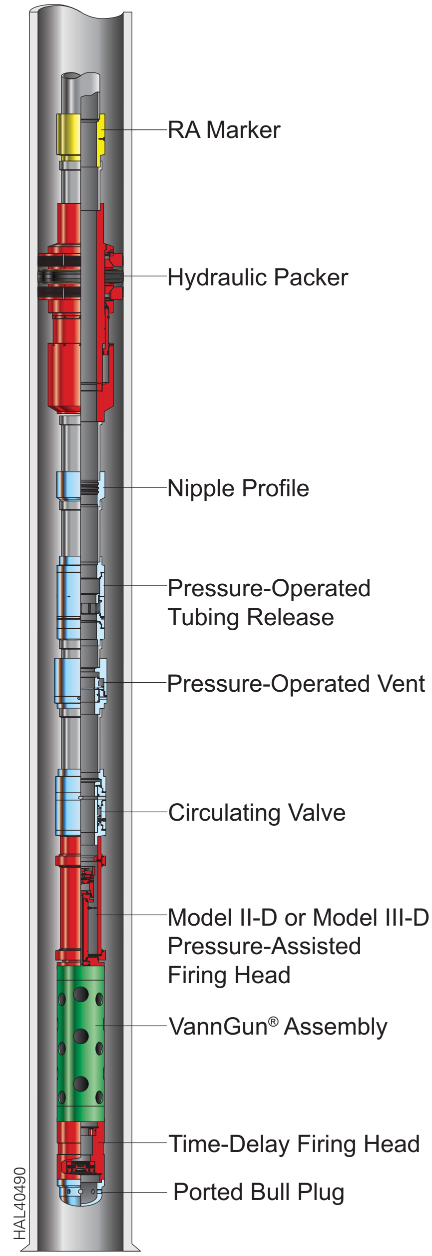
To limit underbalance/dynamic underbalance pressures, the Vann™ circulating valve runs in open but closes automatically when a predetermined pressure is reached.



Vann™ Circulating Valve

With Pressure-Operated Tools

Halliburton developed this string of pressure-operated tools when the use of wireline is not feasible.



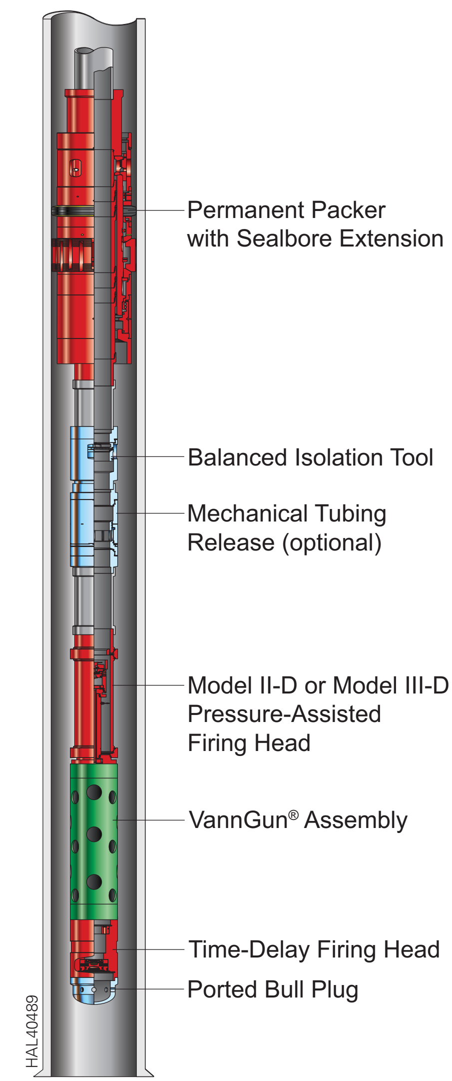
Pressure-Operated Tools

Perforating Below a Permanent Packer

Guns Sting Through Packer

Perforating charge explosives deteriorate rapidly at high downhole temperatures. (See the Time vs. Temperature chart in the Firing Heads section of this catalog.) Running and setting a large-bore packer on wireline, then stinging the perforating string through it minimizes the charges' exposure to high temperatures. Once the perforating string is spaced out, circulating mud and heavy fluids out of the tubing string establishes underbalance.

This design offers another advantage. If required, the guns can be retrieved without drilling out the packer.

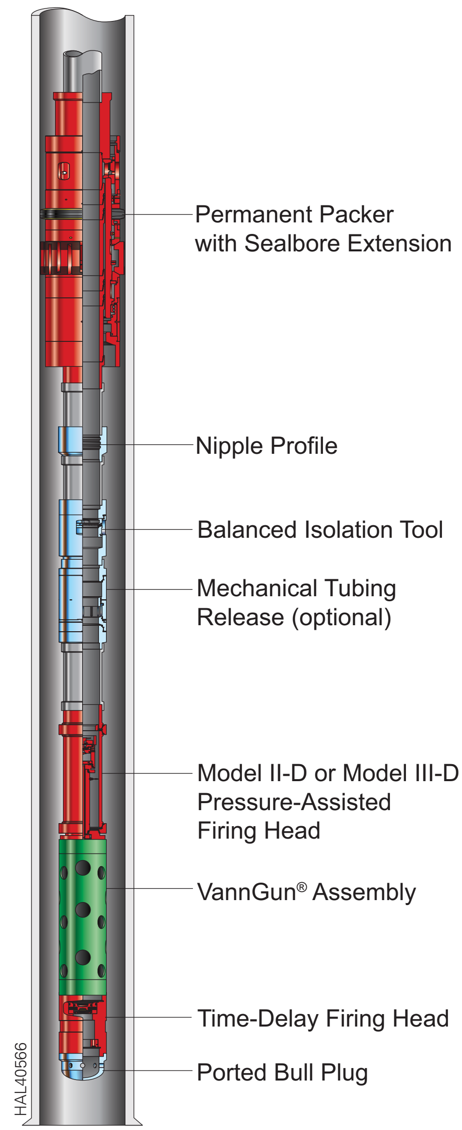


Guns Sting Through Packer

Guns Run with Packer

Running VannGun® assemblies with the permanent packer eliminates the packer bore restrictions on gun size. This allows larger guns to be run. The packer and guns are run in on drillpipe, tubing, or wireline.

String design places the VannGun assemblies across the interval to be perforated when the packer is set. After displacing mud and heavy fluids out of the tubing to create the underbalance, the tubing seal is stung into the packer and the guns fired.



Guns Run with Packer

Horizontal Completions

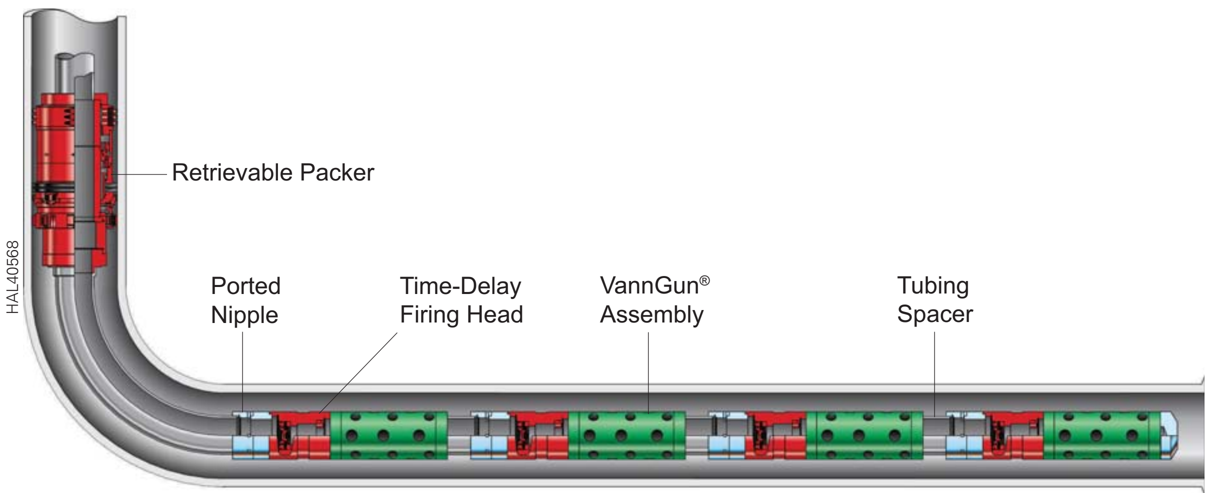
Horizontal completion strings perforate extremely long horizontal intervals, maximizing the productive potential of horizontal completions, while providing the economies of single-trip perforating.

Typically, the string incorporates short, but widely separated gun sections. Using pressure-actuated Halliburton time-delay firing heads on each gun eliminates misfires caused by the breaks that so frequently occur in long firing trains. Because the guns fire virtually simultaneously, all intervals are perforated and underbalanced.

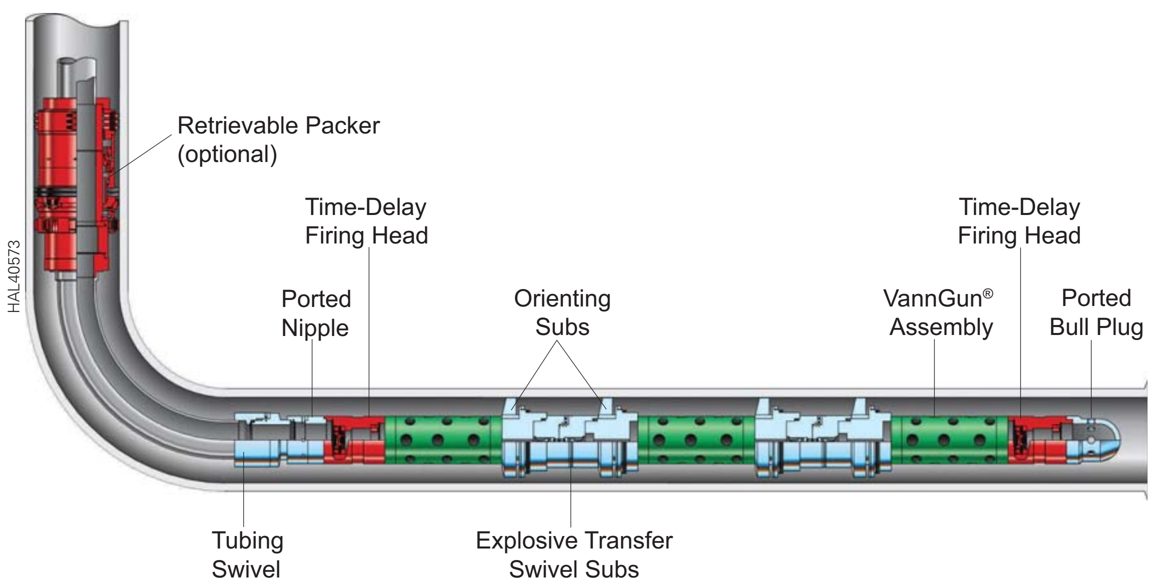
Explosive Transfer Swivel Sub

The explosive transfer swivel sub allows two sections of guns to rotate independently of one another. This independent rotation is important on long strings of guns in horizontal wells when it is necessary to orient them in a specific direction. It is easier to orient several short sections of guns than one long gun section.

This swivel sub can be run as a connector between two guns to allow them to rotate independently without breaking the explosive train. In other words, this sub passes on the explosive transfer to the next gun.



Horizontal Completion



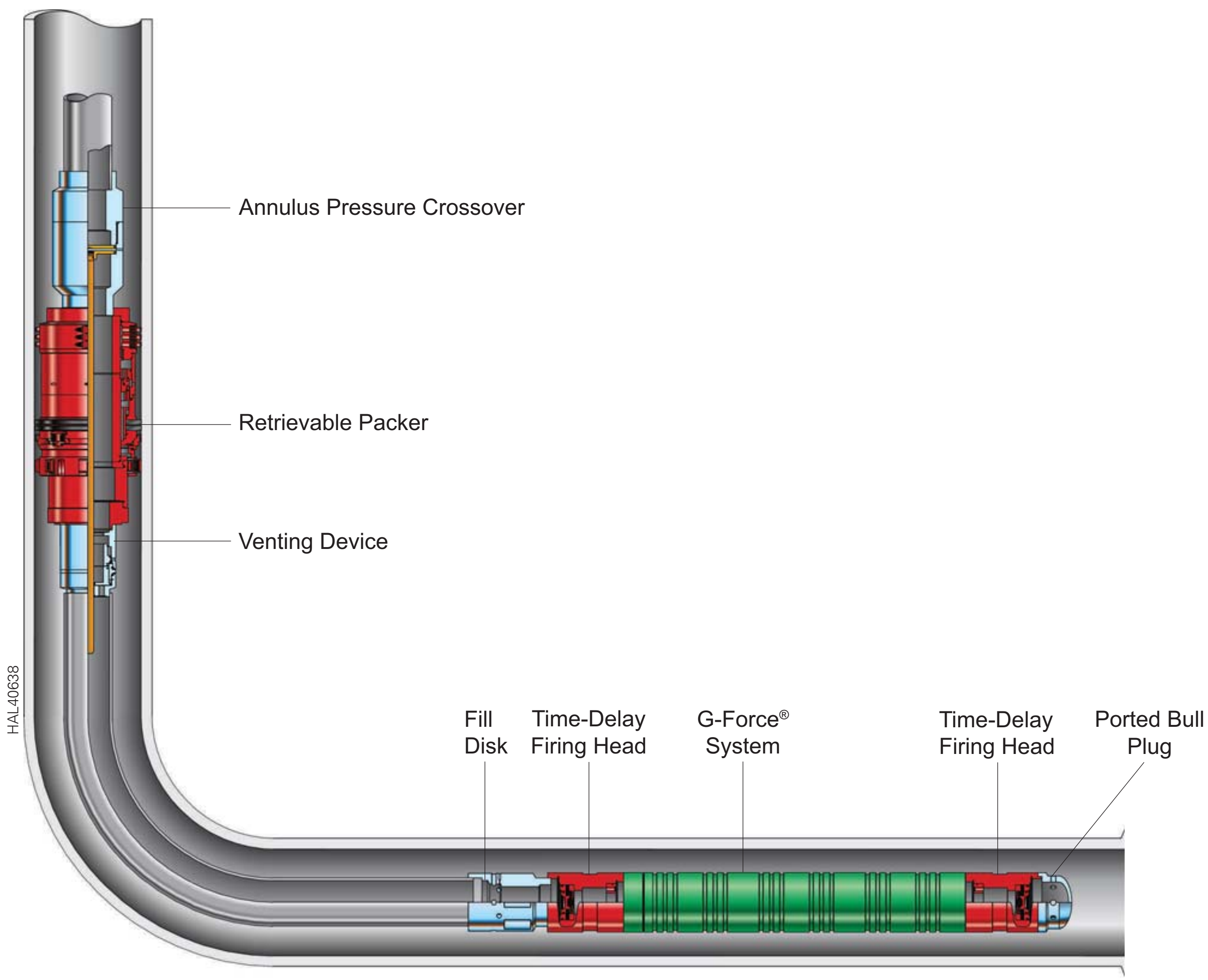
Swivel Sub Installation

G-Force® Precision Oriented Perforating System

The combination of orienting fins, swivels, and low-side VannGun® assemblies keep shots oriented toward fracture planes or other areas of interest in horizontal completions.

The introduction of the G-Force® internal orienting system allows accurate gravity-based charge orientation.

This system features an internal orienting charge tube assembly and gun carrier, which allows perforating in any direction, irrespective of the gun's position relative to the casing.



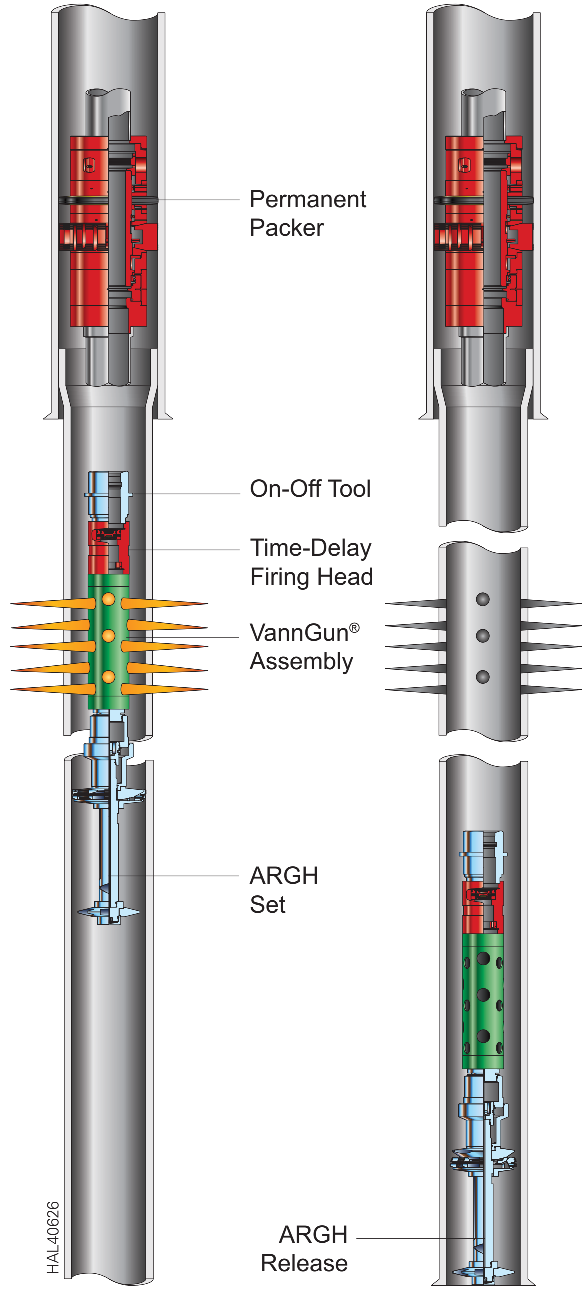
G-Force® System

Automatic-Release Gun Hangers

For high volume testing and production, the automatic-release gun hanger (ARGH) allows perforating and testing of a zone without imposing downhole restrictions. The perforating assembly can be positioned and retained adjacent to the desired interval. The drillpipe or tubing is then removed. After all surface equipment is installed, the guns are detonated and then released automatically into the bottom of the well.

ARGH Completion Below a Retrievable Packer

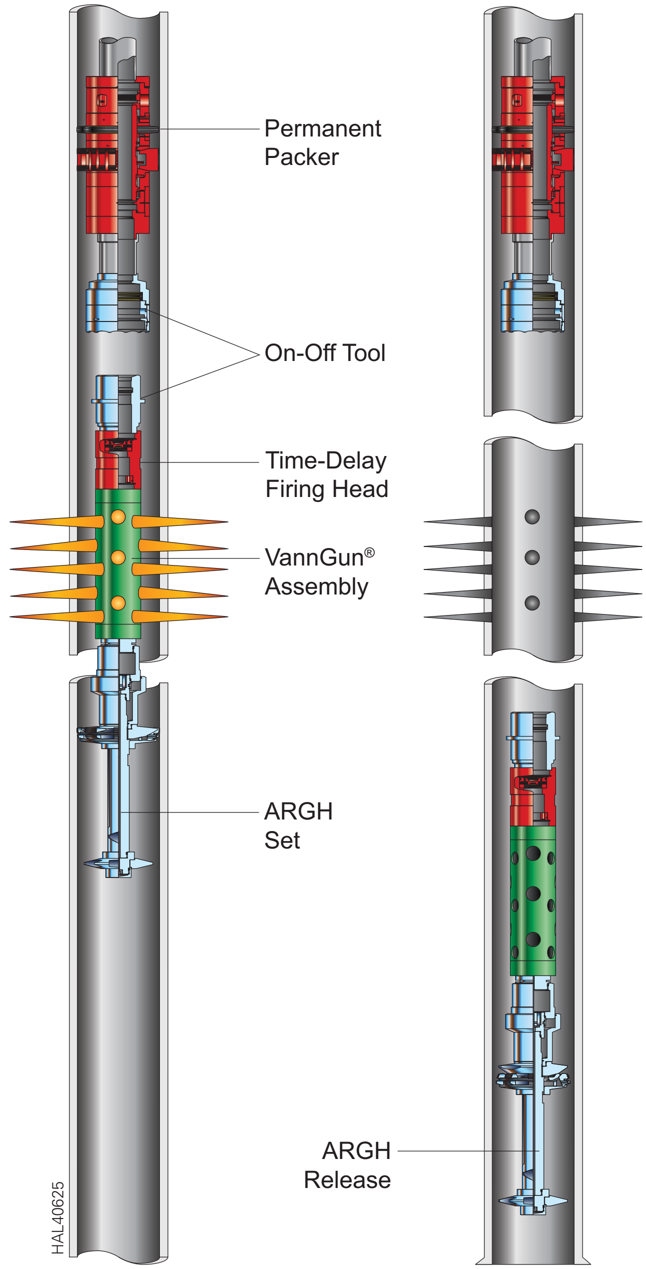
When using an ARGH completion below a retrievable packer, the completion uses the maximum desired underbalance. Modular design allows for the use of less makeup space. Additional perforations can be added through the tubing at a later date. Other benefits include no tubing required between guns and packer, no wireline work required to drop the assembly, and no restrictions left in casing below the packer.



Automatic-Release Gun Hanger (ARGH) Completion Below a Retrievable Packer

Automatic-Release Gun Hanger Completion Below a Permanent Packer

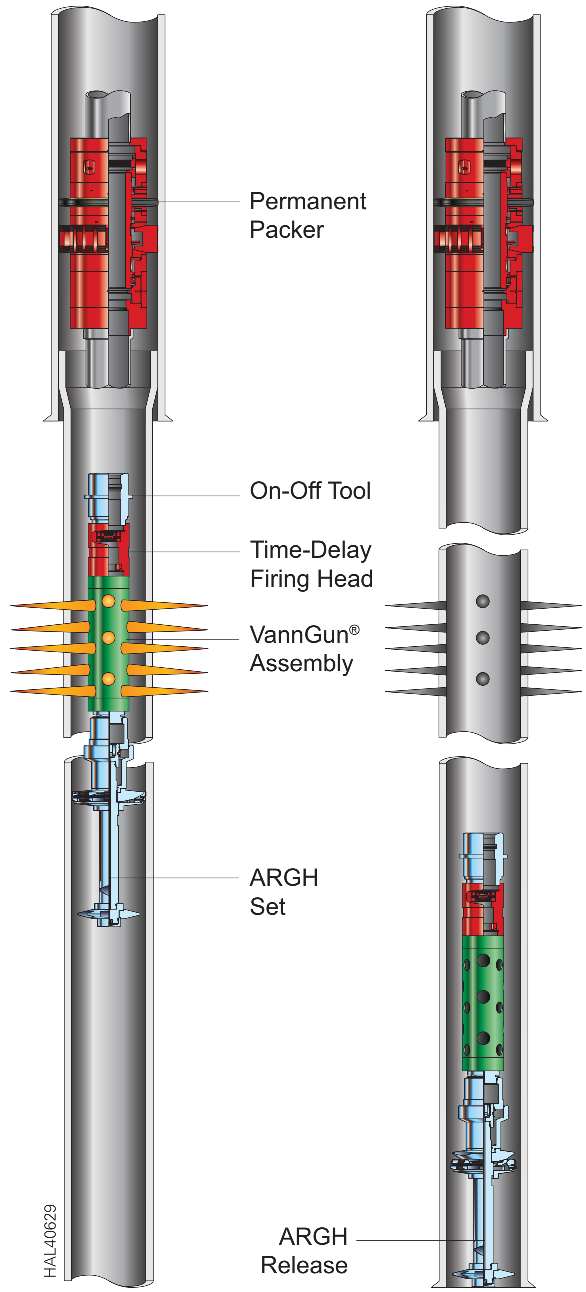
When using an automatic-release gun hanger (ARGH) completion below a permanent packer, the permanent packer sets on wireline, while the ARGH and guns are run on the work string. Other benefits include less risk of presetting the packer, and lower pressure needed to fire guns since setting the packer requires no pressure. One of the main benefits of using the ARGH completion below a permanent packer is that the production tubing is run and tested independently of other tools.



Automatic-Release Gun Hanger (ARGH) Completion Below a Permanent Packer

Monobore Completion Below a Permanent Packer

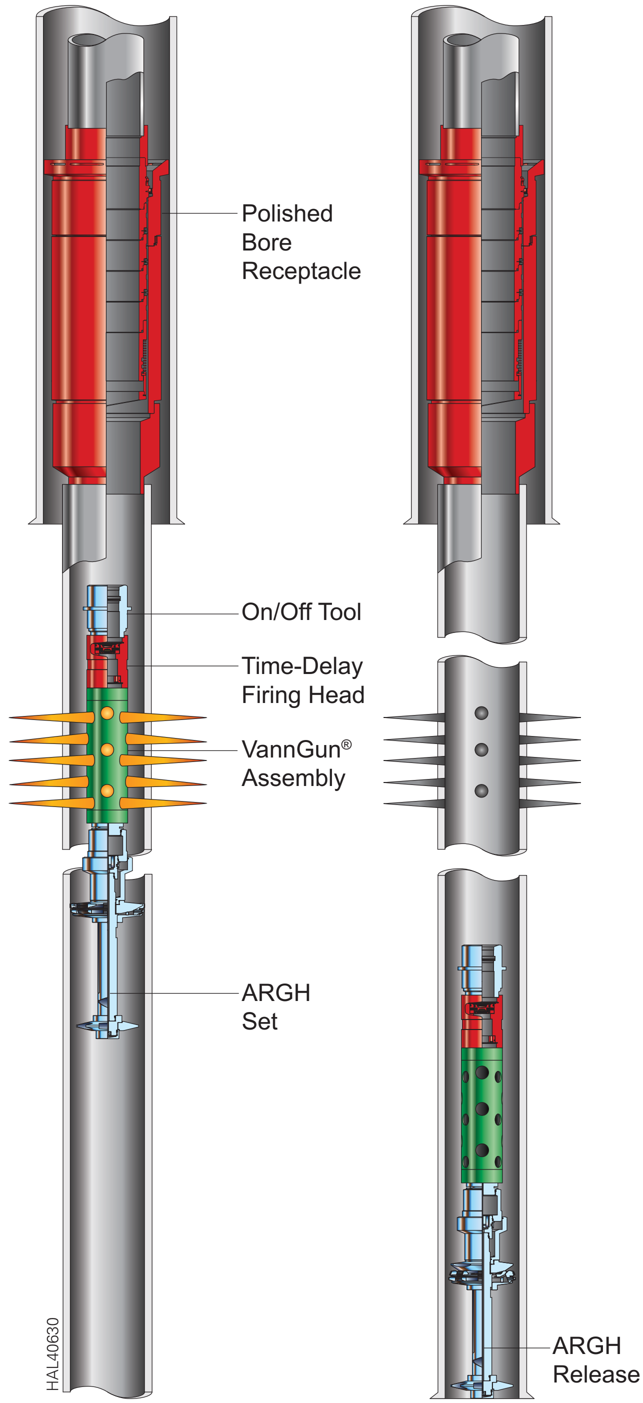
When using a monobore completion below a permanent packer, production tubing and a permanent packer are installed before running the automatic-release gun hanger (ARGH) assembly. This allows retrieval and replacement of the perforating assembly without tripping expensive production tubing. Remedial work can be performed without pulling production equipment. Other benefits include having the guns on bottom for a shorter period of time, and the use of lower firing pressures because production equipment is tested before installing guns in the well.



Monobore Completion Below a Permanent Packer

Monobore Completion Below a Polished Bore Receptacle

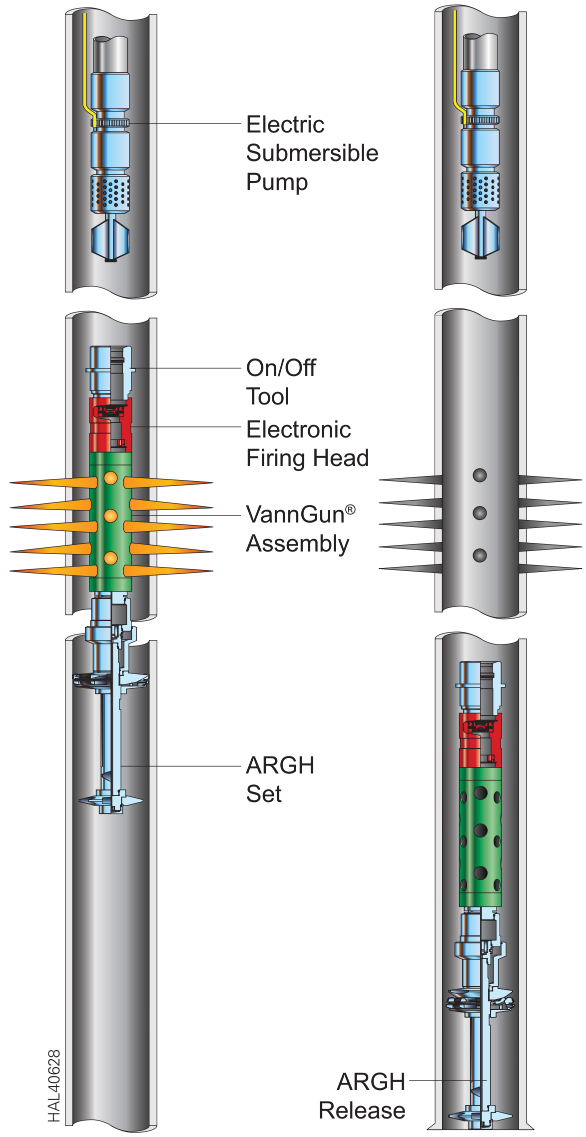
When using a monobore completion below a polished bore receptacle (PBR), the production tubing and seal assembly are installed in the PBR and tested before running the automatic-release gun hanger (ARGH) and guns. The full ID of the liner and production tubing can be used for fluid flow, while the sealbore of the PBR is protected from any damage that might occur. Other benefits include having the guns on bottom for a shorter period of time.



Monobore Completion Below a Polished Bore Receptacle

Automatic-Release Gun Hanger Completion Below an Electric Submersible Pump

The automatic-release gun hanger (ARGH) completion below an electric submersible pump (ESP) allows the well to be perforated underbalanced, while continuing production via the ESP. No tubing is required below the pump, and because the guns are not connected with the tubing, they do not transmit any mechanical shock. Even in wells with casing too small to run a tubing string along the ESP, all benefits of tubing-conveyed perforating are provided.



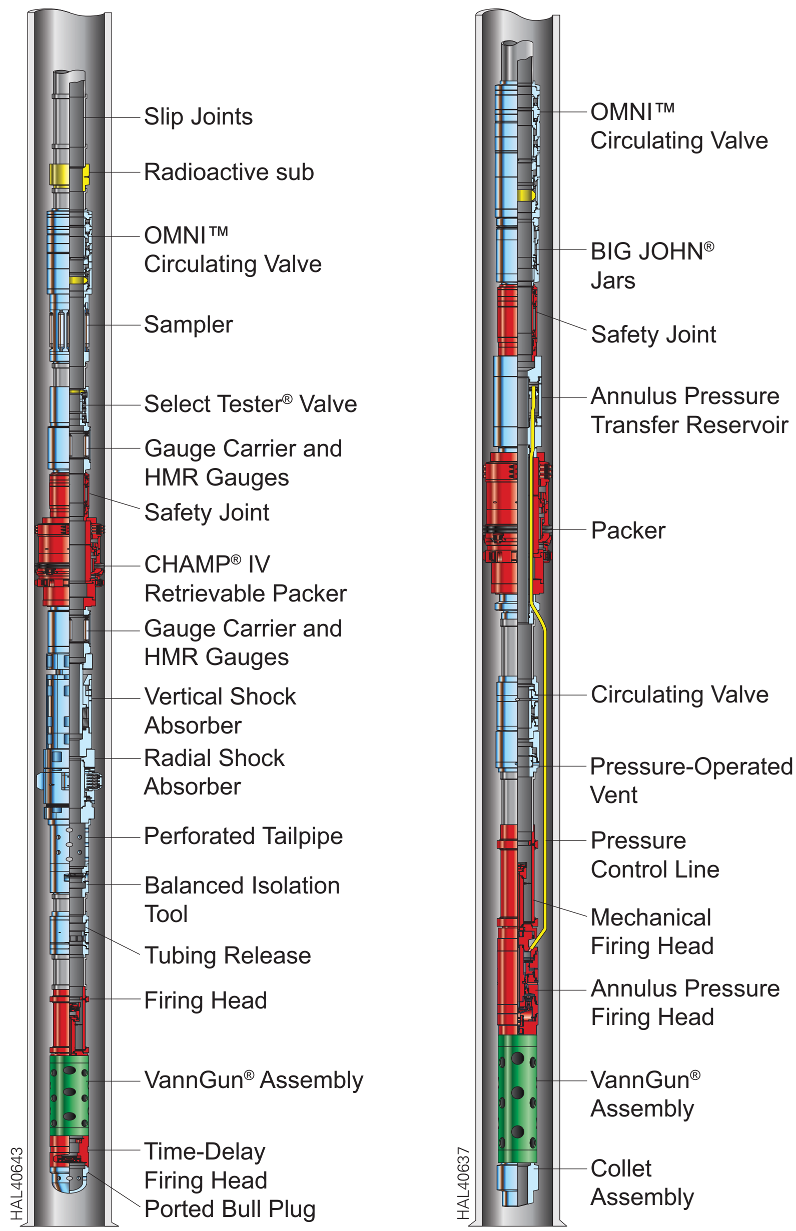
Automatic-Release Gun Hanger (ARGH) Completion Below an Electric Submersible Pump (ESP)

Single-Trip Perforating and Testing

These one-trip strings combine the benefits of Halliburton tubing-conveyed perforating and advanced testing technology. Perforating underbalanced removes damage that can adversely impact data accuracy and production. Sophisticated, accurate Halliburton data collection technology provides the information needed to evaluate formation potential.

Halliburton one-step procedures incorporate redundant well control systems — surface control equipment in place, downhole safety valves, and tester valves. This schematic illustrates tools typically used in single-zone, one-step perforate and test procedures. Well conditions, economics, and testing objectives determine the specific tools used.

All tools are pressure operated, eliminating the rig-time costs involved in calling out and running wireline equipment. The annulus pressure firing head provides the benefits of tubing-conveyed perforating in situations when heavy muds or regulations preclude use of drop bars.

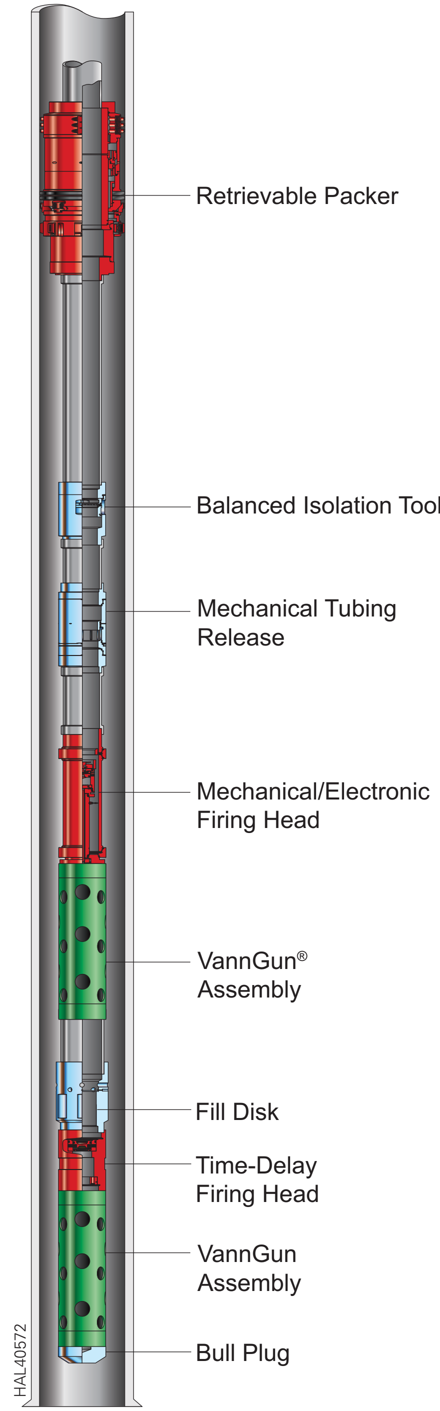


Single-Trip Perforating and Testing

Multizone Perforating and Testing

Piggy Back Multizone Completion

With this system, it is possible to perforate and test the lower zone and then perforate the upper zone, commingling flow from both zones for the second test — all in a single trip. The upper zone can be evaluated by comparing data from the two tests.

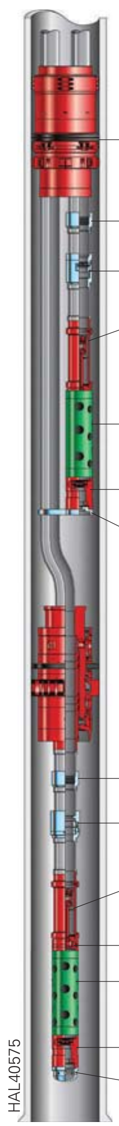


Piggy Back Multizone Completion

Dual-String Completion

This typical dual-zone Halliburton VannSystem® service configuration maintains maximum underbalance when each zone is perforated. Well conditions, economics, and preferences determine the actual configuration. In some situations, the bottom packer can be run and set on wireline, and then both strings run simultaneously.

Usually, the long string is run first, the packer set and tested, and the VannGun® assemblies fired. After cleanup, a plug is set in the packer, the tubing pulled, and the dual packer and string run, set, and tested before perforating the upper zone.



Dual Completion

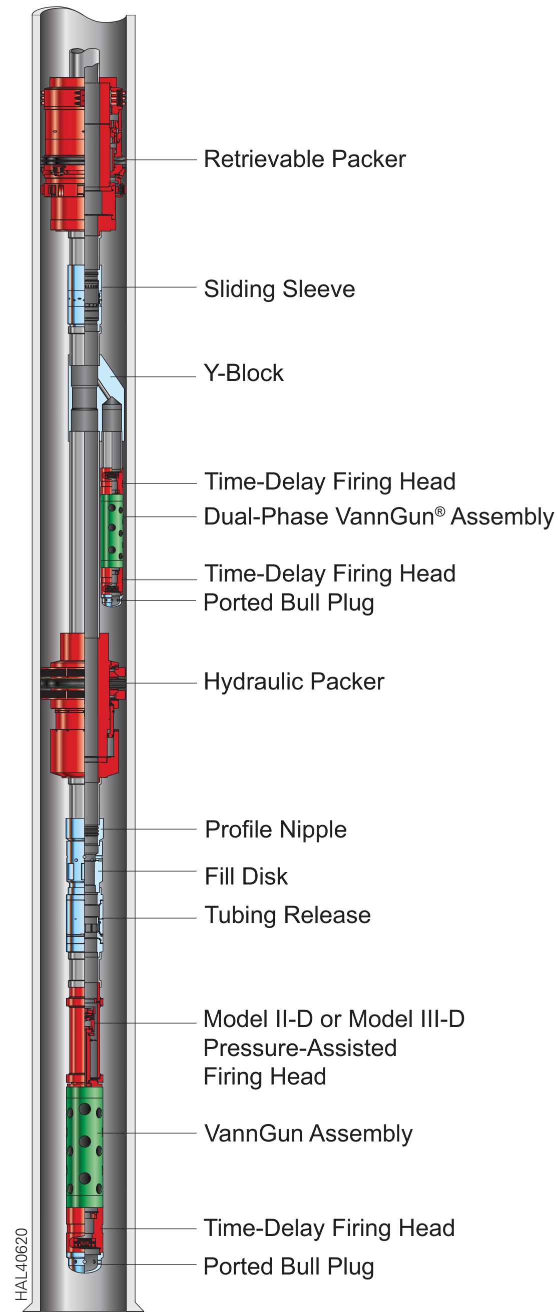
Dual String with Y-Block

The Halliburton Y-block provides the flexibility to perforate widely separated intervals without the cost of gun spacers and long detonating cord runs. Drilling fluids in the short string are displaced by lighter fluids or nitrogen to provide underbalance.

Halliburton Y-Block

Single-String Selective Completion

Combining the Vann™ Y-block with Halliburton sliding sleeves allows multiple zones to be perforated, tested, and selectively produced through a single string. While the diagram shows a typical completion, the tools can be used to complete multiple zones.

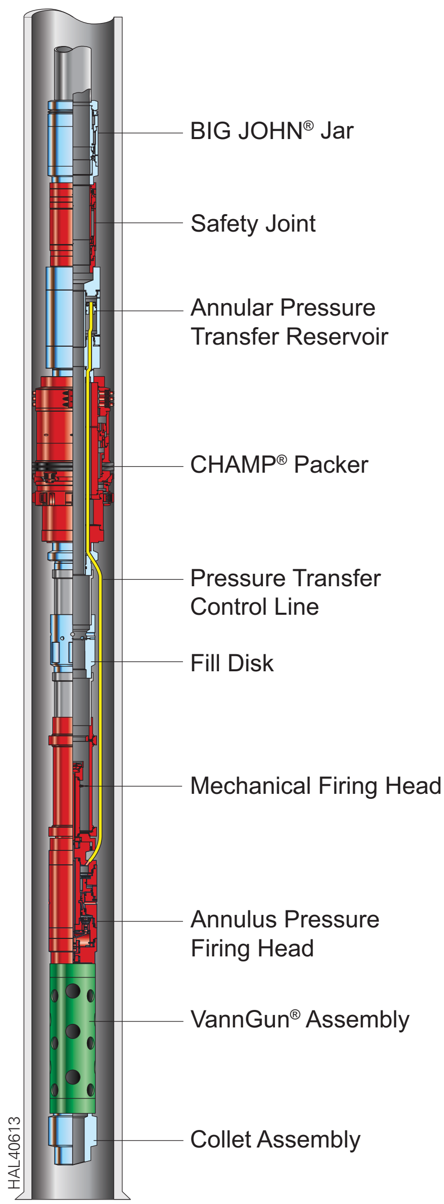


Single-String Selective Completions

Annulus-Fired Systems

Annulus Pressure Firer-Control Line

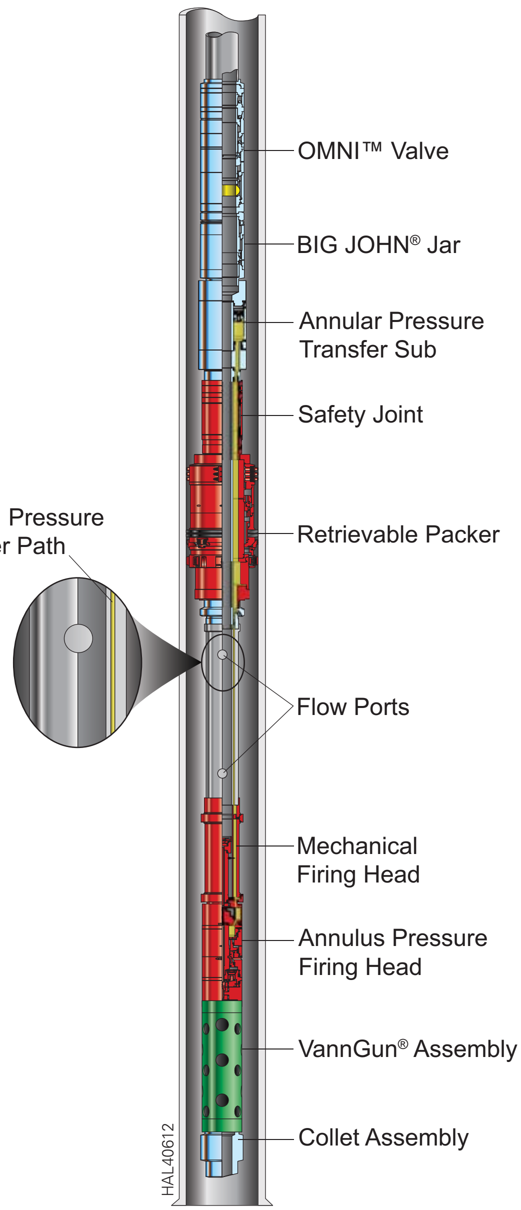
This string maximizes underbalance pressures — ideal for situations when nitrogen is unavailable or too costly. Tubing runs in dry or with a minimal fluid pad. Annulus pressure firer-control line (APF-C) tools enable firing of the guns without pressuring tubing — maintaining maximum underbalance.



Annulus Pressure Firer-Control Line (APF-C)

Slimhole Annulus Pressure Firer-Internal Control

The operation of the slimhole annulus pressure firer-internal control (APF-IC) system depends on the transfer of annular pressure through the packer down to the APF-IC firing head. This is accomplished through the use of concentric tubing, which eliminates the need for external control line.

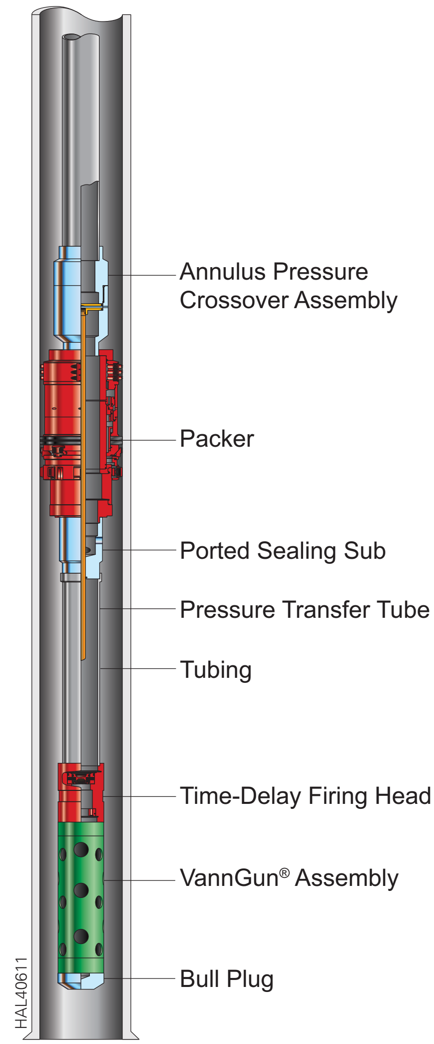


Slimhole Annulus Pressure Firer-Internal Control (APF-IC)

Annulus Pressure Crossover Assembly

The annulus pressure crossover assembly (APCA) allows the use of annulus pressure to actuate any one of several firing heads. This assembly is compatible with retrievable packers of all types and sizes.

The APCA creates a pressure chamber above the firing head that is equalized with the pressure in the casing annulus. Once the packer is set, the pressure on the annulus can be increased to actuate a pressure-actuated firing head. The pressures in the annulus and the tubing can also be manipulated to create the differential pressure necessary to actuate a differential-type firing head.



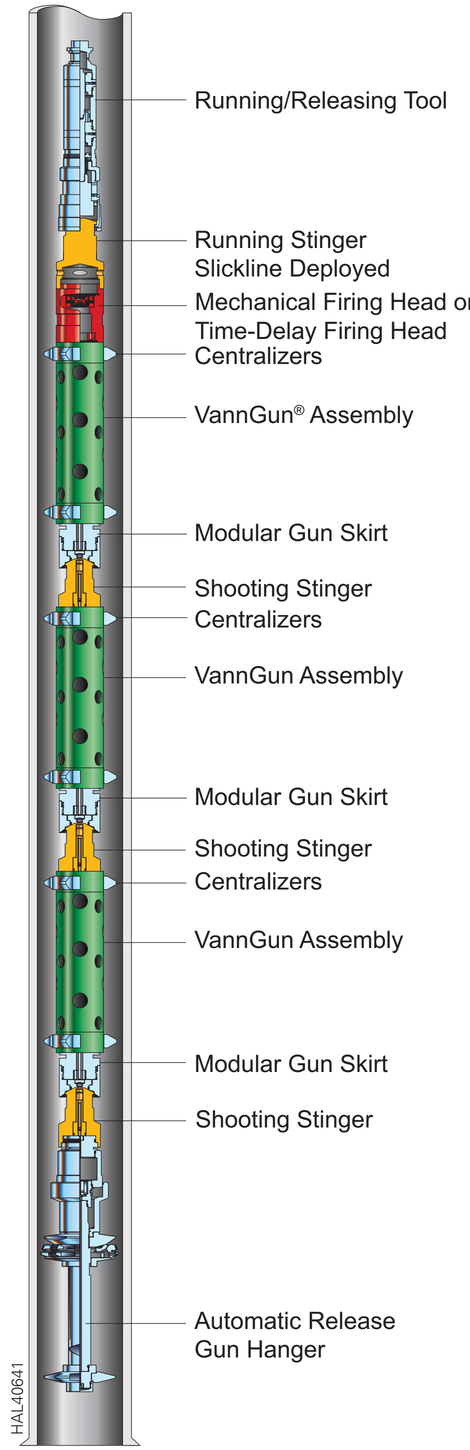
Annulus Pressure Crossover Assembly

Modular Gun System

The Halliburton modular gun system brings tubing-conveyed perforating advantages to monobore completions — without creating flow restrictions.

The system also eliminates the need for — and the cost of — tubing between the guns and packer in conventional completions.

The automatic-release gun hanger (ARGH) is set, then VannGun® assemblies with modular gun connectors attached are run in on wireline and stacked. Surface equipment is installed and tested. Then, the guns are fired — causing the ARGH to release and fall into the rathole with all perforating tools, or the expended guns can be removed on wireline.

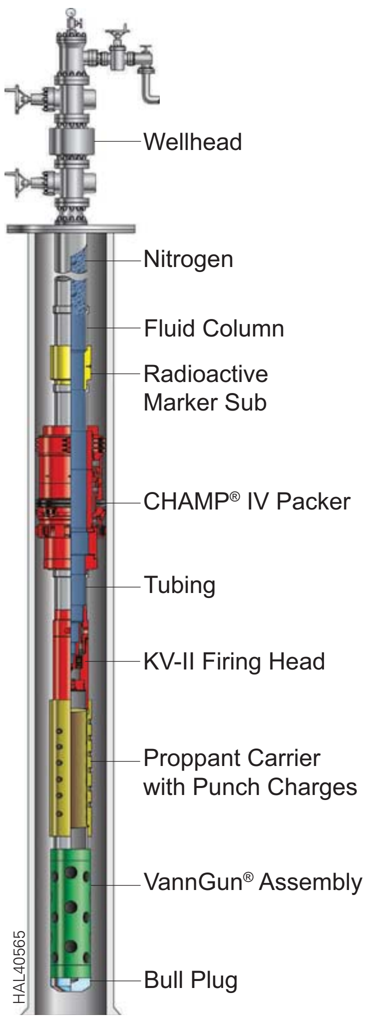


Modular Gun System

Enhanced Overbalanced Perforating Solutions

Powr*Perf™ Process

The Powr*Perf™ process uses bauxite to mechanically scour perforations, aiding in damage removal. The system also produces information that can improve stimulation treatment design.



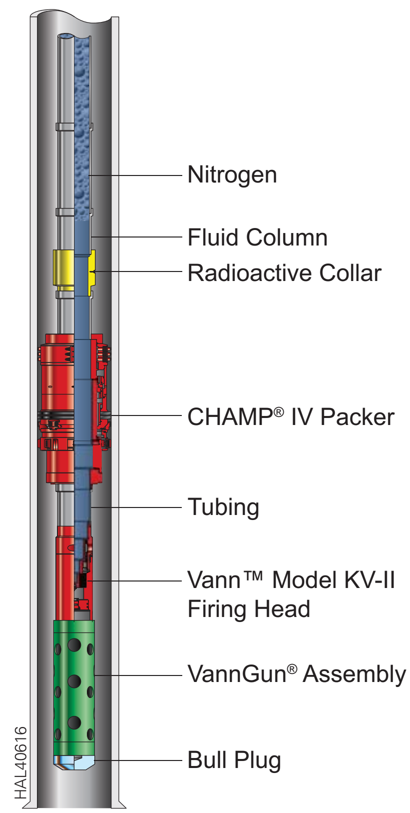
*Powr*Perf™ Process*

Powr*Perf™ is a trademark of Marathon Oil Company and licensed by Halliburton.

PerfStim™ System

The PerfStim™ system, an extreme overbalanced (EOB) perforating system, not only produces cleaner perforations in low-pressure formations, it also initiates fractures in the formation, reducing stimulation costs.

The EOB — a pressure gradient of at least 1.4 psi/ft (31 Kpa/m) — creates a high-pressure surge at the instant of perforation, driving a fluid spear into the formation. The spear removes crush-zone damage and initiates fractures in the formation, often creating negative skin factors.



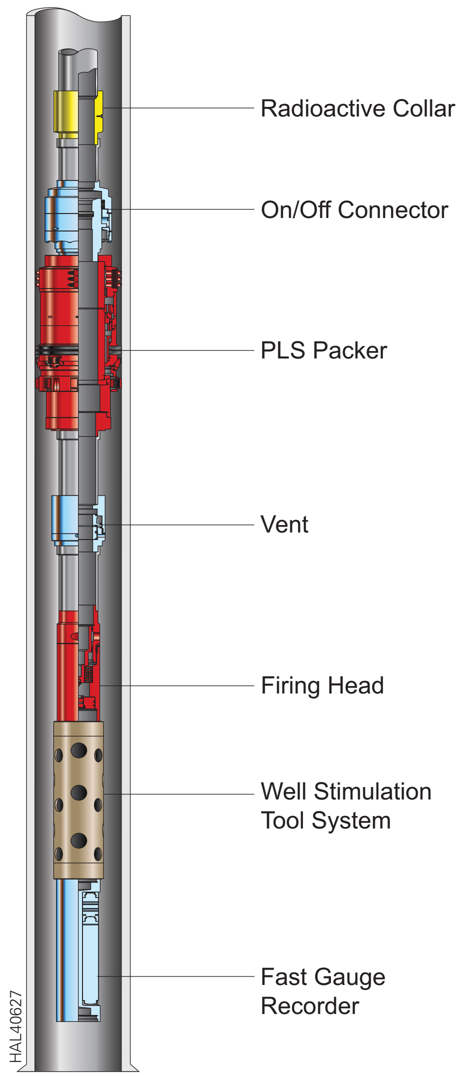
PerfStim™ System

PerfStim™ is a patent and trademark of Oryx Energy Company and licensed by Halliburton.

Well Stimulation Tool

The well stimulation tool creates a surge of high-pressure gas at the formation face that cleans up damage, initiates fractures, and removes emulsion blocks from existing perforations. Typical applications include stimulating thin zones with nearby gas or water and selectively stimulating multiple zones without running and setting packers for each zone.

The service can be used in cased holes after perforations have been shot or in open hole. The tool runs on standard Halliburton tubing-conveyed perforating strings or wireline.

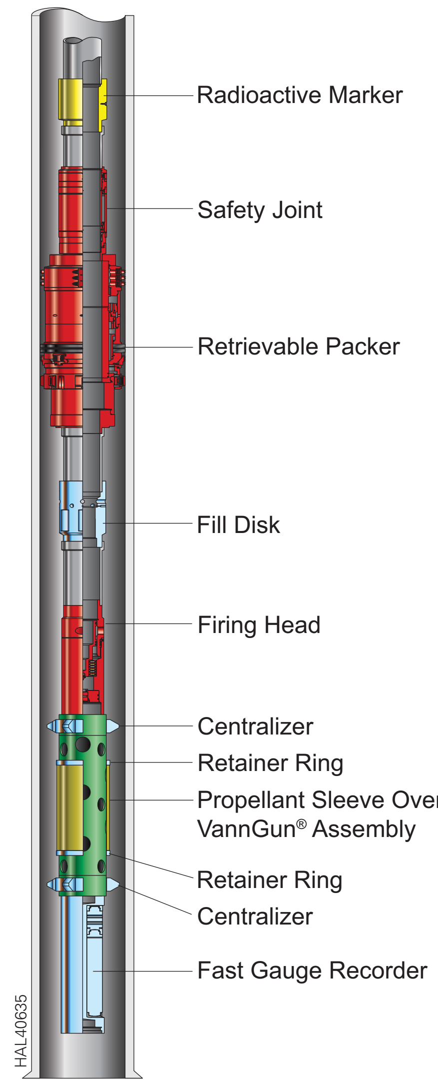


Well Stimulation Tool

StimGun™ Tool

The StimGun™ tool generates large volumes of high-pressure gas the instant the guns fire. The gas enters the perforations, breaks through crush-zone damage, and enters and fractures the formation. The system produces cleaner perforations, lowers hydraulic fracturing costs, and improves production.

Slipping a propellant sleeve over a conventional VannGun® assembly before it is run creates the StimGun tool. The pressure and shock wave created when the perforating charges fire ignites the sleeve.



StimGun™ Tool

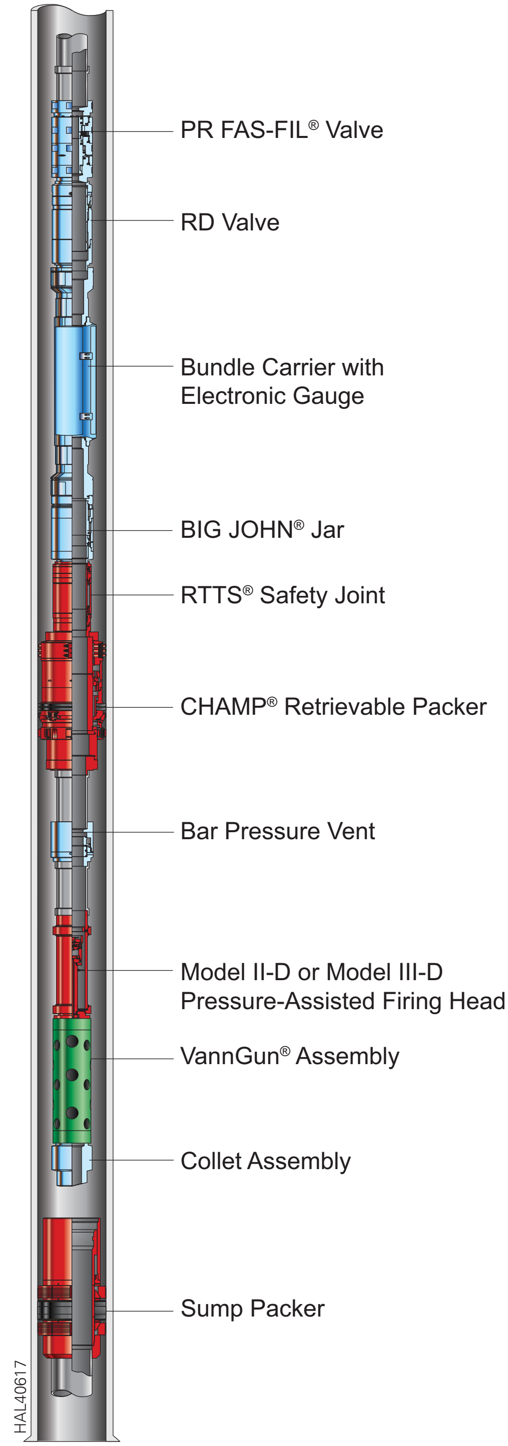
StimGun™ is a trademark of Marathon Oil Company.

Sand Control Solutions

Shoot and Pull

Halliburton shoot and pull controls underbalance, while limiting sand production and surging perforations.

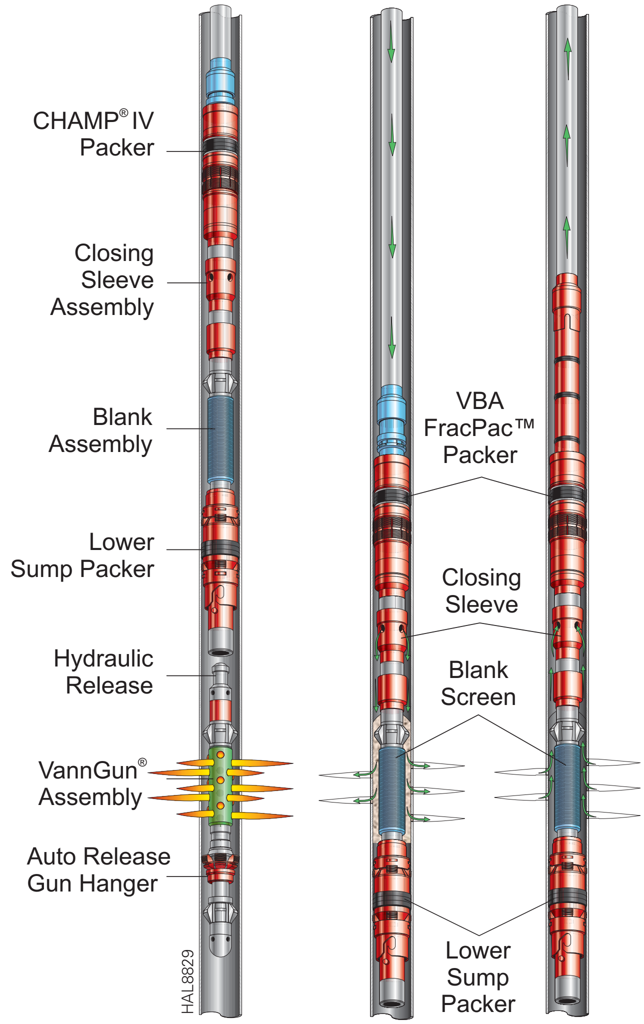
After perforating, the string is pulled from the well. The Halliburton annulus pressure-operated OMNI™ valve provides for reversing out produced fluids, spotting a fluid-loss pill across the perforated interval, and circulating the kill fluid without requiring tubing movement.



Shoot and Pull

STPP™-GH Single-Trip Perf/Pack System

The STPP™-GH single-trip perf/pack system provides cost-effective, single run completions that combine perforating and frac packing into a single string. With the STPP-GH system, the guns are detached from the packer before perforating to eliminate impact loads on the packer. After perforating, the auto-release gun hanger mechanism allows the expended guns to drop to the bottom of the well. After the well is perforated, the CHAMP® IV packer is lowered and set below the perforations to complete frac-pack operations. The STPP-GH system provides increased safety and economic benefits by combining multiple operations in a single pipe trip. The single-trip system can minimize completion fluid loss, reduce rig costs, and reduce well control risks.



STPP™-GH Single-Trip Perf/Pack System

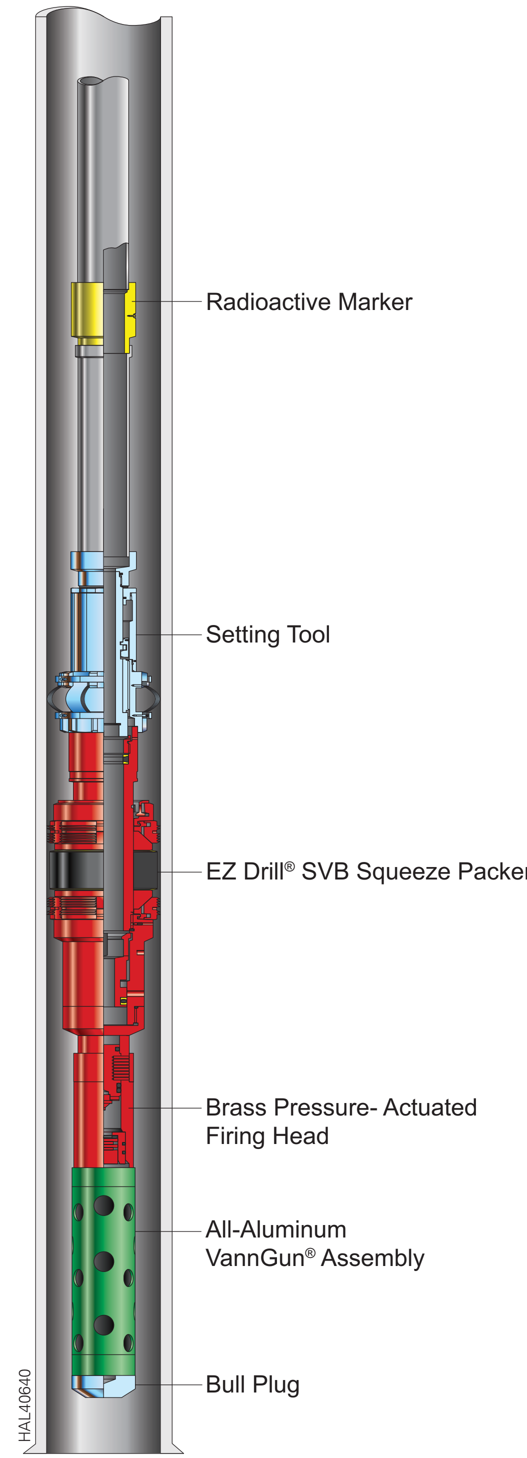
Perforate and Squeeze

Single-Trip Block Squeeze DrillGun™ System

The unique Halliburton all-aluminum VannGun® system and brass firing head significantly reduce the costs of block squeeze procedures — particularly in highly deviated wells.

The packer is set and perforations shot in the same trip. After pulling the work string and pumping the squeeze job, the packer and aluminum gun are drilled out.

The system provides another substantial savings. The well is controlled without replacing clear fluids with drilling mud while perforating, thus eliminating mud disposal problems.



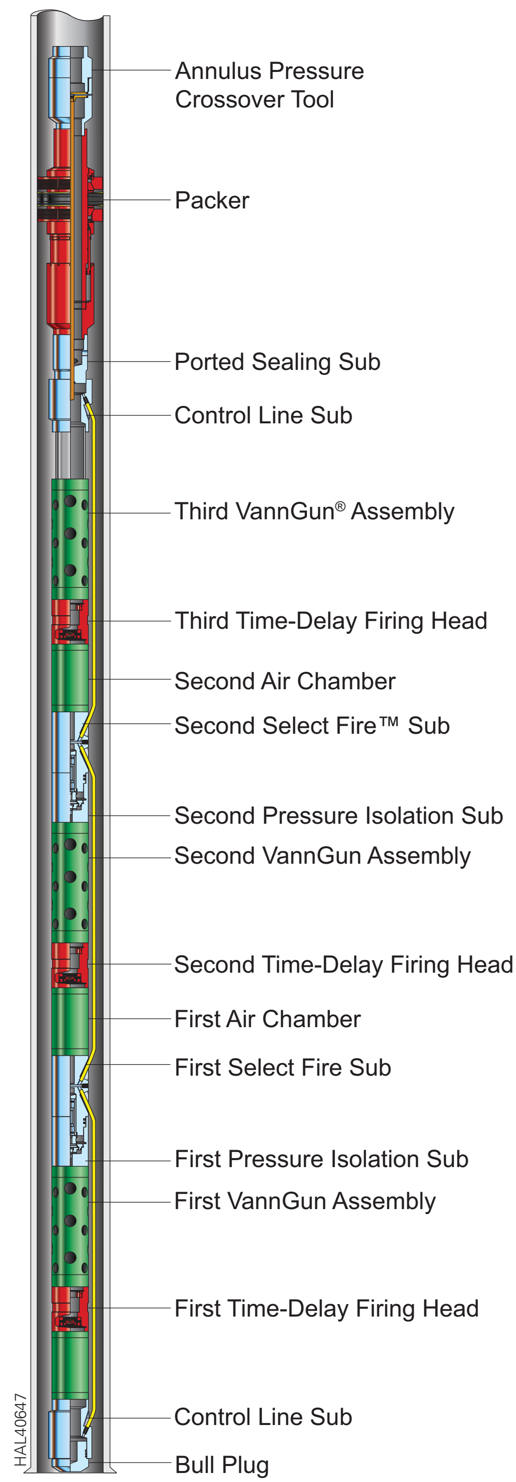
Single-Trip Block Squeeze DrillGun™ System

Select Fire™ Systems

The Halliburton unique Select Fire™ system provides unprecedented flexibility. Guns can be configured to fire sequentially top down or bottom up — or in any order. Zones can be isolated for perforating and testing or flow from each new set of perforations can be commingled with flow from earlier perforations. The system provides the following benefits:

- Eliminates the need to kill the well
- Eliminates pulling and rerunning the test string after firing each set of guns
- Eliminates the need to reestablish well flow

The sequence on the following page illustrates perforating and testing each zone sequentially from the bottom up and commingling flow from the zones. (If conditions require isolating each zone, the packer would be moved and reset after each zone is shot and tested.)

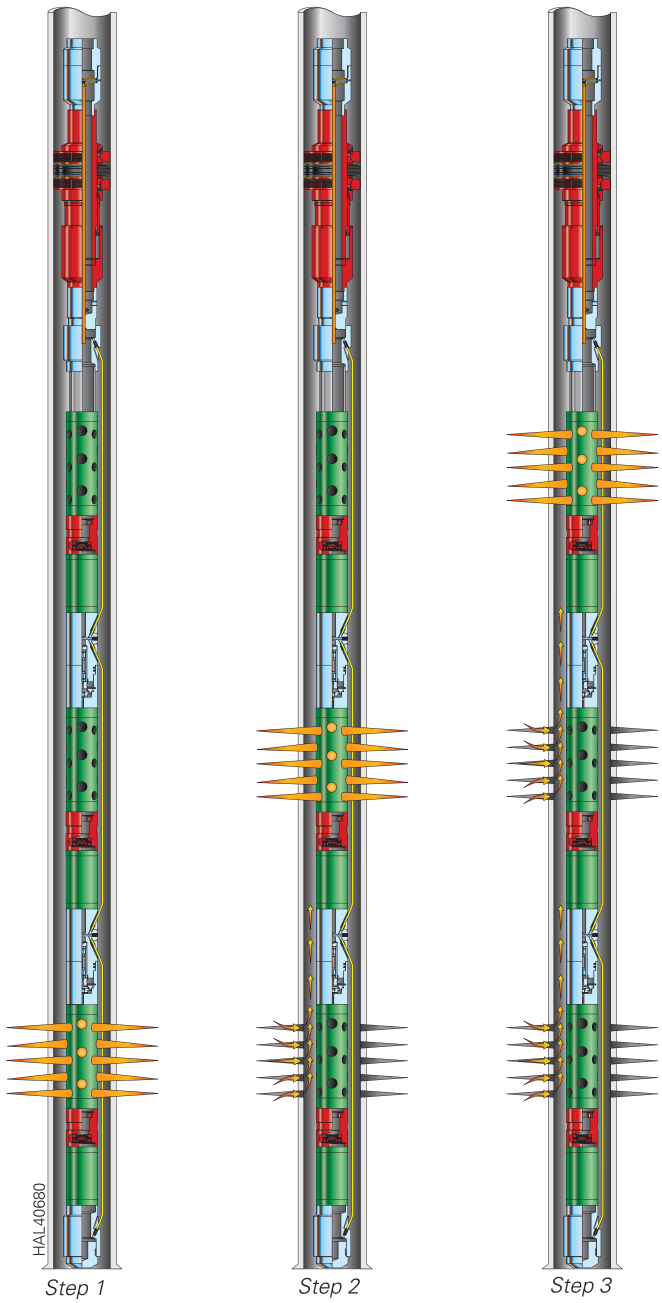


Select Fire™ Systems

Step 1: Annulus pressure from above the packer enters the crossover tool and is applied to the first (bottom) time-delay firing head. The first Select Fire™ sub prevents pressure from reaching the second firing head. The time delay provides time to bleed off pressure. When the guns detonate, the firing train continues to the Select Fire™ sub. The sub fires, creating a path to the second firing head. The zone is tested.

Step 2: Annulus pressure is reapplied and travels to the second time-delay firing head. The first pressure isolation sub prevents pressure from venting through the first set of perforations. Pressure is released, the gun fires, and the second Select Fire sub fires and opens a path to the third gun. Production from the second zone is commingled with pressure from the first zone for testing.

Step 3: Pressure applied to the annulus passes through the annulus pressure crossover and down the control line to the third time-delay firing head. The second pressure isolation sub prevents pressure from venting through perforations in the first and second zones. Pressure is released, the guns fire, and flow from all three are commingled for testing.

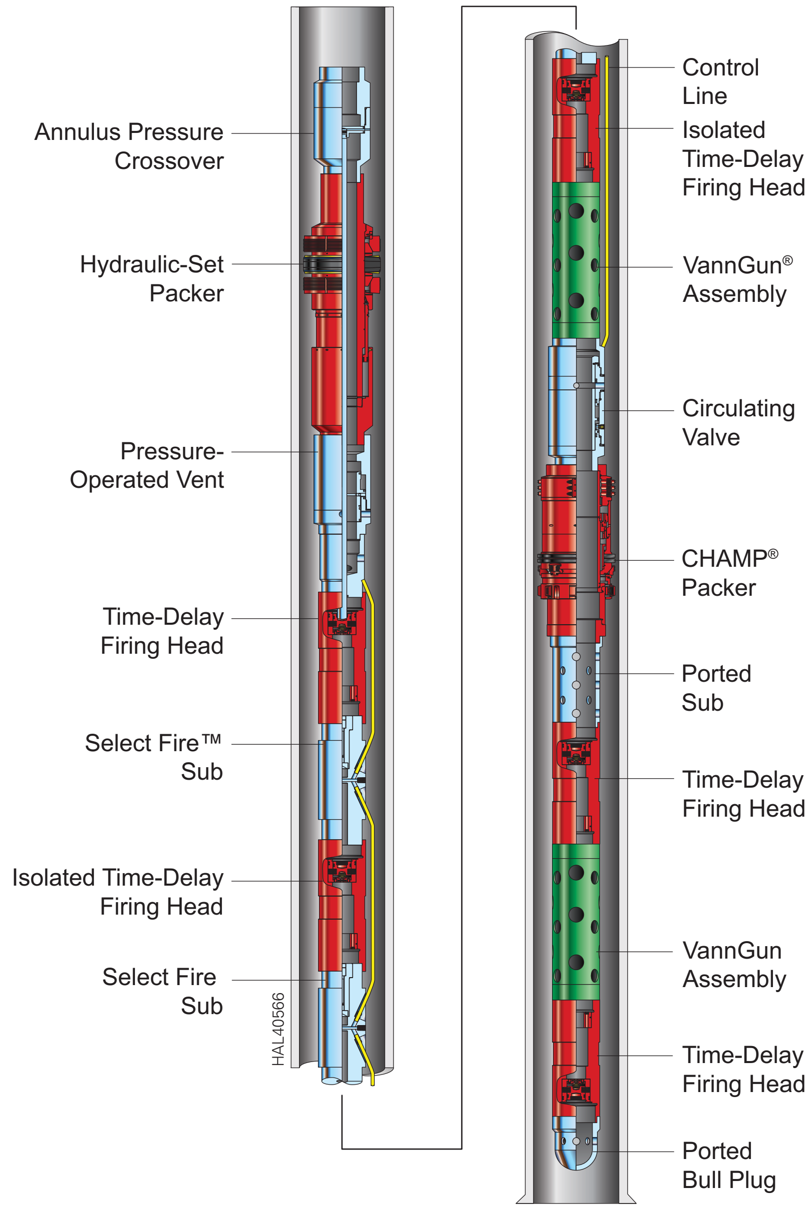


Dual Drillstem Test System

Incorporating components of the Halliburton innovative Select Fire™ system, this string isolates each zone for perforating and testing.

The CHAMP® retrievable packer sets mechanically while tubing pressure sets the top packer. After setting packers, pressuring up on the tubing opens the pressure-operated vent to provide communication below the lower packer. Additional pressure fires the lower set of guns.

After testing, annulus pressure closes the Vann™ circulating valve, isolating the lower zone. Produced fluid is reversed out using the OMNI™ valve. Increasing and releasing annulus pressure fires the upper guns.



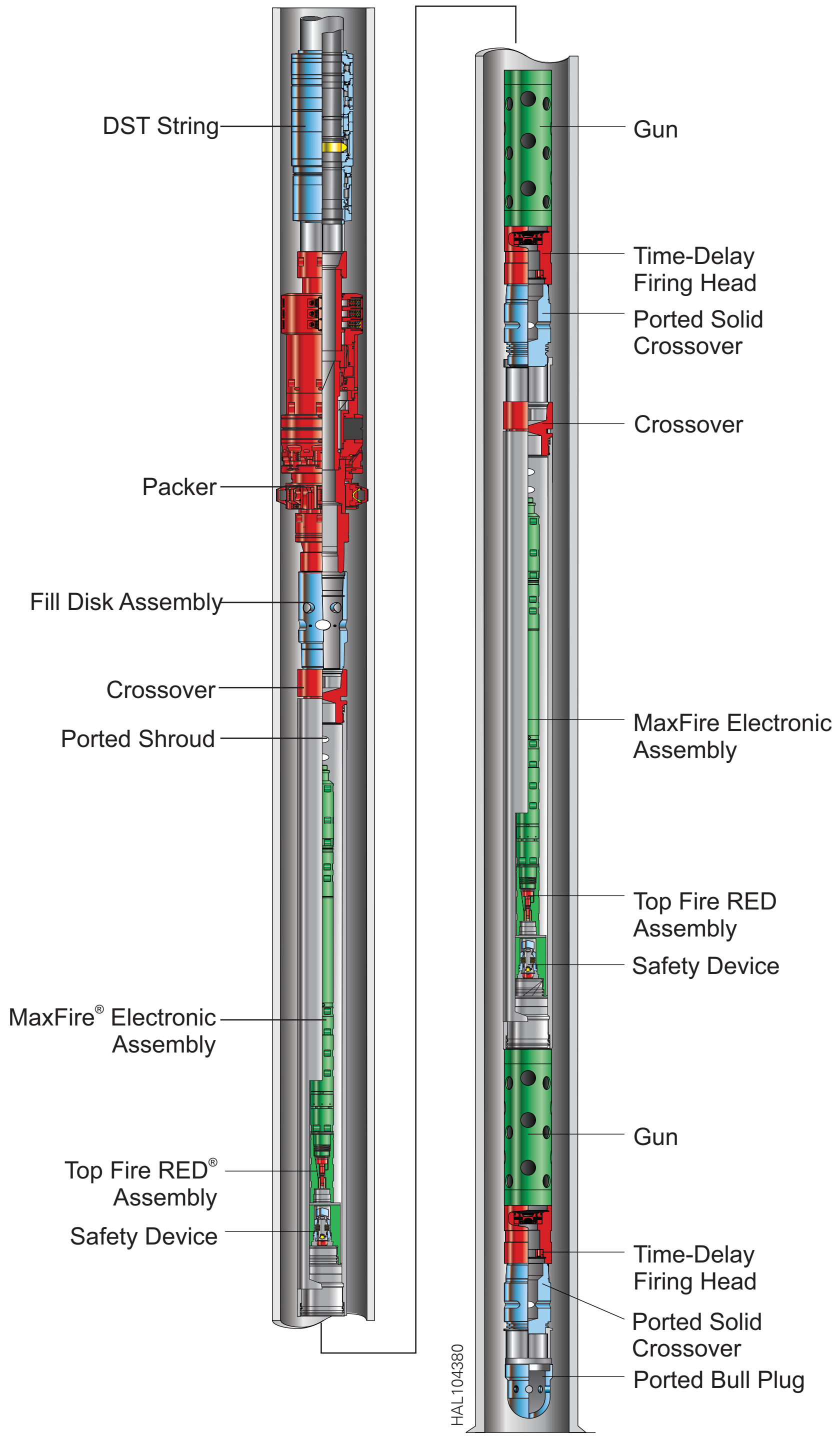
Dual Drillstem Test System

Dual Drillstem Test System with Electronic Firing Heads

The Halliburton unique electronic firing heads provide unprecedented flexibility during drillstem test (DST) operations. Guns can be configured to fire sequentially top down or bottom up — or in any order. Zones can then be flow commingled.

Benefits

- Provides economic value by allowing multizone testing with one DST string
- Eliminates the need to kill the well
- Eliminates pulling and rerunning the test string after firing each set of guns
- Eliminates the need to reestablish well flow



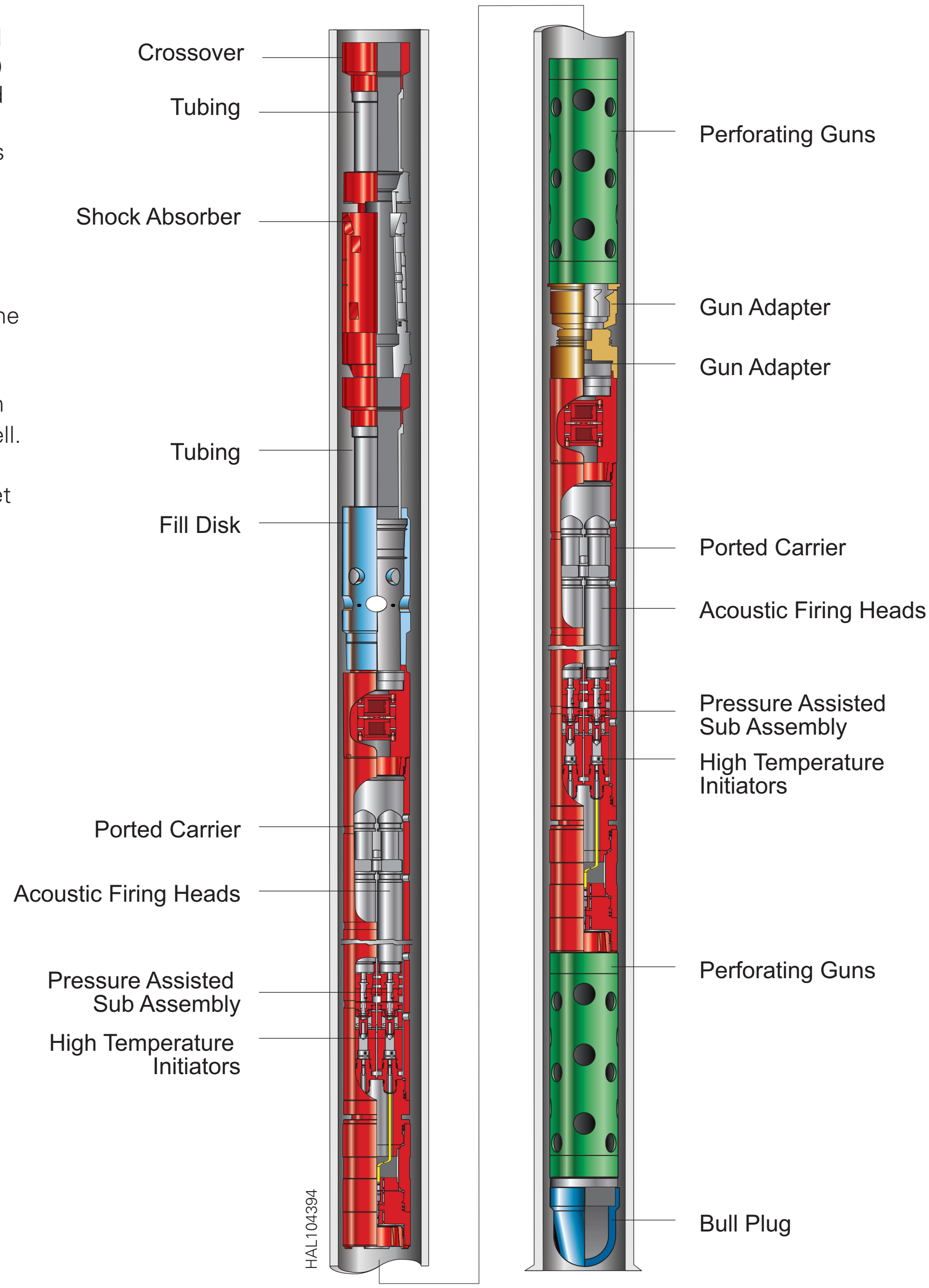
Commingled DST Operation with Dual Electronic Firing Heads

Dual Drillstem Test System with Acoustic Firing Heads

The Halliburton unique electronic firing heads provide unprecedented flexibility during drillstem test (DST) operations. Guns can be configured to fire sequentially top down or bottom up — or in any order. Zones can then be flow commingled.

Benefits

- Provides economic value by allowing multizone testing with one DST string
- Eliminates the need to apply pressure for firing head activation
- Eliminates the need to kill the well.
- Eliminates pulling and rerunning the test string after firing each set of guns
- Eliminates the need to reestablish well flow



Commingled DST Operation with Dual Acoustic Firing Heads

Live Well Perforating

Ratchet Connector

The innovative design behind the Halliburton ratchet connector significantly reduces the costs of using perforating techniques in live wells.

Benefits

- Delivers the advantages of live well perforating with no costly kill fluids, no kill fluid-caused formation damage, formation back-surge pressures clean perforations
- Connection time of approximately 20 minutes or less per VannGun® assembly — a fraction of the time required by other systems
- Can run tools with a Halliburton hydraulic workover (HWO) unit, freeing the drilling rig
- Uses standard blowout preventer (BOP) stacks with no need for special ram assemblies
- Maintains positive pressure control — does not compromise pressure control systems engineered into Halliburton HWO units — because at least one BOP ram closes during every running in and retrieval step
- Helps eliminate the risk of damaging producing zones with kill fluids when reperforating producing wells

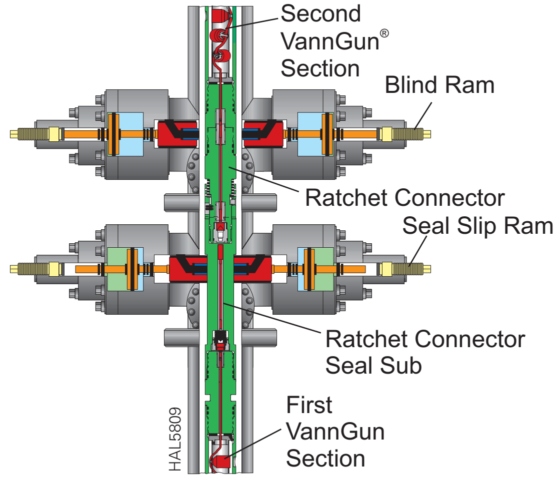
The following steps outline what occurs when VannGun assemblies are run under pressure with the Halliburton ratchet connector.

Step 1: Closing the seal slip rams around the ratchet connector seal sub hangs the first VannGun assembly section in the BOP stack. The blind rams are closed.

Step 2: The second VannGun assembly section, with the ratchet section of the ratchet connector attached, is stripped through the open stripper rams (not shown).

Step 3: Once the gun section passes, the stripper rams are closed and the blind ram opened. The second gun section is lowered until the two ratchet connector sections meet. Turning to the left activates the ratchet, connecting the two sections.

Step 4: The guns are lowered until the ratchet connector seal sub atop the second VannGun assembly section is opposite the seal ram. After closing the ram, turning to the right releases the running tool. The running tool is raised above the blind ram, which is then closed, and the stripper ram opened. The next VannGun assembly section is attached and the procedure repeated. The procedure is reversed during retrieval of the perforating assembly.



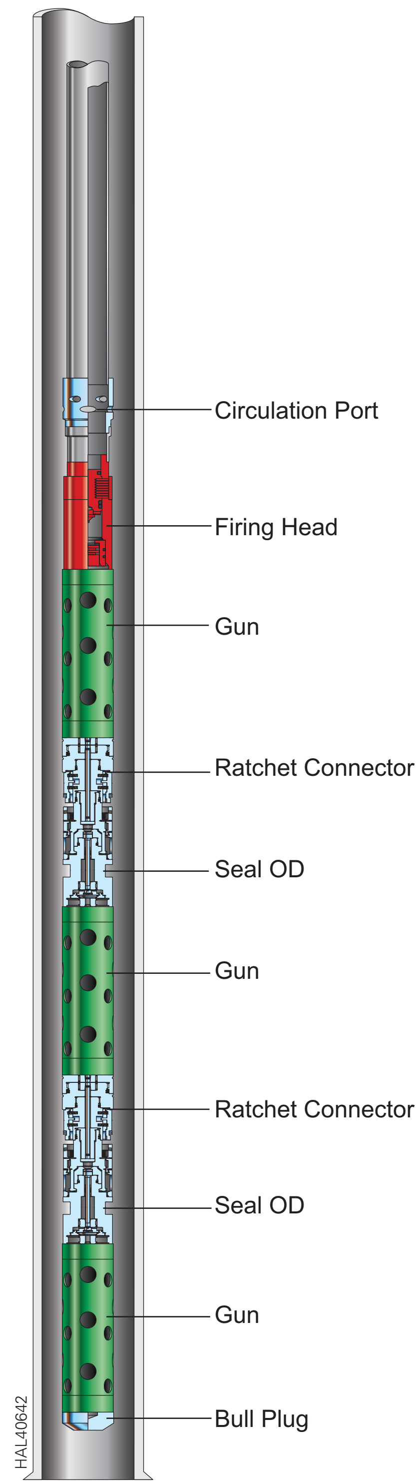
Ratchet Connectors

Operation

The ratchet connector connects with left-hand rotation. Shear pins prevent disconnecting when rotating to the right.

The connection sequence begins with one VannGun® assembly hung in the blowout preventer (BOP) stack with the seal slip rams and blind rams closed. The second VannGun assembly, with the ratchet made up at the bottom, is stripped through the open stripper ram. Once the connector and VannGun assemblies are past the stripper rams, they are closed and the blind rams opened. When the tool components meet, rotating to the left activates the ratchet, joining the two VannGun assembly sections. The string is lowered until the seal area of the connector is next to the seal/slip ram area. The ram is closed. Left-hand rotation shears the brass pins and allows the tool to disconnect. The running tool is lifted above the blind rams, which are then closed.

To retrieve the perforating assembly, the connection sequence is reversed.



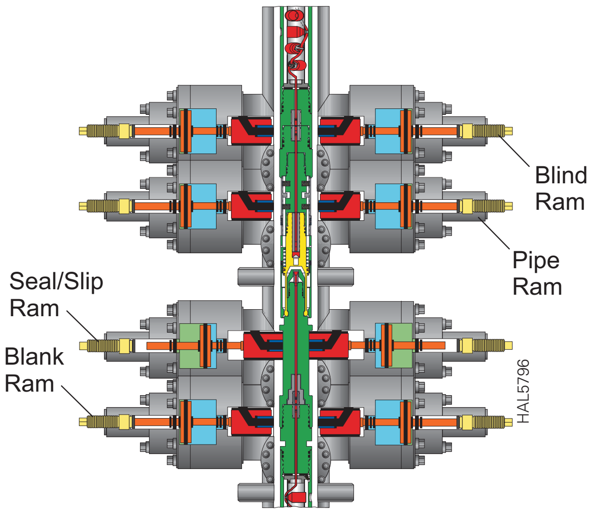
Ratchet Connector Operation

AutoLatch™ Release Gun Connector

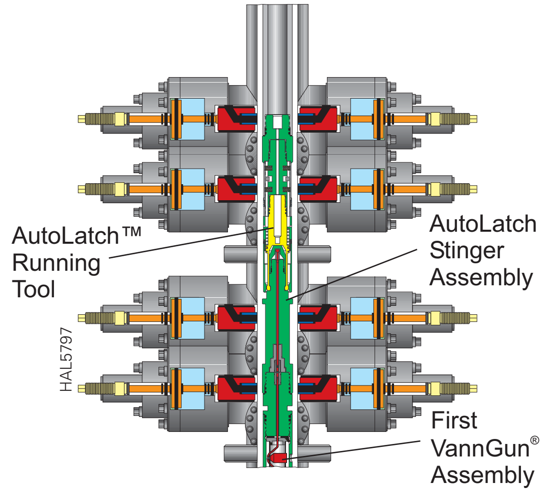
The Halliburton AutoLatch™ release gun connector literally latches VannGun® assembly sections together in the blowout preventer (BOP) stack as they run in. No rotation is required to connect the guns; therefore, guns can be run and retrieved on coiled tubing or even wireline. Connections make up in a fraction of the time required by conventional snubbing systems.

Benefits

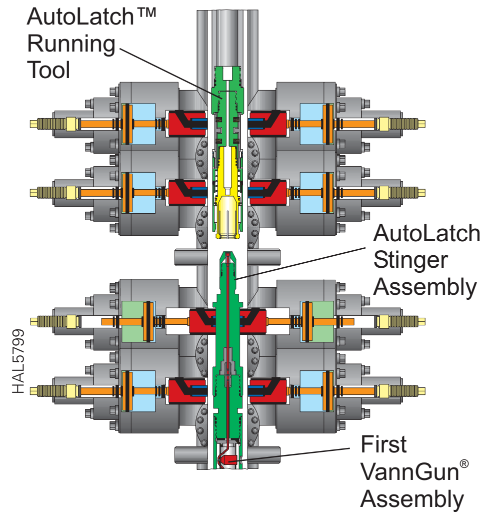
- Delivers the advantages of live well perforating with no kill fluids, no kill fluid-caused formation damage, formation back-surge pressures clean perforations — without the cost of a drilling rig
- Can run and retrieve guns using Halliburton coiled tubing or wireline units
- Uses standard BOP stacks — no special ram assemblies required
- Maintains positive pressure control — at least one BOP ram closed during every running in and retrieval step
- Perforates new zones in producing wells without kill fluids, eliminating the risk of damaging currently producing zones



AutoLatch™ Release Gun Connector

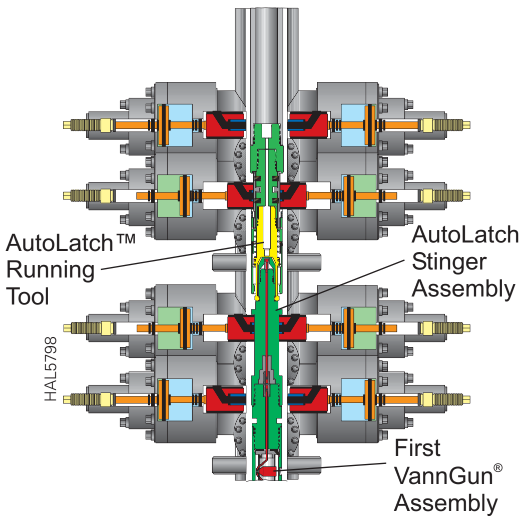


Each VannGun® assembly section is connected to the AutoLatch™ running tool on the surface and run into the BOP through the stripper rams (not shown).

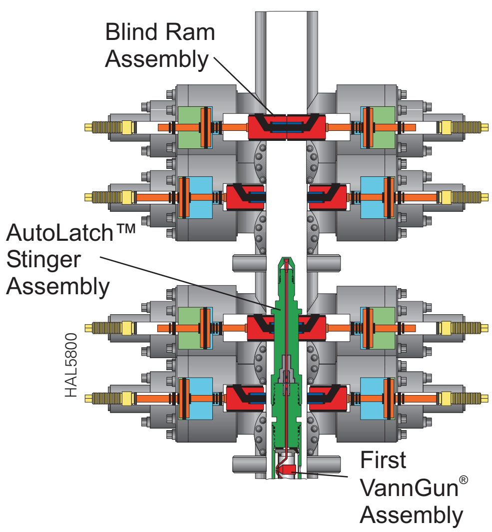


The AutoLatch running tool is pulled out of the BOP stack, leaving the stinger and VannGun assembly section suspended by the seal/slip rams.

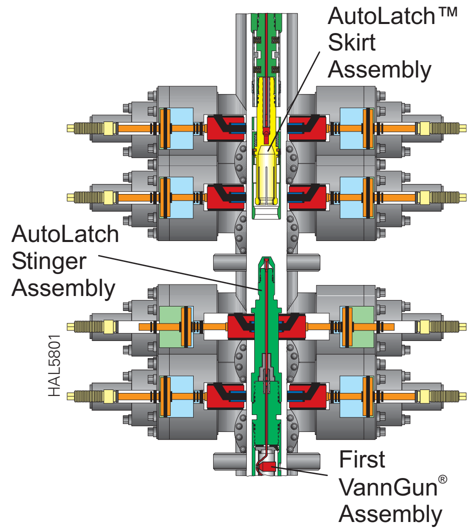
HALLIBURTON | Wireline & Perforating



The assembly is lowered until the seal area of the AutoLatch™ stinger is opposite the seal/slip rams. The seal/slip rams are closed to suspend the first VannGun® assembly section and stinger assembly in the blowout preventer (BOP) stack. Closing the pipe rams compresses stop-release pads on the AutoLatch running tool, unlatching the tool.



Once the AutoLatch running tool is above the blind rams, the rams are closed.



The AutoLatch skirt assembly is made up on the bottom of the second VannGun assembly section. The assembly is lowered onto the AutoLatch stinger atop the first VannGun assembly section.

Operation

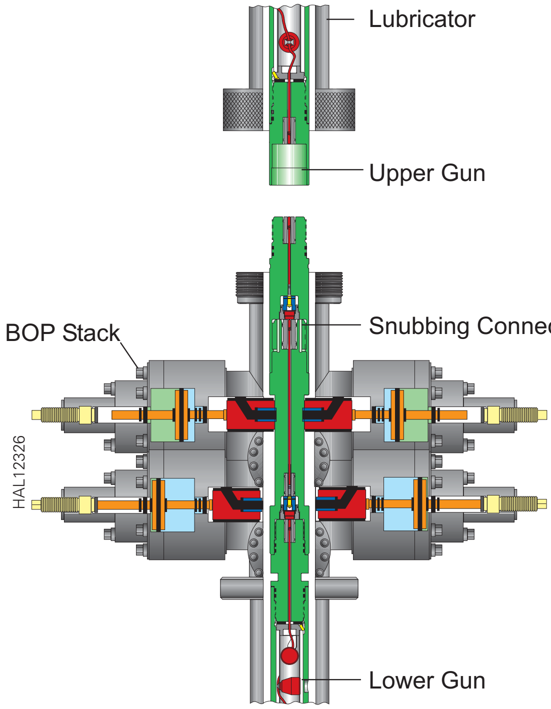
The AutoLatch release gun connector consists mainly of the stinger and latching/releasing assemblies. To operate, the stinger assembly is threaded into the top of the first VannGun assembly section, and the latching/releasing assembly is threaded into the bottom of the second VannGun assembly section.

The first VannGun section is run into the well and set in the seal/slip rams. (There is a seal area on the stinger for the rams.) The running tool is released from the first VannGun assembly section and then pulled from the BOP stack.

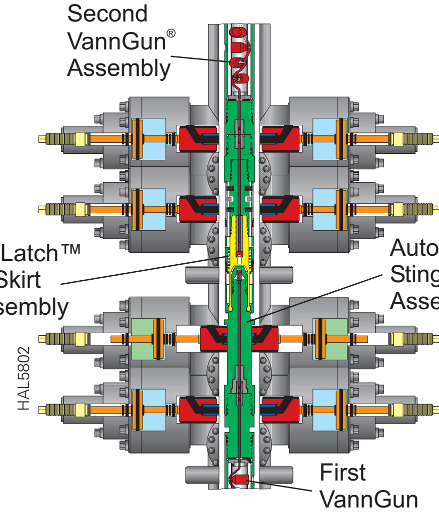
The second VannGun assembly section is then run into the well and set over the stinger. Weight is set down on the latching/releasing assembly to shear the screws and latch the collet fingers onto the stinger. Once the two VannGun assembly sections are latched, the seal/slip rams are opened and the two VannGun assembly sections are lowered into the well until the seal area on the stinger assembly (at the top of the second perforating gun section) is positioned in the seal/slip rams, which are then closed on the stinger. The running tool is released and pulled out of the well.

This procedure is repeated until all VannGun assembly sections are run into the well. Refer to the operating manual for procedures when running and retrieving under pressure, or when using coiled tubing, hydraulic workover, or wireline.

Isolation Subassembly



The isolation subassembly provides the customer the capability to complete or recomplete the well without killing it. The well can be producing before, during, and after the guns are deployed in or out of the well.



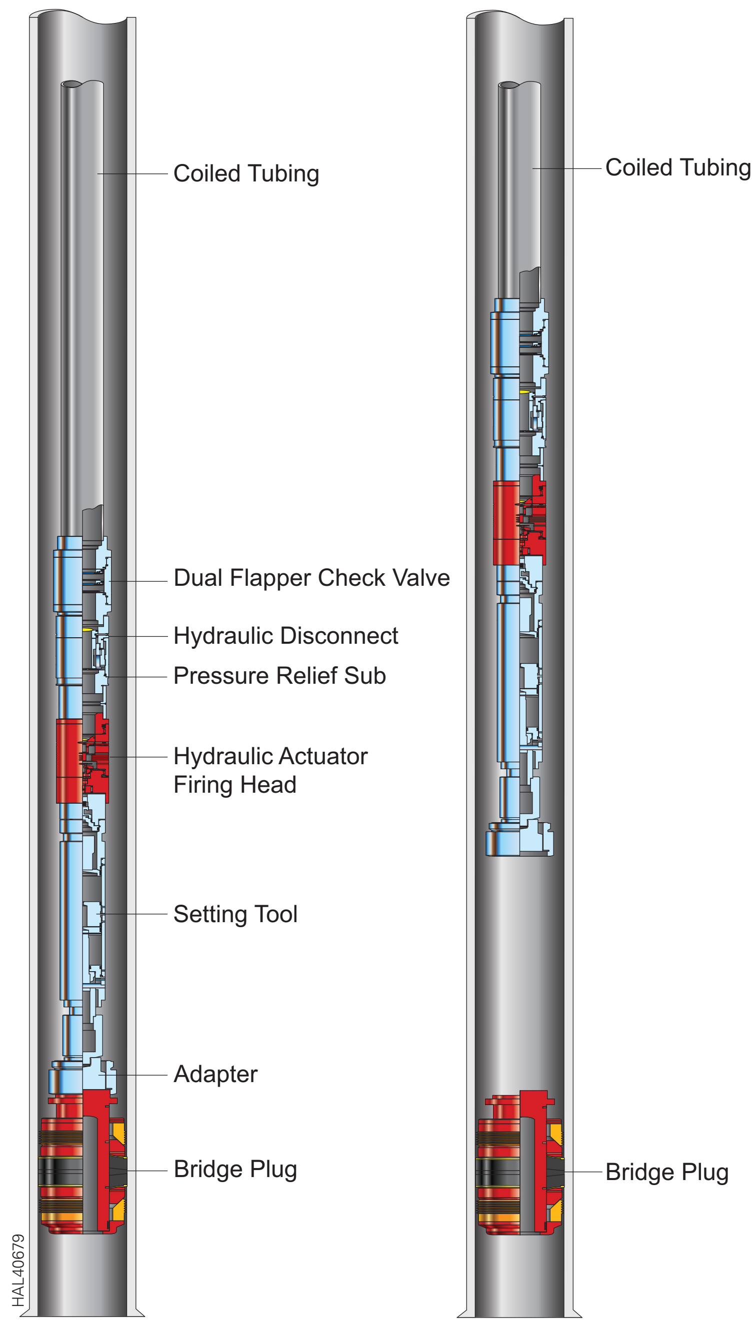
The AutoLatch™ skirt on the second VannGun® assembly section sits down on and latches to the AutoLatch stinger atop the first VannGun assembly section, and the cycle begins again.

Guns are retrieved by reversing running-in procedures.

Coiled Tubing Perforating

Coiled tubing is another method to deploy perforating guns and other tools into a well. The firing mechanisms are hydraulically operated. The firing heads are the ball drop actuator firing head, which is also available with a swivel, and the pressure-actuated firing heads such as time-delay firers (TDFs), Model K, KV-II, etc.

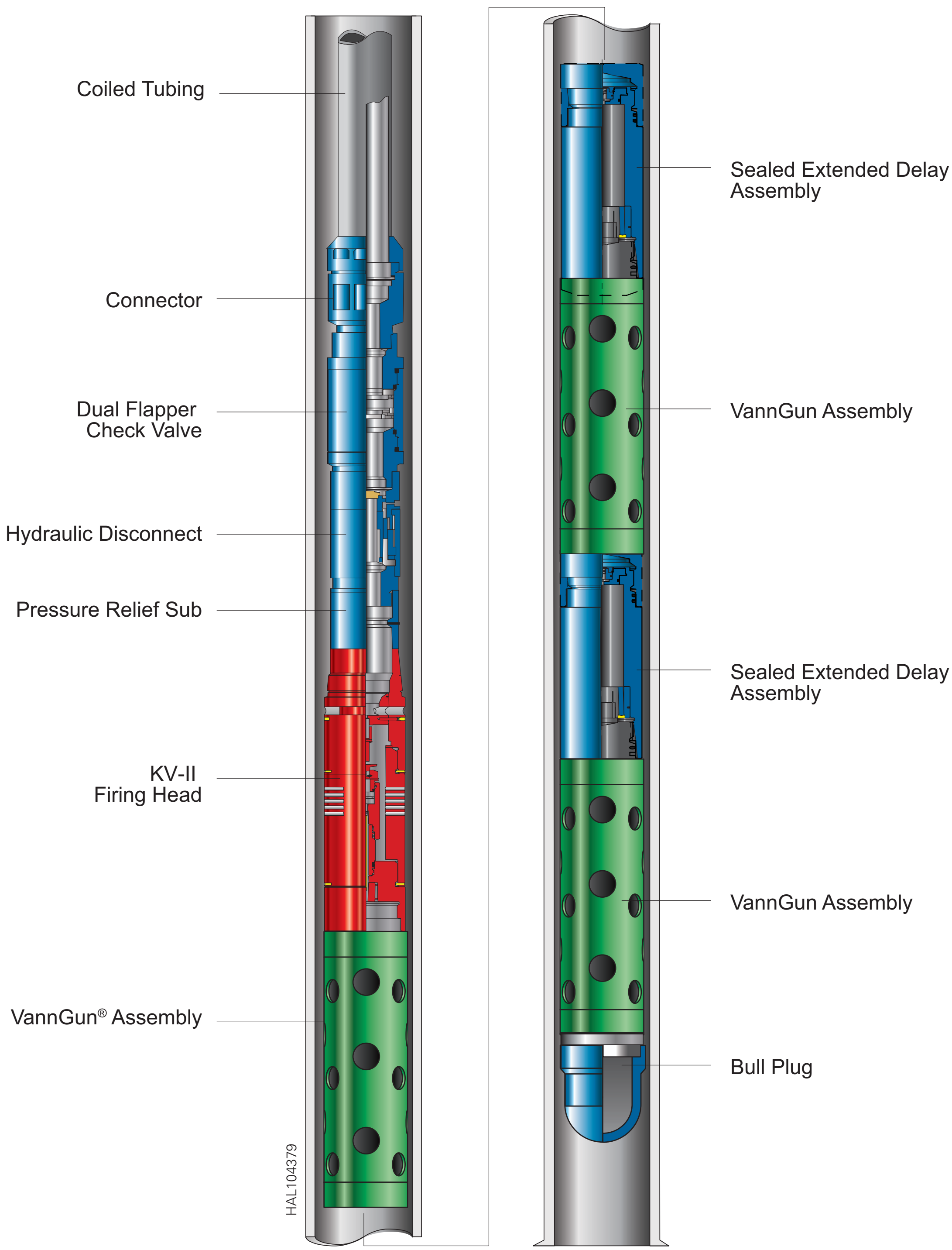
Coiled Tubing-Conveyed Bridge Plug with Pressure Firing Head



Coiled Tubing-Conveyed Bridge Plug with Pressure Firing Head

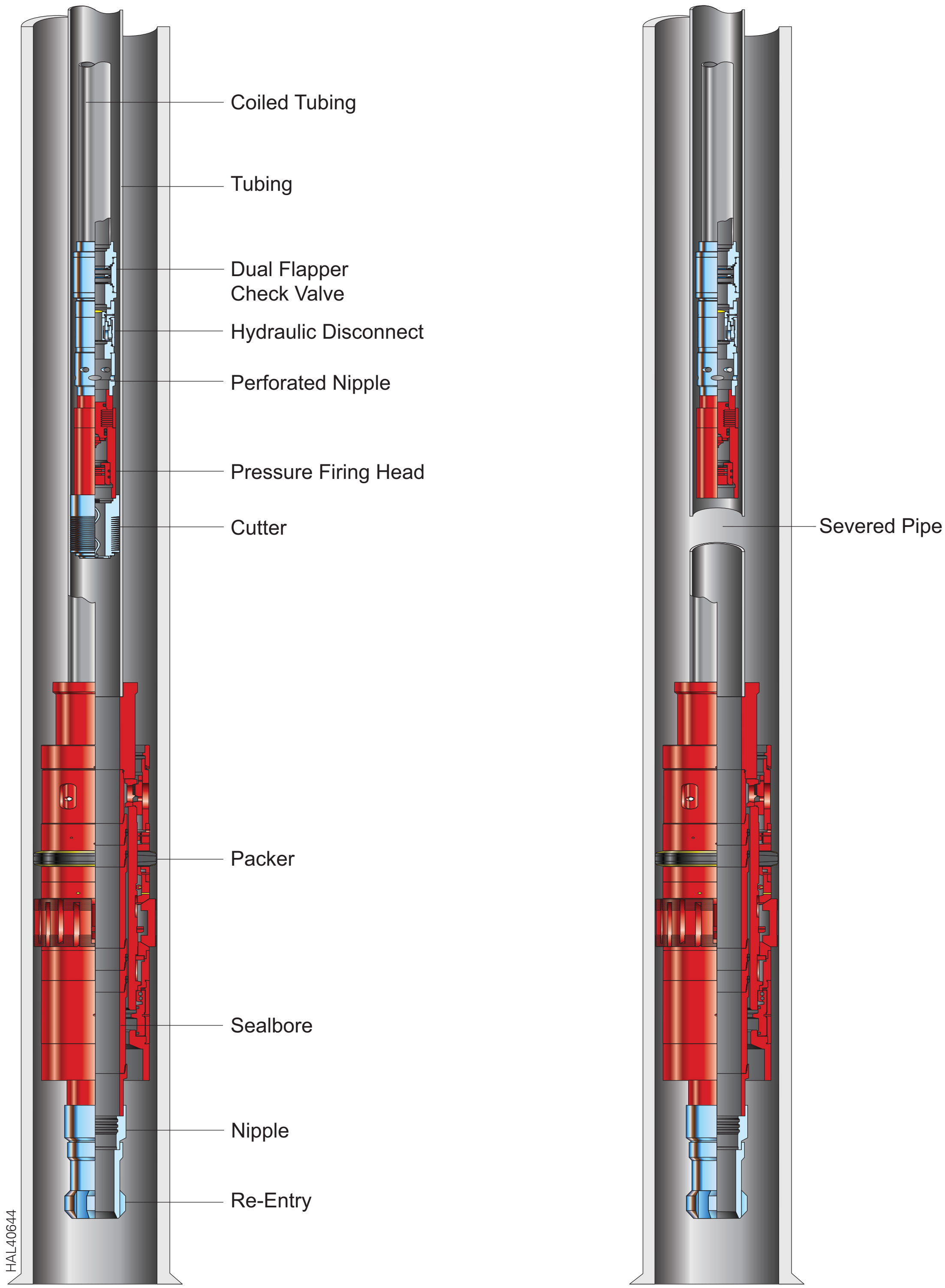
Multizone Perforating with Coiled Tubing

Using the Halliburton MZSP technology, operators can deploy multiple guns, with our reliable line of firing heads and extended delay assemblies, into a well and perforate the lowermost zone and additional zones automatically at ±6-minute intervals, as the guns are repositioned.



Multizone Perforating with Coiled Tubing

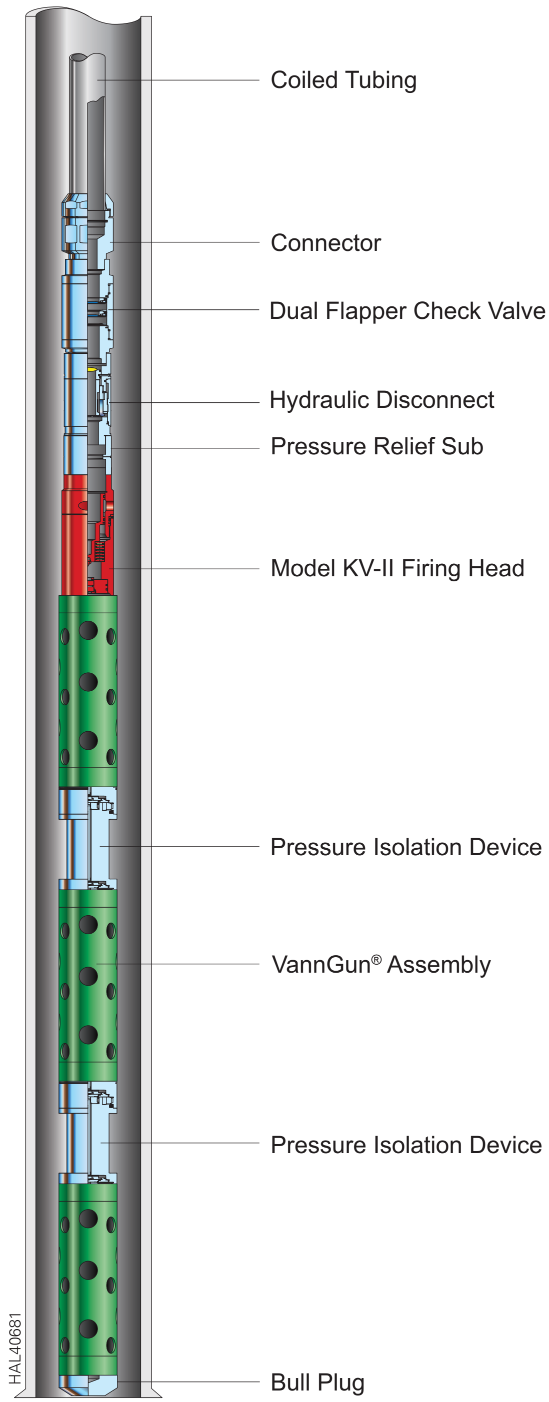
Coiled Tubing-Conveyed Pipe Cutter with Pressure Firing Head



Coiled Tubing-Conveyed Pipe Cutter with Pressure Firing Head

Coiled Tubing-Conveyed Perforating with Pressure Isolation

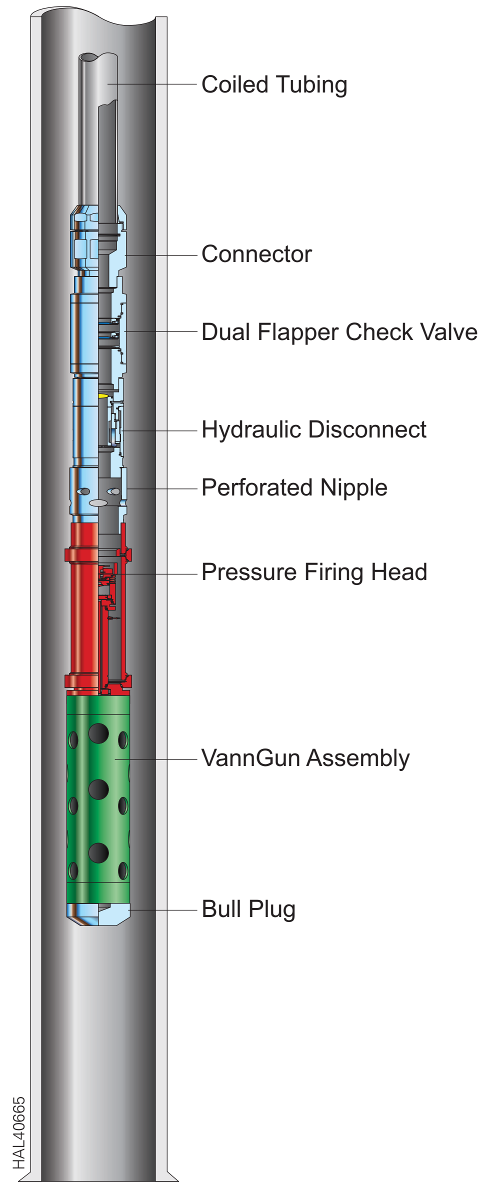
Long Intervals Exceeding Lubricator Length



Coiled Tubing-Conveyed Perforating with Pressure Isolation

Coiled Tubing-Conveyed Perforating

Short Intervals Not Exceeding Lubricator Length

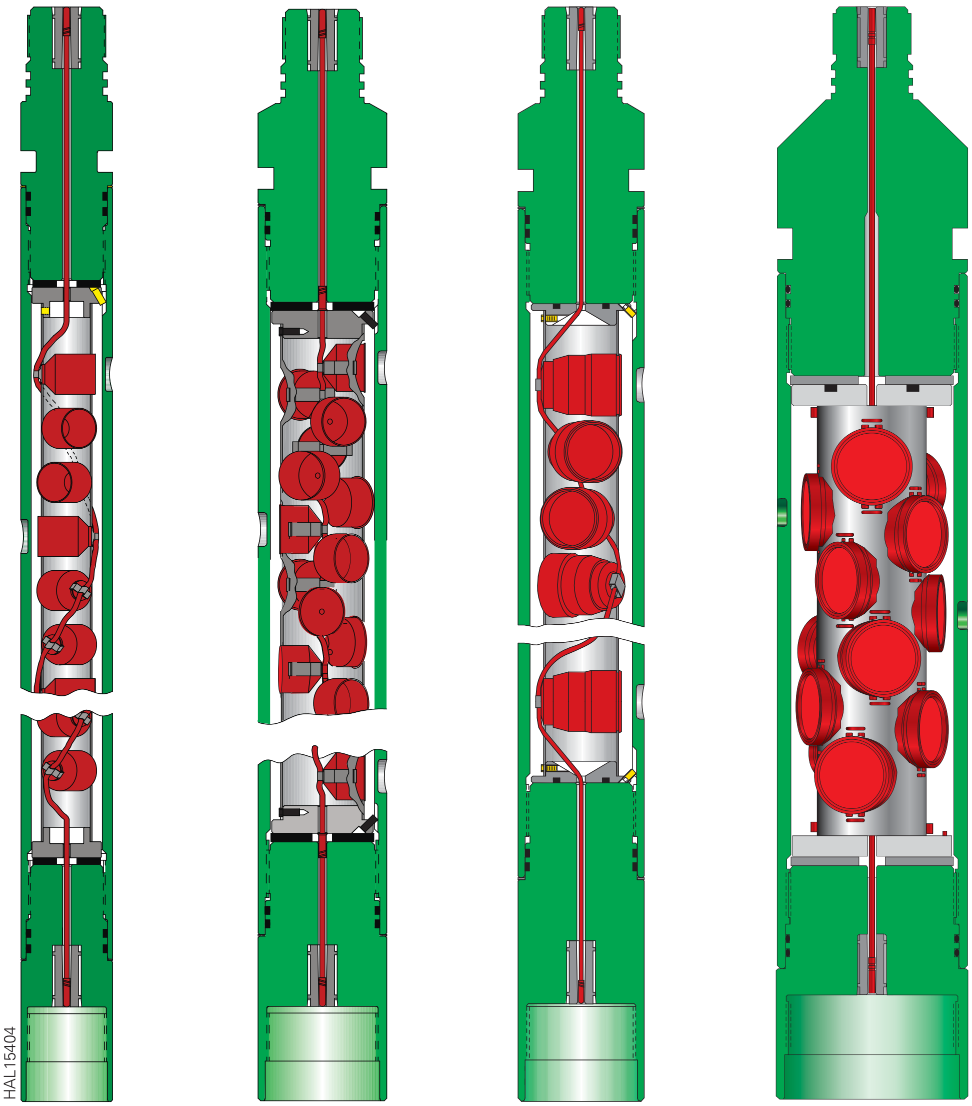


Coiled Tubing-Conveyed Perforating

04

VannGun® Assemblies

The heart of the Halliburton VannSystem® service is the VannGun® assembly. The VannGun assembly uses bidirectional boosters, nonlead azide explosives, specialized connectors and inserts, and high-velocity low-shrink detonating cord. All these, as well as premium-quality gun material, are manufactured to Halliburton proprietary specifications. The primary design factors for these components are safety and reliability. All VannGun assemblies incorporate machined scallops. This helps optimize charge performance and prevent casing damage from perforating exit hole burrs. Additionally, shot phasing is designed to maintain the integrity and collapse resistance of the casing after perforating.



3 3/8-in. 6-spf 60° Phasing

4 5/8-in. 12-spf 30°/150° Phasing

4 5/8-in. 5-spf 60° Phasing

7-in. 14-spf 138° Phasing BH/SH

History of Perforation Techniques

Original cased-hole completions used various mechanical tools to gouge or penetrate casing to establish reservoir-to-wellbore communication. Mechanical tool use at the time was inefficient and time consuming, particularly when longer pay zones were encountered.

In 1926, bullet perforators were patented and by the 1930s had gained widespread acceptance. Bullet perforators used a propellant-driven bullet that would penetrate the casing, cement, and formation. The obvious drawback was the lodging of the bullet or projectile in the perforation tunnel, which restricted reservoir fluid flow into the wellbore. Another drawback was the penetration depth achieved with a bullet perforator was quite short — usually only a few inches at best. Bullet perforators are rarely used today except in cases that require uniform casing hole size for using ball sealers for acid diversion.

Shaped charges or jet perforators were introduced to the oil field in the late 1940s. Design and use of these charges is based on the same principles as the steel armored tank penetrating bazooka technology from World War II. Currently, shaped charges account for more than 95% of the cased and perforated completions around the world. The simple design of the shaped charge features primary components that include a charge case, explosive powder, and liner. The shaped charge liner can be designed to either create a jet that makes a small casing exit hole with deep formation penetration or a large casing exit hole with minimal formation penetration. Shaped charges are generically classified as either deep penetrating (DP) or big hole (BH).

In the 1950s, special through-tubing gun systems (small OD hollow steel carriers and expendable strip guns) were developed. The through-tubing gun systems offered significant advantages over the casing gun technology of the time, which required perforating be performed in an overbalanced condition. The through-tubing gun systems allowed operators to run the completion and nipple up a tree for well control and then establish an underbalance before perforating. This led to better perforation cleanup and well productivity. By the 1970s, Vann Tool Company had perfected the tubing-conveyed perforating (TCP) technique, allowing operators to convey unlimited lengths of perforating guns and safely creating much higher underbalance pressures than were possible with through-tubing gun systems. TCP guns systems (using percussion-type detonators) provided a much safer alternative to through-tubing gun systems (with electrical-type detonators) available at the time and also enabled operators to perforate the entire pay zone with the given underbalanced condition for optimum well productivity.

In the 1990s, ORYX Energy Company developed the PerfStim™ process, which used TCP applications wherein the wellbore is overpressured above the fracture gradient before the perforating event to promote fracturing in the near-wellbore region and improve well productivity. Marathon Oil Company improved on this process by introducing the Powr*Perf™ process, which used proppant carriers above the perforating guns. The proppant carriers are designed to release proppant or any other scouring agent into the flow stream after the guns are detonated, and the nitrogen/fluid cushion is injected into the perforations. In 1997, Marathon Oil Company introduced the StimGun™ assembly, which combines conventional TCP gun systems with a propellant energy source. The TCP gun is actuated by conventional means, and then the propellant is ignited to generate CO_2 gas at pressures above the fracture gradient to create small narrow fractures in the near-wellbore region.

Hydraulic perforators were originally introduced in the 1960s as a means to penetrate the casing by pumping high-pressure fluids with an abrasive agent (sand) to abrade the casing, cement, and formation. Hydraulic perforating is very slow and can be expensive because only a few holes are created simultaneously. In recent years, this technique gained some renewed interest, particularly as a precursor to planned limited-entry hydraulic fracturing in which only a few holes are required in the casing to pump the treatment.

Perforating Techniques Timeline

Year	Perforation Technique
1930s	Bullet Perforators
1940s	Shaped Charges
1950s	Through-Tubing Guns
1960s	Hydraulic Perforators
1970s	Tubing-Conveyed Perforating (TCP)
1987	Horizontal Multizone Perforating
1990s	Extreme Overbalance (EOB) Perforating
1991	High Shot Density Gun Systems*
1997	Extreme Overbalance with StimGun™ Assembly*
1997	Live Well Intervention*
1998	Side-Mounted Guns*
2002	Gun Hangers*
2003	Modular Guns*
2004	G-Force® Internal Orientation System*
2005	Dominator® Shaped Charge (Custom Charges)*
2007	Perforating Dynamic Modeling*
2009	Dynamic Unbalanced Cleanup*
2011	Ultrahigh-Pressure/High-Temperature Systems*
2013	Dynamic Finite Element Analysis (FEA) Modeling*
2015	Ultralow-Debris Gun Systems*

*Developed by Halliburton.

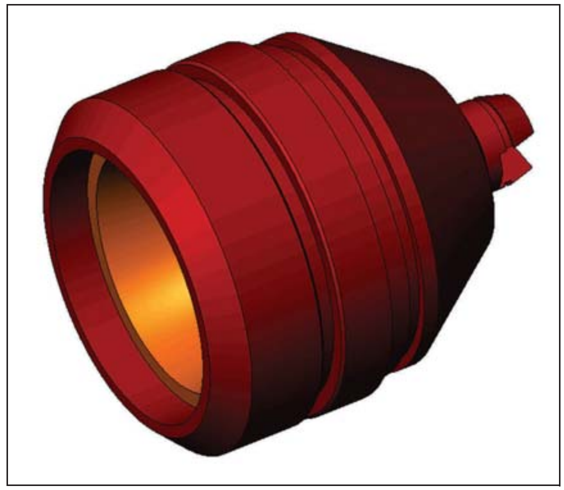
MaxForce® Shaped Charges

MaxForce® super-deep-penetrating charges deliver maximum propulsion and greater depth of penetration to improve perforation in hard-to-penetrate conditions. MaxForce shaped charges are manufactured with the highest level of quality assurance, resulting in a lower standard deviation to provide consistent charge performance.

Features

MaxForce deeper penetration charges:

- Increase productivity
- Penetrate past any near-wellbore damage with deeper penetration
- Potentially intersect more natural fractures with deeper penetration
- Reduce pressure drop at perforations, which can potentially delay scale, paraffin, or asphaltene deposits



MaxForce® Shaped Charge

6 3/4-in. 18-spf MaxForce® Deep-Penetrating Deepwater Gun Systems

The 6 3/4-in. 18-spf MaxForce® deep-penetrating (DP) system is designed to address divergent permeability layers. Some layers thieve all the acid, leaving the lower permeability zones untreated. Thus, no increased productivity from these zones occurs, and all production comes from the higher permeability zones. Chemical and mechanical diverting techniques have been used but have been ineffective.

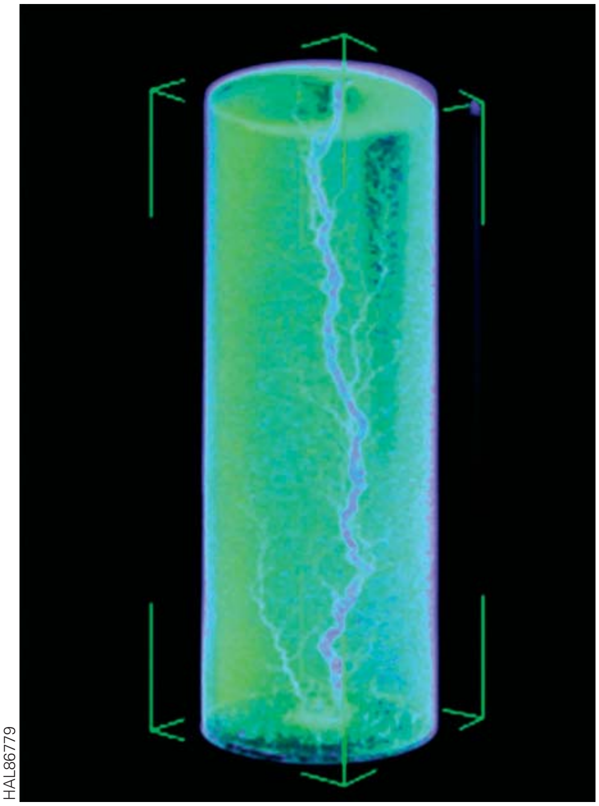
The high-shot density of the 6 3/4-in. 18-spf MaxForce DP system gains more connectivity with the layered reservoir. The MaxForce DP system addresses the issues of high- and low-permeability layers that traditionally make stimulation effectiveness difficult because of the high-permeability zones thieving the treatment fluids from the low-permeability intervals.

Well productivity is improved because of the low-permeability zone contribution that was incapable of being stimulated with traditional gun systems. Additionally, well intervention can be minimized because of increased perforations and cleaner perforation tunnels early in the well completion.

Benefits

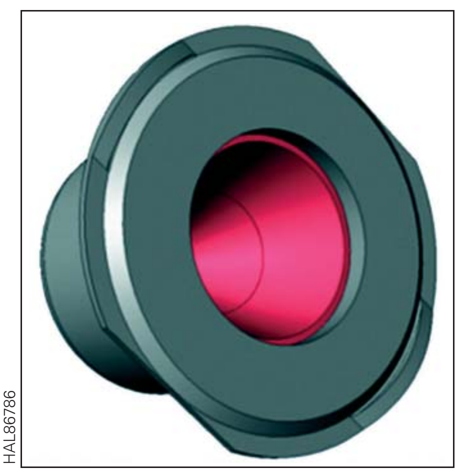
- High-pressure rating suitable for deepwater operations
- High-shot density with maximum phasing delivers a high-flow area
- Better connectivity with divergent permeability layers
- Designed for perf/acid system to optimize the acid treatment across the entire interval
- Improved well productivity because of the low-permeability zone contribution that was not possible with traditional gun systems during stimulation programs
- Reduced risk of well intervention because of increased perforations and cleaner perforation tunnels early in the well completion
- Limited stress using shot phasing, which helps prevent tunnel-to-tunnel stress failures
- Maximized gun size with fishing ability in heavier wall casings

HAL86779



CT scan of a carbonate core with an acid wormhole

HAL86786



The 6 3/4-in. 18-spf MaxForce® DP system provides a higher flow area from the reservoir to the wellbore, maximizing the flow capacity provided by the production string.

6 3/4-in. 18-spf MaxForce® Flow™ Deepwater Gun Systems Solutions

The 6 3/4-in. 18-spf MaxForce® Flow™ deepwater gun systems can perforate reservoirs to increase production and improve simultaneous operations reliability with the least debris possible.

Deepwater exploration and development present a wide range of challenges — from designing and constructing wells to optimizing recovery. As wells are drilled deeper, the need for perforating systems to perform at the maximum design capacity in challenging high-pressure/high-temperature conditions becomes more prominent. Nonproductive time, operation efficiencies, and rig costs place a cumulative pressure on operators to select products and services intelligently.

Halliburton Jet Research Center (JRC) designed the 6 3/4-in. 18-spf MaxForce Flow perforating solutions to stand up to some of the world's most challenging environments, without sacrificing the key drivers for perforating — flow area, low debris, dynamic survivability, and fishing ability — that provide for effective completions and maximize production potential.

MaxForce Flow perforating solutions include three independent 6 3/4-in. 18-spf MaxForce Flow gun systems.

6 3/4-in. 18-spf MaxForce Flow System

The increased flow area of the 6 3/4-in. 18-spf big hole (BH) MaxForce Flow system helps enhance both conventional and flux-based completion approaches. Maximized flow area helps reduce the pressure drop across the perforations and the effective force on the individual sand grains. This results in less screen washouts and potential for sand production — all without sacrificing fishing ability in heavy-wall casings.

Benefits

- Extensive flow area of 14.7 in.²/ft
- 1.07 in. per perforation

6 3/4-in. 18-spf MaxForce Flow Low-Debris Zinc System

The 6 3/4-in. 18-spf MaxForce Flow low-debris (LD) zinc charges provide a clean wellbore for a gravel pack, frac pack, or high-rate water pack. This system offers all the advantages of the MaxForce Flow system, with an increased flow area that minimizes the pressure drop across the perforations. It also uses patented LD charges.

Benefits

- Extensive flow area
- Clean wellbore for a gravel pack, frac pack, or high-rate water pack
- LD zinc charges help significantly reduce debris mass and particle size

6 3/4-in. 18-spf MaxForce Flow Ultra-Kleen™ System

With a proprietary charge tube design, the MaxForce Flow Ultra-Kleen™ dynamic control system provides an almost debris-free operation, even in severe doglegs and high-angle wells. The 6 3/4-in. 18-spf BH MaxForce Flow Ultra-Kleen dynamic control system helps ensure that debris created from shaped charges is minimized, containing larger debris pieces within the gun system for safe, clean perforating without sacrificing flow area. It also reduces dynamic transient forces during the perforation event, which safeguards the completion and tubing-conveyed perforating string.

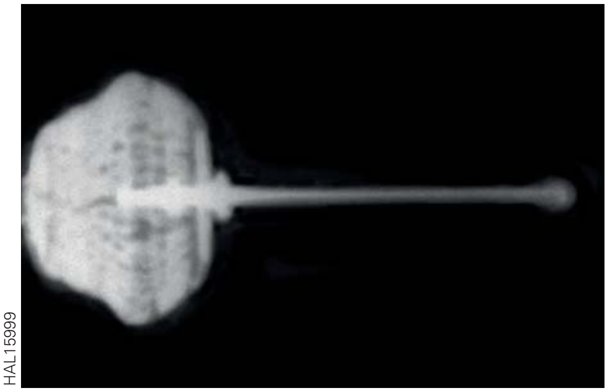
Benefits

- Extensive flow area of 14.14 in.²/ft
- Lowest debris per foot in the industry at 16 g/ft
- Gun system integrity through reduced dynamic transient forces during the perforation event

MaxForce® Flow™ Deepwater Gun Systems Solutions

Dominator® Shaped Charges

Dominator® shaped charges are designed to optimize perforating performance in reservoir rock and increase hydrocarbon production. To achieve that goal, Dominator charges were evaluated in terms of geometry and flow performance in sandstone targets at simulated downhole conditions instead of by their ability to penetrate API 19B Section I unstressed concrete. As a result, these shaped charges far exceed the performance of current, comparable charges.



HAL15999

Flash X-ray of a Charge During Detonation Sequence

A Revolutionary Approach to Charge Development

To maximize well inflow performance for a specific reservoir, it is necessary to engineer the shaped-charge explosive jet-tip velocity profile with consideration to the target properties (compressive strength, particle grain size, pore fluid type, etc.). Optimized shaped-charge design combined with perforating best practices per the Halliburton perforating tool kit (HPTK) help ensure all perforations are surged at the optimum underbalance pressure to minimize perforation skin effects. Naturally shaped charges engineered for a given reservoir should be validated with API 19B Section IV testing (i.e., Perforation Flow Laboratory) at as close to in-situ properties as possible.

Dominator shaped charges were developed at the Halliburton Jet Research Center (JRC) Perforation Flow Laboratory by firing perforating charges into actual rock under simulated downhole conditions, including rock effective stress, wellbore underbalance, and rock pore pressure. By analyzing post-shot results from the testing program, it was possible to rapidly develop a design with favorable jet characteristics.

HAL15956 HAL15957

Actual charge performance in formation core samples comparing standard charge (left) vs. the Dominator® charge (right).

Using the Perforation Flow Laboratory in the design process also avoided the pitfalls associated with translating data from surface shot concrete targets to productivity estimations in downhole reservoirs.

The improvement in penetration performance is evident from the results. In one example, penetration increased by an average of 52% in the gas-filled samples and by an average of 37% in liquid-filled samples. These penetration results, along with improvement in core flow efficiency, contribute to increased flow performance.

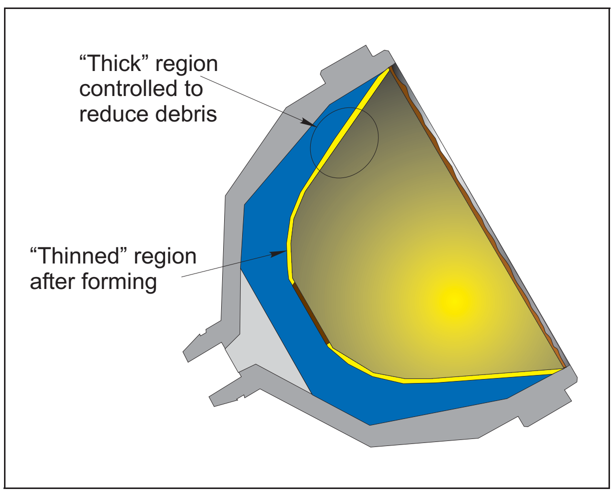
Mirage® Shaped Charges

The Mirage® detonator line of big hole (BH) shaped charges was introduced as an improved low-debris system. The Mirage shaped charge line provides more of a total perforating system debris-reduction solution. With the Mirage shaped charge line, gun debris associated with all components of the perforating assembly is reduced.

Previous BH gun systems required that the shaped charges be positioned and retained in the charge tube holder using bend tabs. The bend tab is a significant source of gun debris because of the metal slivers generated during gun detonation.

The improved Mirage system incorporates a twist lock feature in the charge tube holder, eliminating the debris associated with the bend tabs.

In addition to metallurgical considerations, the geometry of the Mirage shaped charge liner is carefully controlled during the manufacturing process such that those portions of the liner that might contribute to slug creation are removed. This process results in a charge liner with a controlled geometry liner.



HAL16270

Mirage® Super Hole Perforator

HAL16361

Initial (Copper) 7-in. BH Liner Technology

HAL16360

Current (Brass) 7-in. BH Liner Technology

HAL16366

Latest Mirage® 7-in. BH Liner Technology

Maxim® Shaped Charges

Well completions in unconsolidated formations generally require some form of sand control or gravel pack for flow assurance. During cased and perforated sand control completions, the perforating strategy typically calls for perforations with the largest possible exit hole in the casing and as high a shot density [shots per foot (spf)] as possible. The large casing exit hole helps improve the likelihood of placing sand or gravel into the perforation tunnel. Higher spf increases the effective flow area, which lowers the pressure drop across the completion during production.

As completion targets in deepwater environments go deeper, drilling challenges are compounded. In many cases, operators are forced to set the casing shoe point higher than planned to safely reach deeper primary targets. Unfortunately, this scenario results in secondary pay zones that have multiple casing strings across portions or the entire length of the pay zone. This situation presents a serious technical challenge because the typical big hole (BH) perforating system cannot efficiently penetrate multiple casing strings and still produce an adequate casing exit hole. The results using conventional BH perforating systems in the past yielded a large exit hole in the first casing string and a small exit hole in the second casing string with minimal formation penetration.

Revolutionary Shaped Charge Liner Design Meets the Challenge

Shaped charge design engineers at the Halliburton Jet Research Center (JRC) have unleashed the power of Maxim® shaped charges by using hydrocode modeling software and flash X-ray imaging to develop a proprietary shaped charge liner that optimizes the casing exit hole size when penetrating multiple casing strings.

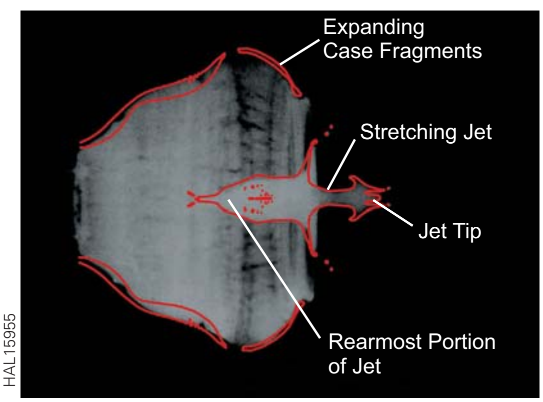
The effectiveness of the Maxim shaped charge concept was demonstrated with the development of a 5-in. 8-spf 47-g charge for a completion scenario with 7 5/8-in. 47.1-lb/ft P-110 and 9 5/8-in. 47-lb/ft P-110 casing.

A standard 5-in. 12-spf 28-g BH gun system was tested under the completion configuration described resulting in a casing exit hole of 0.28-in.

The Maxim perforating system resulted in a casing exit hole size of 0.66-in. with an impressive formation penetration of 6.0-in. These results show a 136% improvement in casing exit hole size and 270% improvement in flow area on a per foot basis.

Maxim® Dual-String Technology

Existing Dual-String Technology



Flash X-ray and hydrocode simulation of a shaped charge during detonation sequence.

Maxim® Charge Performance Data

Charge Part No.	Gun OD	spf	Explosive Load	Inner Casing	Exit Hole	Outer Casing	Exit Hole	Penetration*
101350449	5.00	8	47	7 5/8 47.1-lb P-110	0.75	9 5/8 47-lb P-110	0.66	6.00
101357518	5.75	10	56.5	8 5/8 60.8-lb P-110	0.78	11 3/4 65-lb P-110	0.63	7.50
101357518	7.00	14	56.5	9 5/8 47-lb IL-80	0.61	13 3/8 72-lb P-110	0.68	8.77

*Penetration is in cement measured from the OD of the outer casing.

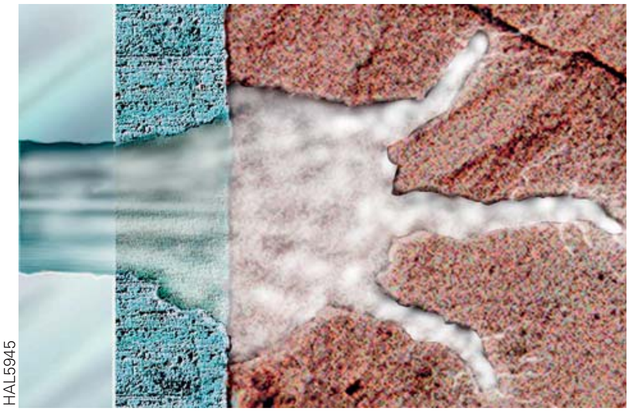
KISS™ Low-Damage Perforating Charge

The KISS™ charge provides all the benefits expected from big hole (BH) charges — yet produces significantly less damage in unconsolidated formations.

KISS charges limit perforating damage with minimal penetrator design charges, reducing damaged material eight-fold. Damaged material is near the casing with 200% of the cross-sectional area a possibility. Penetration past the cement is not a problem, and lower explosive weight charges are less susceptible to carrier failure.

In an extensive series of laboratory tests comparing KISS low-damage charges with conventional BH perforating charges under simulated downhole conditions, the KISS charge more than proved its superiority. In these tests:

- KISS charges created holes in the casing that were equal to or larger in diameter than those created by conventional BH perforating charges.
- Perforation depth was appropriately reduced, so there was far less damage to the formation as well as a significantly reduced crushed zone (less than 1/3 of a conventional BH charge).
- KISS charges easily penetrated 2-in. thick cement sheaths, proving they can be effective even in wellbores in which washouts have occurred.
- Less damage occurred to the cement surrounding the entrance hole, and the cement damage area was smaller.



The unique KISS™ perforating charge is designed to just penetrate the formation while the high-pressure gas breaks through the crushed zone in the tunnel and creates fractures in the formation.

Features

- Can be run in standard VannGun® perforating guns and conveyed on tubing or wireline
- Complements the Halliburton StimGun™ service by producing an instantaneous, high-pressure surge into the formation to enhance perforating and stimulation results
- Specialists help determine if the KISS low-damage perforating charge is a productive choice for a specific well
- Low impact on unconsolidated formations for a positive impact on completions
- Provides better gravel packs because of greatly improved fluid injectivity — whether running a conventional gravel pack, a FracPac™ system, or a high-rate water pack
- Reduces fines movement
- Reduces sand production

210 MaxForce®-FRAC Charge

Perforating charges are traditionally designed for natural completions, which focus on depth of penetration with little regard to hole size and consistency. Oil and gas reservoirs, including unconventionals that require stimulation to be productive, benefit from consistent hole size to improve fracture placement.

The Halliburton MaxForce®-FRAC charge is an engineered charge that addresses perforating for stimulation. The charge is designed to maximize hole size performance, while maintaining entry hole consistency in the casing, regardless of the gun's azimuth orientation and standoff.

Benefits

- Hole size consistency without centralization
- Helps ensure even distribution of fracture pumping pressure
- Highly suited for ball seal applications
- Designed for stimulation or injection wells
- Helps improve injection rates
- Reduces treating pressures
- Increases flow efficiency

Features

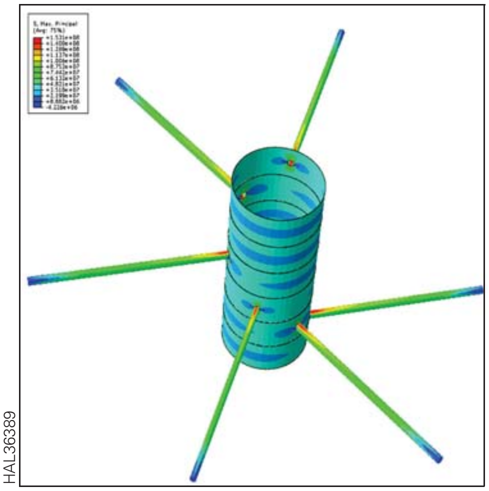
- Compatible with industry-standard perforating guns
- High-pressure systems available up to 25,000 psi (172.4 MPa)

Modeling

Advanced fracture simulations using finite element analysis support the performance improvements demonstrated by consistent hole sizes and observed during extensive field testing.

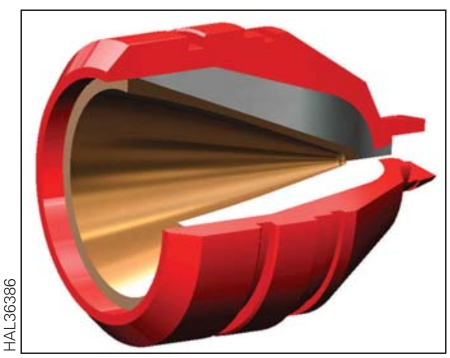
Results show that if the variation of the entrance hole diameter of the neighboring perforation tunnels is too large, then the fracture can initiate at the edge of the larger holes, leaving the smaller hole diameter perforations less effective during stimulation.

The MaxForce-FRAC charge provides less variance of the entrance hole diameters compared to conventional deep-penetrating (DP) and good-hole (GH) charges, thus improving pressure distribution, even treatment of perforations, and stimulation efficiency.



HAL36389

Sample results from finite element analysis model. Ideally, the average hole size published would be the result at every phase of the gun, but in the real world, it varies significantly. The local maximum principal stress is always on the surface of the perforation tunnel near the entrance; therefore, the entrance hole diameter is the dominant parameter in fracture initiation, not the tunnel length.



HAL36386

MaxForce®-FRAC Charge

Hole Size Consistency (Percent Standard Deviation)*

Charge	MaxForce®-FRAC Charge	A	B
3 1/8-in. System	10.9	24.7	28.8
3 3/8-in. System	25.6	57.1	75.0

*(Maximum – Minimum/Average Hole Size) × 100

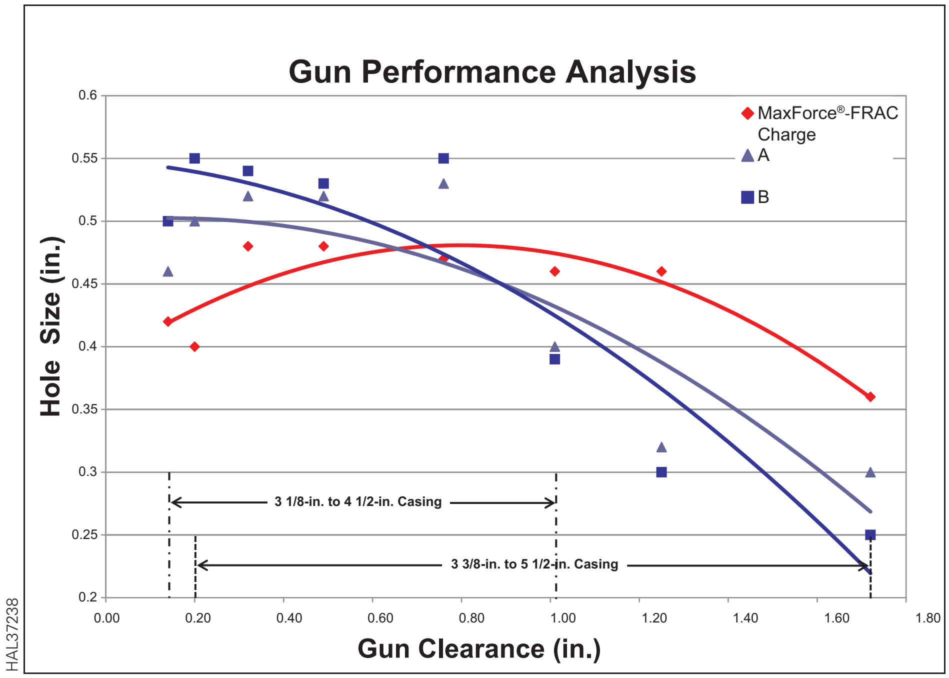
Case Histories

Martin County, Texas, USA

Using the 210 MaxForce®-FRAC charge in a 3 3/8-in. 6-spf 60° gun system, an operator increased injectivity by 20% during a stimulation treatment compared to the same cluster, hole density, phasing, and good-hole (GH) charge used previously.

Reagan County, Texas, USA

The 210 MaxForce-FRAC charge was thoroughly and independently evaluated over 15 separate frac stages to comparable offset wells perforated with an industry-available GH shaped-charge perforating system. The MaxForce-FRAC charge consistently demonstrated lower treating pressures at the same pump rate, or 8 to 10% higher pump rate at the same treating pressure.



Hole size vs. gun clearance of MaxForce®-FRAC charge compared to competitor charges A and B

210 MaxForce®-FRAC Charge Specifications

Gun Size in.	Explosive Type	JRC Part No.	Gun Type	Maximum Shot Density per ft	Explosive Mass g	Casing Size Tested in.	Average Exit Hole Diameter in.	Hole Size Variation %
3 1/8	RDX	102045430	HSC	6	21.0	4 1/2	0.46	10.9
3 3/8	RDX	102045430	HSC	6	21.0	5 1/2	0.43	25.6
3 1/8	HMX	102127122	HSC	6	21.0	4 1/2	0.49	8.2
3 3/8	HMX	102127122	HSC	6	21.0	5 1/2	0.45	33.3

Charge Performance Data

Deep-Penetrating Charges

Gun Size in.	Shot Density spf (spm)	Phasing	JRC Part No.	Charge Name	Penetration in. (mm)	Normalized Penetration in. (mm)	Entrance Hole in. (mm)	Casing Size in.	Target Strength psi	Explosive Load g	Charge Case	Data Type
1 9/16	4 (13)	0	100157028	1 9/16-in. Millennium™, HMX, IS	11.3 (288.0)	11.9 (302.0)	0.21 (5.3)	4 1/2	5,967	3.4	Steel	RP43
1 9/16	6 (20)	60	100157028	1 9/16-in. Millennium™, HMX, IS	8.3 (210.8)	9.1 (231.4)	0.23 (5.8)	2 7/8	6,949	3.4	Steel	19B
1 11/16	4 (13)	0	100005450	1 11/16-in. Dyna-Star®, RDX	10.5 (266.7)	10.6 (268.7)	0.39 (9.9)	4 1/2	5,149	13.4	Capsule	19B
1 11/16	6 (20)	0	101398891	1 11/16-in. Millennium™ Dyna-Star®, HMX	24.0 (609.6)	24.5 (622.6)	0.29 (7.4)	4 1/2	5,426	8.0	Capsule	QC
1 11/16	8 (26)	0	101521848	080 MaxForce®, Deep Star, HMX	19.9 (505.5)	22.1 (560.3)	0.26 (6.6)	4 1/2	7,170	8.0	Capsule	19B
2	6 (20)	60	101603801	070 MaxForce®, HMX	20.3 (515.6)	21.0 (533.7)	0.24 (6.1)	2 7/8	5,697	7.0	Steel	19B
2	6 (20)	60	101208224	2-in. Millennium™, HMX	19.2 (487.7)	20.6 (523.5)	0.26 (6.6)	3 1/2	6,470	6.8	Steel	RP43
2	6 (20)	60	101208224	2-in. Millennium™, HMX	18.3 (464.8)	19.2 (488.4)	0.22 (5.6)	2 7/8	6,019	6.8	Steel	19B
2	6 (20)	0	100157018	2-in. Sidewinder II™, HNS	11.8 (299.7)	12.4 (314.2)	0.23 (5.8)	4 1/2	5,960	6.9	Steel	QC
2 1/8	8 (26)	0	101210198	2 1/8-in. Millennium™ Deep Star, HMX	30.7 (779.8)	30.9 (787.1)	0.35 (8.9)	5 1/2	5,189	15.9	Capsule	RP43
2 1/8	6 (20)	0	100005448	2 1/8-in. Dyna-Star®, RDX	16.6 (421.9)	17.1 (433.3)	0.42 (10.7)	5 1/2	5,538	15.5	Capsule	RP43
2 1/8	4 (13)	0	100005448	2 1/8-in. Dyna-Star®, RDX	15.5 (393.7)	17.3 (438.2)	0.35 (8.9)	5 1/2	5,292	15.5	Capsule	19B
2 1/8	8 (19)	0/45/90	101210198	2 1/8-in. Millennium™ Deep Star, HMX	20.6 (523.2)	22.4 (568.7)	0.30 (7.6)	5 1/2	6,740	15.9	Capsule	19B
2 1/2	6 (20)	60	101418095	2 1/2-in. Millennium™ II, HMX, IS	24.5 (622.3)	25.7 (653.3)	0.32 (8.1)	3 1/2	5,996	11.1	Steel	19B
2 1/2	6 (20)	60	101206251	2 1/2-in. Millennium™, HMX	26.5 (673.1)	27.6 (701.8)	0.32 (8.1)	3 1/2	5,854	11.0	Steel	RP43
2 3/4	6 (20)	60	101318485	2 3/4-in. Millennium™, HNS	27.5 (699.8)	28.5 (724.2)	0.30 (7.6)	4 1/2	5,694	15.1	Steel	QC
2 3/4	6 (20)	60	101233817	2 3/4-in. Millennium™, HMX	26.0 (660.4)	27.8 (706.4)	0.30 (7.6)	4 1/2	6,394	15.0	Steel	19B
2 7/8	6 (20)	60	101826652	175 MaxForce®, HMX	38.6 (980.4)	39.4 (1000.3)	0.37 (9.4)	4 1/2	5,405	17.5	Steel	19B
2 7/8 (HW)	6 (20)	60	101233817	2 3/4-in. Millennium™, HMX	30.0 (762.0)	30.2 (766.8)	0.35 (8.9)	4 1/2	5,124	15.0	Steel	19B3
2 7/8	6 (20)	60	101388406	2 7/8-in. Millennium™, HMX	26.6 (676.4)	28.6 (726.4)	0.38 (9.7)	4 1/2	6,522	17.5	Steel	QC
2 7/8	6 (20)	60	101233817	2 3/4-in. Millennium™, HMX	27.3 (693.4)	29.2 (741.7)	0.31 (7.9)	4 1/2	6,388	15.0	Steel	19B
2 7/8	6 (20)	60	101388407	2 7/8-in. Millennium™, HNS	22.8 (579.1)	24.9 (633.0)	0.28 (7.1)	4 1/2	6,859	18.5	Steel	19B
3 1/8	6 (20)	60	101366678	3 1/8-in. Millennium™, HMX, IS	38.3 (972.8)	40.6 (1031.2)	0.40 (10.2)	4 1/2	6,200	21.0	Steel	QC
3 1/8	6 (20)	60	101618994	3 1/8-in. Millennium™ Express SDP, RDX, IS	37.9 (962.6)	39.3 (998.5)	0.38 (9.7)	4 1/2	5,745	21.0	Steel	QC
3 1/8	6 (20)	60	101366678	3 1/8-in. Millennium™, HMX	33.9 (861.1)	34.9 (886.5)	0.34 (8.6)	4 1/2	5,598	21.0	Steel	19B
3 3/8	6 (20)	60	101233819	3 3/8-in. Millennium™, HMX	37.5 (952.5)	38.9 (988.3)	0.45 (11.4)	4 1/2	5,754	25.0	Steel	19B
3 3/8	6 (20)	60	100008249	3 3/8-in. Super DP, HMX	28.7 (729.0)	30.3 (768.9)	0.40 (10.2)	5	6,097	25.0	Steel	RP43

Deep-Penetrating Charges

Gun Size in.	Shot Density spf (spm)	Phasing	JRC Part No.	Charge Name	Penetration in. (mm)	Normalized Penetration in. (mm)	Entrance Hole in. (mm)	Casing Size in.	Target Strength psi	Explosive Load g	Charge Case	Data Type
3 3/8	6 (20)	60	100008249	3 3/8-in. Super DP, HMX	26.2 (665.5)	27.5 (697.7)	0.40 (10.2)	4 1/2	5,967	25.0	Steel	19B
3 3/8	6 (20)	60	101293450	3 3/8-in. Super DP, RDX, LD	27.0 (685.8)	27.8 (706.4)	0.38 (9.7)	4 1/2	5,602	24.0	Zinc	QC
3 3/8	6 (20)	60	101365876	3 3/8-in. Millennium™, HNS	22.1 (561.3)	23.8 (605.5)	0.31 (7.9)	4 1/2	6,578	25.0	Steel	19B
4	4 (13)	90	101355271	4-in. Millennium™, RDX	51.7 (1312.7)	54.5 (1384.8)	0.42 (10.7)	5 1/2	6,100	39.0	Steel	QC
4	4 (13)	90	101210636	4-in. Millennium™, HMX	43.4 (1102.4)	46.4 (1177.5)	0.38 (9.7)	5 1/2	6,365	39.0	Steel	19B
4	6 (20)	60	100005322	4 5/8-in. DP, RDX	40.5 (1028.7)	41.1 (1042.9)	0.60 (15.2)	7	5,277	32.0	Steel	QC
4 1/2	5 (16)	60	101210636	4-in. Millennium™, HMX	39.6 (1005.8)	43.1 (1095.0)	0.37 (9.4)	7	6,775	39.0	Steel	19B
4 1/2	12 (39)	150/30	101210674	4 1/2-in. Millennium™, HMX	26.8 (680.7)	31.5 (799.3)	0.38 (9.7)	7	8,484	22.7	Steel	RP43
4 5/8 G-Force®	4 (13)	180	101446899	4 5/8-in. KleenZone® DP, HMX	42.8 (1087.1)	43.2 (1098.6)	0.36 (9.1)	7	5,208	39.0	Steel	19B
4 5/8 G-Force®	4 (13)	350/10	101446899	4 5/8-in. KleenZone® DP, HMX	41.7 (1059.2)	42.6 (1081.0)	0.35 (8.9)	7	5,412	39.0	Steel	19B
4 5/8	4 (13)	180	101287306	4-in. Super DP, HNS	30.2 (767.1)	32.2 (818.9)	0.29 (7.4)	7 5/8	6,349	39.0	Steel	19B
4 5/8	5 (16)	72	102054947	390 MaxForce®, HMX	61.6 (1564.6)	63.2 (1604.8)	0.33 (8.4)	7	5,513	39.0	Steel	19B
4 5/8	5 (16)	72	102624465	4 5/8-in. Millennium™ II, HMX	53.3 (1353.8)	54.4 (1381.76)	0.43 (10.9)	7	5,420	39.0	Steel	19.B
4 5/8	5 (16)	60	101210636	4-in. Millennium™, HMX	52.0 (1320.8)	53.3 (1354.1)	0.37 (9.4)	7	5,502	39.0	Steel	RP43
4 5/8	5 (16)	60	101210636	4-in. Millennium™, HMX	43.6 (1107.4)	44.7 (1136.1)	0.35 (8.9)	7	5,518	39.0	Steel	19B
4 5/8	5 (16)	60	101287306	4-in. Super DP, HNS	31.2 (792.5)	35.2 (893.8)	0.33 (8.4)	7	7,559	39.0	Steel	19B
4 5/8	6 (20)	60	100005322	4 5/8-in. DP, RDX	30.5 (773.7)	30.9 (786.1)	0.43 (10.9)	7	5,325	32.0	Steel	RP43
4 5/8	6 (20)	60	101332806	4 5/8-in. DP, HNS	30.3 (769.6)	31.5 (800.9)	0.45 (11.4)	7	5,814	32.0	Steel	QC
4 5/8	12 (39)	150/30	101826652	175 MaxForce®, HMX	36.5 (927.1)	38.2 (970.5)	0.38 (9.6)	7	5,937	17.5	Steel	19B
4 5/8	12 (39)	150/30	101210674	4 1/2-in. Millennium™, HMX	26.1 (662.2)	26.2 (666.5)	0.37 (9.4)	7	5,107	22.7	Steel	RP43
4 5/8	12 (39)	150/30	101210674	4 1/2-in. Millennium™, HMX	24.4 (619.8)	26.0 (660.7)	0.38 (9.7)	7	6,322	22.7	Steel	19B
4 5/8	12 (39)	150/30	100005340	4 5/8-in. DP OMNI, HMX, LD	18.4 (466.6)	19.0 (482.6)	0.30 (7.6)	7	5,685	22.7	Zinc	RP43
4 5/8	12 (39)	150/30	101343830	4 5/8-in. DP OMNI, HNS	28.0 (711.2)	28.0 (712.0)	0.35 (8.9)	7	5,020	21.5	Steel	QC
6 3/4	18 (59)	60/120	101972806	330 MaxForce®, HMX	37.4 (950.0)	37.9 (962.7)	0.40 (10.2)	9 5/8	5,241	33.0	Steel	19B
7	12 (39)	135/45	102054947	390 MaxForce®, HMX	55.7 (1414.8)	57.8 (1468.5)	0.32 (8.1)	9 5/8	5,760	39.0	Steel	19B
7	12 (39)	135/45	101207997	7-in. Millennium™, HMX	43.3 (1099.8)	47.6 (1209.8)	0.36 (9.1)	9 5/8	7,006	39.0	Steel	RP43
7	12 (39)	135/45	101702911	4 5/8-in. Millennium™ II, HMX	47.1 (1196.2)	49.4 (1255.1)	0.43 (10.9)	9 5/8	5,982	39.0	Steel	19B
7	12 (39)	135/45	101207997	7-in. Millennium™, HMX	38.7 (983.0)	41.4 (1051.6)	0.42 (10.7)	9 5/8	6,397	39.0	Steel	19B

MaxForce®-FRAC Shaped Charges

Gun Size	Shot Density, spf (spm)	Phasing	JRC Part No.	Charge Name	Entrance Hole in. (mm)	Casing Size in.	Explosive Load g	Case Material	Data Type
2 3/4	6 (20)	60	102186883	150 MaxForce®-FRAC, HMX, IS	0.41 (10.4)	4 1/2	15.0	Steel	QC
3 1/8	6 (20)	60	102127122	210 MaxForce®-FRAC, HMX, IS	0.49 (12.4)	4 1/2	21.0	Steel	QC
3 1/8	6 (20)	60	102045430	210 MaxForce®-FRAC, RDX, IS	0.46 (11.7)	4 1/2	21.0	Steel	QC
3 3/8	6 (20)	60	102127122	210 MaxForce®-FRAC, HMX, IS	0.45 (11.4)	5 1/2	21.0	Steel	QC
3 3/8	6 (20)	60	102045430	210 MaxForce®-FRAC, RDX, IS	0.43 (10.9)	5 1/2	21.0	Steel	QC

Big Hole Shaped Charges

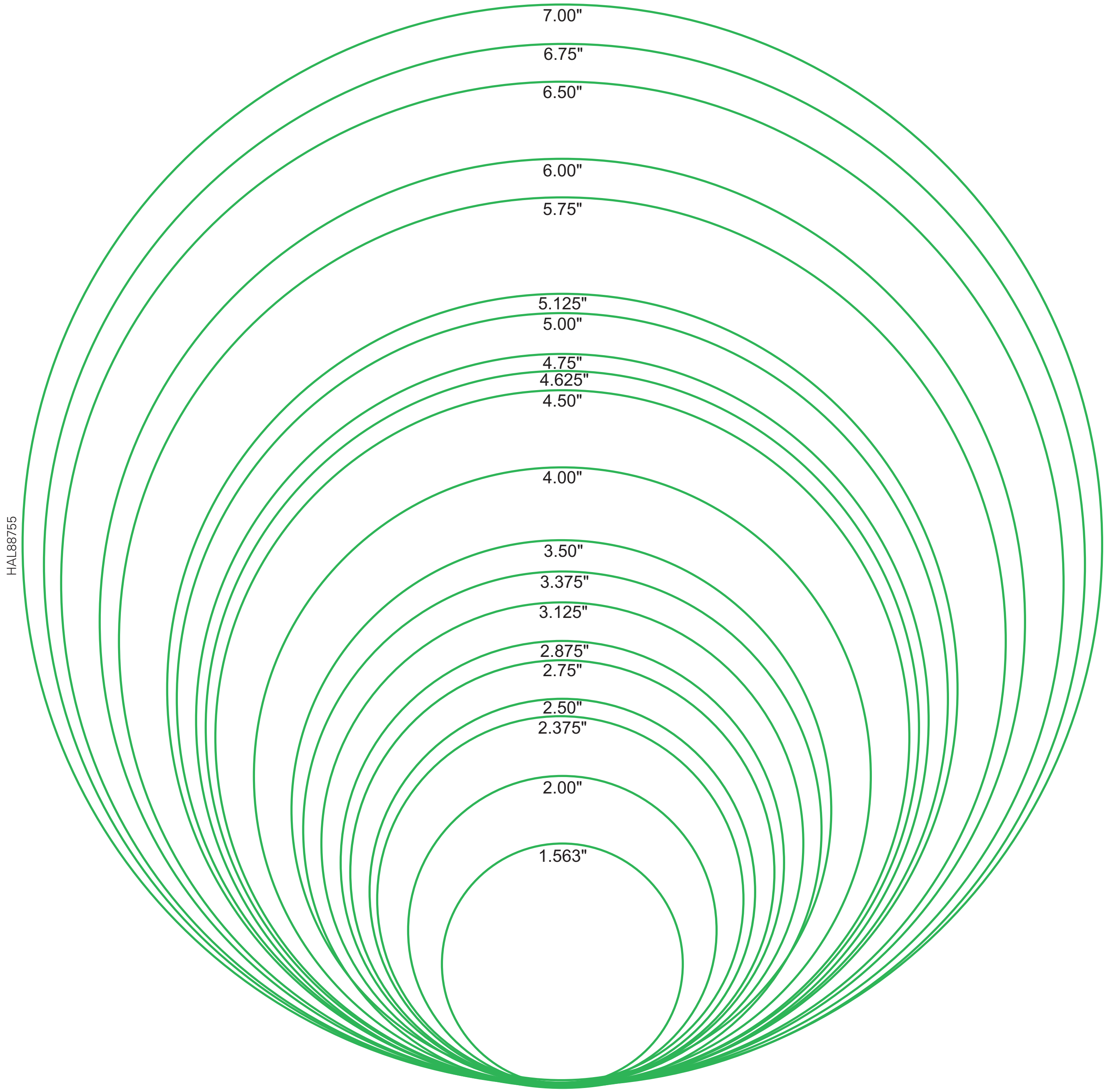
Gun Size	Shot Density spf (spm)	Phasing	JRC Part No.	Charge Name	Penetration in. (mm)	Normalized Penetration in. (mm)	Entrance Hole in. (mm)	Casing Size in.	Target Strength psi	Explosive Load g	Case Material	Data Type
2	6 (20)	0	101206246	2-in. BH, HMX	5.1 (129.5)	5.4 (138.7)	0.39 (9.9)	3 1/2	6,418	6.8	Steel	RP43
2	6 (20)	60	101206246	2-in. BH, HMX	3.0 (76.2)	3.3 (85.1)	0.48 (12.2)	3 1/2	7,332	6.8	Steel	19B
2 3/4	6 (20)	60	101270158	2 3/4-in. HMX BH	4.2 (106.7)	4.7 (119.4)	0.65 (16.5)	4 1/2	7,381	15	Steel	19B
3 1/8	10 (33)	135/45	102327840	140 MaxForce®-Flow, HMX	4.4 (111.8)	4.4 (112.5)	0.66 (16.8)	5	5,076	14	Steel	19B
3 1/8	10 (33)	135/45	101351605	3 1/8-in. Mirage®, HMX, LD	3.8 (96.5)	4.0 (101.9)	0.64 (16.3)	5	6,100	14	Zinc	QC
3 3/8	12 (39)	135/45	101351605	3 1/8-in. Mirage®, HMX, LD	4.1 (105.4)	4.0 (101.9)	0.63 (16.0)	5 1/2	6,100	14	Zinc	QC
3 3/8	6 (20)	60	100005321	3 3/8-in. BH, RDX	4.7 (118.4)	4.9 (125.0)	0.86 (21.8)	4 1/2	6,101	24	Steel	QC
3 3/8	12 (39)	150/30	100008251	3 3/8-in. BH, OMNI, RDX	5.3 (135.4)	6.1 (154.4)	0.62 (15.7)	5 1/2	7,802	14	Steel	RP43
3 1/2	12 (39)	135/45	101542642	3 1/2-in. Mirage®, HMX, LD	4.2 (106.7)	4.4 (112.5)	0.65 (16.5)	5 1/2	6,100	15	Zinc	QC
4 5/8	12 (39)	150/30	100005319	4 5/8-in. BH, RDX	6.4 (162.8)	7.0 (177.8)	0.74 (18.8)	7	6,840	25	Steel	RP43
4 5/8	12 (39)	150/30	100005326	4 5/8-in. BH OMNI, RDX, LD	5.5 (140.0)	6.2 (156.5)	0.65 (16.5)	7	7,346	22.7	Zinc	RP43
4 5/8	12 (39)	150/30	100157006	4 5/8-in. BH, HMX	7.0 (178.3)	7.3 (184.7)	0.75 (19.1)	7	5,723	25	Steel	QC
4 5/8	12 (39)	150/30	100005311	4 5/8-in. Super BH, RDX	6.3 (160.0)	6.9 (175.8)	0.93 (23.6)	7	6,982	28	Steel	RP43
4 5/8	12 (39)	150/30	100156995	4 5/8-in. Super Hole, HMX	5.0 (127.3)	5.0 (127.3)	0.96 (24.4)	7	5,016	28	Steel	RP43
4 5/8	12 (39)	150/30	101233690	4 5/8-in. Super Hole, HMX, LD	5.3 (134.6)	5.5 (138.7)	0.85 (21.6)	7	5,622	28	Zinc	RP43
4 5/8	14 (46)	26/231	100156995	4 5/8-in. Super Hole, HMX	6.0 (152.4)	6.3 (160.0)	0.90 (22.9)	7	6,009	28	Steel	19B
4 5/8	18 (59)	135/45	100156990	4 5/8-in. BH, RDX	6.2 (157.0)	6.3 (161.3)	0.73 (18.5)	7	5,553	20	Steel	RP43
4 3/4 (HW)	14 (46)	135	101787632	4 3/4-in. Mirage®, HMX, LD	5.9 (149.9)	6.3 (161.0)	0.71 (18.0)	7	6,506	21	Zinc	19B
5	12 (39)	150/30	100005311	4 5/8-in. Super Hole, RDX	6.9 (175.3)	6.9 (177.0)	0.91 (23.1)	7	5,192	28	Steel	RP43
5	12 (39)	150/30	100005319	4 5/8-in. BH, RDX	8.8 (223.5)	9.5 (240.3)	0.84 (21.3)	7	6,508	25	Steel	QC
5	12 (39)	150/30	100156995	4 5/8-in. Super Hole, HMX	6.0 (152.4)	6.4 (163.8)	1.00 (25.4)	7	6,487	28	Steel	QC

Big Hole Shaped Charges

Gun Size	Shot Density spf (spm)	Phasing	JRC Part No.	Charge Name	Penetration in. (mm)	Normalized Penetration in. (mm)	Entrance Hole in. (mm)	Casing Size in.	Target Strength psi	Explosive Load g	Case Material	Data Type
5	12 (39)	150/30	100005311	4 5/8-in. Super Hole, RDX	6.6 (168.9)	7.6 (193.3)	0.83 (21.1)	7 5/8	7,877	28	Steel	RP43
5	21 (69)	120 Cluster	101292616	5-in. BH, RDX	5.3 (134.6)	5.4 (137.4)	0.72 (18.3)	7 5/8	5,411	21	Steel	19B1
5 1/8	12 (39)	135	101307494	5-in. Mirage®, RDX, LD	6.6 (167.6)	6.8 (172.5)	0.88 (22.4)	7 5/8	5,576	32	Zinc	19B
5 1/8	21 (69)	120 Cluster	101292616	5-in. BH, RDX	5.6 (143.5)	5.9 (152.1)	0.74 (18.8)	7 5/8	6,246	21	Steel	QC
5 3/4	18 (59)	60/120	101688614	5 3/4-in. Mirage®, RDX, LD	6.5 (165.1)	6.8 (173.7)	0.94 (23.9)	8 5/8	6,050	28	Zinc	QC
6 1/2	12/14 (39/46)	135/45/ 138	101304878	6 1/2-in. Mirage®, RDX, LD	5.6 (142.2)	6.2 (156.7)	1.07 (27.2)	8 5/8	7,043	47	Zinc	19B
6 1/2	12/14 (39/46)	135/45/ 138	101304878	6 1/2-in. Mirage®, RDX, LD	6.8 (172.7)	6.8 (172.7)	0.91 (23.1)	9 5/8	5,088	47	Zinc	19B2
6 1/2	12/14 (39/46)	135/45/ 138	101304878	6 1/2-in. Mirage®, RDX, LD	6.8 (172.7)	7.4 (189.5)	0.90 (22.8)	9 7/8	6,949	47	Zinc	19B2
6 3/4	18 (59)	60/120	102505344	390 MaxForce® Flow™ Ultra-Kleen™, HMX	5.4 (137.2)	5.8 (147.3)	1.00 (25.4)	9 5/8	6,350	39	Steel	19B
6 3/4	18 (59)	60/120	102428572	390 MaxForce® Flow™, HMX	5.5 (139.7)	6.1 (154.9)	1.02 (25.9)	9 5/8	7,131	39	Steel	19B
6 3/4	18 (59)	60/120	102528007	390 MaxForce® Flow™, HMX	6.1 (155)	6.6 (167.6)	0.82 (20.8)	9 7/8	6,671	39	Zinc	19B
7	12/14 (39/46)	135/45/ 138	102322115	7-in. Mirage® Super Hole, HMX	5.6 (142.2)	5.99 (152.1)	0.88 (22.4)	9 5/8	6,383	39	Zinc	19B
7	12/14 (39/46)	138	101329124	6 1/2-in. Mirage®, HMX, LD	6.9 (175.3)	7.2 (181.9)	1.00 (25.4)	9 5/8	5,740	47	Zinc	19B
7	12/14 (39/46)	135/45/ 138	101304878	6 1/2-in. Mirage®, RDX, LD	6.1 (154.9)	6.5 (164.1)	1.07 (27.2)	9 5/8	6,178	47	Zinc	19B
7	12/14 (39/46)	135/45/ 138	101213474	7-in. Super Hole, RDX	5.8 (147.3)	6.1 (154.4)	1.29 (32.8)	9 5/8	5,975	56.5	Steel	19B
7	14 (46)	135/45/ 138	101484232	7-in. Mirage®, RDX, LD	6.3 (160.0)	6.7 (170.2)	1.04 (26.4)	9 5/8	6,270	39	Zinc	19B
7	18 (59)	60/120	101711688	7-in. Mirage®, HMX, LD	7.6 (194.1)	8.0 (203.2)	1.03 (26.2)	9 7/8	5,950	39	Zinc	QC
7	18 (59)	60/120	101414821	7-in. Mirage®, HMX, LD	6.5 (165.1)	6.7 (172.4)	1.02 (25.9)	9 5/8	5,893	45	Zinc	19B
7	18 (59)	60/120	102351458	7-in. BH, HMX	6.4 (162.6)	6.9 (174.5)	1.08 (27.4)	9 5/8	6,474	39	Steel	19B
7	12/14 (39/46)	135/45/ 138	101228037	7-in. Mirage® Super Hole, RDX, LD	4.7 (119.4)	4.9 (124.0)	1.03 (26.2)	9 5/8	5,746	39	Zinc	19B

[1]Registered 19B data except fired in 7 5/8-in. 47-lb P110 casing
[2]Registered 19B data except fired in 9 5/8-in. 71-lb N-80 casing
[3]Registered 19B data except fired in air instead of fluid
IS = Industry Standard design
BH = Big Hole
LD = Low Debris
SH = Super Hole
HW = Heavy Wall Gun
Charge performance will vary due to well conditions. For wellbore condition simulation, please contact JRC for testing in our API Section IV Perforation Flow Laboratory.
Penetration normalization is not certified by API for 19B.
RP43 testing is no longer endorsed by API and will not be available on new or improved JRC charges.

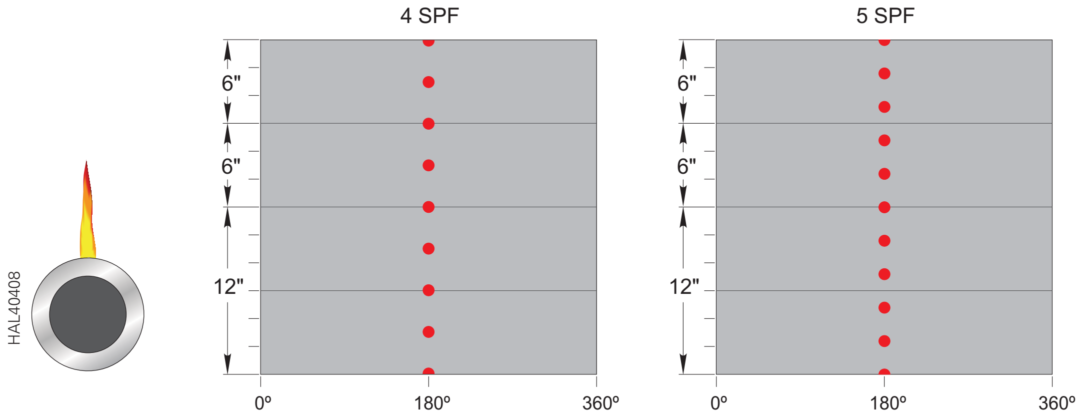
VannGun® Assemblies
1 9/16 to 10 3/4 in. and 4 to 21 spf



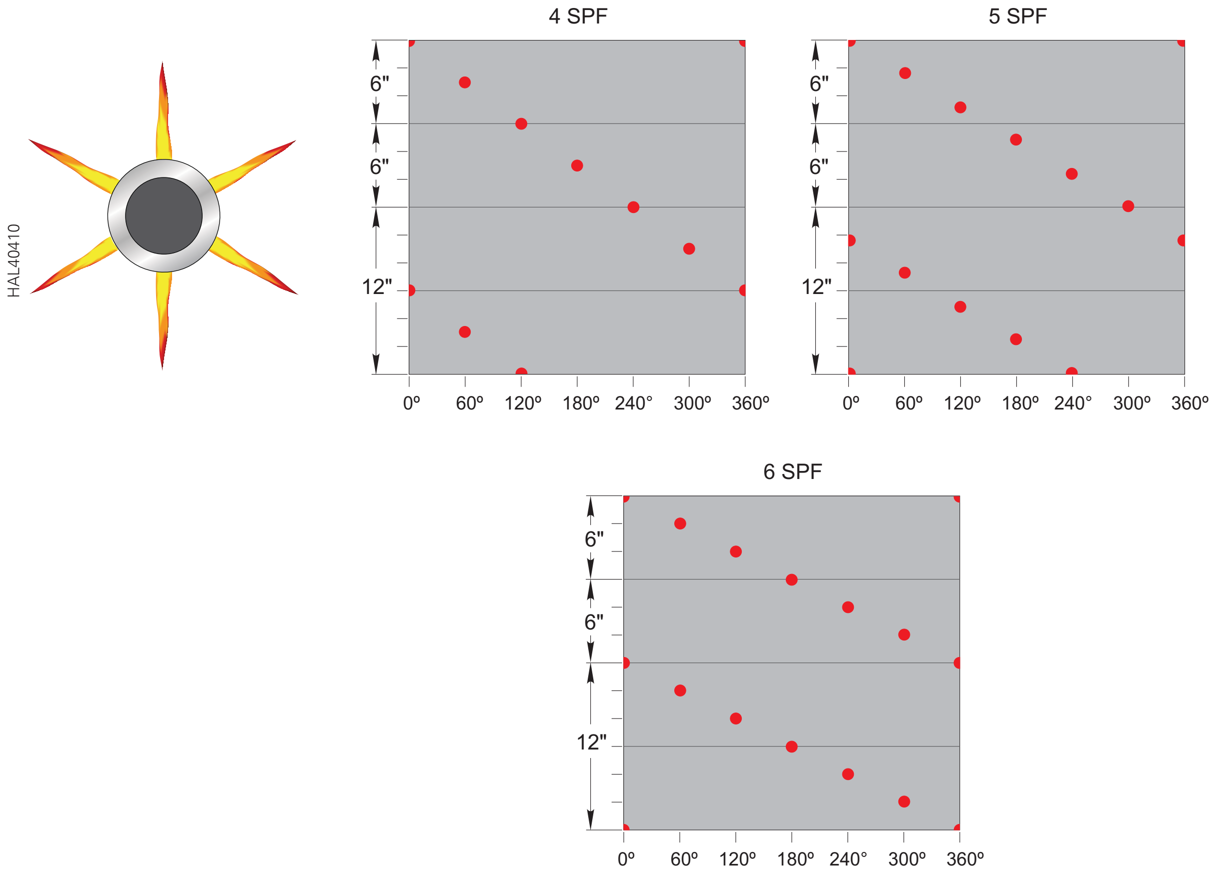
Only sizes 1 9/16- through 7-in. are shown.

VannGun® Phasing and Shot Patterns*

0° Phasing 4 and 5 spf

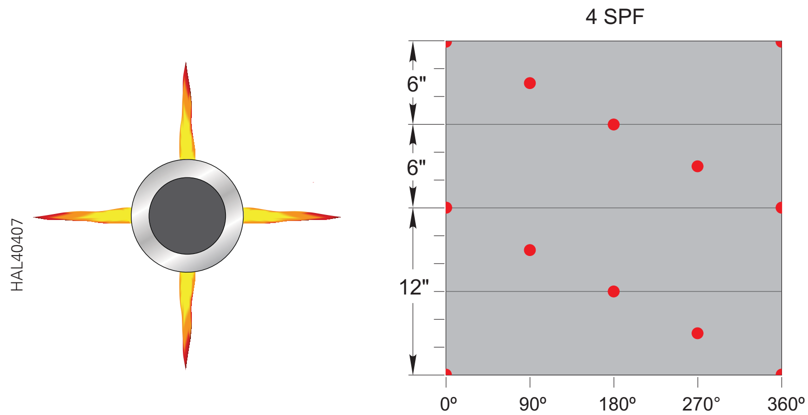


60° Phasing 4, 5, and 6 spf

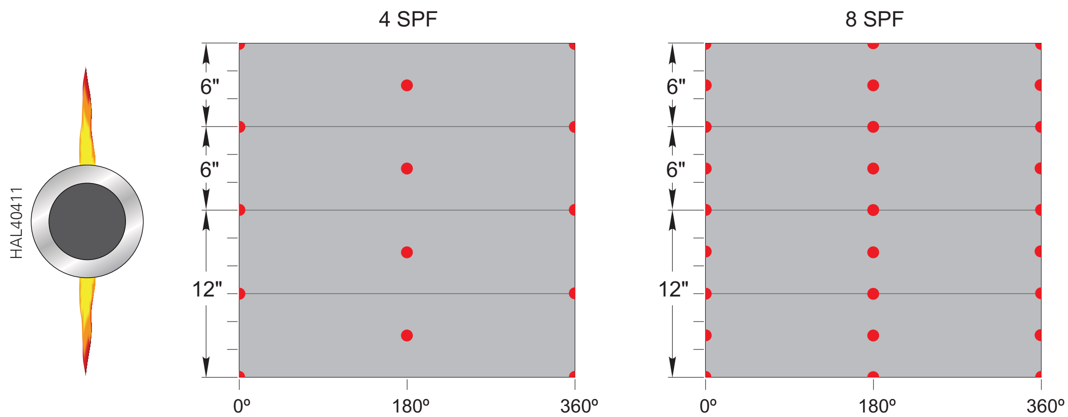


*Other shot densities and phasings are available upon request.

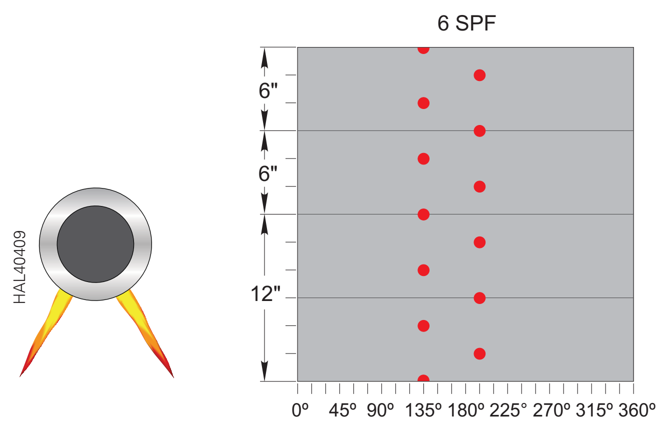
90° Phasing 4 spf



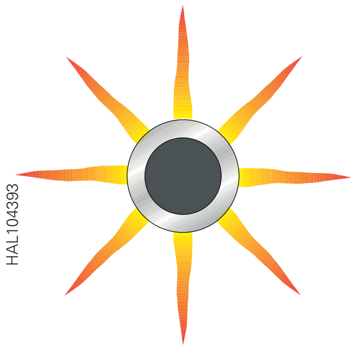
0 to 180° Phasing 4 and 8 spf

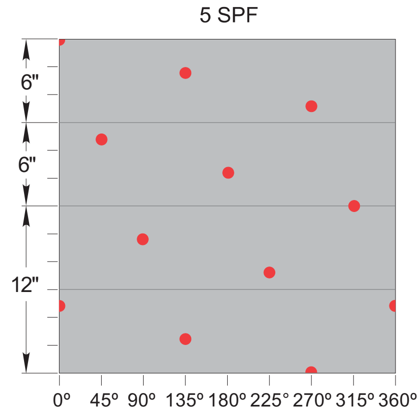


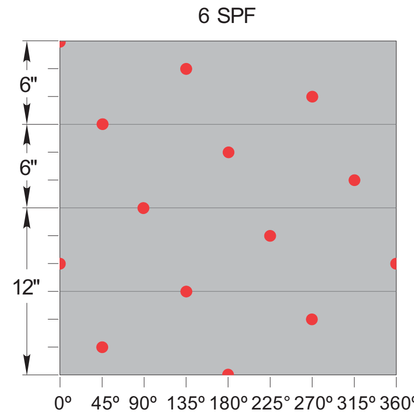
60° Phasing 6 spf 2 Planes

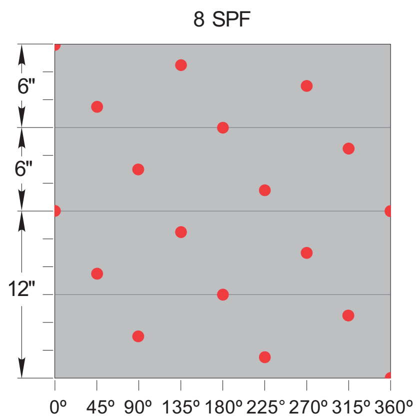


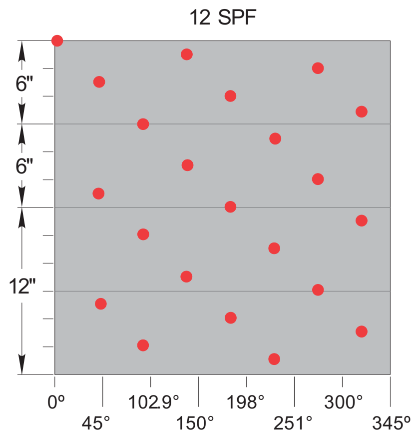
45°/135° Phasing 5, 6, 8, 12, and 18 spf

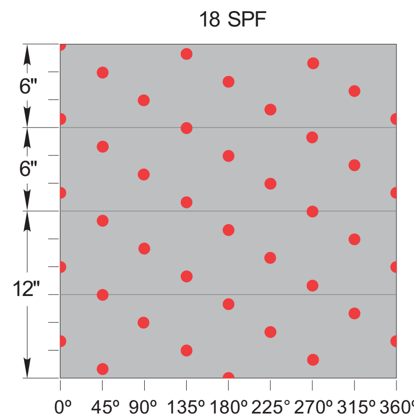




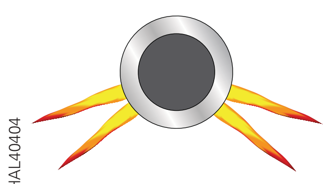


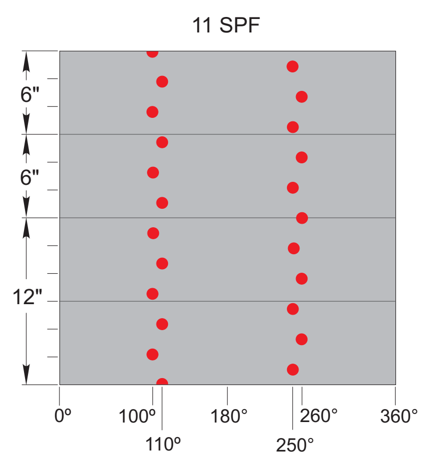




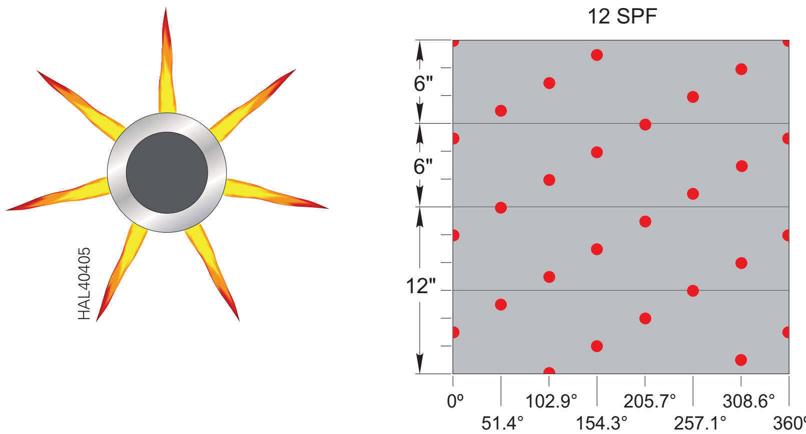


140°/160° Phasing 11 spf

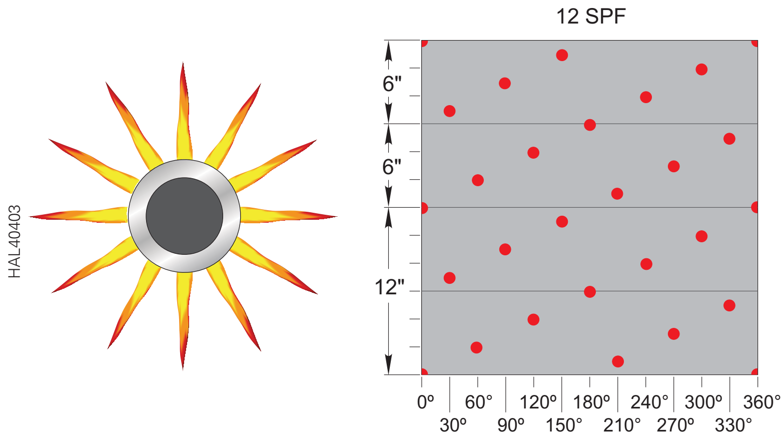




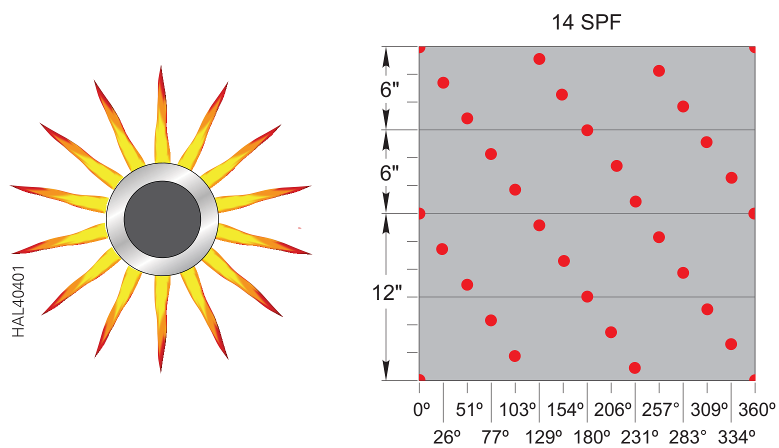
154.3° Phasing 12 spf



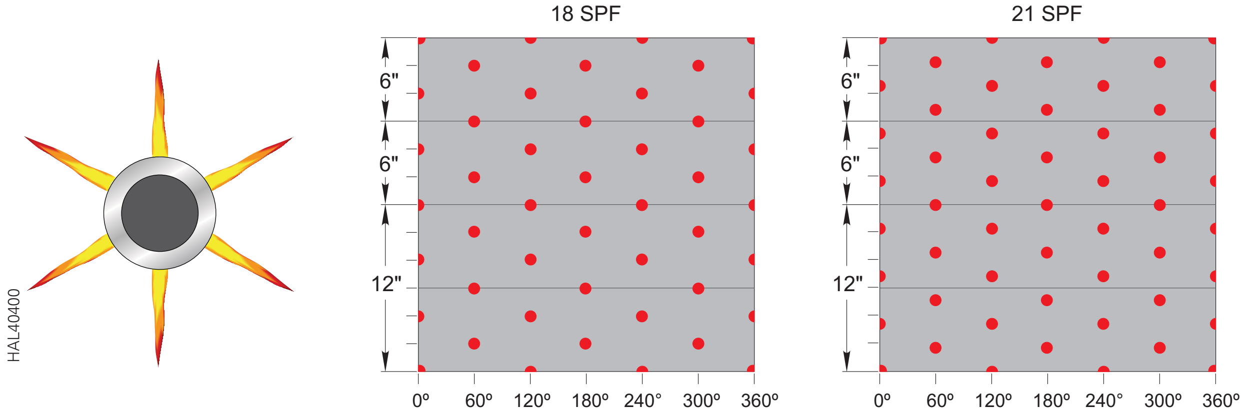
150° Phasing 12 spf



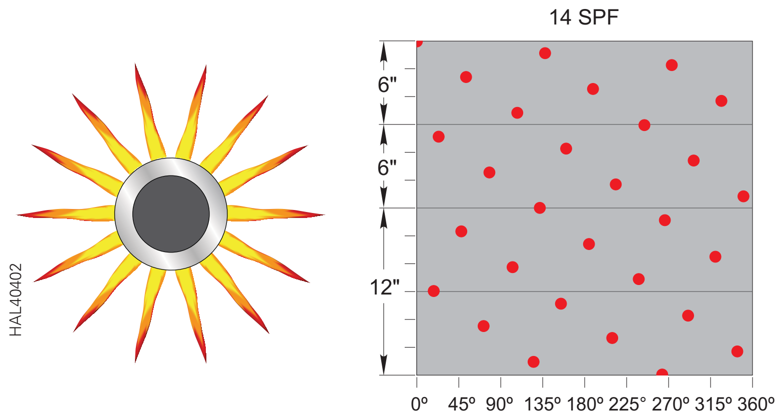
128.5° Phasing 14 spf



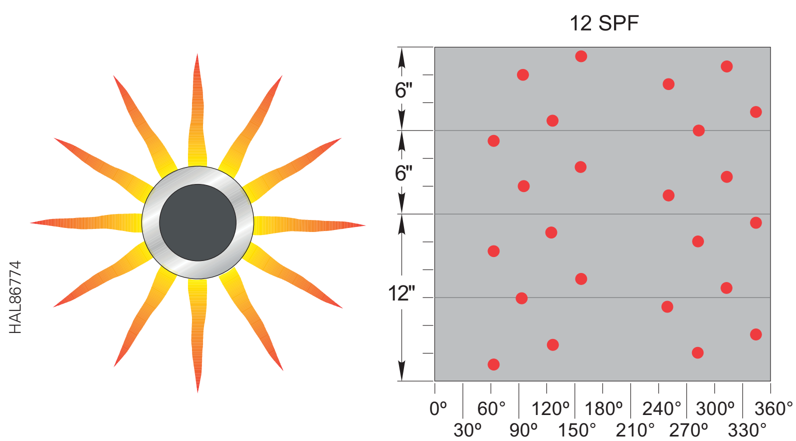
60°/120° Phasing, 3 Shots per Plane, 18 and 21 spf



138° Phasing 14 spf



150° Phasing, 4 Shots Shift, 90° 8 spf

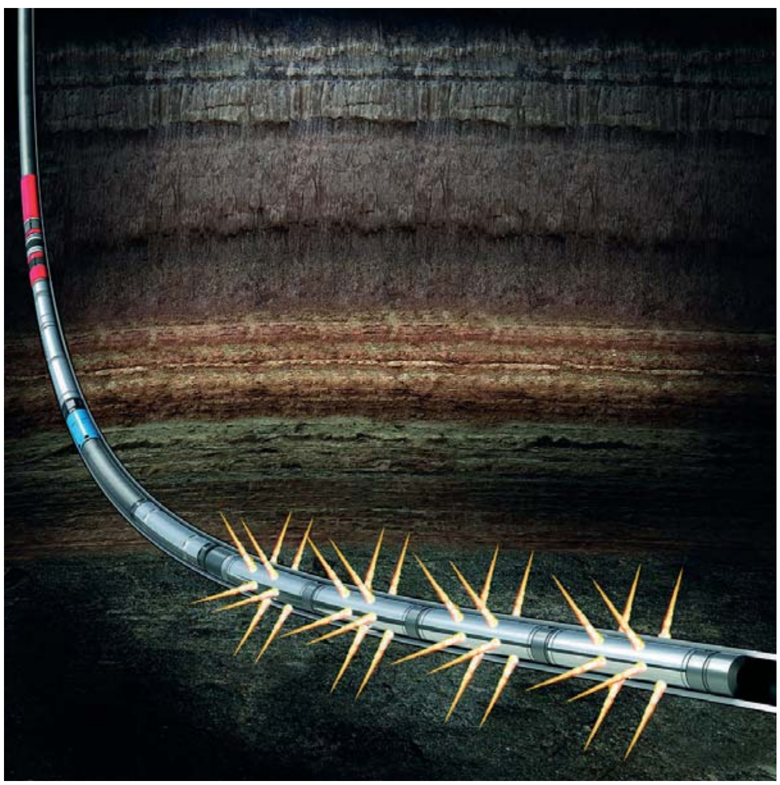


CHE™ Corrosive Hostile Environment System

Corrosion constantly threatens virtually all areas of the oil and gas industry. As the industry moves to exploit hostile reservoirs, perforating equipment (i.e., guns, subs, firing heads, sensors, etc.) must be able to withstand harsh environments, including exposure to H_2S, CO_2, high pressure and high temperatures, chemicals, gases, and/or other corrosive fluids.

The Halliburton CHE™ corrosive hostile environment systems provide exceptional corrosion protection from H_2S, CO_2, saltwater immersion, corrosive vapors, and other hostile environments because of its transmission properties. The CHE system incorporates special materials designed specifically for corrosive and hostile environments, providing protection that can more than triple the service life of components, thus providing access to reservoirs that once were not technologically viable to produce. The CHE systems provide the long-term assurance needed to protect downhole and surface investments.

The novel tubing-conveyed CHE gun system targets corrosive environments, which would deteriorate standard system components over time, leading to increased downhole debris. This could potentially damage millions to tens of millions of dollars of surface production equipment when flowed to surface. Initially designed for a 3 trillion ft^3 of liquids-rich gas corrosive and hostile reservoir, the CHE system needed to survive downhole without significant deterioration for ±20 years. All exposed system components were modified with special CHE machinable materials to resist deterioration in the presence of H_2S, CO_2, produced hydrocarbons, and other wellbore and completion fluids. The components included perforating gun bodies, gun connectors, firing systems, firing head shrouds, deployment connectors, and detach tools.



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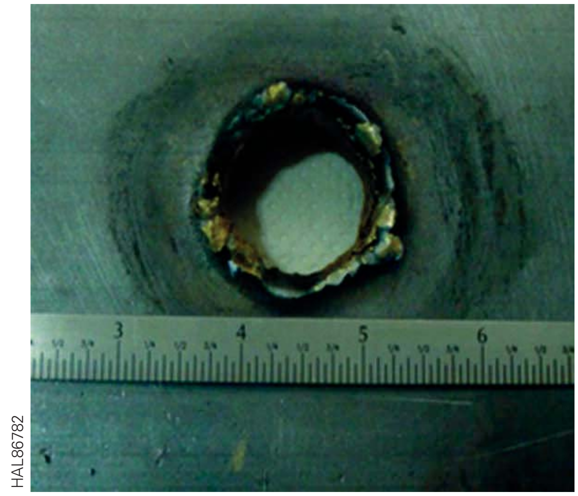
CHE™ Corrosive Hostile Environment System

Deepwater Gun Systems

6 3/4-in. 18-spf MaxForce® Flow™ System

The increased flow area of the 6 3/4-in. 18-spf MaxForce® Flow™ system enhances both conventional and flux-based completion approaches. Maximizing the flow area reduces the pressure drop across the perforations and the effective force on the individual sand grains, resulting in fewer screen washouts and less potential for sand production. All of this is achieved without sacrificing fishing ability in heavy wall casings.



The 6 3/4-in. 18-spf MaxForce® Flow™ system features a flow area of 14.7 in.²/ft.

Applications

- Provides an effective perforation solution focused on:
  - Deep water
  - Sand control completions
  - Stimulation completions
  - Natural completions
- Helps eliminate potential costs associated with sand production without mechanical segregation techniques

Features

- Extensive flow area of 14.7 in.²/ft
- 1.07-in. entry hole per perforation

Benefits

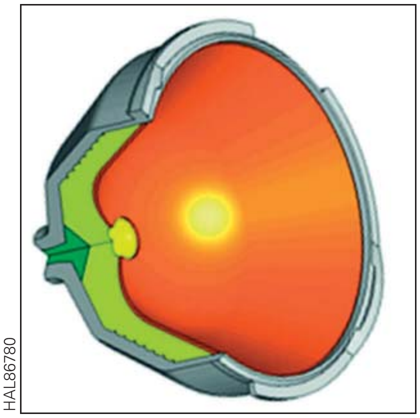
- High-pressure rating suitable for deep water
- High shot density with maximum phasing delivers a high flow area of 14.7 in.²/ft
- Reduces risk of screen washout by reducing pressure drawdown and flow rate per perforation
- Reduces risk of sanding production caused by drag from fluid or gas turbulence
- Helps prevent tunnel-to-tunnel stress failures with shot phasing that limit stress contrast
- Helps provide maximized gun size with fishing ability in heavier wall casings

6 3/4-in. 18-spf MaxForce® Flow™ System Specifications

API Section 1 System Test: 9 5/8-in. 47-lb L-80 Casing	
Flow Area	14.7 in.²/ft
Average Casing Hole Diameter	1.07 in.
Average Total Penetration	5.50 in.
API Section 1 System Test: 10 1/8-in. 79.2-lb Q-125 Casing	
Flow Area	8.3 in.²
Average Casing Hole Diameter	0.77 in.
Average Total Penetration	5.80 in.
Mechanical	
Gun OD	6 3/4 in.
Pressure Rating	25,000 psi
Tensile Rating	814,000 lb
Connections	Standard gun threads (pin × box)
Shots per Foot	18 spf 3/plane
Phasing	60°/120°
390 MaxForce® Flow™, HMX, BH Charges	
Explosive Load	39.0 g
Environmental	
Temperature	400°F for 1 hour

6 3/4-in.18-spf MaxForce® Flow™ Low-Debris Zinc System

When a clean wellbore is necessary for a gravel pack, frac pack, or high-rate water pack, 6 3/4-in. 18-spf MaxForce® Flow™ low-debris (LD) zinc charges are the answer. This system offers all the advantages of the MaxForce Flow charges, with an increased flow area that minimizes the pressure drop across the perforations. It also uses patented low-debris charges.



The 6 3/4-in. 18-spf MaxForce® Flow™ low-debris zinc charges help significantly reduce debris mass and particle size.

Applications

- » Provides an effective perforation solution focused on:
  - Deep water
  - Sand control completions
  - Stimulation completions
  - Gravel pack, frac pack, or high-rate water pack
  - Natural completions
- » Helps eliminate potential costs associated with sand production without mechanical segregation techniques
- » Helps eliminate potential issues associated with perforating debris

Features

- » Maximized flow area
- » Clean wellbore for a gravel pack, frac pack, or high-rate water pack
- » LD zinc charges help significantly reduce debris mass and particle size

Benefits

- » High-pressure rating suitable for deep water
- » High shot density with maximum phasing that delivers a high flow area of 9.52 in.^{2}/ft
- » Risk of screen washout reduced by reducing pressure drawdown and flow rate per perforation
- » Risk of sanding production caused by drag from fluid or gas turbulence reduced
- » Downhole risks for mechanical problems related to charge debris during stimulation treatments reduced
- » Shot phasing limits stress contrast and helps prevent tunnel-to-tunnel stress failures
- » Maximized gun size with fishing ability in heavier wall casings
- » Charge debris that can be dissolved with acid

6 3/4-in. 18-spf MaxForce® Flow™ LD Zinc System Specifications

API Section 1 System Test: 9 7/8-in. 62.8-lb Q-125 Casing	
Flow Area	9.52 in.^{2}/ft
Average Casing Hole Diameter	0.82 in.
Average Total Penetration	6.1 in.
Mechanical	
Gun OD	6 3/4 in.
Pressure Rating	25,000 psi
Tensile Rating	814,000 lb
Connections	Standard gun threads (pin × box)
Shots Per Foot	18 spf 3/plane
Phasing	60°/120°
390 MaxForce® Flow™, HMX, BH Charges	
Explosive Load	39.0 g
Environmental	
Temperature	400°F for 1 hour

6 3/4-in. 18-spf MaxForce® Flow™ Ultra-Kleen™ System

The 6 3/4-in. 18-spf MaxForce® Flow™ Ultra-Kleen™ system family features a proprietary charge tube design and provides an almost debris-free operation, even in severe doglegs and high-angle wells.

The 6 3/4-in. 18-spf big hole (BH) MaxForce Flow Ultra-Kleen system helps ensure that debris created from shaped charges is minimized, containing larger debris pieces within the gun system for safe, clean perforating without sacrificing flow area. The system also reduces dynamic transient forces during the perforation event, which safeguards the completion and tubing-conveyed perforating string.

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The 6 3/4-in. 18-spf MaxForce® Flow™ Ultra-Kleen™ system only generates 16 g/ft debris.

Applications

» Provides an exceptional effective perforation solution focused on:
  – Deep water
  – Sand control completions
  – Stimulation completions
  – Gravel pack, frac pack, or high-rate water pack
  – Natural completions
» Helps eliminate potential costs associated with sand production without mechanical segregation techniques
» Helps eliminate potential issues associated with perforating debris

Features

» Maximum flow area
» Lowest debris per foot in the industry (16 g/ft)
» Helps ensure gun system integrity
» Helps reduce dynamic transient forces during the perforation event

Benefits

» Has the lowest amount of debris that exits the carrier during and after the perforating event
» High-pressure rating that is suited for deep water
» Delivers high flow area of 13.04 in.²/ft
» Helps reduce dynamic transient forces during the perforation event
» Helps reduce risks of screen washout by reducing pressure drawdown and flow rate per perforation
» Helps reduce risks of sanding production caused by drag from fluid or gas turbulence
» Helps reduce risks downhole for mechanical problems related to charge debris during stimulation treatments
» Shot phasing that limits stress contrast and helps prevent tunnel-to-tunnel stress failures
» Maximized gun size without sacrificing the ability to fish in heavier wall casings

6 3/4-in. 18-spf MaxForce® Flow™ Ultra-Kleen™ System Specifications

API System Test: 9 7/8-in. × 62.8-lb Q125 Casing Testing	
Flow Area	13.04 in.^{2}/ft
Average Casing Hole Diameter	0.97 in.
Average Total Penetration	6.8 in.
Mechanical	
Gun OD	6 3/4 in.
Pressure Rating	25,000 psi
Tensile Rating	814,000 lb
Connections	Standard gun threads (pin × box)
Shots Per Foot	18 spf 3/plane
Phasing	60°/120°
390 MaxForce® Flow™, HMX, BH Charges	
Explosive Load	39.0 g
Environmental	
Temperature	400°F for 1 hour

Tensile ratings on the following tables are based on the box × pin connection.

1 9/16-in. VannGun® Assemblies

Shot Density	Phase	Charge Part No.	Explosive Type	Charge Type	Explosive Weight g	Maximum Swell in.	Collapse Pressure psi	Tensile Strength lb	Test Environment
6*	60°	100157028	HMX	Millennium™	3.7	1.760	20,000	51,000	Water
	0°	100157028	HMX	Millennium™	3.7	N/A	15,000	51,000	
4*	0°/180°	100157028	HMX	Millennium™	3.7		18,000	51,000	Water
	90°	Same group of charges as gun system above					20,000	51,000	Water
	60°	Same group of charges as gun system above					20,000	51,000	Water
	0°	Same group of charges as gun system above					15,000	51,000	Water

*Not VannSystem® service

2.00-in. VannGun® Assemblies

Shot Density	Phase	Charge Part No.	Explosive Type	Charge Type	Explosive Weight g	Maximum Swell in.	Collapse Pressure psi	Tensile Strength lb	Test Environment
6*	60°	101603801	HMX	MaxForce®	7	2.165	20,000	79,000	Water
		101208224	HMX	Millennium™	6.8	2.225			
		101206246	HMX	BH	6.8				
		100157018	HMX	DP	6.2				
	0°	101208224	HMX	Millennium™	6.8	2.177	17,000	79,000	Water
		101206246	HMX	BH	6.8				
		100157018	HMX	DP	6.2				
4*	0°/180°	101603801	HMX	MaxForce®	7		17,000	79,000	Water
		101208224	HMX	Millennium™	6.8				
		101206246	HMX	BH	6.8				
		100157018	HMX	DP	6.2				
	90°	Same group of charges as gun system above					20,000	79,000	Water
	60°	Same group of charges as gun system above					23,000	79,000	Water
	0°	Same group of charges as gun system above					17,000	79,000	Water
4	0°	101434895	HMX	BH	2.6	2.048	32,000	68,500	Water

*Not VannSystem® service

2 1/2-in. VannGun® Assemblies

Shot Density	Phase	Charge Part No.	Explosive Type	Charge Type	Explosive Weight g	Maximum Swell in.	Collapse Pressure psi	Tensile Strength lb	Test Environment
6*	60°	101418095	HMX	Millennium™ II	11.1	2.632	23,000	130,000	Water
		101244923	HNS	DP	11		18,000	97,000	Water
4*	0°/180°	101418095	HMX	Millennium™ II	11.1		20,000	130,000	Water
		101244923	HNS	DP	11				
	90°	Same group of charges as gun system above					20,000	130,000	Water
	60°	Same group of charges as gun system above					20,000	130,000	Water
	0°	Same group of charges as gun system above				2.647	18,000	130,000	Water

*Not VannSystem® service

2 3/4-in. VannGun® Assemblies

Shot Density	Phase	Charge Part No.	Explosive Type	Charge Type	Explosive Weight g	Maximum Swell in.	Collapse Pressure psi	Tensile Strength lb	Test Environment
6	60°	101233817	HMX	Millennium™	15	2.992	24,000	125,000	Water
		101318485	HNS	Millennium™	15.1				
		101233817	HMX	Millennium™	15	2.925	27,000	139,000	Water
		101318485	HNS	Millennium™	15.1				
		101206793	RDX	BH	14.7	2.995	22,000	135,000	Water
		Same group of charges as gun system above					24,000	125,000	Water
	±30°	101233817	HMX	Millennium™	15	2.915	20,000	135,000	Water
		101318485	HNS	Millennium™	15.1				
	0°	101206793	RDX	BH	14.7	2.876	18,000	135,000	Water
	0°/180°	Same group of charges as gun system above					29,000	135,000	Water
4	0°/180°	101233817	HMX	Millennium™	15		29,000	135,000	Water
		101318485	HNS	Millennium™	15.1				

2 7/8-in. VannGun® Assemblies

Shot Density	Phase	Charge Part No.	Explosive Type	Charge Type	Explosive Weight g	Maximum Swell in.	Collapse Pressure psi	Tensile Strength lb	Test Environment
6	99°	101826652	HMX	MaxForce®	17.5	3.021	20,000	141,000	Water
	60°	101233817	HMX	Millennium™	15	3.046	27,000	139,000	Air
		101318485	HNS	Millennium™	15.1				Water
		101826652	HMX	MaxForce®	17.5	3.070	27,000	141,000	Water
		101388406	HMX	Millennium™	17.5	3.108	27,000	139,000	Water
		101388407	HNS	Millennium™	18.5				
	60° (HW)	101233817	HMX	Millennium™	15	3.044	25,000	180,000	Air
		101318485	HNS	Millennium™	15.1				Water
4	0°/180°	101233817	HMX	Millennium™	15		26,000	141,000	Water
		101318485	HNS	Millennium™	15.1				

3 1/8-in. VannGun® Assemblies

Shot Density	Phase	Charge Part No.	Explosive Type	Charge Type	Explosive Weight g	Maximum Swell in.	Collapse Pressure psi	Tensile Strength lb	Test Environment
10*	45°/135°	102327840	HMX	MaxForce® Flow™	14	3.285	17,000	87,000	Water
	45°/135°	101351605	HMX	Mirage® SH	14		21,000	108,000	Water
6	99°	101826652	HMX	MaxForce®	17.5	3.296	23,000	149,000	Water
6*	60°	101366678	HMX	Millennium™ -IS	21	3.338	25,000	108,000	Water
		101618994	RDX	Millennium™ -IS	21				
		102045430	RDX	MaxForce®-FRAC	21				
		102322540	HNS	Millennium™ -IS	21				
		102036926	HMX	MaxForce® Flow™	22	3.320	25,000	97,000	Water
		102185516	HMX	MaxForce® Flow™ (LD)	22				
		101388406	HMX	Millennium™	17.5	3.333	25,000	108,000	Air
5*	90°	101895090	HMX	Dominator®	19	3.324	25,000	97,000	Air

3 1/8-in. VannGun® Assemblies

Shot Density	Phase	Charge Part No.	Explosive Type	Charge Type	Explosive Weight g	Maximum Swell in.	Collapse Pressure psi	Tensile Strength lb	Test Environment
4	0°/180°	100008249	HMX	SDP	25		25,000	151,000	Water
		101207640	HMX	DP-LD	24				
		101233819	HMX	Millennium™	25				
		101309223	HMX	Dominator®	25.1				
		101365876	HNS	Millennium™	25				
		102326523	HNS	Dominator®	25				

*Not VannSystem® service

3 3/8-in. VannGun® Assemblies

Shot Density	Phase	Charge Part No.	Explosive Type	Charge Type	Explosive Weight g	Maximum Swell in.	Collapse Pressure psi	Tensile Strength lb	Test Environment
12	30°/150°	100005312	HMX	BH	14	3.568	22,000	220,000	Water
		100008251	RDX	BH	14	3.538			
		Same group of charges as gun system above					23,000	237,000	Water
		101351605	HMX	Mirage®-SH	14	3.548	23,000	237,000	Water
10	45°/135°	102327840	HMX	MaxForce® Flow™	14	3.500	22,000	216,300	Water
6	±30°	100008249	HMX	SDP	25		19,000	220,000	Water
		101207640	HMX	DP-LD	24				
		101233819	HMX	Millennium™	25				
		101309223	HMX	Dominator®	25.1				
		101365876	HNS	Millennium™	25				
		102326523	HNS	Dominator®	25				
		100005321	RDX	BH	23		23,000	237,000	Water
		100005332	HMX	DP	26				
		100005333	RDX	DP	22				
	60°	101366678	HMX	Millennium™	21		23,000	220,000	Water
		101618994	RDX	Millennium™	21				
		102045430	RDX	MaxForce®-FRAC	21				
		102322540	HNS	Millennium™	21				
		Same group of charges as gun system above					25,000	237,000	Water
		Same group of charges as gun system above				3.6	21,000	199,000	Water
		100008249	HMX	SDP	25	3.585	30,000	291,000	Water
		101207640	HMX	DP-LD	24				
		101233819	HMX	Millennium™	25				
		101309223	HMX	Dominator®	25.1				
		101365876	HNS	Millennium™	25				
		102326523	HNS	Dominator®	25				
		Same group of charges as gun system above				3.695	23,000	225,000	Water
		Same group of charges as gun system above					21,000	199,900	Water
		102036926	HMX	MaxForce® Flow™	22		23,000	216,300	Water
		100005321	RDX	BH	23	3.583	23,000	222,000	Water
		100005332	HMX	DP	26				
		100005333	RDX	DP	22				

3 3/8-in. VannGun® Assemblies

Shot Density	Phase	Charge Part No.	Explosive Type	Charge Type	Explosive Weight g	Maximum Swell in.	Collapse Pressure psi	Tensile Strength lb	Test Environment
5	0°	100008249	HMX	SDP	25		20,000	237,000	Water
		101207640	HMX	DP-LD	24				
		101233819	HMX	Millennium™	25				
		101309223	HMX	Dominator®	25.1				
		101365876	HNS	Millennium™	25				
		102326523	HNS	Dominator®	25				
		Same group of charges as gun system above					TBD*	220,000	Water
4	0°/180°	100005322	RDX	DP	32		25,000	242,000	Water
		100008249	HMX	SDP	25	3.546			
		101207640	HMX	DP-LD	24				
		101233819	HMX	Millennium™	25				
		101309223	HMX	Dominator®	25.1				
		101332806	HNS	DP	32				
		101365876	HNS	Millennium™	25				
		102326523	HNS	Dominator®	25				
		Same group of charges as gun system above					25,000	220,000	Water
	60°	100005322	RDX	DP	32	3.592	25,000	232,000	Water
		100008249	HMX	SDP	25				
		101207640	HMX	DP-LD	24				
		101233819	HMX	Millennium™	25				
		101309223	HMX	Dominator®	25.1				
		101332806	HNS	DP	32				
		101365876	HNS	Millennium™	25				
		102326523	HNS	Dominator®	25				
		Same group of charges as gun system above					18,000	215,000	Water
	90°	Same group of charges as gun system above					25,000	237,000	Water
		Same group of charges as gun system above					18,000	215,000	Water

3.5-in. VannGun® Assemblies

Shot Density	Phase	Charge Part No.	Explosive Type	Charge Type	Explosive Weight g	Maximum Swell in.	Collapse Pressure psi	Tensile Strength lb	Test Environment
6	60°	100008249	HMX	SDP	25		22,000	290,000	Water
		101207640	HMX	DP-LD	24				
		101233819	HMX	Millennium™	25				
		101309223	HMX	Dominator®	25.1				
		101365876	HNS	Millennium™	25				
		102326523	HNS	Dominator®	25				
	60° (13% Cr)	101365876	HNS	Millennium™	25	3.67	20,000	135,000	Water
		102326523	HNS	Dominator®	25				
		101365876	HNS	Millennium™	25		17,000	116,000	Water
		102326523	HNS	Dominator®	25	3.86			

4.00-in. VannGun® Assemblies

Shot Density	Phase	Charge Part No.	Explosive Type	Charge Type	Explosive Weight g	Maximum Swell in.	Collapse Pressure psi	Tensile Strength lb	Test Environment
7	30°/150°	100005311	RDX	SH	28		13,000	264,000	Water
		100156995	HMX	SH	28				
		101233690	HMX	SH-LD	28	4.849			
6	60°	100005322	RDX	DP	32		18,000	264,000	Water
		100008249	HMX	SDP	25				
		101207640	HMX	DP-LD	24				
		101233819	HMX	Millennium™	25				
		101309223	HMX	Dominator®	25.1				
		101332806	HNS	DP	32				
		101365876	HNS	Millennium™	25				
		102326523	HNS	Dominator®	25				
		Same group of charges as gun system above					13,000	284,000	Water
4	60°	Same group of charges as gun system above					13,000	284,000	Water
		Same group of charges as gun system above					18,000	264,000	
	90°	Same group of charges as gun system above					13,000	264,000	
		Same group of charges as gun system above					18,000	284,000	

4 5/8-in. VannGun® Assemblies

Shot Density	Phase	Charge Part No.	Explosive Type	Charge Type	Explosive Weight g	Maximum Swell in.	Collapse Pressure psi	Tensile Strength lb	Test Environment
18	45°/135°	100157005	HMX	DP	15		18,000	406,000	Water
		100156990	RDX	BH	20	4.730	18,000	406,000	
14	26°/231°	100005311	RDX	SH	28		20,000	406,000	Water
		100156995	HMX	SH	28				
12	30°/150°	100005311	RDX	SH	28		20,000	406,000	Water
		100156995	HMX	SH	28				
		101233690	HMX	SH-LD	28	4.849			
		Same group of charges as gun system above					19,000	377,000	Water
		100005319	RDX	BH	25		19,000	377,000	Water
		100005326	RDX	BH-LD	22.7	4.84			
		100005340	HMX	DP-LD	23	4.925			
		100157006	HMX	BH	25				
		101210674	HMX	Millennium™	22.7	4.985			
		120038060	HMX	BH-LD	22.7	4.802			
		101343830	HNS	DP	21.5				
		Same group of charges as gun system above					20,000	406,000	Water
		Same group of charges as gun system above				4.812	15,000	284,000	Water
	45°/135°	Same group of charges as gun system above					19,000	377,000	Water
	30°/150°	101826652	HMX	MaxForce®	17.5	4.805	19,000	377,000	Water
		101826652	HMX	MaxForce®	17.5	4.812	15,000	284,000	
11	Oriented ±70°/±80°	100005319	RDX	BH	25		15,000	377,000	Water
		100005326	RDX	BH-LD	22.7				
		100157006	HMX	BH	25				
		101210674	HMX	Millennium™	22.7				
		120038060	HMX	BH-LD	22.7				
		101343830	HNS	DP	21.5				
		Same group of charges as gun system above					16,000	406,000	Water

4 5/8-in. VannGun® Assemblies

Shot Density	Phase	Charge Part No.	Explosive Type	Charge Type	Explosive Weight g	Maximum Swell in.	Collapse Pressure psi	Tensile Strength lb	Test Environment
8	0°/180°	100005319	RDX	BH	25		16,000	377,000	Water
		100005326	RDX	BH-LD	22.7	4.86			Air
						4.78			Water
		100157006	HMX	BH	25				
		101210674	HMX	Millennium™	22.7				
		120038060	HMX	BH-LD	22.7				
		101343830	HNS	DP	21.5				
		Same group of charges as gun system above					18,000	406,000	Water
		100005311	RDX	SH	28	4.770	18,000	406,000	Water
		100156995	HMX	SH	28				
		101233690	HMX	SH-LD	28	4.800			
		Same group of charges as gun system above					16,000	377,000	Water
6	60°	101505061	HMX	MaxForce®	31		20,000	406,000	Water
		101505061	HMX	MaxForce®	31		18,000	377,000	
		100005322	RDX	DP	32	4.758	18,000	377,000	
		100008249	HMX	SDP	25				
		101207640	HMX	DP-LD	24				
		101233819	HMX	Millennium™	25				
		101309223	HMX	Dominator®	25.1				
		101332806	HNS	DP	32				
		101365876	HNS	Millennium™	25				
		102326523	HNS	Dominator®	25				
		Same group of charges as gun system above					20,000	406,000	Water
5	60°	101207997	HMX	Millennium™	39	4.867	20,000	406,000	Water
		101210636	HMX	Millennium™	39	4.944	19,000	377,000	Water
						4.999			Air
		101287306	HNS	DP	39				Water
		101355271	RDX	Millennium™	39				
		101356077	HNS	Dominator®	39				
		Same group of charges as gun system above					20,000	406,000	Water
		Same group of charges as gun system above				4.887	17,000	284,000	Water
		101702911	HMX	Millennium™ II	39	4.887	17,000	284,000	Water
		102054947	HMX	MaxForce®	39				
		Same group of charges as gun system above					20,000	398,000	Water
	72°	101702911	HMX	Millennium™ II	39	4.866	18,000	377,000	Water
		102054947	HMX	MaxForce®	39	4.884			Air
		Same group of charges as gun system above				4.887	17,000	284,000	Water
		Same group of charges as gun system above					20,000	406,000	Water
	45°/135°	101228037	RDX	Mirage® SH	39		20,000	377,000	Water
		101304878	RDX	Mirage®	47				
		101329124	HMX	Mirage®	47				
		101357518	RDX	Maxim®	56.5	4.904			
		102322115	HMX	Mirage®	39				
4	0°	101210636	HMX	Millennium™	39	4.887	20,000 (SlickWall)	367,000	Air
		101287306	HNS	DP	39				Water
		101355271	RDX	Millennium™	39				
		101356077	HNS	Dominator®	39				
	0°/180°	Same group of charges as gun system above					17,000	377,000	Water

4 3/4-in. VannGun® Assemblies

Shot Density	Phase	Charge Part No.	Explosive Type	Charge Type	Explosive Weight g	Maximum Swell in.	Collapse Pressure psi	Tensile Strength lb	Test Environment
12	30°/150°	100005319	RDX	BH	25		22,000	509,000	Water
		100005326	RDX	BH-LD	22.7				
		100005340	HMX	DP-LD	23				
		100157006	HMX	BH	25				
		101210674	HMX	Millennium™	22.7				
		120038060	HMX	BH-LD	22.7				
		101343830	HNS	DP	21.5				
		100005311	RDX	SH	28		22,000	509,000	
		100156995	HMX	SH	28				
		101233690	HMX	SH-LD	28	4.922			

4 3/4-in. Heavy Wall VannGun® Assemblies

Shot Density	Phase	Charge Part No.	Explosive Type	Charge Type	Explosive Weight g	Maximum Swell in.	Collapse Pressure psi	Tensile Strength lb	Test Environment
14	45°/135°	101787632	HMX	BH-LD	21	4.995	31,000	547,000	Water

5.00-in. VannGun® Assemblies

Shot Density	Phase	Charge Part No.	Explosive Type	Charge Type	Explosive Weight g	Maximum Swell in.	Collapse Pressure psi	Tensile Strength lb	Test Environment
21	60°/120°	101292616	RDX	BH	22	5.198	16,000	388,000	Water
12	30°/150°	100005311	RDX	SH	28		20,000 (Sleeved)	388,000	Water
		100156995	HMX	SH	28				
		101233690	HMX	SH-LD	28				

5 1/8-in. VannGun® Assemblies

Shot Density	Phase	Charge Part No.	Explosive Type	Charge Type	Explosive Weight g	Maximum Swell in.	Collapse Pressure psi	Tensile Strength lb	Test Environment
21	60°/120°	101292616	RDX	BH	22	5.268	16,000	501,000	Water
14	26°/231°	100005311	RDX	SH	28		16,000	465,000	Water
		100156995	HMX	SH	28				
		101233693	HMX	SH-LD	28				
		100157007	RDX	SH	32	5.332		501,000	
		100157011	HMX	SH	32				
		Same group of charges as gun system above						465,000	
12	30°/150°	100005319	RDX	BH	25		16,000	501,000	Water
		100005326	RDX	BH-LD	22.7				
		100005340	HMX	DP-LD	23				
		100157006	HMX	BH	25				
		101210674	HMX	Millennium™	22.7				
		120038060	HMX	BH-LD	22.7				
		101343830	HNS	DP	21.5				

5 3/4-in. VannGun® Assemblies

Shot Density	Phase	Charge Part No.	Explosive Type	Charge Type	Explosive Weight g	Maximum Swell in.	Collapse Pressure psi	Tensile Strength lb	Test Environment
21	60°/120°	101292616	RDX	BH	22	6.065	19,000	489,000	Water
18	60°/120°	101688614	HMX	BH-LD	28	5.835	19,000	489,000	Water

5 3/4-in. VannGun® Assemblies

Shot Density	Phase	Charge Part No.	Explosive Type	Charge Type	Explosive Weight g	Maximum Swell in.	Collapse Pressure psi	Tensile Strength lb	Test Environment
10	45°/135°	101357518	RDX	Maxim®	56.5	5.990	20,000	489,000	Water

6 1/2-in. VannGun® Assemblies

Shot Density	Phase	Charge Part No.	Explosive Type	Charge Type	Explosive Weight g	Maximum Swell in.	Collapse Pressure psi	Tensile Strength lb	Test Environment
14	138°	101213474	RDX	SH	56.5		18,000	543,000	Water
		101228037	RDX	Mirage®-SH	39				
		102322115	HMX	Mirage®-SH	39				
		101304878	RDX	Mirage®	47				
		101329124	HMX	Mirage®	47				
		Same group of charges as gun system above					15,000	552,000	
12	45°/135°	Same group of charges as gun system above					15,000	552,000	Water

6 1/2-in. Heavy Wall VannGun® Assemblies

Shot Density	Phase	Charge Part No.	Explosive Type	Charge Type	Explosive Weight g	Maximum Swell in.	Collapse Pressure psi	Tensile Strength lb	Test Environment
14	138°	101213474	RDX	SH	56.5		21,000	685,000	Water
		101228037	RDX	Mirage®-SH	39				
		102322115	HMX	Mirage®-SH	39				
		101304878	RDX	Mirage®	47	6.546			
		101329124	HMX	Mirage®	47				
		101357518	RDX	Maxim®	56.5				
12	45°/135°	101329124	HMX	Mirage®	47		22,000	859,000	Water
		101213474	RDX	SH	56.5				
		101228037	RDX	Mirage®-SH	39				
		101304878	RDX	Mirage®	47				

6 3/4-in. VannGun® Assemblies

Shot Density	Phase	Charge Part No.	Explosive Type	Charge Type	Explosive Weight g	Maximum Swell in.	Collapse Pressure psi	Tensile Strength lb	Test Environment
18	60°/120°	102428572	HMX	MaxForce® Flow™	39	6.845	30,000	1,043,000	Air
		102528007	HMX	MaxForce® Flow™ (LD)	39				
		102428572	HMX	MaxForce® Flow™	39		25,000	814,000	Water
		102528007	HMX	MaxForce® Flow™ (LD)	39	6.906			
		101972806	HMX	MaxForce®	33				
		102505343	HMX	MaxForce® Flow™ Ultra-Kleen™	39	6.845	30,000	1,043,000	Air
		Same group of charges as gun system above				6.846	25,000	814,000	Water
14	138°	101213474	RDX	SH	56.5		27,000	814,000	Water
		101228037	RDX	Mirage®-SH	39				
		102322115	HMX	Mirage®-SH	39				
		101304878	RDX	Mirage®	47				
		101329124	HMX	Mirage®	47	6.955			
		101357518	RDX	Maxim®	56.5	6.925			

6 3/4-in. VannGun® Assemblies

Shot Density	Phase	Charge Part No.	Explosive Type	Charge Type	Explosive Weight g	Maximum Swell in.	Collapse Pressure psi	Tensile Strength lb	Test Environment
12	45°/135°	101329124	HMX	Mirage®	47		27,000	814,000	Water
		101213474	RDX	SH	56.5				

7.00-in. VannGun® Assemblies

Shot Density	Phase	Charge Part No.	Explosive Type	Charge Type	Explosive Weight g	Maximum Swell in.	Collapse Pressure psi	Tensile Strength lb	Test Environment
18	60°/120°	101711688	HMX	Mirage®	39	7.255	18,000 (Sleeved)	762,000	Water
		102351458	HMX	BH	39				
		101833421	HMX	Mirage®	40	7.148	13,000	762,000	
		101711688	HMX	Mirage®	39				
		102351458	HMX	BH	39	7.114			
14	138°	101213474	RDX	SH	56.5		13,000	770,000	Water
		101228037	RDX	Mirage®-SH	39				
		102322115	HMX	Mirage®-SH	39				
		101304878	RDX	Mirage®	47				
		101329124	HMX	Mirage®	47				
		101357518	RDX	Maxim®	56.5				
		Same group of charges as gun system above					12,000	802,000	
12	45°/135°	101228037	RDX	Mirage®	39		11,000	720,000	Water
		102322115	HMX	Mirage®	39				
		101304878	RDX	Mirage®	47				
		101213474	RDX	SH	56.5				
		101228037	RDX	Mirage®-SH	39				
		102322115	HMX	Mirage®-SH	39				
		101304878	RDX	Mirage®	47				
		101329124	HMX	Mirage®	47				
		101357518	RDX	Maxim®	56.5				
		101702911	HMX	Millennium™ II	39	7.227	13,000	777,000	
		102054947	HMX	MaxForce®	39	7.230			
		101702911	HMX	Millennium™ II	39	7.227	11,000	722,000	
		102054947	HMX	MaxForce®	39				
		101207997	HMX	Millennium™	39		13,000	777,000	
		101207997	HMX	Millennium™	39	7.306	11,000	720,000	

VannGun® Pressure Ratings

Halliburton VannGun® assemblies have remained an industry-leading product because of the company's commitment to high-quality construction. Halliburton uses only the best materials and conducts rigorous tests to help ensure a reliable VannGun assembly.

VannGun assemblies are rated to a specific collapse and tensile strength. Each system is qualified at 450°F (232°C) and meets all the requirements of API RP 19B Section 3: Evaluation of Well Perforators. All VannGun assemblies are made of a high-quality seamless tubular that must meet strict metallurgical and mechanical property standards.

In addition to these requirements, during testing each test gun is cut with a minimum scallop thickness to help ensure the scallop is not a failure point. Using these criteria also reduces any additional strength a thicker scallop might bring to the area around the scallop.

Once a VannGun collapse test is conducted and documented, the information is reviewed. If a VannGun assembly is collapsed during testing, the initial gun rating is reduced to the last pressure at which it survived for 1 hour. If no failure occurred, the VannGun initial rating will be the last pressure at which the gun survived for 1 hour before the testing was terminated.

After the initial rating is determined, the rating is reduced to reflect a gun cut to minimum material conditions. This helps ensure that even if a VannGun assembly is manufactured to the worst allowable tolerances, it will still survive the pressure rating. After the adjustment is made for minimum material conditions, the gun rating is lowered again, so there is a minimum safety factor of 5% as required by API RP 19B Section 3: Evaluation of Well Perforators. These calculations can be found in the section marked "Collapse Rating Calculations" for each VannGun assembly tested.

In some instances, the maximum collapse pressure rating of VannGun assemblies might be higher than tested because the pressure chamber used to qualify most VannGun assemblies do not exceed a pressure of 30,000 psi (2068 bar). A pressure chamber that allowed higher pressures in some cases would allow higher ratings for VannGun assemblies.

The raw material and test criteria under which VannGun assemblies must be tested help ensure every VannGun tool run will survive the required collapse pressure rating.

Thermal Decomposition of Explosives

Explosives are energetic materials with decomposition rates that are exponential functions of temperature. At room temperature, where the decomposition rate is extremely small, the effective shelf life of an explosive can be 1 million years. However, the same material will react within microseconds at 825°C. Other decomposition rates and corresponding lifetimes exist between these two extremes. The decomposition of explosives is a process that generates heat and releases gaseous byproducts. This decomposition is called "thermal outgassing," and if the heat generated by decomposition can be balanced by heat dissipation to the surroundings, then the explosive quietly decomposes until none remains. If, however, the heat generated by decomposition is not removed quickly enough, then it is possible for the process to become unstable and the reaction to accelerate uncontrollably until an explosion occurs (sometimes called "thermal runaway"). The process can be stated in simple terms.

Rate of temperature rise in the explosive	=	Rate of heat generation caused by decomposition	–	Rate of heat loss to the surroundings caused by conduction

The first term on the right-hand side of the equation is an exponential function of temperatures. The second term is linear with respect to temperature. Thus, it becomes apparent that as the temperature increases, the heat generated by decomposition quickly begins to dominate and can result in a variety of outcomes, including catastrophic thermal explosion. To aggravate the process further, it is also possible that the gaseous byproducts generated by decomposition can serve as catalysts to the reaction, thus increasing the rate even more.

The outcomes of thermal decomposition are somewhat distinct and can be divided into the following categories:

- Full detonation: A supersonic reaction consuming all explosive material. Fragments are formed from metallic charge cases, and jets are produced from lined cavity devices.
- Partial detonation: Some of the energetic material is consumed by detonation, but other explosive material can be thrown burning or unreacted. The reaction along the length of the explosive train might cut off.
- Explosion (strong deflagration): A subsonic but rapid burning of the explosive material leading to violent rupture of confining cases and pressure vessels.
- Deflagration: A slightly less rapid reaction than an explosion but still sufficiently strong to rupture cases and pressure vessels into large, relatively slow-moving pieces.
- Burning (weak deflagration): A consumption of energetic material by flame. No significant breakup of cases or metallic components occur. The "shell" of detonating cord might remain intact.
- Exudation (extrusion): The energetic material extrudes, or flows out of its confining structure. Exudation can result in the energetic material coming into contact with other materials not chemically compatible with energetics, which can stimulate more violent reactions.
- Performance degradation: No violent reactions have occurred, but the explosive has thermally degraded to the point it compromises performance and/or reliability.
- Quiet decomposition: The explosive has decomposed at a rate corresponding to its thermal history, but the amount of decomposition is so slight it does not compromise performance or reliability.

To provide guidelines for quiet decomposition vs. violent events, time-temperature curves have been generated for various explosives. As long as conditions remain below the time-temperature curve for a given explosive, it will function properly.

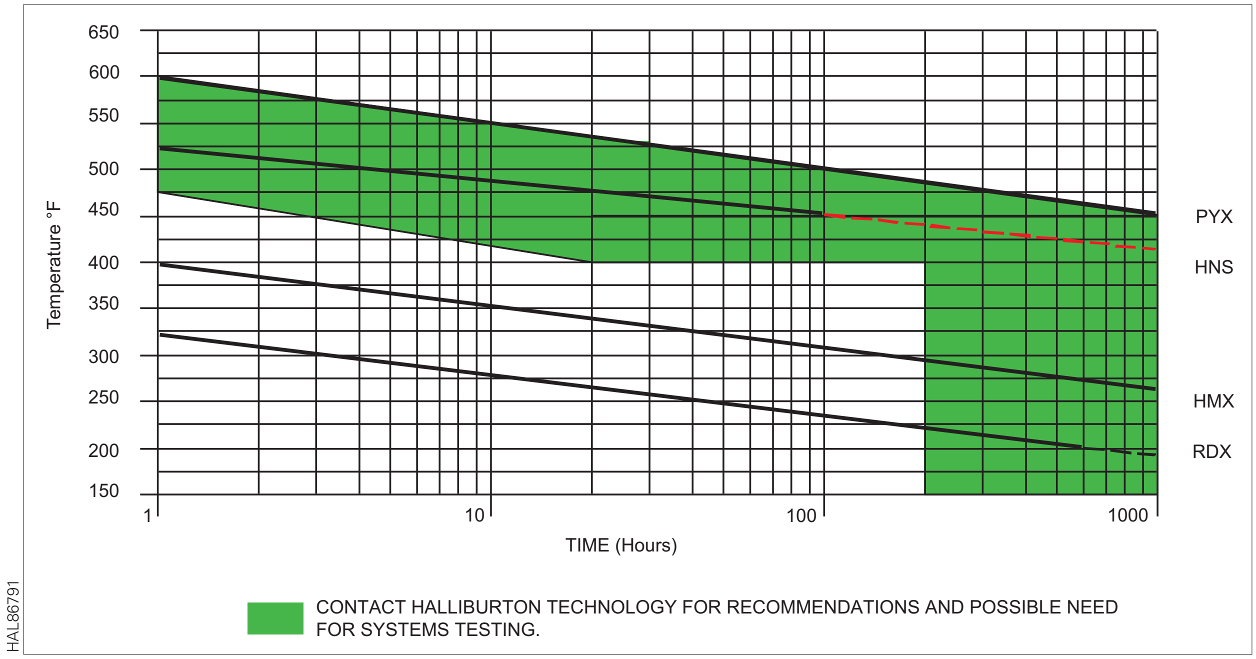
If conditions go above the curve, quiet decomposition might or might not take place, which means it is entirely possible that a violent event can occur. Thus, procedures are in place to remain below the curves. It is also important to recognize that no safety factor is built into these curves, and this must be accounted for when planning any downhole operation requiring the use of energetic materials. Always consider the accuracy of the bottomhole temperature and how long the explosives will remain at that temperature under worst case conditions and adjust accordingly. Past experience related to exposure time has shown that a minimum safety factor of 50% should be applied when choosing the explosive type. For example, if the estimated time on bottom is 60 hours, then add 30 hours for a total of 90 hours when selecting an explosive from the time-temperature chart.

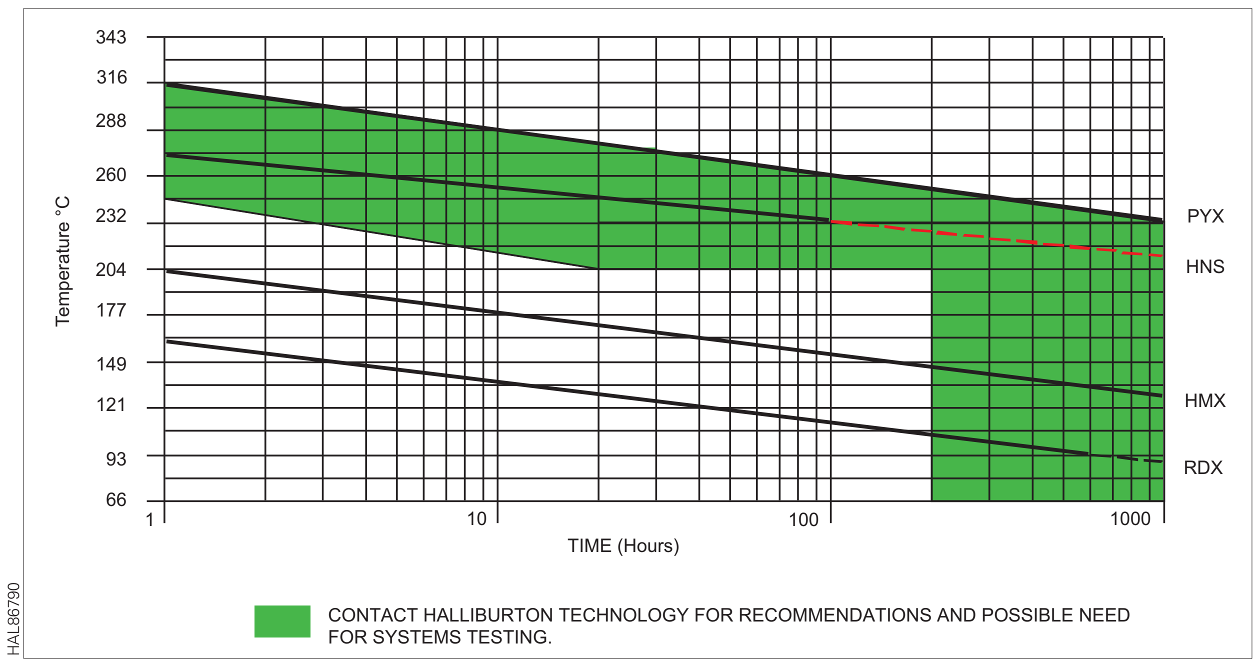
The curve is applicable only for hollow carrier guns wherein the explosive is exposed solely to the effects of temperature. In the case of capsule guns, wherein detonation cord is exposed to both temperature and pressure, the time-temperature relationship is different. Also, the dotted-line portions of the curves are extrapolations of what the time-temperature relationships would be for longer exposure times. For any jobs that fall in these extrapolated ranges of time, it is mandatory that an explosive systems test be conducted by Halliburton Technology.

For more information on thermal decomposition, please contact your local Halliburton representative.

Time vs. Temperature Chart

Operational Limits for Hollow Carrier Gun Systems





Notes:

1. This chart is valid for the explosive train inside hollow carrier guns only: non-electric boosters, detonating cord, and shaped charges.
2. It is not valid for TCP firing systems, electric detonators, or capsule guns.
3. Contact your local Halliburton representative for information regarding these other components.

05

Firing Heads

Time vs. Temperature Charts (page 143)
These charts display time vs. temperature for the PYX initiator, time-delay firer, and high-temperature initiator.

Detonation Interruption Device (page 144)
The detonation interruption device (DID) provides added safety for the VannSystem® service by helping prevent firing at surface conditions. This device contains a eutectic metal, which has a very low melting point. When the metal is in a solid state, the firing head could detonate, but the explosive train will not transmit through the interrupt device to the guns.

Mechanical Firing Head (page 146)
The extended mechanical firing head (MFH) is a special application tool that should only be used when well conditions preclude use of an alternate firing device.

Model II-D Mechanical Firing Head (page 147)
The Model II-D and Model III-D mechanical firing heads are pressure-assisted mechanical firing heads. The detonating bar strikes the firing pin, releasing the firing piston. Hydrostatic pressure then forces the firing piston into the initiator.

Pressure-Actuated Firing Head (page 149)
The pressure-actuated firing head (PAFH) can run with small OD tubing or coiled tubing to detonate small OD perforating guns and is detonated by applied pressure.

Model K and K-II Firing Heads (page 150)
Model K firing heads were developed for conditions that are unfavorable for dropping a detonating bar in a horizontal well. The Model K firing head is a pressure-sensitive tool designed to hydraulically detonate at a prescribed pressure. These firing heads use tubing pressure applied to a piston-type firing pin.

Model KV-II Firing Head (page 152)
The Model KV-II firing head combines a firing head with a vent assembly, which makes firing of the guns and opening of the vent one operation instead of two. This tool helps enable more accurate control of when the vent opens in relation to when the guns fire.

Time-Delay Firer (page 153)
The time-delay firer (TDF) allows under- or overbalanced perforating through the use of a PAFH with a time-delay fuse. With the delay fuse, the actuating pressure can be adjusted in the tubing to achieve the desired pressure before firing the guns.

Multi-Action Delay Firing Head (page 154)
The multi-action-delay firing head is a pressure-actuated redundant firing system that can be run with any one of several other firing heads.

MaxFire® Electronic Firing System (page 153)
The MaxFire® electronic firing system for tubing-conveyed perforating boasts the highest pressure rating in the industry — 40,000 psi (276 MPa) — making it the tool of choice in ultradeepwater applications. Triggering pressure of other tools can exceed the pressure limit of the casing used at the bottom of ultradeep wells. In such cases, the MaxFire system can be programmed to trigger after recognizing a specific sequence of small pressure variations over time.

Quick Change Trigger Device (page 154)
The quick change trigger (QCT) device is a 15,000-psi fully programmable electronic firing head. This unmatched perforating technology is also capable of low-pressure cycle operation and allows for immediate or delayed detonation.

Annulus Pressure Firer-Control Line (page 157)
The annulus pressure firer-control line (APF-C) was developed as a dual-firing system that allows the perforating guns to be detonated by annular pressure, a drop bar, or tubing pressure. The APF-C system consists of a pressure transfer reservoir, a sleeve through the packer mandrel, an adapter below the packer, and a control line to transmit pressure from the annulus above the packer to the APF-C firing head assembly on top of the guns. Any of the mechanical or pressure firing heads can be attached to the top of the APF-C firing head.

Annulus Pressure Transfer Reservoir (page 158)

The annulus pressure transfer reservoir (APTR) is an integral component of the APF-C. It is the mechanism that transmits pressure from above the packer to a differential pressure or pressure-actuated firing head on top of the perforating assembly.

Slimhole Annulus Pressure Firer-Internal Control (page 159)

The slimhole APTR system assembles in a similar manner to the 7- and 9 5/8-in. APTR systems. Only two design changes have been implemented in the new 5-in. APTR system. First, a series of concentric tubes below the packer replaces the control line from larger APTR systems. Second, a single tube mandrel runs through the packer, replacing the series of threaded tube mandrels from the larger APTR systems.

Differential Firing Head (page 160)

The differential firing head was designed to allow underbalanced perforating with a differential pressure-actuated firing system. The firing head works by requiring the internal pressure to be greater than the external pressure. This condition can be created when pressure is applied to the ID or when the OD pressure is reduced. The pressure required to actuate the firing head can be lower than that used for other pressure-operated firing heads because it is operated by differential pressure.

Hydraulic Actuator Firing Head (page 161)

The hydraulic actuator firing head (HAF) is a pressure-balanced tool that automatically fills the tubing string while it is running in the well. A stainless steel ball is dropped from the surface or circulated into position. Pressure applied to the tubing string actuates the HAF. A smaller swivel-type HAF incorporates a swivel into the firing head assembly, which allows the lower portion of the firing head and the attached explosive assembly to rotate independently from the tubing string.

Mechanical Metering Hydraulic-Delay Firing Head (page 163)

The mechanical metering hydraulic-delay firing head provides a retrievable firing system with an adjustable delay for situations where longer delay times are necessary. Delay time can be adjusted and is affected by temperature, tool weight above the piston, the number of jets used, and the amount of fluid in the tool.

Slickline-Retrievable Time-Delay Firer Firing Head (page 165)

The slickline-retrievable time-delay firer (TDF) firing head combines two assemblies — the slickline-retrievable firing head and a 1 11/16-in. TDF firing head. It is a pressure-actuated firing head with built-in pyrotechnic time delay.

Extended Delay Assembly (page 167)

Delay fuses are explosive devices with a slow burning fuse. Extended and modular delay fuses add time between the actuation of the firing head and the actual detonation of the guns. Each delay fuse lasts for 6 minutes at 70°F.

Modular Mechanical Firing Head (page 168)

The modular mechanical firing head is designed to be a retrievable firing system using a standard mechanical firing head with a specialized drop bar for detonation. This system will allow the operator the flexibility to run the gun assemblies independently of the firing system. Once the guns are in place, the firing head is set on the top module and released. The perforation assembly is detonated by use of a special fluted bar dropped from surface.

Annulus Pressure Crossover Assembly (page 171)

The annulus pressure crossover assembly allows the use of annulus pressure to actuate any one of several firing heads. The assembly is compatible with retrievable packers of all types and sizes.

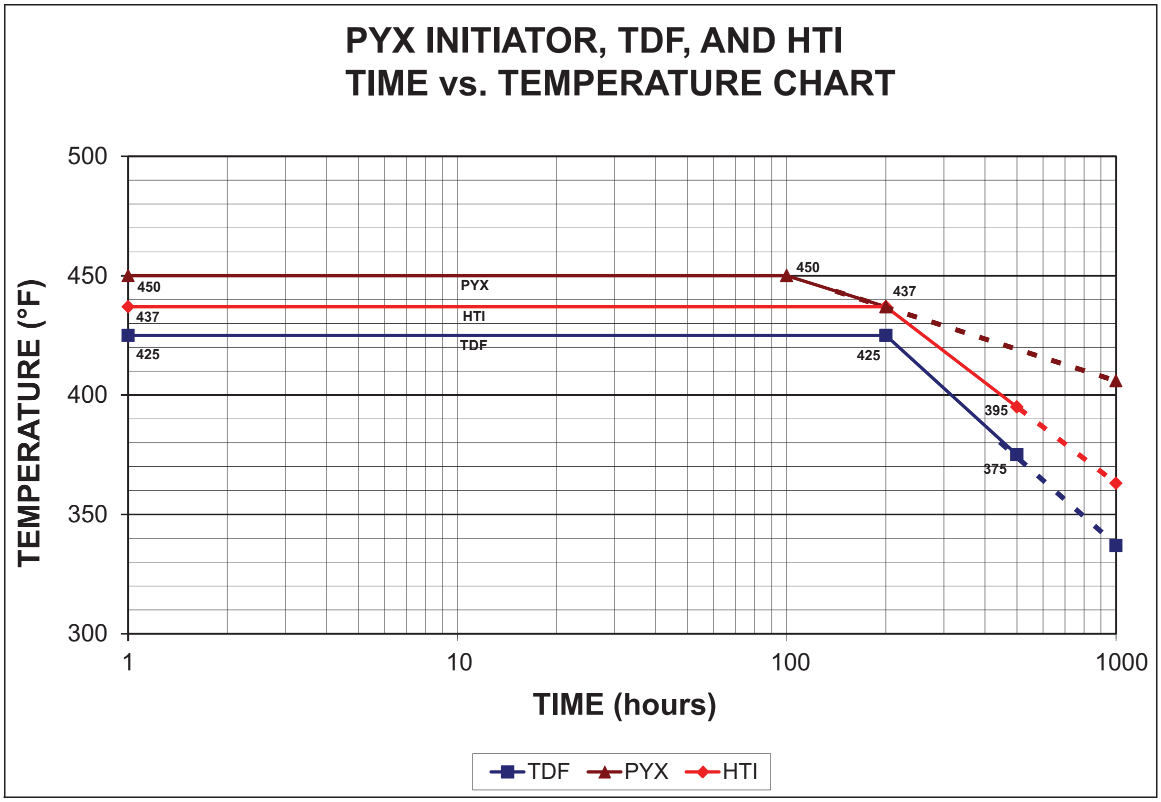
Pump-Through Firing Head (page 172)

The 1 11/16-in. pump-through firing head is designed to be run on coiled tubing and is used for breaking the ceramic flapper valve disk on a one-trip coiled tubing operation.

EZ Cycle™ Multi-Pressure Cycle Firing Head (page 173)

The EZ Cycle™ firing head is a pressure-operated tool that can be cycled several times before firing the perforating guns. Several pressure operations can also be performed on the well including tubing testing, packer setting, and packer testing before firing the perforating guns.

Time vs. Temperature Charts



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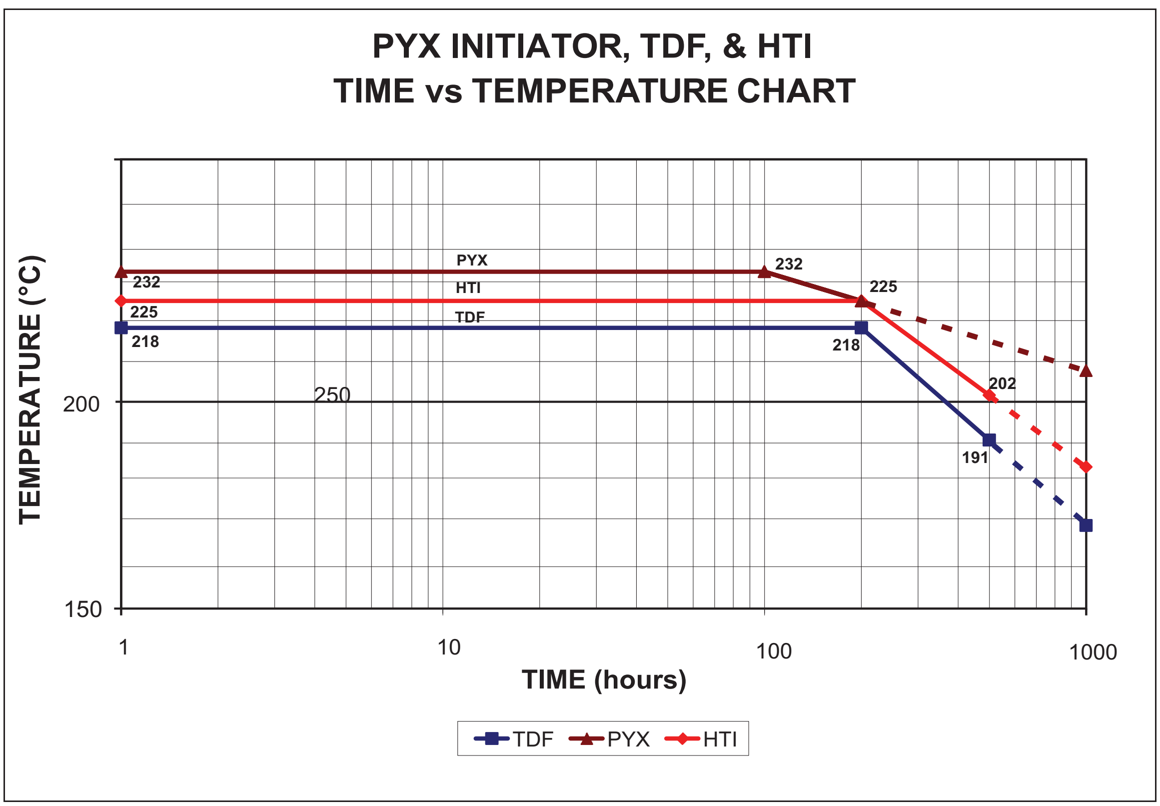

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Detonation Interruption Device

The detonation interruption device (DID) provides added safety for the VannSystem® service by helping prevent firing at surface conditions. This device contains a eutectic metal, which has a very low melting point. When the metal is in a solid state, the firing head could detonate, but the explosive train will not transmit through the interrupt device to the guns.

Features

- Compatible with most firing heads
- Disables transmission of explosive train at surface

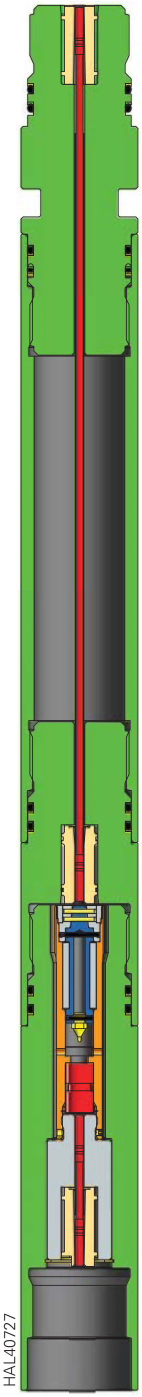
Operation

The eutectic metal will remain solid as the assembly lowers into the hole, assuming the tool temperature is lower than 117°F. When exposed to the bottomhole temperature (minimum 135°F for operational purposes), the metal becomes liquid, allowing the transfer of the explosive train from the firing head to the gun.

To help prevent accidental gun detonation when lowering or retrieving unfired guns, the metal returns to a solid state upon reaching a cooler surface temperature.

Note: The "all fire" temperature for the DID assembly is 135°F and higher. The "no fire" temperature for the DID is lower than 110°F. At temperatures between 110 and 135°F, it is possible the DID could transfer the detonation to the guns. For safety reasons, assume it will transfer; however, for operational planning, assume it will not reliably transfer.

Note: Eutectic material with a higher melt point is available for special applications. Contact TCP Technology for more details.



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Detonation Interruption Device (DID)

Detonation Interruption Device (DID) Specifications

SAP No.	Thread Size and Type in. (mm)	Maximum OD in. (mm)	Makeup Length ft (m)	Maximum Operating Pressure psi (bar)	Minimum Required Temperature Rating °F (°C)	Tensile Strength lb (kg)
101348455	2 1/2 Gun Pin × 2 1/2 Gun Box	2.50 (63.5)	3.41 (1.04)	20,000 (1380)	135 (57)	98,000 (44 452)
101204860	2 3/4 Gun Pin × 2 3/4 Gun Box	2.75 (69.85)	3.62 (1.1)	22,000 (1517)	135 (57)	108,000 (49 215)
100155746	3 3/8 Gun Pin × 3 3/8 Gun Box	3.375 (85.73)	3.04 (0.93)	22,000 (1517)	135 (57)	195,700 (88 768)
102508493	3 1/8 Gun Box × 3 1/8 Gun Pin	3.18 (80.77)	2.04 (0.62)	22,700 (1565)	135 (57)	140,700 (63 820)
102285169[1]	2 1/2 Gun Pin × 2 1/2 Gun Box	2.50 (63.5)	3.41 (1.04)	20,000 (1380)	158 (70)	98,000 (44 452)

[1]Special application: Check with TCP Technology Department.
All available sizes might not be included. Review Enterprise for a complete listing.
Maximum temperature is determined by explosives.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

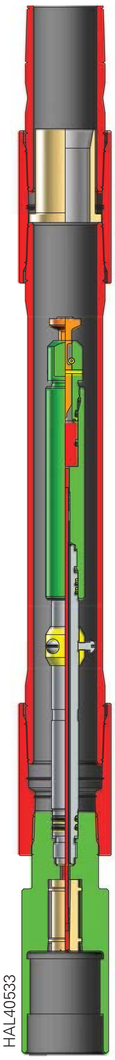
Mechanical Firing Head

The extended mechanical firing head (MFH) special application tool should only be used when well conditions preclude the use of an alternate firing device. When included on a job, the MFH must be used according to Halliburton standard operating procedures.

Operation

The operation of the MFH depends on the amount of force delivered to the firing pin by the detonating bar. This firing pin must be hit with sufficient force to shear the spiral pin that holds the firing pin in place and to detonate the initiator. The firing pin is driven into a percussion detonator that fires the guns.

The detonation interruption device (DID) and a minimum 10 ft of safety spacer must always be used with the MFH.



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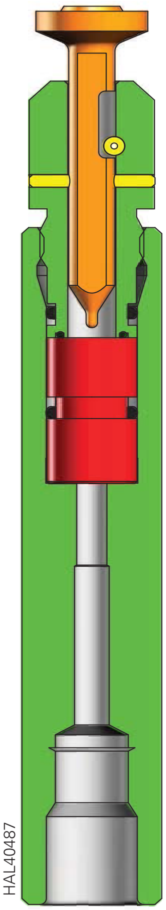
Mechanical Firing Head (MFH)



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Firing Head Subassembly

Mechanical Firing Head (MFH) Specifications

SAP No.	Thread Size and Type in. (mm)	Maximum OD in. (mm)	Makeup Length (with Tubing Sub) ft (m)	Maximum Operating Pressure psi (bar)	Minimum ID (No-Go) in. (mm)	Tensile Strength (FH Body) lb (kg)
100155741	1 7/16 (36.51) 8 UN 2 B Box × 1.90 (48.26) NU 10RD Pin	2.0 (50.8)	1.48 (0.45)	20,000 (1380)	1.53 (38.86)	60,000 (27 200)
100005223	1.90 (48.26) NU 10RD Pin × 2 3/8 (60.33) 6P Acme Box	2.75 (69.85)	4.92 (1.50)	20,000 (1380)	1.56 (39.62)	140,000 (63 400)
100005228	2 3/8 (60.33) EUE 8RD Pin × 2 7/8 (73.03) 6P Acme Box	3.375 (85.73)	4.92 (1.50)	20,000 (1380)	1.56 (39.62)	238,000 (107 900)

All available sizes might not be included. Review Enterprise for a complete listing.
Burst and collapse pressures are determined by handling sub.
Temperature rating is determined by explosives.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

Model II-D Mechanical Firing Head

The Model II-D mechanical firing head (MFH) is a pressure-assisted MFH. The detonating bar strikes the firing pin, releasing the firing piston. Hydrostatic pressure then forces the firing piston into the initiator.

Applications

- Deviated wells

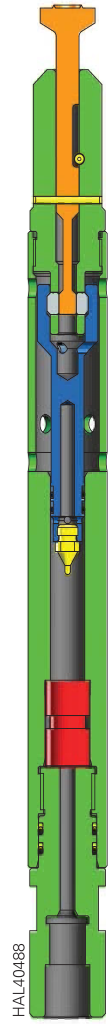
Features

- Cannot be detonated accidentally at surface
- Ideal for use in mud environments in which spudding could be necessary

Operation

The Model II-D MFH requires a minimum of 1,500-psi hydrostatic pressure in the tubing to actuate the firing head properly.

Adding more pressure to the tubing after the detonating bar has struck the firing pin will not actuate the firing head.



Model II-D Mechanical Firing Head (MFH)

Model II-D MFH Assembly

Model II-D Mechanical Firing Head Specifications

SAP No.	Thread Size and Type in. (mm)	Maximum OD in. (mm)	Minimum ID (No-Go) in. (mm)	Makeup Length (with Tubing Sub) ft (m)	Maximum Operating Pressure psi (bar)	Minimum Operating Pressure psi (bar)	Tensile Strength (FH body) lb (kg)
100014156	1.90 (48.26) EUE 10RD Pin × 2 3/8 (60.33) 6P Acme Box	2.75 (69.85)	1.56 (39.62)	4.92 (1.50)	20,000 (1380)	1,500 (103)	140,000 (63 400)
100005227	2 3/8 (60.33) EUE 8RD Pin × 2 7/8 (73.03) 6P Acme	3.375 (85.73)	1.56 (39.62)	4.92 (1.50)	20,000 (1380)	1,500 (103)	238,000 (107 900)

All available sizes might not be included. Review Enterprise for a complete listing.
Burst and collapse pressures are determined by handling sub.
Temperature rating is determined by explosives.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

Model III-D Mechanical Firing Head

The Model III-D mechanical firing head (MFH) is a pressure-assisted MFH. The detonating bar strikes the firing pin, releasing the firing piston. Hydrostatic pressure then forces the firing piston into the initiator.

The Model III-D MFH requires a minimal amount of hydrostatic pressure to actuate the firing head.

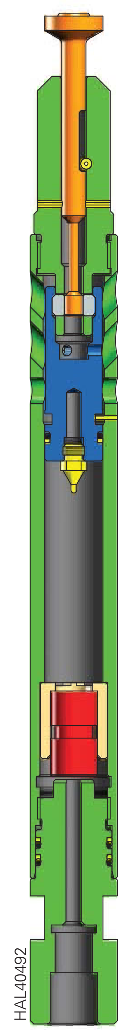
Features

- Cannot be detonated accidentally at surface
- Minimal hydrostatic pressure necessary to actuate the firing head

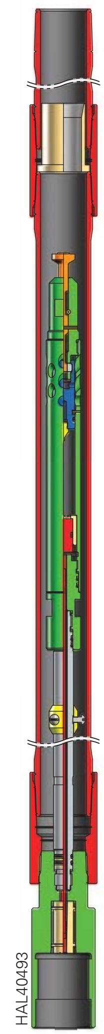
Operation

The Model III-D MFH requires a minimum of 250-psi hydrostatic pressure in the tubing to actuate the firing head properly. This minimal actuating pressure is ideal for applications that require maximum differential pressures.

If a detonating bar is dropped on the Model III-D MFH with less than 250-psi hydrostatic pressure in the tubing, and the head does not fire, increasing the hydrostatic pressure in the tubing could cause it to fire.



Model III-D Mechanical Firing Head (MFH)



Model III-D MFH Assembly

Model III-D Mechanical Firing Head Specifications

SAP No.	Thread Size and Type in. (mm)	Maximum OD in. (mm)	Minimum ID (No-Go) in. (mm)	Makeup Length (with Tubing Sub) ft (m)	Maximum Operating Pressure psi (bar)	Minimum Operating Pressure psi (bar)	Tensile Strength (FH Body) lb (kg)
100155742	1.90 (48.26) EUE 10 Rd Pin × 2 3/8 (60.33) 6P Acme Box	2.75 (69.85)	1.56 (39.62)	4.92 (1.50)	8,000 (550)	250 (17)	140,000 (63 400)
100005191	2 3/8 (60.33) EUE 8 Rd Pin × 2 7/8 (73.03) 6P Acme Box	3.375 (85.73)	1.56 (39.62)	4.92 (1.50)	8,000 (550)	250 (17)	238,000 (107 900)

All available sizes might not be included. Review Enterprise for a complete listing.
Burst and collapse pressures are determined by handling sub.
Temperature rating is determined by explosives.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

Pressure-Actuated Firing Head

The 1 11/16-in. pressure-actuated firing head (PAFH) can run with small OD tubing or coiled tubing to detonate small OD perforating guns. The PAFH is detonated by applied pressure.

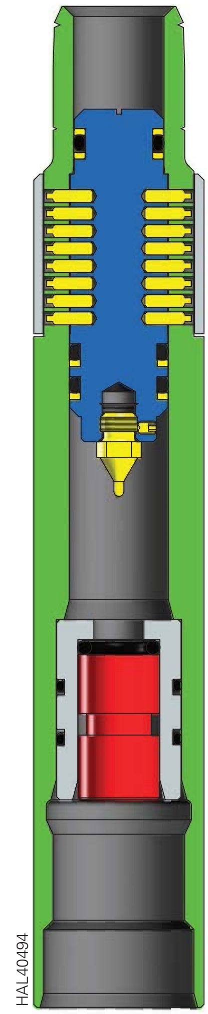
Features

- Can be run on the top and bottom of the gun assembly
- Initiates a bridge-plug setting tool
- Initiates tubing cutters
- Detonates tubing punch charges for squeeze or circulating operations
- Can be run to remain closed after detonation
- Can be modified to be run as a slickline-retrievable firing head and a time-delay firing head (TDF)

Operation

The 1 11/16-in. PAFH consists of an upper housing with circulating ports, a firing piston shear-pinned in place across the circulating ports, and an initiator contained in a lower housing.

Pressure applied to the tubing string shears the shear set, which forces the firing piston into the initiator to detonate the explosive component attached to the PAFH. The downward movement of the firing piston opens the circulating ports.



Pressure-Actuated Firing Head (PAFH)

Pressure-Actuated Firing Head (PAFH) Specifications

SAP No.	Thread Size and Type in. (mm)	Maximum OD in. (mm)	No. and ID of Ports in. (mm)	Flow Area of Ports in.² (cm²)	Makeup Length ft (m)	Maximum Operating Pressure psi (bar)	Minimum Operating Pressure psi (bar)	Tensile Strength lb (kg)	Collapse Pressure psi (bar)
100005224	1.315 (33.40) NU-10RD Pin × 17/16 (36.51) 8 UN-2 B Box	1.70 (43.18)	2 at 0.75 (19.05)	0.64 (4.13)	0.73 (0.22)	22,100 (152 374)	2,200 (150)	38,500 (17 463)	27,000 (1860)

All available sizes might not be included. Review Enterprise for a complete listing.
Temperature rating is determined by explosives.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

Model K and K-II Firing Heads

The Model K and K-II firing heads were developed for conditions unfavorable for dropping a detonating bar in a horizontal well. The Model K and K-II firing heads are pressure-sensitive tools designed to hydraulically detonate at a prescribed pressure. These firing heads use tubing pressure applied to a piston-type firing pin.

Applications

- Ideal for balanced or overbalanced perforating
- Well suited for highly deviated well completions

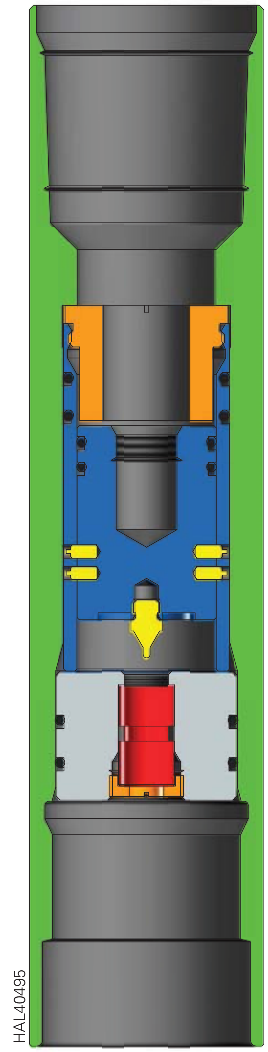
Features

- Allows the operator to determine the exact time guns will fire because firing heads require a predetermined pressure before detonation
- Works with full-opening or non-full-opening downhole tools
- Can be used for dual completions, drillstem testing, or production perforating
- Can be run on the top or bottom of the perforating assembly
- Can be easily redressed

Operation

The Model K and K-II firing heads are designed to provide a reliable, cost-effective method for firing guns using hydrostatic pressure. Each firing head contains a firing piston shear-pinned in place above an initiator. The number of shear pins used varies for each well scenario.

When sufficient hydrostatic pressure is applied to the piston, the shear pins shear, thereby allowing the firing pin on the lower end of the piston to be driven into the initiator. This action detonates the guns. These firing heads do not have a built-in delay.



Model K Firing Head

Model K Firing Head Specifications

SAP No.	Thread Size and Type in. (mm)	Maximum OD in. (mm)	Makeup Length ft (m)	Maximum Operating Pressure psi (bar)	Minimum Operating Pressure psi (bar)	Tensile Strength lb (kg)	Collapse Pressure psi (bar)
100014211	2 7/8 (73.03) EUE 8RD Box × 2 7/8 (73.03) 6P Acme Box	3.375 (85.73)	1.25 (0.38)	13,000 (895)	4,000 (275)	220,000 (99 700)	30,000 (2070)

All available sizes might not be included. Review Enterprise for a complete listing.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

Model K-II Firing Head Specifications

SAP No.	Thread Size and Type in. (mm)	Maximum OD in. (mm)	Makeup Length ft (m)	Maximum Operating Pressure psi (bar)	Minimum Operating Pressure psi (bar)	Tensile Strength lb (kg)	Collapse Pressure psi (bar)
100005190	1.90 (48.26) EUE 10RD Pin × 2 3/8 (60.33) 6P Acme Box	2.75 (69.85)	1.24 (0.38)	19,500 (1345)	4,000 (275)	187,000 (84 800)	25,000 (1725)
100014215	2 7/8 (73.03) EUE 8RD Box × 2 7/8 (73.03) 6P Acme Box	3.375 (85.73)	1.64 (0.50)	19,500 (1345)	4,000 (275)	220,000 (99 700)	30,000 (2070)

All available sizes might not be included. Review Enterprise for a complete listing.
Temperature rating is determined by explosives.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

Model KV-II Firing Head

The Model KV-II firing head combines firing the guns and opening the vent into one operation. This tool allows the operator more accurate control of when the vent opens in relation to when the guns fire.

Applications

- Ideal for deviated wells
- Wells with open perforations in which it is not possible to pressure up on the wellbore to actuate a firing head
- Perforating and stimulation jobs in which the tubing pressure exceeds the casing limitations

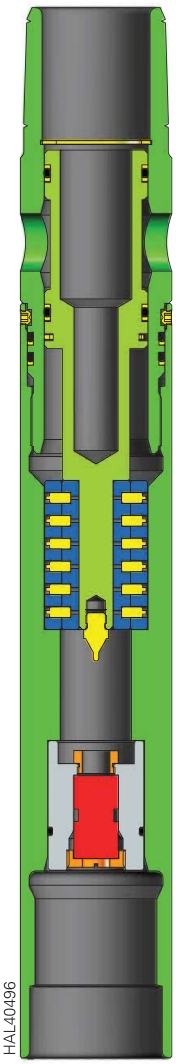
Features

- Firing head and vent operate at one pressure
- Piston mechanically locked after firing

Operation

In many tubing-conveyed perforating applications, it is either desirable or necessary to keep the tubing closed until the guns are detonated. In the past, the tubing was kept closed by a firing head with some type of vent assembly. Coordination between the two tools was sometimes hard to achieve, and the vent often opened too early or too late. The Model KV-II firing head combines a firing head and a vent assembly.

In the Model KV-II firing head, a piston is sheared, which causes the guns to detonate and the ports to open and equalize (or vent) pressure. This venting feature allows operators to run the tubing in the hole dry if needed. In the standard KV-II firing head, the ports in the tool open the instant the firing head is actuated and the guns detonate. To delay the gun detonation, one or more delay devices can be added to the assembly.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Model KV-II Firing Head

Model KV-II Firing Head Specifications

SAP No.	Thread Size and Type in. (mm)	Maximum OD in. (mm)	Flow Area in.^{2} (cm^2)	Minimum Makeup Length ft (m)	Maximum Operating Pressure psi (bar)	Minimum Operating Pressure psi (bar)	Maximum Differential Pressure psi (bar)	Tensile Strength lb (kg)
100014153	2 3/8 (60.33) EUE 8RD Pin × 2 3/8 (60.33) 6P Acme Box	2.75 (69.85)	2.79 (18.0)	1.33 (0.41)	25,000 (1725)	3,000 (206)	15,000 (1035)	145,000 (65 700)
100014155	2 7/8 (72.88) EUE 8RD Pin × 2 7/8 (72.88) 6P Acme Box	3.375 (85.73)	3.14 (20.27)	1.43 (0.44)	25,000 (1725)	4,000 (275)	15,000 (1035)	235,000 (106 600)

All available sizes might not be included. Review Enterprise for a complete listing.
Temperature rating is determined by explosives.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

Time-Delay Firer

The time-delay firer (TDF) allows under- or overbalanced perforating through the use of a pressure-actuated firing head with a time-delay fuse. The delay fuse allows 4 to 6 minutes for adjusting the actuating pressure in the tubing to achieve the desired pressure before firing the guns.

Applications

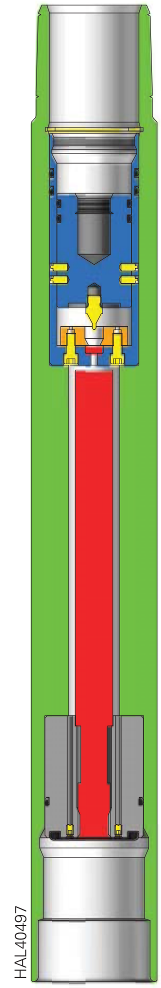
» Ideal for production completions, drillstem testing, and dual completions

Features

» Allows independent perforating of selected zones
» Allows maximum use of under- or overbalanced pressure
» Can be run in heavy mud systems
» Can be used with full-opening or non-full-opening tools
» Helps reduce costs by running multiple guns without gun spacers
» Recommended for running on the top and bottom of gun assemblies
» Allows additional time-delay elements as needed for increasing delay time

Operation

The TDF is run with a predetermined number of shear pins for specific well conditions. Tubing is pressured to the maximum actuating pressure slowly. The maximum pressure shears the pins in the shear set and forces the firing piston into the primer. The primer ignites the pyrotechnic delay fuse. The fuse burns for a predetermined time (between 4 and 6 minutes), depending on the bottomhole temperature, and detonates the perforating assembly.



Time-Delay Firer (TDF)

Time-Delay Firer (TDF) Specifications

SAP No.	Thread Size and Type in. (mm)	Maximum OD in. (mm)	Makeup Length ft (m)	Maximum Operating Pressure psi (bar)	Minimum Operating Pressure psi (bar)	Temperature Rating °F (°C)	Tensile Strength lb (kg)	Collapse Pressure psi (bar)
100014157	1 7/16 (36.51) 8 UN-2 B Box × 1.315 (33.4) NU-10RD Pin	1.688 (42.88)	2.16 (0.65)	21,500 (1482)	2,200 (150)	425 (218) for 200 hours	56,000 (25 400)	26,300 (1813)
100005231	1.90 (48.26) EUE 10RD Pin × 2 (50.8) 6P Acme Box	2.50 (63.5)	1.69 (0.52)	25,000 (1723)	4,000 (275)	425 (218) for 200 hours	120,000 (54 432)	30,000 (2070)
100005230	2 7/8 (73.03) EUE 8RD Pin × 2 7/8 (73.03) 6P Acme Box	3.375 (85.73)	1.81 (0.55)	13,000 (895)	4,000 (275)	350 (176) for 500 hours	220,000 (99 700)	30,000 (2070)

All available sizes might not be included. Review Enterprise for a complete listing.
Temperature rating is determined by explosives or elastomers.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

Multi-Action Delay Firing Head

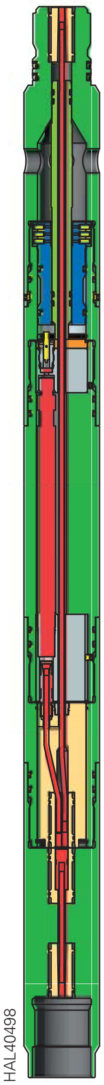
The multi-action delay firing head is a pressure-actuated redundant firing system, which can be run with any one of several other firing heads.

Features

- Allows the use of a redundant firing head without having a firing head on the bottom of the gun string
- Allows multiple redundancy when a multi-action firing head is placed on both the top and bottom of the gun string
- Allows operators to postpone the decision to use the bar drop or pressure side of the firing head as the primary firing mechanism
- Allows use of additional delay elements

Operation

One side of the multi-action firing head will always be pressure actuated. The other side of the firing head can be a bar drop-type head or another pressure-actuated firing head. Either side of the firing head can be used as the primary or backup firing system.



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Multi-Action Delay Firing Head

Multi-Action Delay Firing Head Specifications

SAP No.	Thread Size and Type in. (mm)	Maximum OD in. (mm)	Makeup Length ft (m)	Maximum Operating Pressure psi (bar)	Minimum Operating Pressure psi (bar)	Tensile Strength lb (kg)	Collapse Pressure psi (bar)
100155753	2 3/8 (60.33) 6P Acme Box × Pin	3.10 (78.74)	3.41 (1.04)	18,000 (1240)	4,000 (275)	170,000 (77 100)	22,000 (1515)
100155750	2 7/8 (73.03) 6P Acme Box × Pin	3.375 (85.73)	3.41 (1.04)	25,000 (1725)	4,000 (275)	201,000 (91 100)	29,000 (2000)

All available sizes might not be included. Review Enterprise for a complete listing.
Temperature rating is determined by explosives.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

MaxFire® Electronic Firing System

The MaxFire® electronic firing system for tubing-conveyed perforating (TCP) boasts the highest pressure rating in the industry — 40,000 psi (276 MPa) — making it the tool of choice in ultradeepwater applications. Triggering pressure of other tools can exceed the pressure limit of the casing used at the bottom of ultradeep wells. In such cases, the MaxFire system can be programmed to trigger after recognizing a specific sequence of very small pressure variations over time.

The TCP MaxFire system has mutable accessories, which provide the ability to run redundant systems in tandem above or below on any string design. The dual-firing head carrier allows two TCP MaxFire systems to be run on top and/or bottom of the perforating string. This translates into the capability to run four independent firing heads at once.

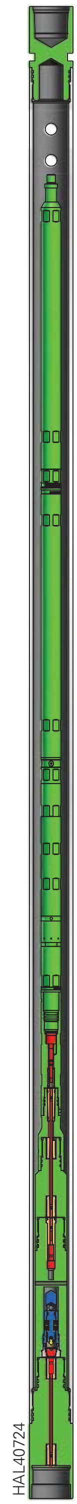
The MaxFire system is used in conjunction with the RED® detonator, which provides triggering options suited to virtually any well. Because the RED detonator is radio-frequency safe, rigsite communications can safely continue during perforation operations.

Features

- Memory = 16 MB
- Data captured before detonation
- Sampling rates
  - 0.25 samples/second in normal mode
  - 10 samples/second in trigger mode, lasting 2 minutes
- Load capacity limited only by strength of shroud

Benefits

- Rated to an industry-leading 40,000 psi
- Can trigger after recognizing a specific pressure variation sequence
- Can record downhole data for up to 30 days, approximately five times longer than the next best competing tool
- Can detonate strings of perforating guns several kilometers long
- Can act as primary or secondary firing head



MaxFire® Electronic Firing System

Quick Change Trigger Device

Halliburton offers the 15,000-psi fully programmable electronic firing heads. This unmatched perforating technology is also capable of low-pressure cycle operation and allows for immediate or delayed detonation.

As more challenging and complex wells are explored, this is the type of flexibility needed for downhole, pressure-operated tools. The Halliburton quick change trigger (QCT) devices provide a safe, precise, and adaptable perforating instrument that initiates a gun system through a predetermined sequence of events.

Programming flexibility can provide delay times from several minutes to hours or days and can be tailored to work under virtually any completion sequence. The intelligent trigger device can be used as a primary or secondary firing head for any tubing-conveyed perforating operation.

Providing maximum reliability, the intelligent trigger device uses the block RED® detonator, an advanced electro-explosive device used to initiate perforating guns. The block RED detonator design features provide significantly improved safety characteristics over conventional resistor devices and allow wellsite activities to continue uninterrupted while perforating.

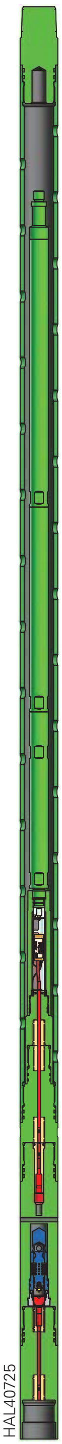
With fully customizable programming, the QCT device provides the total completion procedure flexibility needed for today’s challenges.

Applications

- Ultradeepwater or high-pressure targets
- Low actuation pressure for challenging wells
- Extended delay times for complex well completions

Benefits

- Safe firing mechanism cannot be initiated at surface.
- Lower actuating pressures help prevent damage to lower-rated tools.
- Modular battery design allows extended downhole use and delay times.
- Surface resettable job timer helps reduce rig time and costs.
- 30,000 psi rated transducer and housing to operate in ultrahigh-pressure environments.
- Customizable programming provides completion procedure flexibility.



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Quick Change Trigger (QCT) Device

Quick Change Trigger (QCT) Device Specifications

Pressure Rating psi (bar)	OD in. (cm)	Length in. (cm)	Temperature Rating °F (°C)	Delay Time	Battery Life
15,000 (1034)	1.6875 (4.29)	59.8 (151.9)	315 (157)	5 minutes to 36 hours	9 days

All available sizes might not be included. Review Enterprise for a complete listing.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

Annulus Pressure Firer-Control Line

The annulus pressure firer-control line (APF-C) was developed as a dual-firing system, allowing perforating gun detonation by annular pressure, a drop bar, or tubing pressure. The APF-C system consists of a pressure transfer reservoir, a sleeve through the packer mandrel, an adapter below the packer, and a control line to transmit pressure from the annulus above the packer to the APF-C firing head assembly on top of the guns. Any of the mechanical or pressure-actuated firing heads can be attached to the top of the APF-C firing head.

Applications

- Ideal for deviated wells
- Drillstem testing or shoot and pull for gravel packs

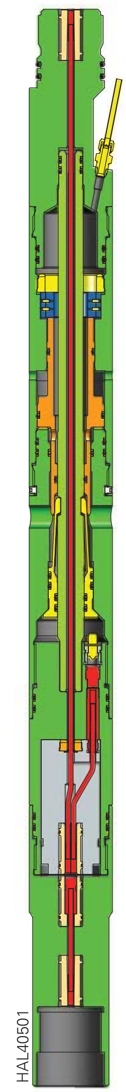
Features

- Can be used with non-full-opening test tools and partially filled tubing strings
- Can be used wherever a pressure-actuated tool is desirable
- Provides a system of two firing heads on top of the guns
- Can be run with a mechanical or pressure-actuated firing head as a secondary firing mechanism
- Enhances safety because the annulus-operated portion is pressure balanced before the packer is set and the tester valve is opened

Operation

The APF-C system depends on the transfer of annular pressure through the packer down to the APF-C firing head. This pressure creates a differential pressure across the mandrel where the firing piston is housed. When the predetermined differential pressure is reached, the pins shear and the mandrel moves up and releases the firing piston, which is driven down by rathole pressure. The piston strikes the firing pin, which detonates the initiator.

The operation of the drop bar or pressure-actuated firing head depends on which firing head system is used.



Annulus Pressure Firer-Control Line (APF-C) Firing Head

Annulus Pressure Firer-Control Line (APF-C) Specifications

SAP No.	Thread Size and Type in. (mm)	Maximum OD in. (mm)	Makeup Length ft (m)	Maximum Operating Pressure psi (bar)	Minimum Operating Pressure psi (bar)	Tensile Strength lb (kg)	Collapse Pressure psi (bar)
100156138	2 7/8 (73.03) 6P Acme Box × Pin	3.68 (93.47)	3.70 (1.13)	20,000 (1380)	250 (17)	174,000 (78 900)	17,000 (1170)

All available sizes might not be included. Review Enterprise for a complete listing.
Temperature rating is determined by explosives.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

Annulus Pressure Transfer Reservoir

The annulus pressure transfer reservoir (APTR) is an integral component of the annulus pressure firer-control line (APF-C). The APTR mechanism transmits pressure from above the packer to a differential pressure or pressure-actuated firing head (PAFH) on top of the perforating assembly.

Applications

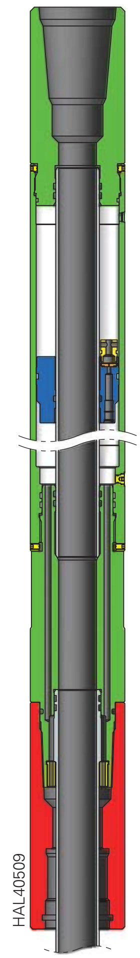
» Applications that require a partial fluid column in the tubing string

Features

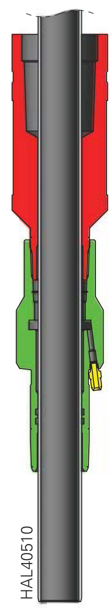
» Full-opening ID
» Compatible with mud environments
» Adapted for RTTS® and CHAMP® IV packers
» No need for nitrogen

Operation

The APTR transmits annulus pressure into a micro-annulus created by the packer mandrel and the APTR mandrel. The pressure is ported to a control-line sub on the lower end of the packer. A stainless steel control line connects the APTR to the pressure-responsive firing head on the perforating assembly.



Annulus Pressure Transfer Reservoir (APTR) Upper Assembly



APTR Lower Assembly

Annulus Pressure Transfer Reservoir (APTR) Specifications

SAP No.	Maximum OD in. (mm)	Minimum ID in. (mm)	Top Assembly	Lower Assembly	Length Above Packer ft (m)	Length Below Packer ft (m)	Tensile Strength lb (kg)	Burst Pressure psi (bar)	Collapse Pressure psi (bar)
100156028	5.00 (127.00)	2.00 (50.8)	3 1/2 4 IF Box × 3 7/8 6 Stub Acme Pin	2 7/8 (73.03) EUE 8RD Box × Pin	5.09 (1.55)	1.02 (0.31)	328,000 (148 700)	18,000 (1240)	15,000 (1035)
101016453	6.12 (155.45)	2.37 (60.20)	4 1/2 4 IF Box × Pin	4 1/2 (114.3) 4 IF Box × 3 1/2 (88.90) EUE 8RD Pin	4.34 (1.32)	1.33 (0.41)	587,000 (266 200)	22,000 (1515)	19,000 (1310)

All available sizes might not be included. Review Enterprise for a complete listing.
Temperature rating is determined by o-rings.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

Slimhole Annulus Pressure Firer-Internal Control

5-in. Annulus Pressure Transfer Reservoir

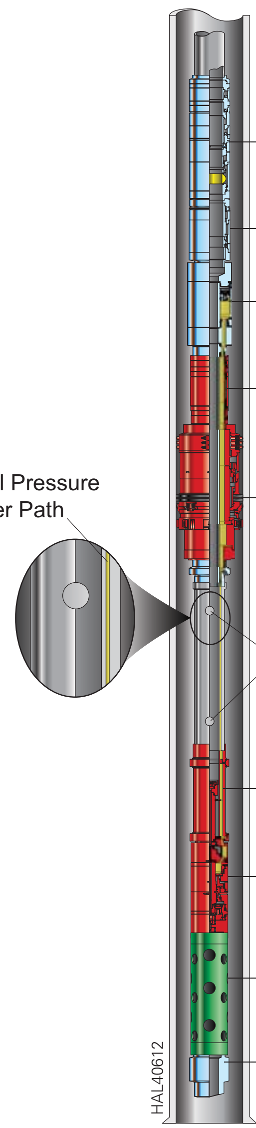
The slimhole annulus pressure transfer reservoir (APTR) system assembles in a similar manner to the 7- and 9 5/8-in. APTR systems. Only two design changes have been implemented in the 5-in. APTR system. First, a series of concentric tubes below the packer replaces the control line from larger APTR systems. Second, a single tube mandrel runs through the packer, replacing the series of threaded tube mandrels from the larger APTR systems.

3 1/8-in. Internal Control

Concentric tubes eliminate the need for an external control line in slimhole casing.

3 1/8-in. Annulus Pressure Transfer Reservoir-Internal Control

The slimhole 3 1/8-in. annulus pressure transfer reservoir-internal control (APF-IC) firing head is designed for use with the 5-in. APTR system with internal control. The firing head design remains the same as the 3 3/8-in. APF-C, with diameter reductions in many of the component parts to achieve a true 3.13-in. OD.



Slimhole Annulus Pressure Firer-Internal Control (APF-IC) Installation

Slimhole Annulus Pressure Firer-Internal Control (APF-IC) Specifications

SAP No.	Thread Size and Type	Maximum OD in. (mm)	Minimum ID in. (mm)	No. of Ports	Makeup Length ft (m)	Maximum Operating Pressure psi (bar)	Minimum Operating Pressure psi (bar)	Tensile Strength lb (kg)	Burst Pressure psi (bar)	Collapse Pressure psi (bar)
101301541	2 3/4-in. 6P Acme Box × Pin	3.13 (79.5)	1.25 (31.75)	2	56.41 (17.2)	20,000 (1378)	250 (17)	87,000 (39 463)	N/A	10,000 (689)

All available sizes might not be included. Review Enterprise for a complete listing.
Temperature rating 325°F (20K psi) with extreme environment kit (162°C 1.406 kg/cm² with extreme environment kit)
Contact Technology for temperatures above 325°F (162°C).
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

Differential Firing Head

The differential firing head (DFH) allows underbalanced perforating with a differential pressure-actuated firing system. The DFH works by requiring the internal pressure be greater than the external pressure. This condition can be created when pressure is applied to the ID, or the OD pressure is reduced.

The pressure required to actuate the DFH can be lower than that used for other pressure-operated firing heads because it is operated by differential pressure.

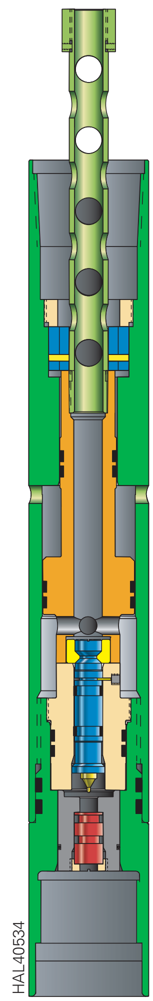
Features

- Allows underbalanced perforating in horizontal wells without a packer
- Ideal for perforating with a sucker rod or submersible pump in place
- Offers added safety because it is pressure balanced when being run into the well
- Allows maximum underbalanced pressure in low-pressure wells when mechanical firing is not desirable
- Can be used when equipment or well conditions do not permit the use of high pressures
- Allows the use of time-delay elements as needed

Operation

The DFH is actuated after a predetermined differential pressure is created in the firing head ID. This differential pressure can be created when surface pressure is applied to the tubing or by reducing the hydrostatic pressure in the annulus.

When the predetermined differential pressure is reached, the shear pins holding the dog retainer piston will shear, allowing the dog retainer to move up. The upward movement releases the dogs holding the firing piston in place, and the internal pressure drives the firing piston into the initiator.



Differential Firing Head (DFH)

Differential Firing Head (DFH) Specifications

SAP No.	Thread Size and Type in. (mm)	Maximum OD in. (mm)	Makeup Length ft (m)	Maximum Operating Pressure (Differential) psi (bar)	Minimum Operating Pressure (Differential) psi (bar)	Tensile Strength lb (kg)	Burst Pressure psi (bar)	Collapse Pressure psi (bar)
120002262	2 3/8 (60.33) EUE 8RD Box × 2 3/8 (60.33) 6P Acme Box	3.0 (76.20)	1.94 (0.59)	10,000 (690)	1,000 (69)	130,000 (58 900)	20,000 (1380)	20,000 (1380)
100014232	2 7/8 (73.03) EUE 8RD Box × 2 7/8 (73.03) 6P Acme Box	3.38 (85.73)	1.98 (0.60)	5,000 (345)	1,000 (69)	220,000 (99 700)	20,000 (1380)	20,000 (1380)

All available sizes might not be included. Review Enterprise for a complete listing.
Temperature rating is determined by explosives or o-rings.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

Hydraulic Actuator Firing Head

The hydraulic actuator firing head (HAFH) is a pressure-balanced tool, which automatically fills the tubing string while it is running in the well. A stainless steel or ceramic ball is dropped from the surface or circulated into position. Pressure applied to the tubing string actuates the HAFH.

There is a version of the 1.69-in. OD tool, which incorporates a swivel mechanism.

Applications

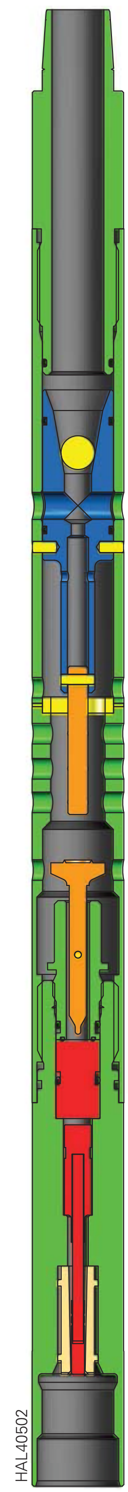
- Coiled tubing-conveyed completions, deviated wells, and through-tubing perforating

Features

- Allows packerless completions
- Makes actuation easily observable
- Reusable

Operation

A stainless steel or ceramic ball is dropped from the surface or circulated downhole into the hammer piston. Pressure applied to the tubing string shears the retaining pins and forces the hammer piston into the firing pin. The firing pin detonates the initiator, which starts the detonation of the perforating assembly. Circulation is regained as soon as the firing pin is sheared.



Hydraulic Actuator Firing Head (HAFH)

Hydraulic Actuator Firing Head (HAFH) Specifications

SAP No.	Thread Size and Type in. (mm)	Maximum OD in. (mm)	Ball OD in. (mm)	No. and ID of Ports in. (mm)	Flow Area of Ports in.² (cm²)	Makeup Length ft (m)	Maximum Operating Pressure (Differential) psi (bar)	Actuating Pressure psi (bar)	Tensile Rating lb (kg)
100156011 (Swivel Type)	1.315 (33.40) NU-10RD Pin × 17/16 (36.51) 8UN-2B Box	1.69 (42.88)	0.625 (15.875)	2 at 0.5 (12.70)	0.39 (2.52)	2.84 (0.87)	20,000 (1379)	3,200 (221)	50,000 (22 680)
100156025	1.315 (33.40) NU-10RD Pin × 17/16 (36.51) 8UN-2B Box	1.69 (42.88)	0.625 (15.875)	2 at 0.5 (12.70)	0.39 (2.52)	2.18 (0.66)	20,000 (1379)	3,200 (221)	50,000 (22 680)
101007031	1.90 (48.26) EUE-10RD 3/4TPF Pin × 2 3/8 (60.33) 6P Acme Box	2.75 (69.85)	0.625 (15.875)	2 at 0.5 (12.70)	0.39 (2.52)	2.28 (0.691)	20,000 (1379)	3,200 (221)	113,000 (51 256)
100156150	2 3/8 (60.33) EUE 8RD Pin × 2 7/8 (73.03) 6P Acme Box	3.38 (85.85)	1.375 (34.925)	4 at 1.0 (25.40)	3.14 (20.26)	2.40 (0.73)	20,000 (1379)	2,000 (138)	135,600 (61 507)
101313489	2 7/8 (73.03) EUE 8RD Pin × 2 7/8 (73.03) 6P Acme Box	3.38 (85.85)	1.375 (34.925)	4 at 1.0 (25.40)	3.14 (20.26)	2.40 (0.73)	20,000 (1379)	2,000 (138)	216,000 (97 976)
102677620	API-NC38 Box 2 7/8 (73.03) 6P Acme Box	4.75 (120.65)	1.375 (34.925)	4 at 1.0 (25.40)	3.14 (20.26)	2.86 (0.87)	20,000 (1379)	2,000 (138)	335,400 (152 135)

All available sizes might not be included. Review Enterprise for a complete listing.
Temperature rating is determined by explosives.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

Mechanical Metering Hydraulic-Delay Firing Head

The mechanical metering hydraulic-delay (MMHD) firing head provides a retrievable firing system with an adjustable delay for situations in which longer delay times are needed. Delay time can be adjusted from 1 to 6 hours. The tool is designed with a 1/2-gal fluid chamber below a weighted piston. The piston meters downward until it travels into a larger bore, which allows it to free-fall and initiate a mechanical firing head.

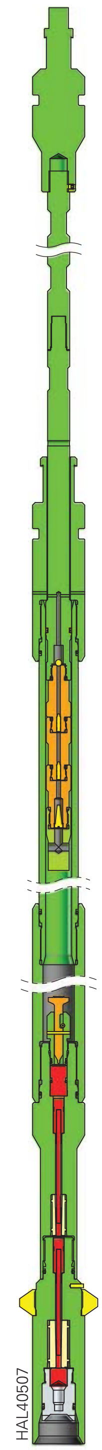
Delay time is affected by temperature, tool weight above the piston, and the number of jets used (maximum of two). Adjustments can be made by running one or two fluid metering jets or by changing the amount of fluid.

Features

- Adjustable time-delay: Time can vary from 1 up to 6 hours.
- Retrievability: Firing head can be pulled and another one run without affecting the rest of the bottomhole assembly.
- Safety: With the ability to run the firing head and the guns separately, this system can greatly reduce the chance of accidental or premature firing of guns.

Operation

The MMHD assembly is run into the well using normal monobore completion techniques. The MMHD firing head is conveyed on a slickline or electric line. For safety and flexibility, the tool will not start metering until it is landed on the top gun. Once in place and released, the firing head starts to meter. The running tools can either be pulled into the lubricator, pulled completely out of the hole, or simply pulled up the hole to a safe distance and secured to await detonation. After the guns have fired, the firing head can be quickly relatched and retrieved using the same conveyance methods as during deployment.



Mechanical Metering Hydraulic-Delay (MMHD) Firing Head

Mechanical Metering Hydraulic-Delay (MMHD) Firing Head Assembly Specifications

SAP No.	Maximum OD in. (cm)	Stinger Fishing Neck in. (cm)	Maximum Stroke Length in. (cm)	Maximum Metering Stroke* Length (Available for Delay) in. (cm)	Overall Length* (Extended) ft (m)	Maximum Operating Pressure (Differential) psi (bar)	Temperature Rating °F (°C)	Tensile Strength lb (kg)	Total Volume (Silicon) gal (L)	Assembly Weight lb (kg)
101201927	Dependent on centralizers	1.75 (4.45)	54.86 (139.34)	46.50 (118.11)	12.44 (3.79)	13,000 (896.6)	350 (176.67)	51,100 (23 100)	1/2 (1.89)	152 (68.95)

*Length from top sub to firing head body (does not include weight bars and/or skirt).
Delay time of 1 hour minimum is recommended for safe operation of system.
Delay time of 6 hours maximum is dependent on temperature, silicon fluid, and number of jets.
All available sizes might not be included. Review Enterprise for a complete listing.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

Slickline-Retrievable Time-Delay Firer Firing Head

The slickline-retrievable time-delay firer (TDF) firing head is a combination of the slickline-retrievable firing head and a 1 11/16-in. TDF firing head. This pressure-actuated firing head features a built-in pyrotechnic time-delay assembly.

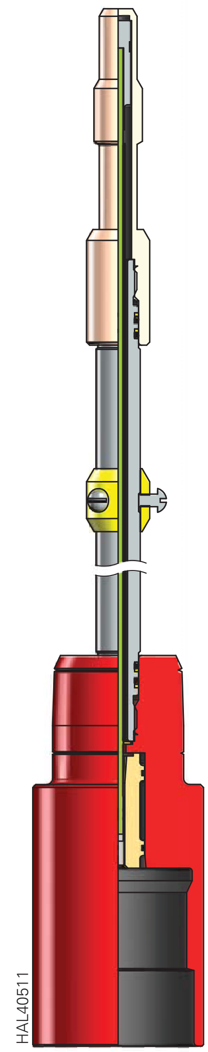
Features

- Allows the guns to be run in the hole without any type of firing mechanism installed
- Allows the retrieval and reinstallation of a malfunctioning firing head without pulling the guns
- Allows greatly reduced actuating pressures because the firing head does not have to be in place when the guns are run

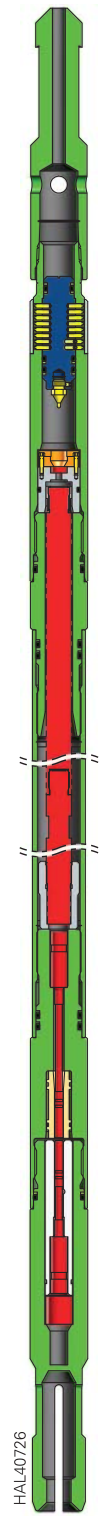
Operation

This firing head does not have to be run until after completing all pressure testing and displacing the heavy fluids, which allows a reduced actuating pressure for the firing head.

This assembly allows the operator to run guns in the hole on the end of tubing without a firing head. The assembly can be run in on slickline and attached to the firing head after the tubing is in the hole. It can also be retrieved on slickline.



Vann™ Jet Stinger Assembly



Slickline Retrievable Time-Delay Firer (TDF) Firing Head

1 11/16-in. Slickline-Retrievable Time-Delay Firer (TDF) Firing Head Specifications

SAP No.	Maximum OD in. (mm)	Overall Length (2 Fuses) ft (m)	Vann™ Jet Collet OD ft (m)	Temperature Rating °F (°C)	Maximum Operating Pressure** psi (bar)	Minimum Operating Pressure psi (bar)	Collapse Pressure*** psi (bar)
102591208*	1.70 (43.18)	4.45 (1.36)	1.58 (40.132)	425 for 200 hours (218 for 200 hours)	12,000 (827.37)	2,200 (150)	12,000 (827.37)
102585785*	1.98 (50.292)	4.45 (1.36)	1.98 (50.292)	425 for 200 hours (218 for 200 hours)	12,000 (827.37)	2,200 (150)	12,000 (827.37)

*Assemblies are designed to be run with two fuses, alternate fuse housings are available.
**Based on collapse pressure rating of delay housing.
***Delay fuse housing rating - alternate 25K single fuse housing is available - 101907315.
All available sizes might not be included. Review Enterprise for a complete listing.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

3 3/8-in. Vann™ Jet Stinger Specifications

SAP No.	Thread Size and Type in. (mm)	Maximum OD in. (mm)	Overall Length ft (m)	Pressure Rating psi (KPa)	Tensile Strength (Tubing Sub) lb (kg)	Weight lb (kg)
102074498	2 3/8 (60.33) EUE 8RD Box × 2 7/8 (73.03) 6P Acme Box	3.38 (85.85)	4.49 (1.37)	27,000 (186 158)	176,000 (79 832.26)	17 (7.71)

These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

Extended Delay Assembly

A delay fuse is an explosive device with a slow-burning fuse. Extended and modular delay fuses add time between the firing head actuation and the actual detonation of the guns. Each delay fuse lasts 6 minutes at 70°F.

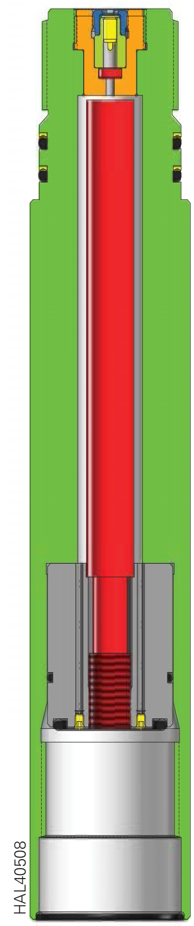
Features

- Increases delay time when nitrogen is used to actuate the firing head to give additional time to bleed the nitrogen pressure down to the desired level
- Allows time for necessary actions to take place downhole, such as increasing pressure to open a pressure-actuated vent assembly

Operation

The extended delay assemblies contain one delay fuse and can be run with any other firing assembly. They are installed between the firing head and the guns.

The modular delays are assembled with the firing head in one housing and become an integral part of the firing system. The modular delays are used primarily with the multi-action delay firing head, the 1 11/16-in. time-delay firer (TDF) firing head, and the slickline-retrievable TDF firing head.



Extended Delay Fuses Assembly

Extended Delay Assembly Specifications

SAP No.	Thread Size and Type in. (mm)	Maximum OD in. (mm)	Makeup Length ft (m)	Maximum Operating Pressure psi (KPa)	Temperature Rating Delay Fuse °F (°C)	Tensile Strength lb (kg)	Special Feature
101929776	2 (50.8) 6P Acme Box × Pin	2.5 (62.5)	1.10 (0.34)	30,000 (206 843)	425 for 200 hours (218 for 200 hours)	81,400 (36 922.42)	Sealing Firing Pin
101696745	2 (50.8) 6P Acme Box × Pin	2.5 (62.5)	1.10 (0.34)	30,000 (206 843)	425 for 200 hours (218 for 200 hours)	81,400 (36 922.42)	
100005229	2 (50.8) 6P Acme Box × Pin	2.5 (62.5)	1.10 (0.34)	30,000 (206 843)	425 for 200 hours (218 for 200 hours)	81,400 (36 922.42)	AFLAS®
100009426	2 7/8 (73.03) 6P Acme Box × Pin	3.375 (85.73)	1.10 (0.34)	22,000 (151 685)	425 for 200 hours (218 for 200 hours)	195,700 (88 768)	Sealing Firing Pin

All available sizes might not be included. Review Enterprise for a complete listing.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.
AFLAS® is a registered trademark of Asahi Glass Co., Ltd.

Modular Mechanical Firing Head

The modular mechanical firing head (MFH) is designed to be a retrievable firing system using a standard MFH with a specialized drop bar for detonation. This system allows the operator the flexibility to run the gun assemblies independent of the firing system. Once the guns are in place, the firing head is set on the top module and released. The perforation assembly is detonated by use of a special fluted bar dropped from surface.

The most common application for this system is to be run with the modular guns in a monobore completion. Special consideration must be given to job setup and execution to help ensure this tool functions properly.

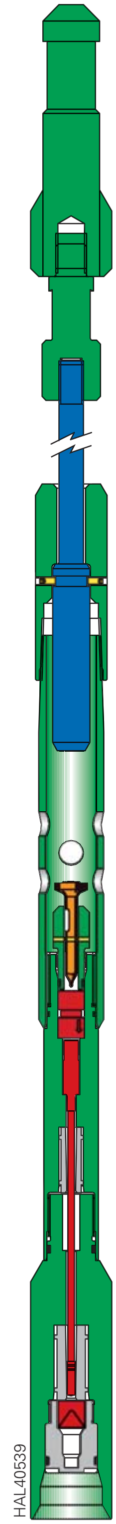
Applications

The modular MFH runs on slickline and sets on the top gun in a monobore completion using a JDC hydraulic running tool. The system is designed with the hammer held above the firing pin with brass shear screws. The two shear screws are rated at 875 lb each. The tool is actuated by dropping a specifically designed drop bar fitted for the proper casing. (Do not use a standard 1 1/4-in. drop bar.) The bar strikes the stinger with sufficient force to shear the brass screws and drive it into the firing pin.

The firing pin and hammer are pressure balanced and therefore are not limited to any specific depth and/or hydrostatic pressure beyond the tool specifications.

Features

- Safety: With the ability to run the firing head and the guns separately, this system helps greatly reduce the chance of accidental or premature firing of the guns.
- Retrievability: In the event of a mechanical malfunction, the firing head can be pulled and another one run without interfering with the rest of the bottomhole assembly.



Modular Mechanical Firing Head

Modular Mechanical Firing Head Specifications

SAP No.	Stinger Fishing Neck 2-in. Stinger in. (mm)	Stinger Fishing Neck 2 1/2-in. Stinger in. (mm)	Maximum Operating Pressure psi (bar)	Tensile Strength lb (kg)	Overall Length* in. (mm)	Maximum Stroke Length in. (mm)	Shear Rating for Brass lb (kg)
120021629	1.38 (35.05)	1.75 (44.45)	13,000 (896.6)	59,000 (26 762)	72.30 (1836.42)	7.88 (200.15)	1,700 (771)

*Will vary with skirt.
All available sizes might not be included. Review Enterprise for a complete listing.
Maximum OD dependent on centralizers used.
Temperature rating is determined by explosives.
Weight dependent on centralizers and skirts.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

Drop Bar Options

SAP No.	Casing and Tubing Size and Weight in./lb (cm/kg)	Casing ID in. (mm)	Total Bar OD in. (mm)
N/A	2 7/8/6.4 (7.30/2.9)	2.441 (62.0)	N/A
101227709	3 1/2/9.2 (8.89/4.17)	2.992 (76.0)	2.50 (63.5)
120125486	4 1/2/9.5 to 13.5 (11.43/4.3 to 6.12)	4.090 (103.9)	3.75 (95.3)
101227719	5/15 to 18 (12.7/6.80 to 8.16)	4.408 (111.9)	4.125 (104.8)
101227720	5 1/2/15.5 to 23 (13.97/7.03 to 10.43)	4.950 (125.7)	4.50 (114.3)

Skirt-Centralizer Selection Chart

SAP No.	Skirt OD in. (mm)	Centralizer OD in. (mm)
101207195	2 (50.8)	N/A
101201882	2.5 (63.5)	3.00 (76.2) 101207187
		3.50 (88.9) 101207198
		3.75 (95.3) 100014297
101228625	2 3/4 (69.9)	3.25 (82.6) 101213087
		3.50 (88.9) 100014299
101201884	3 1/8 (79.4)	3.875 (98.4) 101207193
101226987	3 3/8 (85.7)	3.75 (95.3) 100009581
		4.00 (10.16) 100156785
		4.40 (111.8) 100010177
101205671	4 5/8 (117.4)	5.61 (142.5) 100156224
		5.75 (146.1) 100156225

Annulus Pressure Crossover Assembly

The annulus pressure crossover assembly (APCA) allows the use of annulus pressure to actuate any one of several firing heads. This assembly is compatible with retrievable packers of all types and sizes.

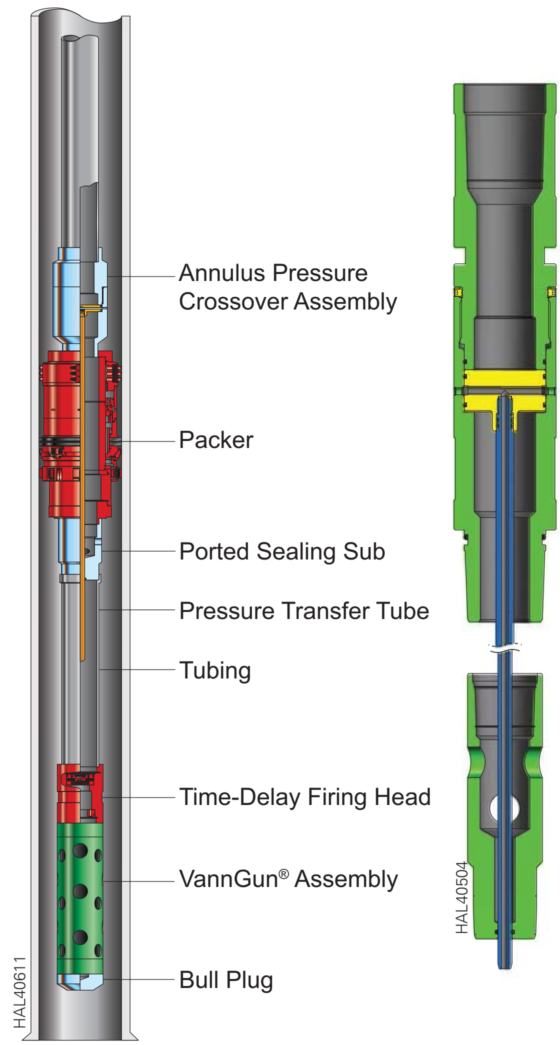
Features

- Can be used as the annulus firing system on wells with non-full-opening test tools and a partially filled drillstring as well as on horizontal wells
- Allows for the use of below-packer venting devices with this assembly

Note: Not recommended for mud environments.

Operation

The APCA creates a pressure chamber above the firing head equalized with the pressure in the casing annulus. Once the packer is set, the pressure on the annulus can be increased to actuate a pressure-actuated firing head (PAFH). The pressures in the annulus and the tubing can also be manipulated to create the differential pressure necessary to actuate a differential-type firing head.



Annulus Pressure Crossover Assembly (APCA)

Annulus Pressure Crossover Assembly (APCA) Specifications

SAP No.	Thread Size and Type in. (mm)	Maximum OD in. (mm)	Minimum ID	Flow Area in.² (cm²)	Minimum Makeup Length ft (m)	Overall Length ft (m)	Maximum Differential Pressure psi (bar)	Tensile Strength lb (kg)	Burst Pressure psi (bar)	Collapse Pressure psi (bar)
100014175	2 3/8 (60.33) EUE 8RD	3.56 (90.42)	Non-full bore	2.25 (14.52)	9.15 (2.79)	12.35 (3.76)	10,000 (689)	104,000 (47 173)	11,200 (772)	11,700 (806)
100155786	2 7/8 (73.03) EUE 8RD	5.0 (127)	Non-full bore	4.75 (30.65)	9.40 (2.87)	12.60 (3.84)	9,500 (655)	145,000 (65 770)	10,500 (723)	11,100 (765)
101241465	3 1/2 (88.9) API IF Tool Joint	5.015 (127.381)	Non-full bore	4.75 (30.65)	9.40 (2.87)	12.60 (3.84)	10,500 (723)	145,000 (65 770)	13,210 (910)	22,500 (1551)

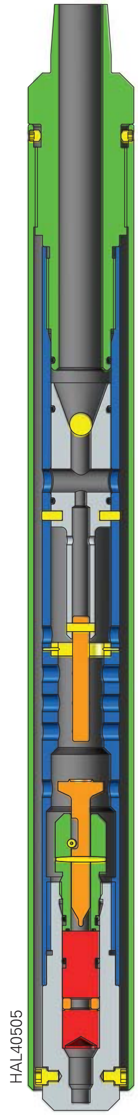
All available sizes might not be included. Review Enterprise for a complete listing.
Maximum operating pressure is determined by tubulars.
Temperature rating is determined by explosives.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

Pump-Through Firing Head

The 1 11/16-in. pump-through firing head is designed to be run on coiled tubing and is used for breaking the ceramic flapper valve disk on a one-trip coiled tubing operation. The firing head originates from proven technology in the 1 11/16-in. pressure-actuated firing head (PAFH). The components are hardened to withstand pumping erosion, and an outer tube is incorporated to allow fluid circulation to the bottom of the tool. A miniature shaped charge is set in the bottom of the firing head to shoot into the ceramic disk. The assembly is actuated by dropping a ball through the coiled tubing, which seats in the assembly to allow a pressure differential to actuate the firing head and shaped charge.

Application

The pump-through firing head can be used to circulate debris off of a barrier, such as a ceramic disk, then shoot into the barrier to break it up. This function is primarily developed toward circulating sand and other debris off of a ceramic disk in a production well, then shooting into the disk to allow access below.



1 11/16-in. Pump-Through Firing Head Assembly

Pump-Through Firing Head Specifications

Thread Size and Type in. (mm)	Maximum OD in. (mm)	Minimum ID* in. (mm)	Maximum Operating Pressure psi (bar)	Flow Area (Before Firing) in.^{2} (mm^2)	Temperature Rating	Axial Load Rating lb (kg)	Collapse Pressure psi (bar)	Overall Length in. (mm)	Mass lb (kg)	Maximum Flow Rate bbl/min (m^3/min)
1.315 (33.40) NU-10RD Pin	2.3 (58.42)	0. 44 (11.18)	3,000 (207) ±10% at 70°F	0.15 (96.77)	As per explosives	54,400 (24 700)	23,200 (1600)	22.69 (576.32)	16.9 (7.68)	2.5 (0.397)

*Through ball seat.
All available sizes might not be included. Review Enterprise for a complete listing.
Minimum operating pressure is not applicable.
Burst pressure is not applicable.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

EZ Cycle™ Multi-Pressure Cycle Firing Head

The EZ Cycle™ firing head is a pressure-operated tool that can be cycled several times before firing the perforating guns. Several pressure operations can also be performed on the well including tubing testing, packer setting, and packer testing before firing the perforating guns. Even if pressure operations are higher than the operating pressure of the firing head, the EZ Cycle firing head should not fire until it has completed all of the preset cycles. The firing head is cycled by applying pressure at the tool to overcome a nitrogen-charged chamber, which operates the cycling piston back and forth until the entire release rod is pulled from the piston collet.

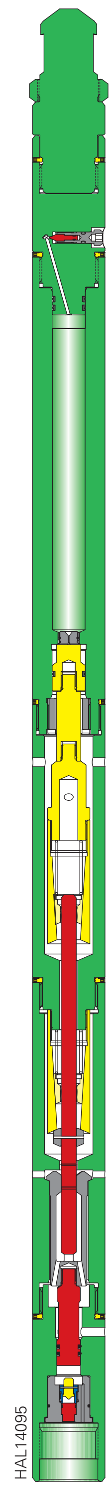
Each EZ Cycle firing head assembly includes a nitrogen chamber, cycling grapple piston, and firing piston with firing pin initiator assembly.

Features and Benefits

- Ideal for completions and drillstem testing
- Time-delay elements can be used as needed for delay time
- Can be used in underbalanced/dynamic underbalanced or overbalanced perforating operations
- It is a surface-safe firing head because it requires pressure to energize the firing piston
- Operates at low pressure
- Can be deployed connected to the gun assembly or run separate on slickline or coiled tubing
- Allows the retrieval and reinstallation of a malfunctioning firing head without pulling the guns
- Can be used when equipment or well conditions will not permit the use of high pressures

Operation

The tool is run in hole with a precharged nitrogen chamber that is set according to the maximum bottomhole pressure. After positioning the gun on depth and all operations before firing the guns have been completed, the firing head is cycled to detonate the perforating guns. Pressure applied at the tool will move the cycle piston and traveling grapple up 0.375 in., pulling the release rod up 0.375 in. Releasing the applied pressure allows the nitrogen charge to move the cycle piston and traveling grapple down, engaging another 0.375 in. of the release rod. These steps are continued until the release rod is completely retrieved from the firing piston collet. At this point, the bottomhole pressure will drive the firing piston into the firing pin, detonating the initiator and the guns.



EZ Cycle™ Firing Head Assembly

3.00 in. Multi-Pressure Cycle Firing Head Assembly Specifications

Upper Connection (External Fishneck) in. (cm)	Lower Thread Size and Type in. (cm)	Makeup Length in. (cm)	Maximum OD in. (cm)	Minimum ID in. (cm)	Temperature Rating °F (°C)	Operating Pressure Range psi (bar)		Tensile Rating* lb (kg)	Burst Pressure* psi (bar)	Collapse Rating* psi (bar)
						Low-Pressure Assembly	High-Pressure Assembly			
2.313 (5.875)	2 3/8 (6.0325) 6P Acme Box	77.32 (83.36)	3.00 (7.62)	N/A	400 (204.4)	1,000 to 5,000 (68.95 to 344.74)	5.000 to 20,000 (344.74 to 1378.95)	100,000 (18 143)	40,000 (1379)	40,000 (1379)

All available sizes might not be included. Review Enterprise for a complete listing.
*Contact your local Halliburton representative or email us at perforatingsolutions@halliburton.com if conditions exceed this value.

06

TCP Tools

Isolation Subassembly (page 177)
The isolation subassembly (ISA) is live well intervention technology designed to provide extreme flexibility in well completions. The ISA allows completion or recompletion of the well without killing it. The well can be producing before, during, and after the guns are deployed in or out of the well.

AutoLatch™ Release Gun Connector (page 178)
The AutoLatch™ release gun connector joins VannGun® assemblies and enables VannGun sections to be run in and out of new or live wells.

Ratchet Gun Connector (page 179)
In addition to perforating new wells, the Halliburton ratchet gun connector system is ideal for reperforating producing wells because the well does not have to be killed and can be left on production. It also allows perforating with all production equipment in place.

Shearable Safety Sub (page 180)
The shearable safety sub is designed to provide a gap in the explosive train that could be severed at surface with the shear rams. It is most commonly used in live well intervention.

Auto-Release Gun Hanger (page 181)
One of the main features of the modular gun system is the auto-release gun hanger. For high volume testing and production, the auto-release gun hanger allows a zone to be perforated and tested with virtually no downhole restrictions.

Detach™ Separating Gun Connector (page 187)
The Detach™ separating gun connector allows operators to deploy long gun sections into the well. The guns are deployed downhole in a single trip and placed across the perforating zone supported by a gun hanger or plug. The guns are fired when desired and then will automatically separate, which allows them to be retrieved in manageable sections or left in the hole.

Explosive Transfer Swivel Sub (page 189)
The explosive transfer swivel sub allows two sections of guns to rotate independently of one another. Such independent rotation is important on long strings that must be oriented in a specific direction in horizontal wells.

Roller Tandem Assembly (page 191)
Roller tandem assemblies are used to reduce the friction between the perforation guns and the casing. In some cases, the frictional drag can be reduced by as much as 90%.

Centralizer Tandem (page 192)
For operations where it is desirable to centralize the guns and other tools in the casing, Halliburton has designed a full range of centralizers for all gun sizes.

Quick Torque™ Connector (page 193)
The Quick Torque™ connector consists of connectors that cover both ends of each gun section to enclose the assembly. The connectors have a common, self-aligning drillpipe thread that allows automatic or manual makeup. Explosive transfer occurs through a web, making the system self contained and totally safe. With these connectors, TCP gun assemblies can now be picked up by the rig equipment and properly made up using iron roughneck equipment, without the need for human intervention. It simplifies the process and saves time by eliminating assembly of the components on the rig.

Modular Gun System (page 196)
Through a special arrangement of perforating equipment, The Halliburton patented modular gun system permits the optimum number of guns to be removed via slickline or E-line so larger intervals can be perforated simultaneously. Halliburton perforating specialists know the equipment, know the well, and know the best techniques to fit your particular application.

Vertical Oriented Perforating (page 198)

Vertical oriented perforating (VOP) is designed to be run in monobore well applications with profiles and/or restrictions that prevent the use of standard gun hangers and where perforating orientation is critical, such as intelligent completions, multiple string completions, reservoir challenges, and fiber optics.

Select Fire™ Systems (page 199)

The Select Fire™ system lets you perforate zones in any order selected. The system provides the ability to perforate multiple zones individually during a single trip.

DrillGun™ Perforating Systems (page 201)

The DrillGun™ perforating system combines rugged, reliable Halliburton perforating components with the versatility of drillable materials. The DrillGun system allows running and setting the squeeze packer and perforating gun in one run, eliminating the need for wireline perforating in many cases.

Oriented Perforating (page 204)

The benefits of sand prevention or improved stimulation performance can be enjoyed using any of the Halliburton leading oriented perforation technologies. Halliburton oriented perforating solutions can be deployed using a wide range of conveyance methods providing reliable world-class results.

G-Force® Precision Oriented Perforating System (page 204)

The G-Force® system features an internal orienting charge tube assembly and gun carrier, which allows perforating in any direction, regardless of the gun's position relative to the casing.

Eccentric Orienting Tandem (page 210)

Eccentric subs allow perforating guns to be oriented in situations in which the fin system is not ideal because of restrictions in the casing, fishing concerns, welding concerns, etc.

StimGun™ Assembly (page 211)

The StimGun™ assembly has been used with great success in conventional underbalanced perforating to obtain benefits of both extreme overbalance (EOB) from propellants and the surging effect from maximum underbalance. The StimGun assembly is a process that combines perforating and perforation breakdown with a propellant in a single tool and operation.

Powr*Perf™ Perforation/Stimulation Process (page 216)

The Powr*Perf™ perforation/stimulation process is a completion process that uses proven EOB perforating techniques. This method is coupled with the release of an erosive agent at the moment of VannGun® detonation to clean and scour near-wellbore damage and enhance conductivity of fractures created by EOB perforating.

PerfStim™ Process (page 218)

The PerfStim™ process combines perforation and stimulation operations in one step by driving a fluid spear into the formation at high flow rates and pressures immediately after perforating.

Isolation Subassembly

The isolation subassembly (ISA) is live well intervention technology designed to provide extreme flexibility in well completions. The ISA allows completion or recompletion of the well without killing it. The well can be producing before, during, and after the guns are deployed in or out of the well.

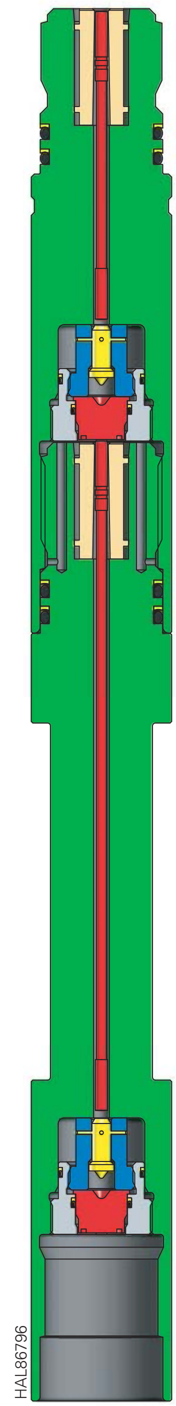
The ISA is a lower cost alternative to other live well intervention assemblies. The ISA incorporates a threaded connection, which is manually connected and disconnected.

Features

- Can run VannGun® assemblies on hydraulic workovers, coiled tubing, or wireline
- Can run VannGun sections to perforate a new well or add perforations to existing zones
- Do not have to kill well to run or retrieve guns
- Can perforate underbalanced or overbalanced

Benefits

- Low cost
- Provides extreme flexibility in well completions



Isolation Subassembly

Isolation Subassembly Specifications

SAP No.	Thread Size and Type in. (mm)	OD Isolation Subassembly with OD Ram Lock in. (mm)	Maximum OD in. (mm)	Overall Length ft (m)	Maximum Operating Pressure psi (bar)	Tensile Strength lb (kg)
101228396	1 11/16 (42.86) 8P Stub Acme 2G	2 with 1 1/2 (50.8 with 38.1)	2.015 (51.18)	2.42 (0.74)	10,000 (689)	64,500 (29 250)
101222274	2 3/8 (60.33) 6P Acme 2G	2 3/4 with 2 (69.85 with 50.8)	2.765 (70.23)	2.28 (0.69)	10,000 (689)	108,000 (49 000)
101226330	2 7/8 (73.03) 6P Acme 2G	3 3/8 with 2 (85.73 with 50.8)	3.395 (86.23)	2.22 (0.68)	10,000 (689)	191,400 (86 800)

All available sizes might not be included. Review Enterprise for a complete listing.
Temperature rating is determined by explosive.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

AutoLatch™ Release Gun Connector

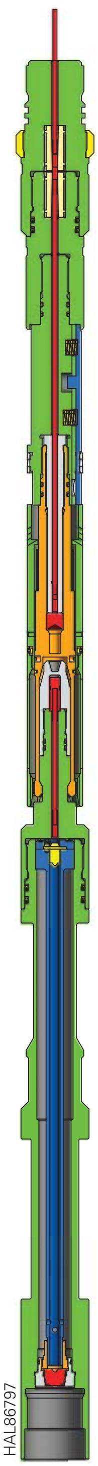
The AutoLatch™ release gun connector is designed to join VannGun® assemblies and enables VannGun sections to be run in and out of new or producing wells.

Using the AutoLatch system, VannGun assemblies are connected without rotation and can be operated with standard blowout preventer (BOP) rams, making this connector ideal for snubbing guns into and out of the wellbore with coiled tubing or a hydraulic workover (HWO) unit.

The AutoLatch connector can also be used to run VannGun assemblies on wireline when the length of the perforating assembly is limited by the lubricator length. The VannGun assemblies can be run in sections (limited by the weight rating of the wireline) and then retrieved in sections. This system reduces the number of wireline runs to perforate longer intervals.

Features

- Can be used to perforate new or existing wells
- Can snub VannGun assemblies into and out of the well
- Uses standard BOPs
- Can be used with coiled tubing, HWO, or wireline
- Can retrieve VannGun assemblies without killing a producing zone
- Can perforate in underbalanced or overbalanced conditions
- Can be used for monobore completions
- Can be used when oriented perforations are required
- Sections quickly connected for time savings
- Can be designed to accommodate different BOP configurations



AutoLatch™ Release Gun Connector

AutoLatch Gun Connectors

SAP No.	Top Thread	Maximum OD in. (mm)	Seal Area OD in. (mm)	Maximum Operating Pressure psi (bar)	Tensile Rating lb (kg)	Makeup Length ft (m)
Upper Assembly 101866203	2 3/4 Gun Pin	2.88 (73.15)	N/A	20,000 (1380)	70,000 (31 751)	2.92 (0.89)
Lower Assembly 101754258	2 3/4 Gun Box	2.88 (73.15)	1.75 (44.45)	20,000 (1380)	85,000 (38 555)	2.03 (0.62)
Lower Assembly 101703408	2 3/4 Gun Box	2.88 (73.15)	2.00 (50.80)	20,000 (1380)	85,000 (38 555)	2.03 (0.62)
Lower Assembly 101205878	2 3/4 Gun Box	2.88 (73.15)	2.38 (60.45)	20,000 (1380)	85,000 (38 555)	1.95 (0.59)
Lower Assembly Shearable 101327224	3 3/8 Gun Box	3.38 (85.85)	2.38 (60.45)	14,000 (965)	85,000 (38 555)	2.72 (0.83)

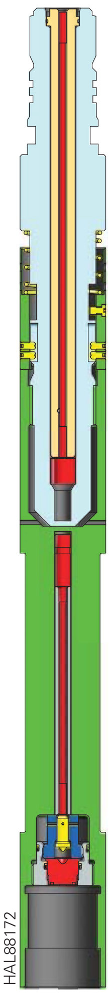
All available sizes might not be included. Review Enterprise for a complete listing.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

Ratchet Gun Connector

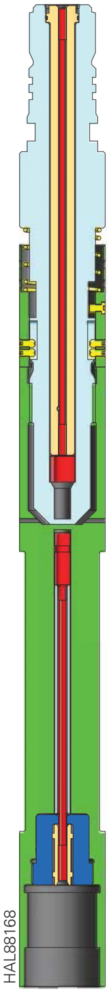
In addition to perforating new wells, the Halliburton ratchet gun connector system is ideal for reperforating producing wells because the well does not have to be killed and can be left on production. It also allows perforating with all production equipment in place. Connections are made inside the lubricator using a left-hand quick connect locking mechanism.

Features

- Can be snubbed into and retrieved from a live well
- Uses standard blowout preventers
- Can perforate long and multiple intervals in a single trip
- Can run or retrieve guns without killing producing zone
- Perforates new wells
- Reperforates producing wells with all production equipment in place
- Perforates underbalanced or overbalanced assemblies
- Connects VannGun® sections together quickly
- Can be used with hydraulic workover


HAL88172

Ratchet Gun Connector Assembly Using Sealed Initiator Assembly


HAL88168

Ratchet Gun Connector Assembly Using Non-Sealed Insert Assembly

Ratchet Gun Connector Specifications

SAP No.	Thread Size and Type in. (mm)	Maximum OD in. (mm)	Makeup Length ft (m)	Maximum Operating Pressure psi (bar)	Tensile Strength lb (kg)
101000794	2 3/8 (60.33) 6P Acme Box × Pin	2.35 (59.69)	2.11 (0.64)	13,000 (896)	100,000 (45 360)
101000793	2 7/8 (73.03) 6P Acme Box × Pin	3.375 (85.73)	2.11 (0.64)	13,000 (896)	220,000 (100 000)

All available sizes might not be included. Review Enterprise for a complete listing.
Temperature rating is determined by explosive.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

Shearable Safety Sub

The shearable safety sub is designed to provide a gap in the explosive train that could be severed at surface with the shear rams. The most common application is in the use of live well intervention.

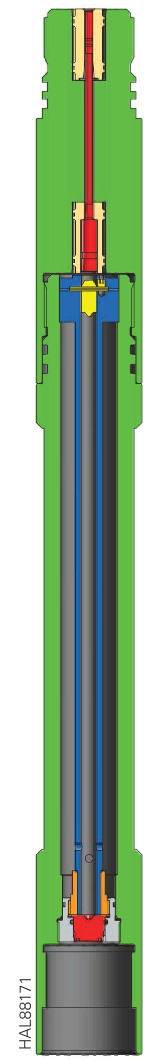
The shearable safety sub provides two levels of defense against wellbore pressures. First, it provides a sub with a smooth profile that is used by closing the sealing rams to control pressure when the gun connection is made up or broken out. Secondly, if the well conditions become dangerous, and the shear rams need to be activated, it provides an area in the gun assembly that does not contain explosives and can be safely severed by the shear rams.

Features

- Continues the explosive train without use of continuous explosives
- Isolates pressure from below
- Allows a smooth sealing area for the pipe rams to seal against
- Uses standard explosives
- Contains standard 3 3/8-in. gun connections above and below
- Can be run with tubing, coiled tubing, wireline, and modular applications
- Can be sheared independently of the guns firing
- Can be redressed at minimal cost

This tool has been successfully sheared during testing using the following:

- Shaffer shear 7 1/16-in. 10k safety head
- Piston diameter of 14 in. (153 in.^{2})
- Sheared at 2,000 psi
- Force required to shear tool = (153 in.^{2}) (2,000 psi) = 306,000 lb



Shearable Safety Sub

Shearable Safety Sub Specifications

SAP No.	Thread Size and Type	Maximum OD in. (mm)	Minimum ID	Makeup Length ft (m)	Maximum Operating Pressure psi (bar)	Minimum Operating Pressure psi (bar)	Tensile Strength lb (kg)	Weight lb (kg)
101245799	2 7/8-in. Acme Box x Pin	3.375 (85.73)	N/A	2.50 (0.76)	20,000 (1380)	N/A	200,000 (90 700)	54.4 (24.6)

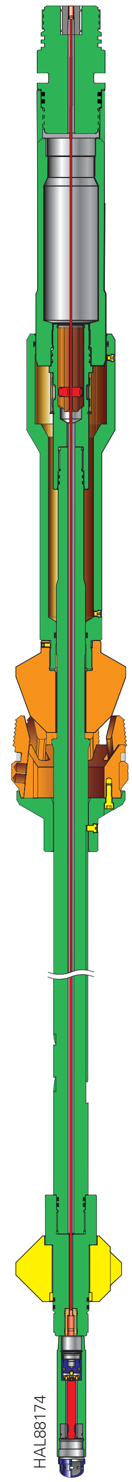
All available sizes might not be included. Review Enterprise for a complete listing.
Temperature rating is determined by explosive.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

Auto-Release Gun Hanger

One of the main features of the modular gun system is the auto-release gun hanger. During high volume testing and production, the auto-release gun hanger allows a zone to be perforated and tested with virtually no downhole restrictions. The auto-release gun hanger is deployed and set at the desired perforating depth. The lowermost gun is then lowered in the well where it is supported by the gun hanger. The remaining guns are then lowered and stacked. The entire perforating assembly can be positioned and retained adjacent to the desired interval until the guns are fired. The assembly is then automatically released to the bottom of the well.

Benefits

- No tubing is required between the guns and the packer.
- No wireline is required to drop the assembly.
- Maximum desired underbalance or overbalance can be used.
- Additional perforations can be added through the tubing at a later date.
- Production tubing can be run and tested independently from other tools.
- The gun hanger and guns are run on a work string, wireline, or slickline.
- In BigBore™ monobore completions, the production tubing and permanent packer are installed before running the monobore perforating assembly.
- Remedial work, such as setting bridge plugs, adding perforations, and running coiled tubing, can be performed without pulling production equipment.
- Lower gun-firing pressures can be used because all production equipment is pressure tested before deploying guns in the well. There is no need to exceed previous test pressures.



Auto-Release Gun Hanger

Automatic-J Gun Hangers

Size and SAP No.	Additional Feature	Maximum Tool OD in.	Minimum Casing ID in.	Maximum Casing ID in.	Pressure Rating psi	Load Rating lb	Bottom Connection	Top Connection
2 7/8 101230621	Solid Mandrel	2.30	2.441	2.441	24,000	9,000	1.315 API-NU	2.00 Gun
2 7/8 101230620	Stinger, Solid Mandrel	2.30	2.441	2.441	35,000	9,000	1.315 API-NU	1.375 Fishneck
3 1/2 101230631	Bottom Release	2.75	3.069	3.188	23,000	20,000	1 11/16 FH	2 1/2 Gun
3 1/2 101230630	Bottom Release	2.75	3.069	3.188	23,000	20,000	2 1/2 TDF	2 1/2 Gun
3 1/2 101230629	Stinger	2.75	2.922	2.922	30,000	20,000	1.900 API-EU	1.750 Fishneck
3 1/2 101230628	Stinger, Bottom Release	2.75	2.922	2.922	13,000	20,000	1 11/16 FH	1.750 Fishneck
3 1/2 101230627	Stinger, Bottom Release	2.75	2.922	2.922	30,000	20,000	2 1/2 TDF	1.750 Fishneck
3 1/2 101230626	Stinger	2.75	2.992	3.068	30,000	20,000	1.900 API-EU	1.750 Fishneck
3 1/2 101230625	Stinger, Bottom Release	2.75	2.992	3.068	13,000	20,000	1 11/16 FH	1.750 Fishneck
3 1/2 101230624	Stinger, Bottom Release	2.75	2.992	3.068	30,000	20,000	2 1/2 TDF	1.750 Fishneck
3 1/2 101230623	Stinger, Bottom Release	2.75	3.069	3.188	13,000	20,000	1 11/16 FH	1.750 Fishneck
3 1/2 101230622	Stinger, Bottom Release	2.75	3.069	3.188	30,000	20,000	2 1/2 TDF	1.750 Fishneck
3 1/2 101230364	Solid Mandrel, Slimhole	2.69	2.922	2.992	24,000	20,000	1.315 API-NU	2.00 Gun
3 1/2 101230363		2.75	2.922	2.922	23,000	20,000	1.900 API-EU	2 1/2 Gun
3 1/2 101230362	Bottom Release	2.75	2.922	2.922	23,000	20,000	1 11/16 FH	2 1/2 Gun
3 1/2 101230361	Bottom Release	2.75	2.922	2.922	23,000	20,000	2 1/2 TDF	2 1/2 Gun
3 1/2 101230360		2.75	2.992	3.068	23,000	20,000	1.900 API-EU	2 1/2 Gun
3 1/2 101230359	Bottom Release	2.75	2.992	3.068	23,000	20,000	1 11/16 FH	2 1/2 Gun
3 1/2 101230358	Bottom Release	2.75	2.992	3.068	23,000	20,000	2 1/2 TDF	2 1/2 Gun
3 1/2 101230357		2.75	3.069	3.188	23,000	20,000	1.900 API-EU	2 1/2 Gun
3 1/2 101228747	Solid Mandrel, Slimhole	2.75	2.750	2.750	24,000	20,000	1.315 API-NU	2.00 Gun
3 1/2 100155797	Stinger, Solid Mandrel, Slimhole	2.75	2.750	2.750	24,000	20,000	1.315 API-NU	1.375 Fishneck
3 1/2 100155795	Stinger, Solid Mandrel, Slimhole	2.69	2.922	2.992	24,000	20,000	1.315 API-NU	1.750 Fishneck
3 1/2 100014180	Stinger	2.75	3.069	3.188	30,000	20,000	1.900 API-EU	1.750 Fishneck
4 1/2 101228748	Bottom Fire	3.75	3.920	4.090	20,000	40,000	2 3/8 API-EU	3 3/8 Gun
4 1/2 101204861	Bottom Fire	3.75	3.920	4.090	20,000	40,000	3 3/8 TDF	3 3/8 Gun
4 1/2 100009580	Bottom Fire	3.75	3.920	4.090	20,000	40,000	2 1/2 TDF	3 3/8 Gun
5.00 101207469	Bottom Fire	3.75	4.276	4.408	20,000	40,000	3 3/8 TDF	3 3/8 Gun
5.00 100155799	Bottom Fire	3.75	4.276	4.408	20,000	40,000	2 3/8 API-EU	3 3/8 Gun

Automatic-J Gun Hangers

Size and SAP No.	Additional Feature	Maximum Tool OD in.	Minimum Casing ID in.	Maximum Casing ID in.	Pressure Rating psi	Load Rating lb	Bottom Connection	Top Connection
5.00 100155798	Bottom Fire	3.75	4.276	4.408	20,000	40,000	2 1/2 TDF	3 3/8 Gun
5 1/2 101230365	Bottom Fire	4.50	4.670	4.950	16,900	40,000	2 1/2 TDF	3 3/8 Gun
5 1/2 100155801	Bottom Fire	4.50	4.670	4.950	16,900	40,000	2 3/8 API-EU	3 3/8 Gun
5 1/2 100155800	Bottom Fire	4.50	4.670	4.950	16,900	40,000	3 3/8 TDF	3 3/8 Gun
7.00 90152	Bottom Fire	5.968	6.184	6.456	16,900	40,000	2 1/2 TDF	3 3/8 Gun
7.00 101230634	Bottom Fire	5.656	5.920	6.094	16,900	40,000	3 3/8 TDF	3 3/8 Gun
7.00 101230633	Bottom Fire	5.656	5.920	6.094	16,900	40,000	2 1/2 TDF	3 3/8 Gun
7.00 101230632	Bottom Fire	5.968	6.184	6.456	16,900	40,000	2 7/8 API-EU	3 3/8 Gun
7.00 101213904	Bottom Fire	5.968	6.184	6.456	16,900	40,000	3 3/8 TDF	3 3/8 Gun
7.00 101004410	Bottom Fire	5.656	5.920	6.094	16,900	40,000	2 7/8 API-EU	3 3/8 Gun
7 5/8 101230640	Bottom Fire	6.453	6.625	6.765	16,900	40,000	2 7/8 API-EU	3 3/8 Gun
7 5/8 101230639	Bottom Fire	6.453	6.625	6.765	16900	40,000	3 3/8 TDF	3 3/8 Gun
7 5/8 101230638	Bottom Fire	6.453	6.625	6.765	16,900	40000	2 1/2 TDF	3 3/8 Gun
7 5/8 101230637	Bottom Fire	6.672	6.875	7.025	16,900	40,000	2 7/8 API-EU	3 3/8 Gun
7 5/8 101230636	Bottom Fire	6.672	6.875	7.025	16,900	40,000	3 3/8 TDF	3 3/8 Gun
7 5/8 101230635	Bottom Fire	6.672	6.875	7.025	16,900	40,000	2 1/2 TDF	3 3/8 Gun
7 3/4 102205070	Bottom Fire, Long Stroke, Button-Type Slips	6.250	6.538	6.625	30,000	150,000	2 1/2 TDF	4 3/4 HW Gun
7 3/4 102205067	Bottom Fire, Long Stroke	6.250	6.538	6.625	30,000	150,000	2 1/2 TDF	4 3/4 HW Gun
7 3/4 102203140	Bottom Fire, Button-Type Slips	6.250	6.538	6.625	30,000	150,000	2 1/2 TDF	4 3/4 HW Gun
7 3/4 102082120	Bottom Fire	6.250	6.538	6.625	30,000	150,000	2 1/2 TDF	4 3/4 HW Gun
9 5/8 101296028	Bottom Fire, Long Stroke	8.218	8.535	8.835	16,900	40,000	2 7/8 API-EU	3 3/8 Gun
9 5/8 101296027	Bottom Fire, Long Stroke	8.218	8.535	8.835	16,900	40,000	3 3/8 TDF	3 3/8 Gun
9 5/8 101296025	Bottom Fire, Long Stroke	8.218	8.535	8.835	16,900	40,000	2 1/2 TDF	3 3/8 Gun
9 5/8 101296016	Bottom Fire, Long Stroke	8.593	8.921	9.036	16,900	40,000	2 7/8 API-EU	3 3/8 Gun
9 5/8 101296015	Bottom Fire, Long Stroke	8.593	8.921	9.036	16,900	40,000	3 3/8 TDF	3 3/8 Gun
9 5/8 101296012	Bottom Fire, Long Stroke	8.593	8.921	9.036	16,900	40,000	2 1/2 TDF	3 3/8 Gun
9 5/8 101230371	Bottom Fire	8.218	8.535	8.835	16,900	40,000	2 7/8 API-EU	3 3/8 Gun
9 5/8 101230370	Bottom Fire	8.218	8.535	8.835	16,900	40,000	3 3/8 TDF	3 3/8 Gun
9 5/8 101230369	Bottom Fire	8.218	8.535	8.835	16,900	40,000	2 1/2 TDF	3 3/8 Gun
9 5/8 101230368	Bottom Fire	8.593	8.921	9.036	16,900	40,000	2 7/8 API-EU	3 3/8 Gun

Automatic-J Gun Hangers

Size and SAP No.	Additional Feature	Maximum Tool OD in.	Minimum Casing ID in.	Maximum Casing ID in.	Pressure Rating psi	Load Rating lb	Bottom Connection	Top Connection
9 5/8 101230367	Bottom Fire	8.593	8.921	9.036	16,900	40,000	3 3/8TDF	3 3/8 Gun
9 5/8 101230366	Bottom Fire	8.593	8.921	9.036	16,900	40,000	2 1/2TDF	3 3/8 Gun
10 3/4 101529374	Bottom Fire, Long Stroke	9.17	9.450	9.660	17,000	250,000	3 3/8 Gun	4 5/8 Gun

All available sizes might not be included. Review Enterprise for a complete listing.
The temperature rating for these tools is determined by the explosives and elastomers used with each tool.
The pressure and load rating values are interdependent; as one goes up, the other goes down. The ratings shown are the maximum values for each one.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

On-the-Job Performance

A customer wanted to perforate a 46-ft interval in a well in central Texas. Total depth was 14,500 ft and included a bottomhole temperature of 370°F and 10-lb brine fluid in the well. Pipe included 7 5/8-in. casing with a 5-in. 23.2-lb/ft liner polished bore receptacle at 12,000 ft. The top of the liner was isolated with a 4-in. bore drillable packer set inside the 7 5/8-in. casing.

Perforating equipment consisted of 3 3/8-in. perforating guns, loaded 4 spf with 32-g PYX charges and 100-grain PYX aluminum-clad prima cord.

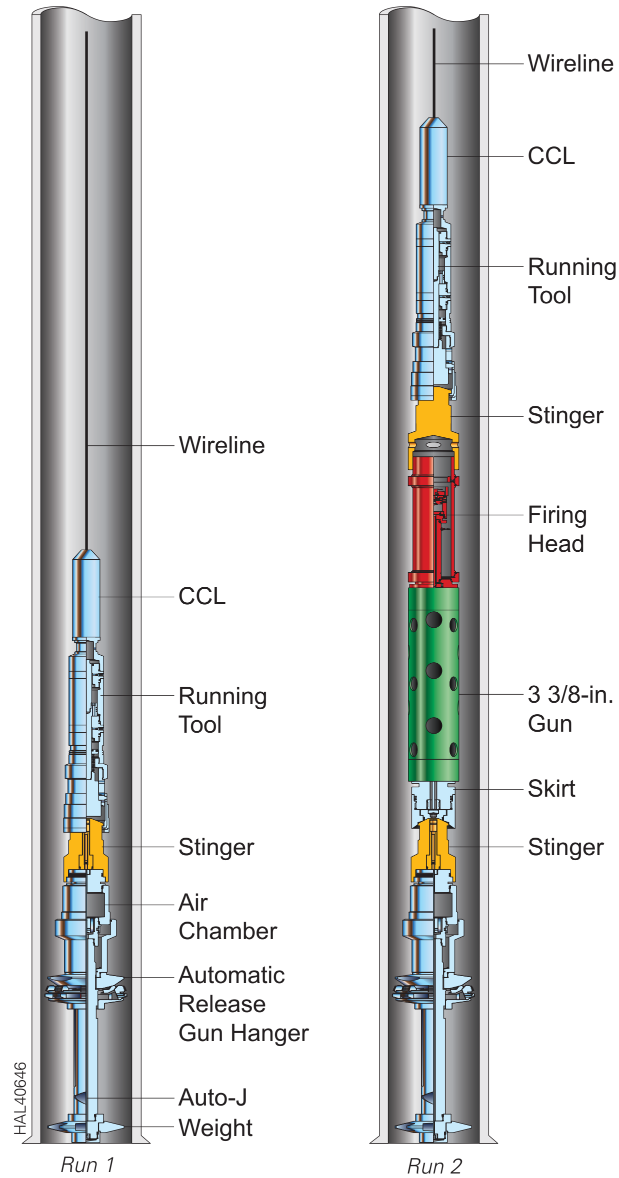
This gun hanger was adapted for hostile environment use. Preparations included dressing the tool with PYX explosives and using water in place of silicone oil inside the hanger. The hanger was fitted with an auto-J latch to allow setting and unsetting with the wireline. A 300-lb weight was installed on the bottom of the gun hanger to permit running on electric wireline.

The running tools were used to deploy the gun hanger and gun module. Crossover subs were used to adapt the running tool threads to the electric wireline.

The gun hanger was attached with a modular stinger onto the running tool, casing collar locator (CCL), and electric wireline and run into the well. After reaching the approximate setting depth, gun hanger position was verified by checking the casing collars with the CCL. The gun hanger was set by up and down movement of the wireline. A decrease in wireline weight at the surface verified the hanger had set. Additional weight was then slacked off. This caused oil to meter through an orifice in the hydraulic running tool. Five minutes later the tool released from the gun hanger.

Next, a running tool was installed onto the gun module firing head handling stinger. The CCL and electric wireline were attached into the running tool, and the entire assembly was run into the well. The gun module assembly was lowered to the top of the gun hanger and the casing collars were again checked with the CCL to verify hanger position. Weight was slacked off to release the running tool. Decrease in weight at the surface verified the running tool had separated from the gun module. The running tool was then pulled out of the well. The entire deployment, from the time the first running tool was lowered into the well until the last running tool was removed, took 5 hours.

Five days later, Halliburton was called to the wellsite to fire the guns. Tubing was pressured to 7,000 psi and released back to zero. Approximately 4 minutes later, the detonation was both felt and heard at the wellhead, indicating the guns had fired. The well immediately began unloading 10-lb brine. A weighted slickline run was made to verify the gun module and auto-release gun hanger had dropped into the rathole. There were no problems encountered during the entire operation. The customer was very pleased with the efficiency of the operation and the performance of the Halliburton crew.



Running Tool Assembly Modular 3.12-in. OD for Baker #20 Setting Tool

Running and Retrieving Tools for the Auto-Release Gun Hanger

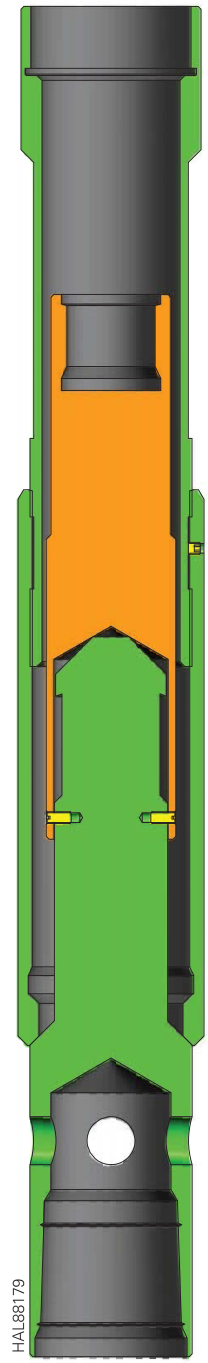
The running and retrieving tools for the modular gun system and the auto-release gun hanger gives customers flexibility in the conveyance of these tools in the well. There are four basic running tools that have been run with these systems: explosive set, jar down, hydraulic, and rotational set. Most of the tools are for wireline and slickline deployment of the systems. The on/off tool requires rotation to operate and is limited to tubing-conveyed applications. All of these tools are reusable with a minimal amount of redressing.

Application

The running and retrieving tools are used for setting gun hangers in position, running modules, and retrieving modules. The tools break down into four categories: explosive set, jar down and jar up, hydraulic, and rotational set. There are many tools that can be used with the modular system.

- Explosive set
  - Adapter kit for Baker #10 setting tool
  - Adapter kit for Baker #20 setting tool
- Jar down
  - Otis® SB and RB shear release and running tool
  - Camco JDC and JUC
- Hydraulic
  - Hydraulic JDC running and retrieving tool
- Rotational set
  - Right-hand release on/off tool

For more specifications, refer to the *Running and Retrieving Tools* manual.



Running Tool Assembly Modular 3.12-in. OD for Baker #20 Setting Tool

Detach™ Separating Gun Connector

The Detach™ separating gun connector allows operators to deploy long gun sections into the well. Guns are deployed downhole in a single trip and placed across the perforating zone supported by a gun hanger or plug. The guns are fired when desired and then will automatically separate, which allows them to be retrieved in manageable sections or left in the hole. The Detach separating gun connector is ideal for use in monobore wells with rathole length restrictions and in rigless completions.

Rathole Length Restriction

In this application, insufficient rathole length causes the uppermost gun modules to remain adjacent to the perforated interval after they are fired, where they might interfere with production from the well. With the Detach separating gun connector, gun sections can be removed from the perforated interval without killing the well.

Rigless Completion

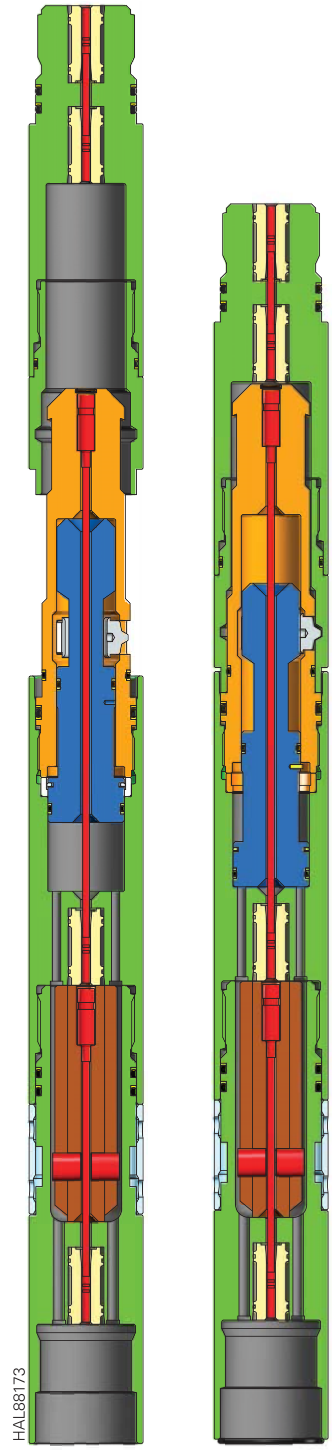
On wells in which the completions are installed with wireline or coiled tubing, the Detach separating gun connector or modular gun system is the preferred method for perforating. No rig is required — saving both time and money.

Operation

When the firing head detonates the detonating cord initiator, the explosives train continues through the tool and detonates two shaped charges that punch holes in the vent sub. At this point, wellbore pressure is allowed to enter the assembly and move the mandrel lock piston upward, allowing the retaining dogs to move inward, releasing the stinger, and allowing the gun sections to separate.

Benefits

- Deploys entire gun assembly to cover the zone of interest in a single trip and retrieve in manageable gun sections without killing the well
- Retrieves or leaves guns at the bottom of the hole
- Allows perforating in either underbalanced or overbalanced conditions over the entire interval



Detach™ Separating Gun Connector

Detach™ Separating Gun Connector Specifications

SAP No.	Upper Thread Size and Type in. (mm)	Lower Thread Size and Type in. (mm)	Maximum OD in. (mm)	Minimum ID	Makeup Length ft (m)	Minimum Operating Pressure psi (bar)	Tensile Rating lb (kg)	Burst Pressure	Collapse Pressure psi (bar)
101363724	2 3/8 (60.450) 6P Acme Pin	2 3/8 (60.450) 6P Acme Box	2.75 (69.850)	N/A	2.86 (0.87)	1,000 (69)	80,000 (36 300)*	N/A	20,000 (1379)
101286871	2 7/8 (73.03) 6P Acme Box × Pin	2 7/8 (73.03) 6P Acme Box	3.38 (85.85)	N/A	2.74 (0.83)	1,000 (69)	110,000 (49 800)	N/A	20,000 (1379)

*Verification testing

All available sizes might not be included. Review Enterprise for a complete listing.

Temperature rating is determined by explosive.

These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

Explosive Transfer Swivel Sub

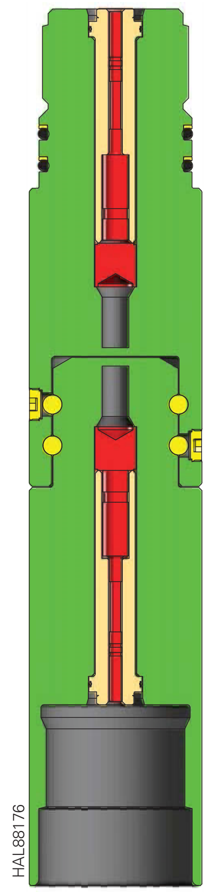
The explosive transfer swivel sub allows two sections of guns to rotate independently of one another. This independent rotation is important on long strings of guns in horizontal wells when they must be oriented in a specific direction. It is easier to orient several short sections of guns rather than one long section.

Features and Benefits

» Useful in horizontal wells when shots need to be oriented in a specific direction to the wellbore
» Bidirectional, allowing firing from either direction

Operation

This swivel sub can be run as a connector between two guns to allow them to rotate independently without breaking the explosive train. In other words, this sub passes on the explosive transfer to the next gun.



Explosive Transfer Swivel Sub Assembly

Explosive Transfer Swivel Subs

SAP No.	Thread Size and Type in. (mm)	Maximum OD in. (mm)	Makeup Length ft (m)	Maximum Operating Pressure* psi (bar)	Collapse Pressure psi (bar)	Ultimate Tensile Rating lb (kg)	Maximum Operating Load lb (kg)	Bidirectional
101757115	2 3/4 (69.85) Pin × Box	2.88 (73.30)	1.14 (0.35)	20,000 (137 895)	25,000 (172 369)	134,000 (60 781)	32,000 (14 515)	No
101271529	2 3/4 (69.85) Pin × Box	2.75 (69.85)	1.13 (0.34)	13,000 (89 632)	25,000 (172 369)	134,000 (60 781)	32,000 (14 515)	Yes
101271672 (Centralizer)	2 3/4 (69.85) Pin × Box	2.75 (69.85)	1.13 (0.34)	13,000 (89 632)	25,000 (172 369)	134,000 (60 781)	32,000 (14 515)	Yes
101763731	Owens 3 1/8 (79.38) Pin × Box	3.13 (79.50)	1.16 (0.35)	21,000 (144 790)	21,000 (144 790)	134,000 (60 781)	32,000 (14 515)	No
101295378	Owens 3 1/8 (79.38) Pin × Box	3.13 (79.50)	1.16 (0.35)	21,000 (144 790)	21,000 (144 790)	134,000 (60 781)	32,000 (14 515)	Yes
101757094	3 3/8 (85.73) Pin × Box	3.38 (85.85)	1.14 (0.35)	20,000 (137 895)	27,000 (186 158)	241,700 (109 633)	40,000 (18 144)	No

Explosive Transfer Swivel Subs

SAP No.	Thread Size and Type in. (mm)	Maximum OD in. (mm)	Makeup Length ft (m)	Maximum Operating Pressure* psi (bar)	Collapse Pressure psi (bar)	Ultimate Tensile Rating lb (kg)	Maximum Operating Load lb (kg)	Bidirectional
101271553	3 3/8 (85.73) Pin × Box	3.38 (85.85)	1.14 (0.35)	13,000 (89 632)	27,000 (186 158)	241,700 (109 633)	40,000 (18 144)	Yes
101271705 (Centralizer)	3 3/8 (85.73) Pin × Box	3.38 (85.85)	1.14 (0.35)	13,000 (89 632)	27,000 (186 158)	241,700 (109 633)	40,000 (18 144)	Yes
101754781	4 5/8 (117.48) Pin × Box	4.63 (117.60)	1.13 (0.34)	20,000 (137 895)	27,000 (186 158)	411,400 (186 608)	60,000 (27 215)	No
101271546	4 5/8 (117.48) Pin × Box	4.63 (117.60)	1.13 (0.34)	13,000 (89 632)	27,000 (186 158)	411,300 (186 562	60,000 (27 215)	Yes
101271871 (Centralizer)	4 5/8 (117.48) Pin × Box	4.63 (117.60)	1.13 (0.34)	13,000 (89 632)	27,000 (186 158)	411,300 (186 562	60,000 (27 215)	Yes
101752922	5 (127.00) Pin × Box	5.00 (127.00)	1.13 (0.34)	20,000 (137 895)	22,000 (151 685)	398,300 (180 666)	60,000 (27 215)	No
101369204	5 (127.00) Pin × Box	5.00 (127.00)	1.13 (0.34)	13,000 (89 632)	22,000 (151 685)	398,300 (180 666)	60,000 (27 215)	Yes
101752131	5 1/8 (130.18) Pin × Box	5.13 (130.302)	1.13 (0.34)	20,000 (137 895)	27,000 (186 158)	515,000 (223 600)	60,000 (27 215)	No
101284187	5 1/8 (130.18) Pin × Box	5.13 (130.302)	1.13 (0.34)	13,000 (89 632)	27,000 (186 158)	515,000 (223 600)	60,000 (27 215)	Yes
101756609	5 3/4 (146.05) Pin × Box	5.75 (146.05)	1.13 (0.34)	20,000 (137 895)	22,000 (151 685)	508,000 (230 425)	60,000 (27 215)	No
101278821	5 3/4 (146.05) Pin × Box	5.75 (146.05)	1.13 (0.34)	13,000 (89 632)	22,000 (151 685)	500,800 (227 159	60,000 (27 215)	Yes

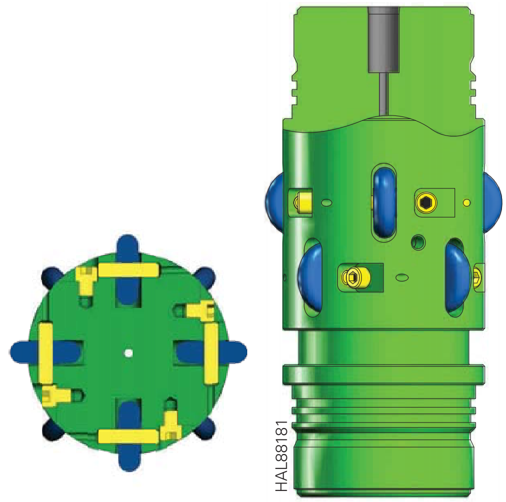
*Maximum operating pressure is based on the o-ring seal ratings.
All available sizes might not be included. Review Enterprise for a complete listing.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

Roller Tandem Assembly

Roller tandem assemblies are used to reduce the friction between the perforating guns and casing. In some cases, the frictional drag can be reduced by as much as 90%.

Applications

- Running guns on coiled tubing in horizontal and highly deviated wells
- Dropping guns into the rathole in highly deviated wells
- Can be deployed in conjunction with the modular gun system



Roller Tandem Assembly

Roller Tandem Assembly Specifications

SAP No.	Size in. (mm)	Effective OD in. (mm)	No. of Rollers	Roller Phasing	Tensile Strength lb (kg)	Makeup Length in. (mm)	Weight lb (kg)
101547314	2 1/2 (63.50)	2.65 (67.31)	6 (2 rows of 3)	60°	135,300 (61 371)	6.97 (177.04)	11 (4.98)
120021632	2 3/4 (69.85)	3.06 (77.72)	6 (2 rows of 3)	60°	219,300 (99 473)	6.97 (177.04)	20 (9.07)
102480739	2 7/8 (73.02)	3.885 (98.68)	6 (2 rows of 3)	60°	280,500 (127 232)	7.56 (192.02)	22 (9.98)
102422201*	3 1/8 (79.37)	3.63 (92.20)	4 (1 row of 4)	45°	295,000 (133 809)	4.00 (101.60)	62 (28.12)
100155770	3 3/8 (85.72)	3.76 (95.50)	8 (2 rows of 4)	45°	258,000 (117 026)	7.70 (195.58)	22 (9.98)
101348759	4 5/8 (117.47)	5.64 (143.25)	8 (2 rows of 4)	45°	453,900 (205 885)	9.25 (234.95)	62 (28.12)
101313551**	7 (177.80)	8.20 (208.28)	8 (2 rows of 4)	45°	444,000 (201 395)	15.52 (394.21)	220 (99.79)
101952943	7 (177.80)	8.20 (208.28)	8 (2 rows of 4)	45°	788,400 (357 612)	9.25 (234.95)	160 (72.57)

*Made by Hunting Titan
**Three-piece body
***Additional special application roller tandems are available in Enterprise.
All available sizes might not be included. Review Enterprise for a complete listing.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

Centralizer Tandem

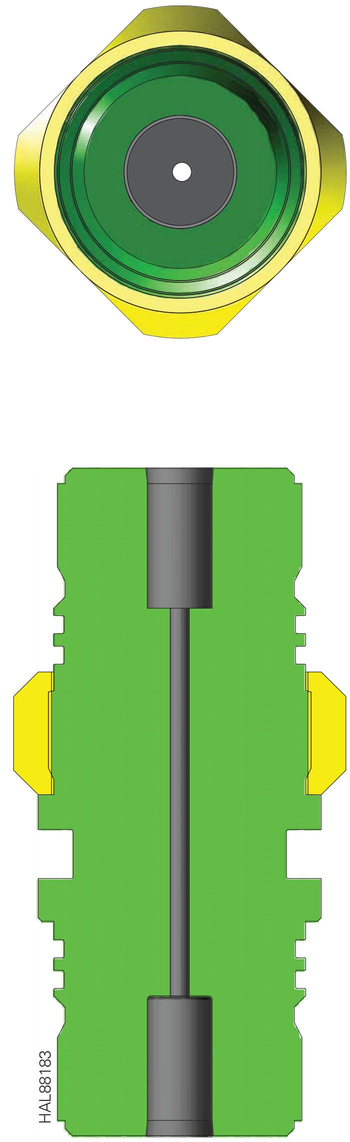
In certain TCP operations, it is desirable to centralize the guns and other tools in the casing. Halliburton has designed a full range of centralizers to meet this requirement for all gun sizes. The centralizers are designed to minimize the possibility of "hanging up" while running or pulling the guns, and maximize the flow area around the centralizers.

Application

Two of the primary applications for the centralizers are:

1. When perforating with big hole charges, it is recommended to centralize the guns to help ensure the exit holes in the casing will all be of a consistent size. If the guns are not centralized, the size of the exit holes will vary according to the clearance from the gun to the casing. This can cause problems with sand control operations.
2. In modular gun completions, it is necessary to centralize the gun modules to obtain a reliable explosive transfer between modules.

Contact your Halliburton representative for a list of available centralizers.



Centralizer Tandem

Vented Tandem Assembly

Vented tandem assemblies are used to elevate the trapped pressure contained in the perforating gun assemblies during the retrieval process.

Applications

- Running guns with blank sections on jointed pipe, coiled tubing
- High-pressure vertical, horizontal, and highly deviated wells
- High gas or condensate wells
- Can be deployed in conjunction with the modular gun that will be retrieved

Quick Torque™ Connector

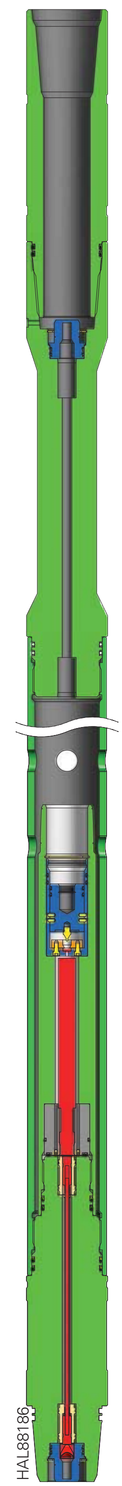
The Quick Torque™ connector consists of connectors that cover both ends of each gun section to enclose the assembly. The connectors have a common, self-aligning drillpipe thread that allows automatic or manual makeup. Explosive transfer occurs through a web, making the system self contained for added safety. With these connectors, TCP gun assemblies can now be picked up by the rig equipment and properly made up using iron roughneck equipment, without the need for human intervention. It simplifies the process and saves time by eliminating assembly of the components on the rig.

Features and Benefits

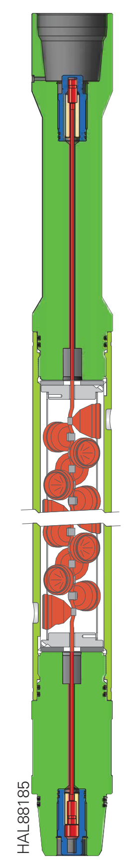
- Standard NC38 thread makeup procedure.
- Redressable.
- Self-contained system increases personnel safety on the rig floor — no human intervention needed.
- Once the thread protectors are removed, all subsequent steps can be automated.
- Efficient, automated system saves rig time.
- Allows venting of any built-up pressure during shipping.
- No exposed explosives.
- Q125 material, sour service >175°F.

Operation

This system can be used on any rig with automatic or manual pipe handling equipment. It can be used with 4 5/8-in. standard or 4 5/8-in. self-orienting TCP gun systems and a 3 3/8-in. OD or smaller firing head.



Firing Head Subassembly



Gun Subassembly

QuickTorque™ Connector: 2 7/8-in. Guns

SAP No.	Part Description	Tool Maximum OD in. (mm)	Maximum Operating Pressure psi (bar)	Tensile Rating lb (kg)	Makeup Length in. (mm)	Temperature Rating	Bidirectional
101717802	Box Assembly 2 7/8 Gun Pin × API-NC26 Box	3.38 (85.85)	22,000 (1516)	239,400 (108 590)	12.5 (317.50)	*	No
101734315	Pin Assembly 2 7/8 Gun Pin × API-NC26 Pin	3.38 (85.85)	22,000 (1516)	239,400 (108 590)	9.3 (236.22)	*	Yes
101635799	Pin Assembly 2 7/8 Gun Pin × API-NC26 Pin	3.14 (79.95)	22,000 (1516)	239,400 (108 590)	9.3 (236.22)	*	Yes
101635792	Box Assembly 2.88 Slip Recess OD API-NC26 Box × 2 7/8 Gun Pin	3.14 (79.95)	22,000 (1516)	239,400 (108 590)	12.5 (317.50)	*	Yes

*Maximum temperature rating determined by explosives and elastomers.
All available sizes might not be included. Review Enterprise for a complete listing.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

QuickTorque™ Connector: 3 3/8-in. Guns

SAP No.	Part Description	Tool Maximum OD in. (mm)	Maximum Operating Pressure psi (bar)	Tensile Rating lb (kg)	Makeup Length in. (mm)	Temperature Rating	Bidirectional
101718313	Box Assembly 2.88 Slip Recess OD API-NC26 Box × 3 3/8 Gun Pin	3.50 (88.90)	22,000 (1516)	335,400 (152 135)	21.20 (538.49)	*	No
101685353	Crossover 2.88 Slip Recess OD,1.50 ID API-NC26 × 3 3/8 Gun Pin	3.50 (88.90)	22,000 (1516)	335,400 (152 135)	21.20 (538.49)	*	N/A
101649636	Box Assembly 2.88 Slip Recess OD API-NC26 Box × 3 3/8 Gun Pin	3.50 (88.90)	22,000 (1516)	335,400 (152 135)	21.20 (538.49)	*	Yes
101649619	Pin Assembly 3 3/8 Gun Pin × API-NC26 Pin	3.50 (88.90)	22,000 (1516)	247,700 (112 355)	9.0 (228.60)	*	Yes

*Maximum temperature rating determined by explosives and elastomers.
All available sizes might not be included. Review Enterprise for a complete listing.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

QuickTorque™ Connector: 4 5/8-in. Guns

SAP No.	Part Description	Tool Maximum OD in. (mm)	Maximum Operating Pressure psi (bar)	Tensile Rating lb (kg)	Make up Length in. (mm)	Temperature Rating	Bidirectional
102011863	Box Assembly API-NC38 Box × 4 5/8 Gun Pin	4.75 (120.65)	22,000 (1516)	493,400 (223 802)	23.08 (586.32)	*	No
102011828	Pin Assembly 4 5/8 Gun Pin × API-NC38 Pin	4.75 (120.65)	22,000 (1516)	493,400 (223 802)	6.75 (171.45)	*	Yes
101381170	Pin Assembly Dual Thread API-NC38 Box × 3 3/8 Gun Pin, 4 5/8 Gun Pin	4.75 (120.65)	22,000 (1516)	493,400 (223 802)	23.08 (586.32)	*	Yes
101352042	Pin Assembly Dual Thread 3 3/8 Gun Pin, 4 5/8 Gun Pin × API-NC38 Pin	4.75 (120.65)	22,000 (1516)	493,400 (223 802)	6.75 (171.45)	*	Yes
101351885	Box Assembly API-NC38 Box × 4 5/8 Gun Pin	4.75 (120.65)	22,000 (1516)	493,400 (223 802)	23.08 (586.32)	*	Yes
101999367	Crossover, 2.0 ID API-NC38 Box × 4 5/8 Gun Pin	4.75 (120.65)	22,000 (1516)	493,400 (223 802)	23.08 (586.32)	*	N/A

*Maximum temperature rating determined by explosives and elastomers.
All available sizes might not be included. Review Enterprise for a complete listing.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

QuickTorque™ Connector: 5-in. Guns

SAP No.	Part Description	Tool Maximum OD in. (mm)	Maximum Operating Pressure psi (bar)	Tensile Rating lb (kg)	Make up Length in. (mm)	Temperature Rating	Bidirectional
101514211	Pin Assembly 5.00 Gun Pin × API-NC38 Pin	5.00 (127)	20,000 (1379)	587,600 (266 531)	23.08 (586.32)	*	Yes
101535542	Box Assembly Centralizer API-NC38 Box × 5.00 Gun Pin	5.00 (127)	20,000 (1379)	587,600 (266 531)	25.2 (640.08)	*	Yes
101514214	Pin Assembly 5.00 Gun Pin × API-NC38 Pin	5.00 (127)	20,000 (1379)	587,600 (266 531)	6.75 (171.45)	*	Yes

*Maximum temperature rating determined by explosives and elastomers.
All available sizes might not be included. Review Enterprise for a complete listing.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

Additional QuickTorque™ Connector Crossovers

SAP No.	Part Description	Tool Maximum OD in. (mm)	Maximum Operating Pressure psi (bar)	Tensile Rating lb (kg)	Make up Length in. (mm)	Temperature Rating	Bidirectional
101720902	Crossover 2.688 ID API-NC38 Box × API-NC38 Pin	4.75 (120.65)	11,161 (769)	450,250 (204 230)	13.56 (344.42)	*	N/A
101686457	Crossover 1.50 ID API-NC26 Pin × 2 7/8-10.40TSH-WT26 Box	3.50 (88.90)	18,600 (1282)	297,000 (134 717)	19.68 (499.87)	*	N/A
101685535	Crossover 1.50 ID 2 7/8-10.40TSH-WT26 Box × API-NC26 Pin	3.50 (88.90)	22,000 (1516)	297,000 (134 717)	16.2 (441.48)	*	N/A
101354907	Crossover 2.68 ID API-NC38 Box × API-NC38 Pin	4.75 (120.65)	11,880 (819)	480,800 (218 087)	13.56 (344.42)	*	N/A

*Maximum temperature rating determined by explosives and elastomers.
All available sizes might not be included. Review Enterprise for a complete listing.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

Modular Gun System

Through a special arrangement of perforating equipment, the modular gun system permits the optimum number of guns to be deployed via slickline or electric line, allowing larger intervals to be perforated simultaneously.

The modular gun system is run by Halliburton perforating specialists who know the equipment, know the well, and know the best techniques to fit the particular application. The system is backed by the Halliburton worldwide network of technical support, reliable equipment, and innovative performance — all of which are ready to go wherever and whenever needed.

Features

» Ideal for monobore completions

» Allows stacking of an optimum number of guns downhole for perforating the maximum interval

» Several features make the modular gun system the best choice for perforating under a wide range of conditions

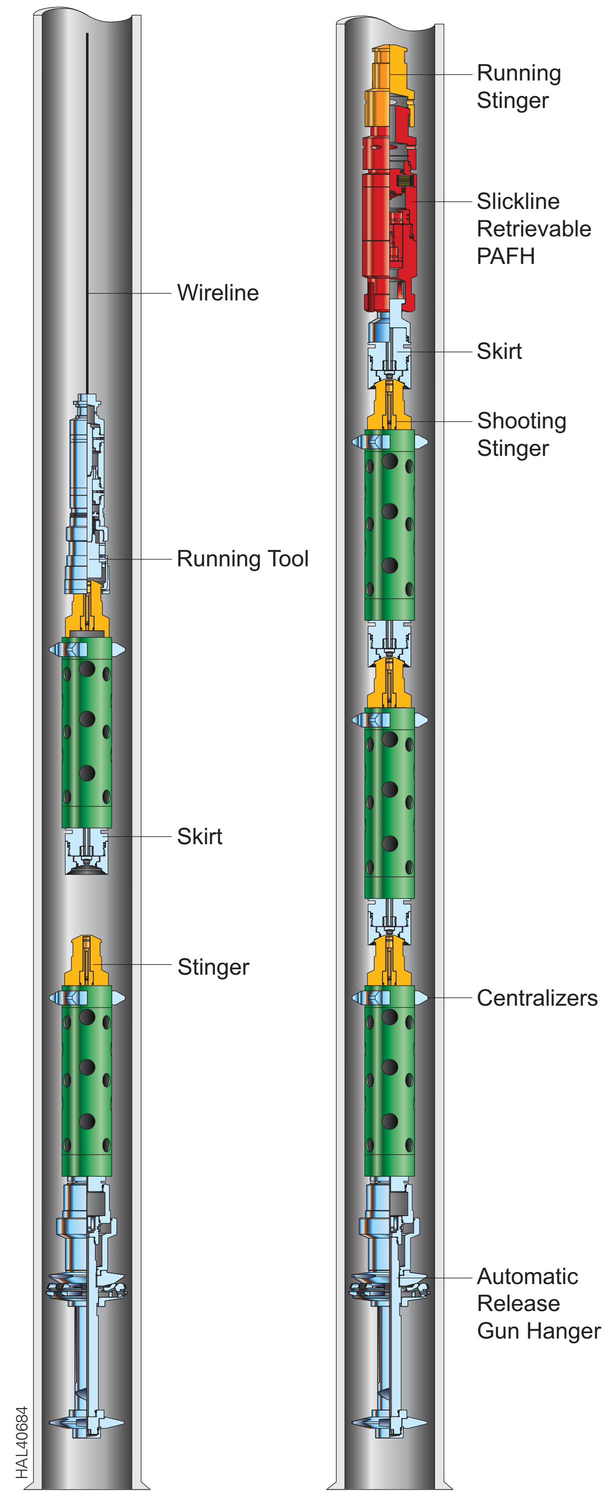
- Guns are retrievable or can be left at the bottom of the hole
- System allows perforating in either underbalanced or overbalanced conditions over the entire interval
- Wide range of gun sizes (2- to 7-in. OD) permits deployment over a wide range of casing from 3 1/2 to 9 5/8 in.

» No rig required

» Can be deployed via coiled tubing, electric wireline, or slickline as well as conventional tubing or drillstring

» Allows a zone to be perforated and tested with no downhole restrictions below or above the packer

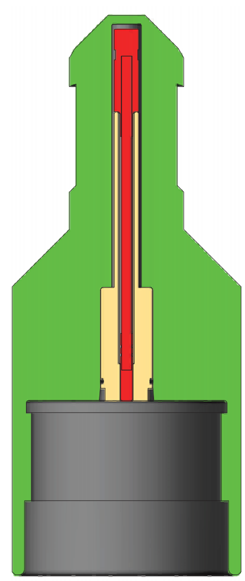
» Proven VannSystem® guns and firing heads are used in the modular gun system



Modular Gun System Configuration

The Modular Gun System Process

The modular gun system allows operators to deploy multiple gun sections to perforate long intervals. Gun modules are deployed downhole individually and stacked on each other at the perforating zone until the appropriate length is achieved with the lowermost gun module being supported by the gun hanger. This method avoids any gun length restrictions caused by the lubricator. The auto-release gun hanger positions the perforating assembly and allows it to remain adjacent to the desired interval. The guns are fired via a pressure-actuated firing head and are then automatically released to the bottom of the hole where they can later be retrieved or left in the hole. The system is ideal for use in wells with rathole length restrictions and rigless completions.



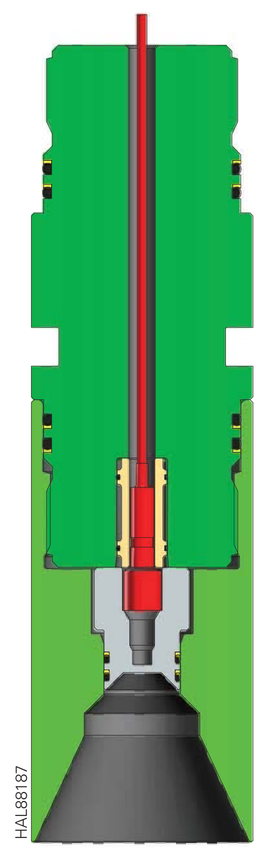
Stinger Assembly

Rathole Length Restriction

In this application, insufficient rathole length causes the uppermost gun modules to remain adjacent to the perforated interval after they are fired — where they might interfere with production from the well. The modular gun system allows the guns to be retrieved in sections without killing the well.

Rigless Completion

On wells in which the completions are installed with wireline or coiled tubing, the modular gun system is the preferred method for perforating. No rig is required, saving both time and money.



Skirt Assembly

Vertical Oriented Perforating

When orienting long gun systems in a vertical well, the vertical oriented perforating (VOP) gun hanger helps ensure successful perforating in the correct orientation, without risking natural or intelligent completions.

The VOP is designed to be run in monobore well applications with profiles and/or restrictions that prevent the use of standard gun hangers and where perforating orientation is critical, such as:

- Intelligent completions
- Multiple string completions
- Reservoir challenges
- Fiber optics

The unique orientating system enables precise positioning of guns in a vertical application. The slips are designed to stay retracted within the slip housing until the tool is set. When actuated, hydrostatic pressure maintains the tool in the set position. Additional weight applied to the hanger will further enhance the setting process.

New operation scenarios address the industry's challenges by providing more options than when using any other gun hanger system.

- Scenario 1: VOP for an orienting gun system designed for shoot and drop.
- Scenario 2: VOP for an orienting gun system designed for shoot but not drop.
- Scenario 3: VOP for orienting gun system designed for shoot but not drop. VOP hanger to be released and retrieved in a single wireline trip.

  When the VOP is released, the slips retract back within the tool ID, which provides a means for the gun hanger to be retrieved back through the restrictions, nipples, and profiles, or enables the VOP hanger to drop to bottom.

Features and Benefits

- Three scenario operation features
- Electric wireline running and setting procedures similar to common bridge plugs and sump packers
- Can be set in the larger ID casing after running through restrictions (nipples, profiles, hangers, subsurface safety valves, etc.)
- Retrievable and redressable
- Ability to auto-release, stay set after gun detonation, or be released and retrieved in a single wireline trip
- Can be set with most wireline packer setting tools
- Contains no explosives
- Deployable on slickline, wireline, coiled tubing, or jointed pipe
- One size sets in multiple casing ranges
- Hydrostatic pressure keeps tool set
- Lower gun firing pressures can be used because guns and firing heads are deployed in the well after production equipment installation

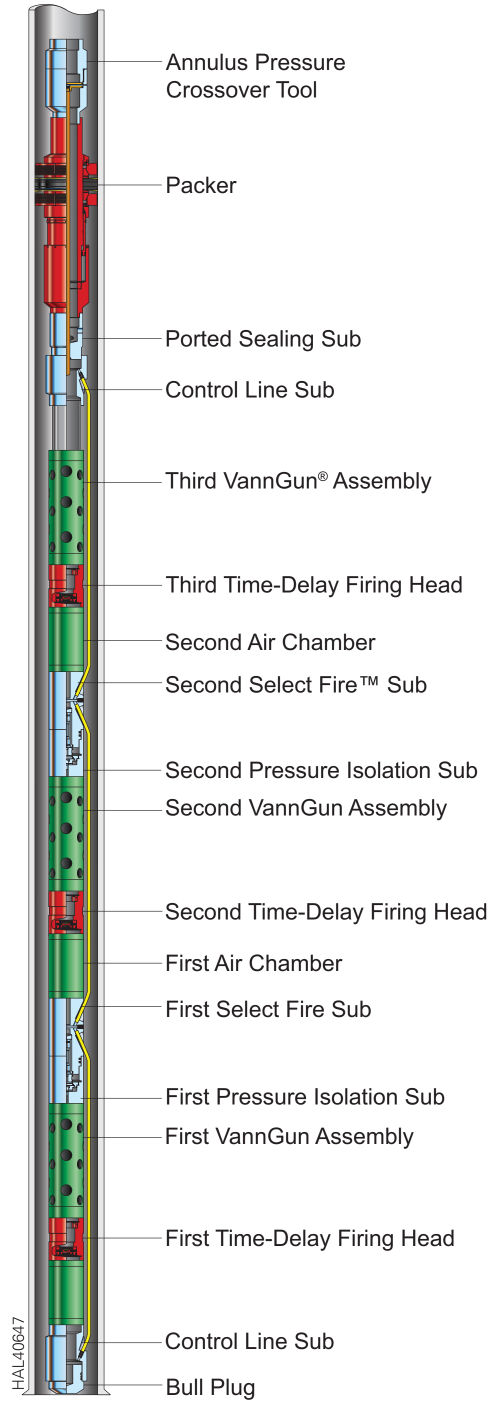
Vertical Oriented Perforating (VOP) Gun Hanger

Select Fire™ Systems

The Select Fire™ system offers flexibility in perforating, testing, and evaluating multiple zones in one trip. The Select Fire system saves rig time and tool charges to help multiply profits.

Features

- Perforating and testing several individual zones — one at a time
- Selecting the order zones are perforated
- Customizing gun configurations for various applications
- Available for all VannGun® assemblies 2 in. and larger
- Helping develop essential reservoir information — potentially saving hundreds of thousands of dollars
- Saving rig time and tool charges to help multiply profits



Select Fire™ Tubing-Conveyed Perforating System

Coiled Tubing-Conveyed Perforating

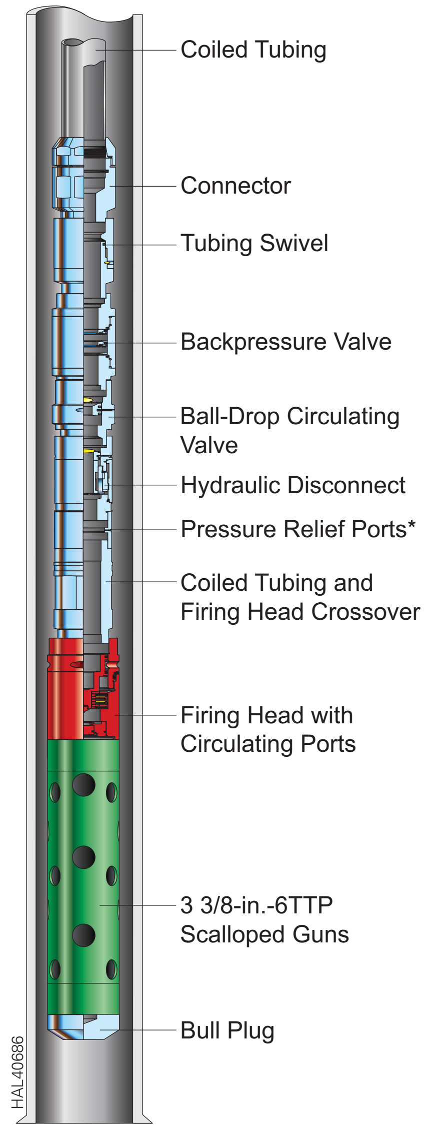
Conveying perforating guns to the zone of interest with coiled tubing has been effectively used for many years in a variety of applications. Benefits include faster run-in times when compared to conventional methods. The guns can be detonated either with wireline or a pressure-activated firing head. Some of the applications include:

» Perforating in underbalanced conditions: Underbalanced conditions occur when hydrostatic pressure in the well is lower than formation pressure. Perforation under these conditions allows increased flow from the formation, which helps clean the perforations and helps reduce near-wellbore damage.

» Horizontal well perforating: Coiled tubing-conveyed perforating can be deployed in horizontal portions of the well where conventional methods of perforating are impractical or impossible.

» Multiple guns can be deployed on a single coiled tubing run using a pressure-activated firing head or hydraulic-actuated firing head (ball drop). Extended delay assemblies are run between each gun to allow for repositioning each gun on depth, while the extended delay fuse is burning.

» Long gun strings can be deployed in live wells on coiled tubing by using either the AutoLatch™ or ratchet connectors.



Perforating Gun String

*Pressure relief ports are added to the bottomhole assembly for coiled tubing perforating jobs to help eliminate the possibility of a pressure increase caused by thermal expansion in a closed chamber.

DrillGun™ Perforating Systems

Halliburton developed the DrillGun™ assembly to be a drillable perforating system that provides reliable, quality performance, while lowering overall wellsite costs by:

- Eliminating the high costs associated with wireline services
- Eliminating the need to switch to a mud system for workovers

The DrillGun perforating system combines rugged, reliable Halliburton perforating components with the versatility of drillable materials. It is this type of innovative design that has made Halliburton the leader in perforating charge performance and delivery systems. This drillable, disposable system helps save time and money — two of the most valuable commodities at the wellsite.

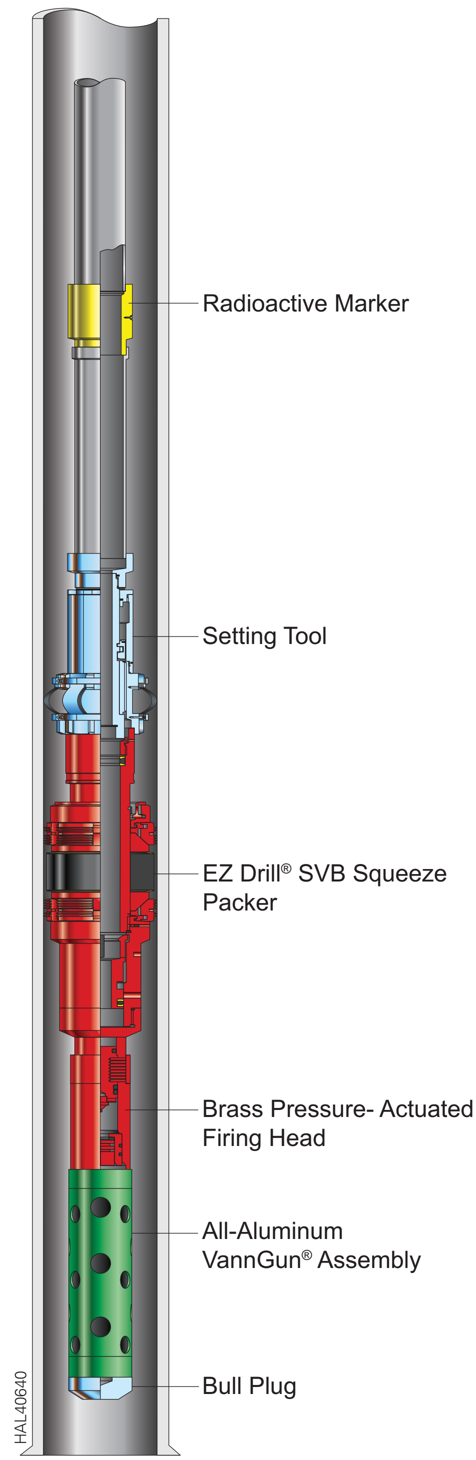
Components of the drillable perforating system are the drillpipe conveyed to the zone of interest, thereby, eliminating mobilization or demobilization charges normally associated with wireline units. Also, because no mud system is needed, clear fluids can remain in place for workover operations. Once in place, the firing head is actuated by pressure applied through the tubing. After perforating, the gun can be drilled out with conventional drilling methods.

The drillable perforating system is ideal for:

- Single-trip perforating, packer placement, and cementing on tubing
- Cementing and perforating in underbalanced conditions
- Plug-to-abandon operations
- Workover cementing with clear fluids
- Plugback set on wireline
- Limited-entry drillstem testing

Components of the drillable perforating system include:

- Aluminum perforating gun
- High-performance perforating charges
- Halliburton industry-proven EZ Drill® SVB packer



DrillGun™ Assembly

DrillGun™ Perforating System: Quick, Economical Solution for Perforating in Unusual Conditions

Savings on Rig Time

Operator challenge: An operator needed to perform a squeeze job on a well. The customer had already switched to a lighter drilling fluid and did not want the high cost of changing to a mud system. As a result, the well would have to be perforated underbalanced.

Halliburton solution: To meet this challenge, Halliburton recommended its DrillGun™ system.

Economic value created: As a result, the operator was able to perform the squeeze job without having to replace the lighter drilling fluid with an expensive mud system. This procedure saved rig time and the expense of a fluid change for a total economic value to the customer of $20,000.

Block Squeeze Application

Operator challenge: An operator had to perform three block squeezes in a 7 5/8-in. liner from 14,400 to 14,800 ft. A primary cement job was not possible; therefore, instead of cement behind the casing, there was 15.5-ppg drilling mud. The well fluid was 10-ppg brine water. However, it would not be necessary to change the well fluid to 15.5-ppg drilling mud to cement.

Halliburton solution: Halliburton logged the first DrillGun system on depth, perforated, and performed the cement job at 4,230 psi underbalanced. For the next two DrillGun system runs, we tagged the first retainer and located it on depth to perform the squeeze.

Economic value created: The three aluminum perforating guns added only 1 hour each to the drillout time. The customer estimates this procedure saved $52,000.

Plug-to-Abandon

Operator challenge: To plug a well before abandoning it, an operator needed to perforate six zones.

Halliburton solution: Halliburton recommended using its DrillGun system rather than employing electric-line perforators, which would normally be selected for the project. The first DrillGun system was started in the well on Sunday evening and was set the next day at a depth of 13,050 ft. The bottom zone was then squeezed. After the procedure was completed, the setting assembly was pulled out of the hole. It went back in with the second stage, and the operation was performed at 8,590 ft. The next day, the final four jobs were run at 5,500, 2,615, 500, and 350 ft, respectively.

Economic value created: All six stages were completed in 2 1/2 days. If electric-line perforators had been used, the total operation would have taken up to 6 days. By using the DrillGun system, the operator saved 4 days of rig-associated costs, consultants, and fluid standby time. An additional savings was realized by using the perforating DrillGun system instead of more expensive electric-line charges. The resulting estimated economic value to the customer was $24,200.

DrillGun™ Assembly Specifications

SAP No.	Thread Size and Type in. (mm)	Maximum OD in. (mm)	Maximum Operating Pressure psi (bar)	Minimum Operating Pressure psi (bar)	Temperature Rating °F (°C)	Maximum Overall Length ft (m)	Shots per Foot	Maximum Number of Shots
101288693 Aluminum	2 7/8 (73.03) EUE 8RD	4.00 (101.6)	15,000 (1035)	3,500 (241)	300 (148.9)*	4.40 (1.341)	6	13
102030818 Aluminum	2 7/8 (73.03) EUE 8RD	4.00 (101.6)	15,000 (1035)	3,500 (241)	300 (148.9)*	6.76 (2.06)	6	31
101288692 Aluminum	2 7/8 (73.03) EUE 8RD	7.00 (177.8)	12,000 (827)	3,500 (241)	300 (148.9)*	4.40 (1.341)	5	11
102037481 Aluminum	2 7/8 (73.03) EUE 8RD	7.00 (177.8)	12,000 (827)	3,500 (241)	300 (148.9)*	6.88 (2.10)	5	26
101598483 Aluminum	2 7/8 (73.03) EUE 8RD	10.00 (254)	6,000 (414)	3,500 (241)	300 (148.9)*	4.12 (1.26)	12	25
101562102 Aluminum	2 7/8 (73.03) EUE 8RD	10.00 (254)	6,000 (414)	3,500 (241)	300 (148.9)*	4.12 (1.26)	14	29
101518156** Aluminum	DrillGun™ Adapter	4.00 (101.6)	15,000 (1035)	N/A	300 (148.9)*	10.00 (3.05)	N/A	N/A

*For use in well temperatures higher than 300°F (148.89°C), consult a Halliburton representative.
**10-ft safety spacer
All available sizes might not be included. Review Enterprise for a complete listing.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

Oriented Perforating

The benefits of sand prevention or improved stimulation performance can be enjoyed using any of the Halliburton leading oriented perforation technologies. Halliburton oriented perforating solutions can be deployed using a wide range of conveyance methods, providing reliable world-class results.

G-Force® Precision Oriented Perforating System

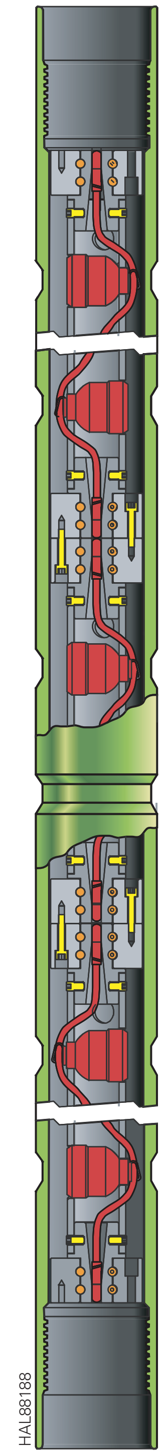
Historically, oriented perforating was attempted via external orienting devices and weights (external to the gun and exposed to the casing environment). In the externally oriented systems, there is added friction created by the guns moving axially down the casing wall, which can significantly work against the orienting mechanism. In addition, doglegs and other discontinuities during the deployment can cause loss of orientation.

It was conceived that if the rotating device could be taken inside the protective environment of the carrier, adverse factors that can significantly decrease the ability to orient the guns in a desired direction could be overcome if not completely eliminated.

The Halliburton G-Force® system comprises an internal orienting charge tube assembly and gun carrier, which allows perforating in any direction regardless of the gun's position relative to the casing.

Features

- Can go through restrictions not possible with older systems
- Because the orienting mechanism of the internal orienting system is contained within the gun carrier, the fundamental orienting design is unaffected by potential restrictions in the completion string
- Can run through tubing and orient in casing
- No need for fin tandems, eccentric tandems, and swivel subs
- Increased orientation accuracy: the operating range will be for wells of 25° deviation and greater. For deviated wells, the accuracy range is ± 5°
- Compatible with live well intervention systems, such as the AutoLatch™ connector, ratchet connector, and the modular gun system
- Gun assemblies can be centralized in the casing
- Can be deployed on coiled tubing, wireline, slickline, or jointed pipe
- No external weight bars required means no gaps between loaded sections and no lost shots



G-Force® System

2 7/8-in. G-Force® Systems Specifications

SAP No.	Length ft (m)	Shot Density	Shot Phasing	Perforation Planes	Collapse Pressure Rating psi (bar)	Tensile Load Rating lb (kg)	Survival Test Medium	Maximum Swell after Firing in. (mm)	Charge
101983899	4 (1.22)	4	90 to 270	2	22,000 (1517)	141,000 (63 957)	Air	2.932 (74.47)	101571815 - DP 11.1 g HMX 102322181 - DP 10.5 g HNS
101600677	22 (6.71)	4	10 to 350	2	22,000 (1517)	141,000 (63 957)	Air	2.932 (74.47)	
101863088[1]	22 (6.71)	4	10 to 350	2	22,000 (1517)	141,000 (63 957)	Air	2.932 (74.47)	
101630791	16 (4.88)	4	10 to 350	2	22,000 (1517)	141,000 (63 957)	Air	2.932 (74.47)	
101863087[1]	16 (4.88)	4	10 to 350	2	22,000 (1517)	141,000 (63 957)	Air	2.932 (74.47)	
101836952	4 (1.22)	4	0 to 180	2	22,000 (1517)	141,000 (63 957)	Air	2.932 (74.47)	
101563379	22 (6.71)	4	0 or 180	1 or 2	22,000 (1517)	141,000 (63 957)	Air	2.932 (74.47)	
101621606	4 (1.22)	4	0 or 180	1 or 2	22,000 (1517)	141,000 (63 957)	Air	2.932 (74.47)	
101740545	2 (0.61)	1	0 or 180	1 or 2	22,000 (1517)	141,000 (63 957)			101251723 - SDP 15.1 g HNS 101201843 - SDP 16 g BRX

[1] Slickwall carrier

All available sizes might not be included. Review Enterprise for a complete listing.

3 3/8-in. G-Force® Systems Specifications

SAP No.	Length ft (m)	Shot Density	Shot Phasing	Perforation Planes	Collapse Pressure Rating psi (bar)	Tensile Load Rating lb (kg)	Survival Test Medium	Charge
101856336[1,2]	22 (6.71)	4	10 to 350	2	25,000 (1724)	232,000 (105 233)		101366678 - Millennium™ 21 g HMX Industry Standard 101618994 - Millennium™ 21 g RDX Industry Standard 101618998 - Millennium™ 21 g RDX Industry Standard 102045430 - 210 MaxForce®-FRAC 21G RDX Industry Standard 102322540 - Millennium™ 21 g HNS Industry Standard
101678098[2]	22 (6.71)	4	10 to 350	2	20,000 (1379)	228,000 (103 419)		
101856207[1,2]	16 (4.88)	4	10 to 350	2	25,000 (1724)	232,000 (105 233)		
101677834[2]	16 (4.88)	4	10 to 350	2	25,000 (1724)	228,000 (103 419)		
101294752[2]	4.83 (1.47)	4	10 to 350	2	25,000 (1724)	228,000 (103 419)		
101407434[2]	22 (6.71)	4	0 or 180	1 or 2	25,000 (1724)	228,000 (103 419)	Air	
101898813	4.83 (1.47)	4	0 or 180	1 or 2	25,000 (1724)	232,000 (105 233)		
101640605[2]	4.83 (1.47)	4	0 or 180	1 or 2	25,000 (1724)	228,000 (103 419)	Air	
101295030[2]	2 (0.61)	3	0 or 180	1 or 2	25,000 (1724)	228,000 (103 419)		
101406739[2]	22 (6.71)	4	0	1	25,000 (1724)	228,000 (103 419)		
102265963[1,2]	22 (6.71)	4	0 to 180	2	25,000 (1724)	232,000 (105 233)		
102265473[1,2]	16 (4.88)	4	0 to 180	2	25,000 (1724)	232,000 (105 233)		
101515354	22 (6.71)	4	0 or 180	1 or 2	25,000 (1724)	228,000 (103 419)		101371884 - 25 g SPD HMX

[1]Slickwall carrier
[2]3 1/8-in. Industry-standard Millennium™/MaxForce®, slickwall
All available sizes might not be included. Review Enterprise for a complete listing.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

4 5/8-in. G-Force® Systems Specifications

SAP No.	Length ft (m)	Shot Density	Shot Phasing	Perforation Planes	Collapse Pressure Rating psi (bar)	Tensile Load Rating lb (kg)	Survival Test Medium	Maximum Swell after Firing in. (mm)	Charge
102192874	22 (6.71)	4	90 to 270	2	20,000 (1379)	366,000 (166 015)	Air	4.855 (123.32)	101210636 - Millennium™ 39 g HMX 101287306 - SDP 39 g HNS 101355271 - Millennium™ 39 g RDX
101426443	22 (6.71)	4	10 to 350	2	20,000 (1379)	373,000 (169 190)	Air		101210636 - 39 g Millennium™ HMX
102388649[1,2]	22 (6.71)	4	10 to 350	2	20,000 (1379)	399,000 (180 983)	Water	4.869 (123.63)	102054947 - 390 MaxForce® 39 g HMX
102307769[1,2]	16 (4.88)	4	10 to 350	2	20,000 (1379)	399,000 (180 983)	Water	4.830 (122.68)	
101917359[1,3]	16 (4.88)	4	10 to 350	2	20,000 (1379)	399,000 (180 983)	Water	4.870 (123.70)	101466192 - 39 g DP HMX KleenZone®
101857980[1,3]	16 (4.88)	4	10 to 350	2	20,000 (1379)	399,000 (180 983)	Water	4.870 (123.70)	
101703366[4]	16 (4.88)	4	10 to 350	2	20,000 (1379)	358,200 (162 477)	Water	4.870 (123.70)	

4 5/8-in. G-Force® Systems Specifications

SAP No.	Length ft (m)	Shot Density	Shot Phasing	Perforation Planes	Collapse Pressure Rating psi (bar)	Tensile Load Rating lb (kg)	Survival Test Medium	Maximum Swell after Firing in. (mm)	Charge
101498446	22 (6.71)	4	0 to 180	2	20,000 (1379)	366,000 (166 015)	Air	4.855 (123.32)	101210636 - Millennium™ 39 g HMX 101287306 - SDP 39 g HNS 101355271 - Millennium™ 39 g RDX
101390900	22 (6.71)	4	0 to 180	2	20,000 (1379)	373,000 (169 190)	Air		101210636 - 39 g Millennium™ SDP HMX
102145268[1,3]	16 (4.88)	4	0 to 180	2	20,000 (1379)	399,000 (180 983)	Water	4.870 (123.70)	101446899 - 39 g DP HMX KleenZone®
101663103[4]	16 (4.88)	4	0 to 180	2	20,000 (1379)	358200 (162 477)	Water	4.870 (123.70)	
101435773	22 (6.71)	4	0	1	20,000 (1379)	373,000 (169 190)	Air		101210636 - 39 g Millennium™ SDP HMX
101664524	5 (1.52)	4	0	1	20,000 (1379)	373,000 (169 190)	Air		
101703365[4]	16 (4.88)	4	0	1	20,000 (1379)	358,200 (162 477)	Water	4.870 (123.70)	101466192 - 39 g DP HMX KleenZone®

[1]Slickwall carrier
[2]MaxForce®, KleenZone®, slickwall
[3]KleenZone®, slickwall
[4]KleenZone®
All available sizes might not be included. Review Enterprise for a complete listing.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

7-in. G-Force® Systems Specifications

SAP No.	Length ft (m)	Shot Density	Shot Phasing	Perforation Planes	Collapse Pressure Rating psi (bar)	Tensile Load Rating lb (kg)	Survival Test Medium	Maximum Swell after Firing in. (mm)	Charge
102180652[1]	16 (4.88)	6	0 to 180	2	15,000 (1034)	643,900 (292 068)			101702911 - Millennium™ II 39 g HMX 102054947 - 390 MaxForce® 39 g HMX
101937950	16 (4.88)	6	0 to 180	2	15,000 (1034)	643,900 (292 068)	Water	7.311 (185.70)	101207997 - Millennium™ 39 g HMX 101326062 - Millennium™ 39 g RDX

[1]MaxForce®
All available sizes might not be included. Review Enterprise for a complete listing.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

Oriented Perforating with Modular Guns

There are several methods available for orienting perforating guns in horizontal and highly deviated wells, such as the G-Force® system. In vertical wells, it can be more difficult to orient perforations in a particular direction. One proven method is the oriented modular gun system.

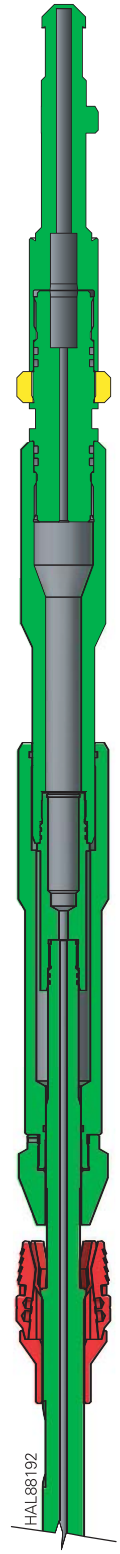
To accomplish this, a standard auto-J gun hanger is used in conjunction with specially modified skirts and stingers for the modular guns. The stingers are made with locating lugs, and the skirts are modified to locate on the lugs.

The gun hanger is run in the well and set on wireline using normal procedures. A gyro steering tool is then run to determine the direction of the locating lug on the gun hanger stinger. The skirts and stingers on the remaining gun modules are then adjusted accordingly; thereby, when they are landed, the shots will be oriented to the desired direction.

This system has been used successfully in standard applications when perforating for production, and in special applications, such as shooting from a relief well into a well that is blowing out.

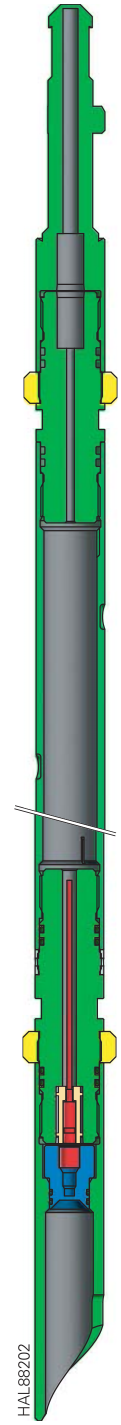
HAL88765

Oriented perforating skirt and stinger position when landed



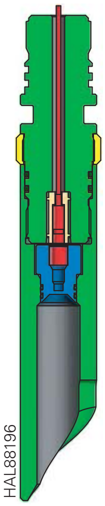
HAL88192

Gun Hanger with Modifications



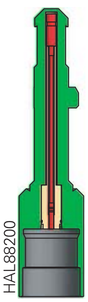
HAL88202

Modular Gun with Modifications



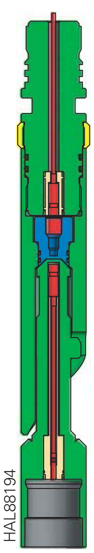
HAL88196

Modified Skirt



HAL88200

Modified Stinger



HAL88194

Modified Skirt and Stinger Assembly

Finned Orienting Tandem

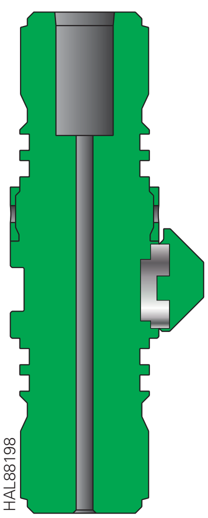
As perforating guns are run into the well, and transition from a vertical to deviated position occurs, the fin orients to the high side of the wellbore. The finned orienting tandem works on the principle of gravity whereby the weight of the perforating guns rotates toward the lowest side of the wellbore and is aided by the additional standoff from the casing wall created by the connected fin.

Features

- Built with an adjustable ring, which makes it possible to orient the shots in the casing to a predetermined direction
- Tensile strength of finned tandem equivalent to the standard gun connectors
- Available for most gun sizes
- Cost-effective perforation orientation solution

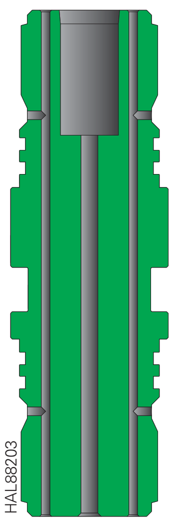
HAL88201

Finned Orienting Tandem



HAL88198

Finned Tandem



HAL88203

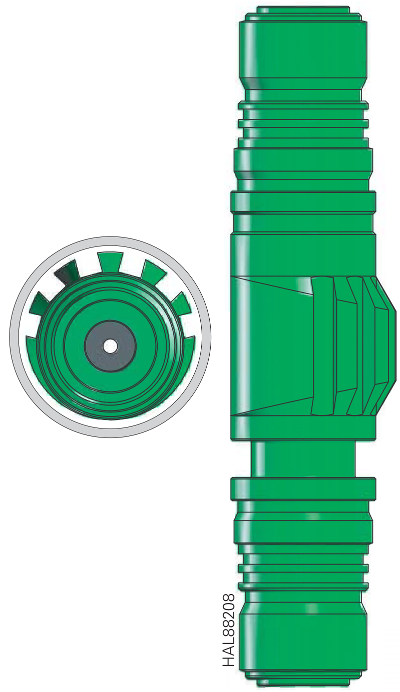
Vented Tandem

Eccentric Orienting Tandem

For several years, Halliburton successfully ran oriented perforating jobs using a fin welded to a gun connection every 30 ft in conjunction with swivel assemblies.

Now, a second method for orienting perforations referred to as eccentric subs has been developed. The eccentric sub is run in place of the finned tandem still in conjunction with a swivel assembly.

The eccentric orienting tandem works on the same principle as the fins. As the guns are run into the well, and transition from a vertical to deviated position occurs, the natural tendency is for the fin to orient to the high side of the wellbore. The eccentric tandem works on the same principle. The eccentric tandem allows for a greater degree of accuracy with an overall smaller profile.



Eccentric Orienting Tandem

Features

Eccentric subs allow perforating guns to be oriented in situations in which the fin system is not ideal because of restrictions in the casing, fishing concerns, welding concerns, etc. Several tests and wells have been perforated using this new technique in the North Sea area and the Gulf of Mexico.

- Built with an adjustable ring, which makes it possible to orient the shots in the casing to a predetermined direction
- Tensile strength of the eccentric sub equivalent to the standard gun connectors
- Available for most gun sizes
- Use of welded fins on the connectors eliminated

Near-Wellbore Stimulation

Increasing conductivity past near-wellbore damage is critical to maximizing well production. Halliburton provides multiple solutions suitable for various stimulation scenarios depending on the well's restriction, completion methods, and reservoir characteristics.

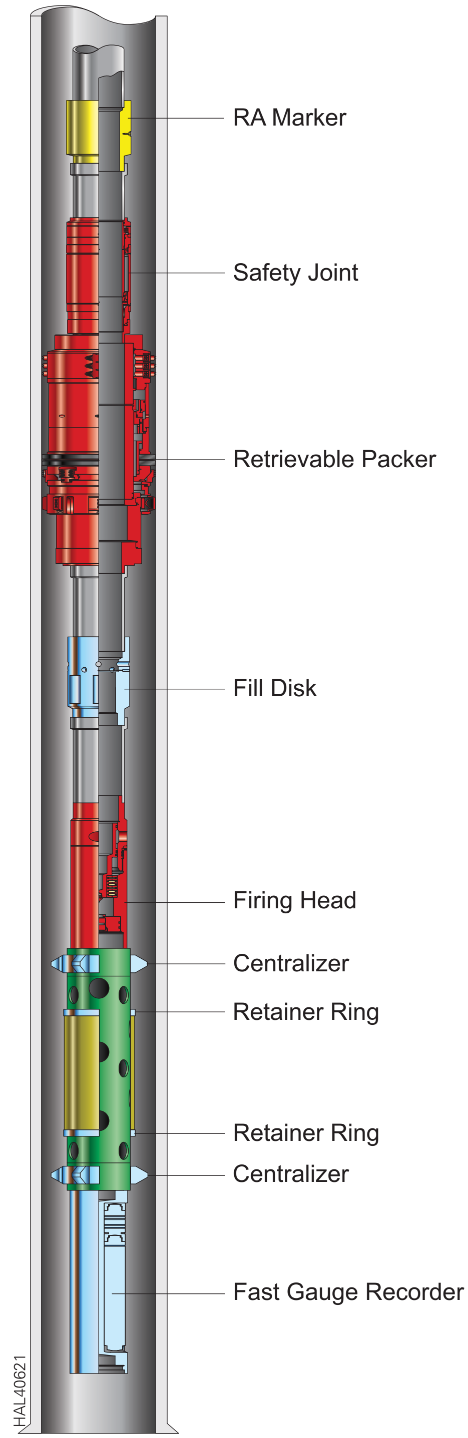
StimGun™ Assembly

The StimGun™ assembly process combines perforating and perforation breakdown with propellant in a single tool and operation. The StimGun assembly has a propellant sleeve over a conventional Halliburton VannGun® perforating gun assembly. When the guns are detonated, the propellant sleeve is ignited, instantly producing a burst of high-pressure CO_2 gas. This gas enters the perforations, breaks through any damage around the perforation tunnel, and creates short fractures near the wellbore. As the gas pressure in the wellbore dissipates, the gas in the formation surges back into the wellbore, carrying with it damaging fines. The StimGun assembly has been used with great success in conventional underbalanced perforating to obtain the benefits of both extreme overbalance (EOB) from propellants and the surging effect from maximum underbalance.

Features

- Improved production or injectivity with greater uniformity in the perforation breakdown
- Improved connectivity to the undamaged reservoir matrix by extending fractures past damage induced by either drilling or completion practices
- Improved conventional underbalanced perforating by combining benefits of EOB in one operation
- Stimulation of near-wellbore on zones that cannot be treated conventionally with acid or hydraulic fracturing because of undesirable production from nearby gas cap or water contact
- Excellent prehydraulic fracture treatment assists in keeping perforations open and minimizes tortuosity effects, resulting in lower breakdown pressures and horsepower requirements on location

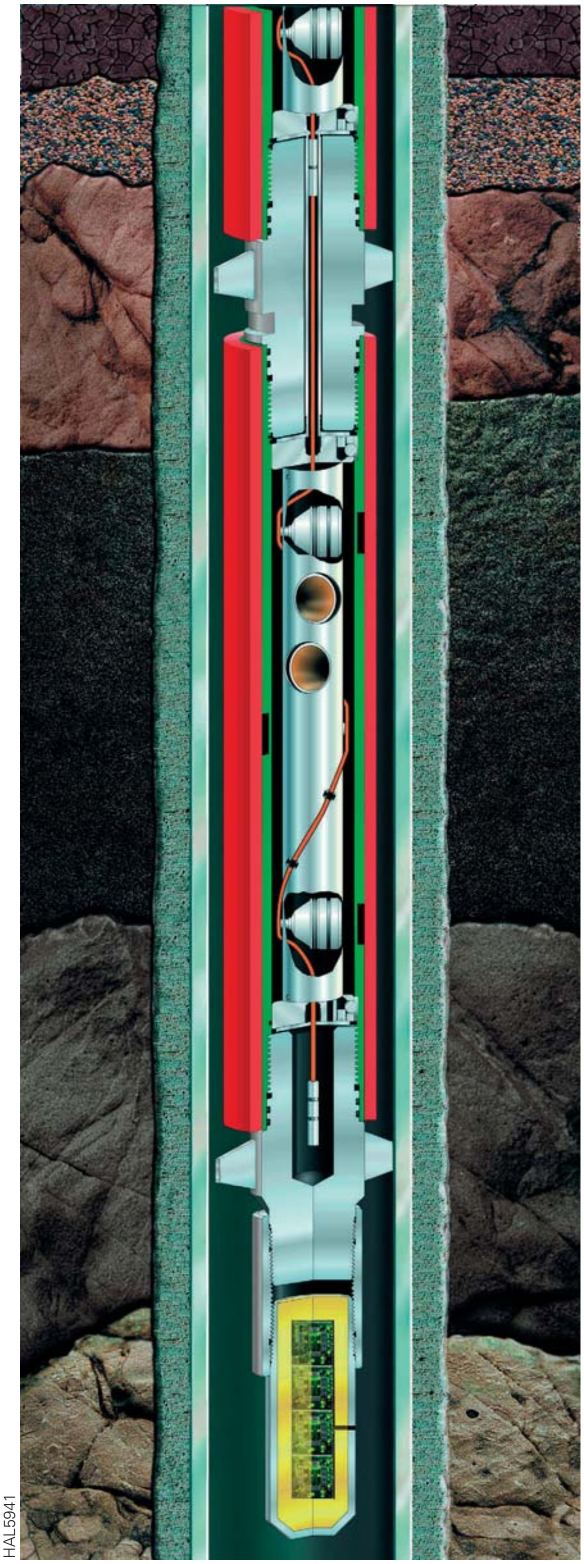
StimGun™ is a trademark of Marathon Oil Company and licensed by Halliburton.



StimGun™ Assembly

Operation

The StimGun™ assembly consists of a cylindrical sleeve of gas-generating propellant-potassium perchlorate that slides in place over the outside of a conventional hollow steel carrier perforating gun. The StimGun assembly can be conveyed on either wireline, coiled tubing, or in a conventional perforation configuration. StimGun sleeves are similar to PVC pipe and must be protected and positioned on the gun, with an oversized retaining collar secured to the gun scallop. Additional sleeve protection is achieved through centralization of the gun sections at the tandems.



The StimGun™ tool can be run on Halliburton tubing-conveyed or wireline equipment.

StimGun™ Assembly Specifications

Gun Size in.	Sleeve SAP No.	Sleeve OD in. (mm)	Sleeve ID in. (mm)	Minimum Centralizer OD* in. (mm)	Propellant Mass** lb/ft (kg/m)
2 1/2	58179	3.11 (78.99)	2.50 (63.50)	3.50 (88.90)	2.01 (2.99)
2 3/4	58190	3.36 (85.34)	2.75 (69.85)	3.76 (95.50)	2.01 (2.99)
3 1/8	58193	3.72 (94.48)	3.21 (81.53)	4.13 (104.90)	2.33 (3.46)
3 3/8	58195	4.02 (102.10)	3.38 (85.85)	4.40 (111.76)	2.67 (3.98)
4	58196	4.71 (119.63)	4.05 (102.87)	5.09 (129.28)	3.68 (5.47)
4 5/8	57514	5.21 (132.33)	4.72 (119.88)	5.63 (143.00)	3.33 (4.96)
5 1/8	101240496	5.81 (147.63)	5.175 (131.44)	6.18 (156.97)	3.99 (5.94)
5 3/4	215347	6.45 (163.83)	5.75 (146.05)	6.95 (176.53)	4.68 (6.97)
7	58159	7.88 (200.15)	7.09 (180.08)	8.25 (209.55)	7.01 (10.43)

StimGun™ sleeves are manufactured in standard 3-ft (0.91-m) lengths and are rated for a service temperature of 350°F (177°C). The sleeves are nonreactive to most commonly used oilfield fluids, including acids.
*The StimGun sleeve is an oxidizer that is bonded with a resin or plastic, making it quite brittle; therefore, it is required the perforating gun be centralized to this minimum OD to provide protection when the assembly is in the wellbore.
**CO_2 gas generated from a propellant burn is estimated at 7.06 scf/kg of material at standard conditions.
All available sizes might not be included. Review Enterprise for a complete listing.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

Retaining Collar Assembly Specifications

SAP No.	Gun Size in.	OD in. (mm)	ID in. (mm)	Sleeve OD in. (mm)	Minimum Centralizer OD in. (mm)	Flow Area through Collar in.² (mm²)
101233588	2 1/2	3.38 (85.85)	2.56 (65.02)	3.11 (78.99)	3.51 (89.15)	1.10 (709.67)
101233598	2 3/4	3.63 (92.20)	2.81 (71.37)	3.36 (85.34)	3.76 (95.50)	1.15 (741.93)
101233215	3 1/8	4.02 (102.10)	3.18 (80.77)	3.72 (94.48)	4.13 (104.90)	1.21 (780.64)
101240387	3 3/8 12 spf	4.27 (108.45)	3.43 (87.12)	4.02 (102.10)	4.40 (111.76)	1.71 (1103.22)
101222271	3 3/8	4.27 (108.45)	3.43 (87.12)	4.02 (102.10)	4.40 (111.76)	1.71 (1103.22)
101233163	4	4.96 (125.98)	4.06 (103.12)	4.71 (119.63)	5.09 (129.28)	2.00 (1290.32)
101227396	4 5/8	5.50 (139.70)	4.69 (119.12)	5.21 (132.33)	5.63 (143.00)	2.00 (1290.32)
101239368	5 1/8	6.05 (153.67)	5.19 (131.82)	5.81 (147.32)	6.18 (156.97)	2.21 (1425.80)
101303748	5 3/4	6.70 (170.18)	5.82 (147.82)	6.45 (163.83)	6.95 (176.53)	2.70 (1741.93)
101292913	7	8.15 (207.01)	7.07 (179.57)	7.88 (200.15)	8.25 (209.55)	3.75 (2419.35)

All available sizes might not be included. Review Enterprise for a complete listing.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

Well Stimulation Tool

The well stimulation tool (WST) uses the same solid propellant technology as the StimGun™ assembly to stimulate existing perforations, slotted liners, or openhole sections when it is not desirable to add perforations. The WST is assembled with propellant and standard detonating cord to provide the ignition system. When the detonating cord is ignited, the solid propellant breaks up into many smaller pieces, allowing it to burn rapidly and produce CO_2 gas. This gas enters the perforations, breaking through any damage around the perforation tunnel, creating short fractures near the wellbore. As the gas pressure in the wellbore dissipates, gas in the formation surges back into the wellbore, carrying with it damaging fines. WST assembly jobs are designed using the Halliburton PulsFrac™ simulator, which assists in achieving consistent results without compromising safety or wellbore integrity.

Features

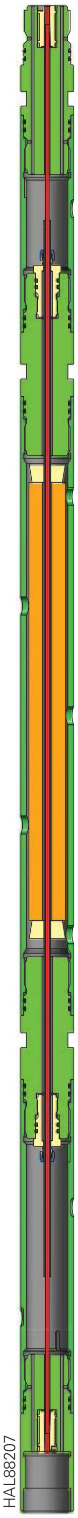
- Helps improve production or injectivity with greater uniformity in the perforation breakdown
- Helps improve connectivity to the undamaged reservoir matrix by extending fractures past damage induced by either drilling or completion practices
- Stimulates near-wellbore on zones that cannot be treated conventionally with acid or hydraulic fracturing because of undesirable production from nearby gas cap or water contact
- Provides excellent prehydraulic fracture treatment that helps keep perforations open and minimizes tortuosity effects, resulting in lower breakdown pressures and horsepower requirements on location
- Provides selective stimulation of long openhole horizontal sections

The WST assembly is currently available in 2 7/8 OD ported carriers. Contact TCP technology for more information.

Operation

The WST assembly consists of a solid stick of gas-generating propellant-potassium perchlorate with detonating cord run through it. It can be conveyed on wireline, coiled tubing, or threaded pipe. Standard perforating safety, arming, and firing procedures are used. The industry-standard detonating cord provides consistent, reliable, and instantaneous ignition over the entire WST assembly length.

When deployed on coiled tubing or threaded pipe, the assembly is run inside a vented hollow steel carrier.



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Well Stimulation Tool (WST) Assembly

Well Stimulation Tool Assembly Specifications

SAP No.	Tool Size in.	Upper Thread Size and Type	Lower Thread Size and Type	Overall Length ft (m)	Makeup Length ft (m)	Maximum OD in. (mm)	Temperature Rating[1] °F (°C)	Pressure Rating[1] psi (bar)	Tensile Rating[2] lb (kg)	Redressable	Weight (No Explosives) lb (kg)
101566827	2 7/8	2 7/8 Gun Pin	2 7/8 Gun Box	26.25 (8.0)	25.98 (7.92)	2.88 (73.2)	300 (149)	8500 (578)	110,800 (50 250)	Yes	249 (113)

[1]Based on control line collapse rating
[2]2 7/8 gun box at top sub
All available sizes might not be included. Review Enterprise for a complete listing.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

Powr*Perf™ Perforation/Stimulation Process

The Powr*Perf™ perforation/stimulation process is a completion process that uses proven extreme overbalance (EOB) perforating techniques. This method is coupled with the release of an erosive agent at the moment of VannGun® system detonation to clean and scour near-wellbore damage and enhance conductivity of fractures created by EOB perforating.

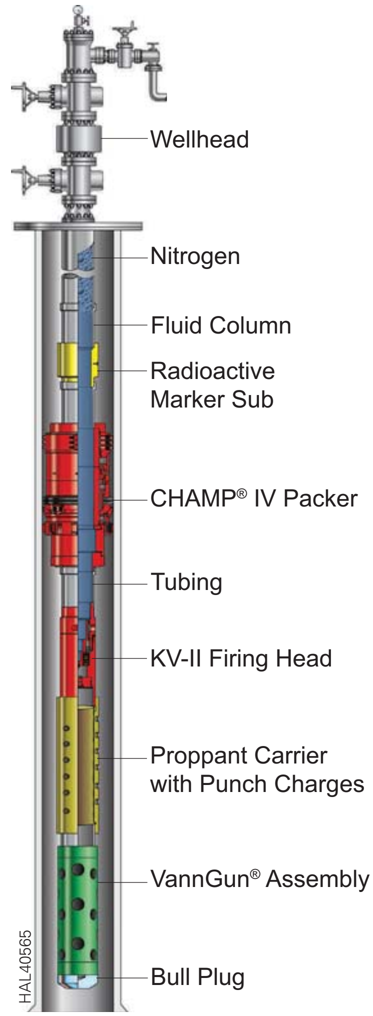
Features

- Overcomes skin damage in low-pressure, high-permeability wells
- Can be a useful prefracturing evaluation tool
- Applicable to both new wells and wells with nearby water or gas
- Compatible with all casing sizes and tubulars

Operation

The Powr*Perf tool is run as a normal part of the completion assembly. A nondamaging fluid is added to the tubing to serve as a medium for carrying the bauxite into the formation. After the assembly is positioned across the producing zone, the tubing is energized with nitrogen gas to create a pressure gradient of no less than 1.4 psi/ft (31 bar/m). A Model KV-II firing head that is preset to function at the desired bottomhole pressure, detonates the VannGun assembly and opens flow ports to allow the fluid and nitrogen to rush toward the formation.

The fluid "spear" is driven ahead of the expanding nitrogen gas into the formation at velocities that can exceed 140 bbl/min. The bauxite material is ejected into the fluid stream at the moment of detonation by specially designed shaped charges. The combination of fluid and bauxite serves to fracture, erode, and scour all of the perforations and to further enhance the fractures created by EOB perforating.



*Powr*Perf™ Perforation/ Stimulation Process*

Powr*Perf™ is a trademark of Marathon Oil Company and licensed by Halliburton.

Powr*Perf™ Perforation/Stimulation Process Specifications

Carrier Sizes in. (mm)	Available Lengths ft (m)	Bauxite Capacities lb (kg)	Assembly Weight lb (kg)	Collapse Pressure psi (bar)	Minimum Ratio Interval
3 1/8 (79)	16 (4.88)	56 (25.40)	250 (113.40)	20,000 (1379)	1:1
	22 (6.71)	80 (36.29)	344 (156.04)		
3 3/8 (86)	16 (4.88)	67 (30.39)	323 (146.51)	25,000 (1724)	1:1
	22 (6.71)	95 (43.09)	447 (202.76)		
4 (102)	16 (4.88)	95 (43.09)	407 (184.61)	19,000 (1310)	1:1
	22 (6.71)	170 (77.11)	599 (271.70)		
4 1/2 (114)	16 (4.88)	140 (63.50)	492 (223.17)	18,000 (1241)	1:1
	22 (6.71)	200 (90.72)	684 (310.26)		

All available sizes might not be included. Review Enterprise for a complete listing.
Maximum operating pressure is determined by tubulars.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

PerfStim™ Process

The PerfStim™ process uses an extreme overbalanced (EOB) condition to simultaneously perforate and stimulate a well. The process not only produces cleaner perforations in low-pressure formations, it also initiates fractures in the formation, reducing stimulation costs.

Features

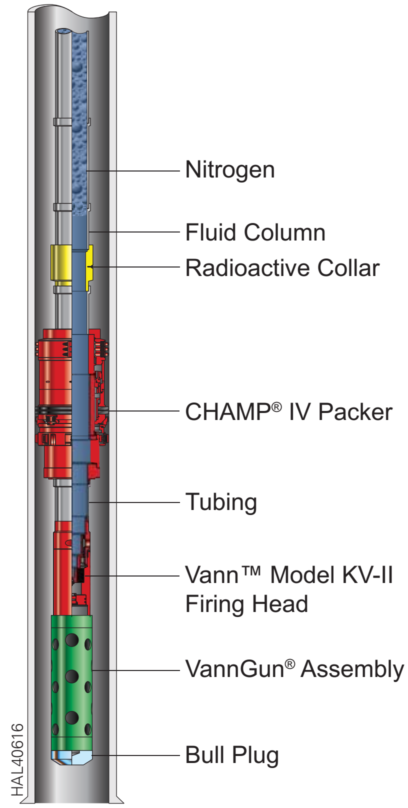
- Gets production flowing quickly
- Saves rig time
- Helps develop negative skin factors
- Gives an early evaluation of a well's potential
- Uses less horsepower than full-scale stimulations

Operation

In the PerfStim process, an EOB condition is created — pressure gradients of at least 1.4 psi/ft (31 bar/m).

When the perforating gun fires, the pressure drives a fluid "spear" into the perforation at velocities exceeding 3,000 ft/sec (900 m/sec) and at rates that can exceed 140 bbl/min. Crushed-zone damage is removed and small fractures are created — improving initial production and treatment results.

PerfStim™ is a trademark of Oryx Energy Company and licensed to Halliburton.



The VannSystem® tool string is used in typical PerfStim™ process procedures. The tubing-conveyed system helps allow for the highest possible bottomhole pressures. A small volume (usually no more than a 300-ft column) of nondamaging fluid is placed above the gun, then pressured with nitrogen. If necessary, a liquid can be bullheaded on top of the nitrogen column. The VannGun® perforating assembly can remain attached to the tool string or dropped into the rathole after the guns are fired.

Fill Disk Assembly

The fill disk assembly (FDA) is used when either packer selection or well conditions preclude the use of a venting device. The FDA is used in place of a perforated sub and replaces the balanced isolation tool (BIT) in wells with reasonably clean fluids. The glass disk prevents debris from settling on the firing head. Pressure is equalized across the glass disk.

The FDA is run between the firing head and packer. The recommended minimum distance from the FDA to the firing head is 30 ft (9.14 m).

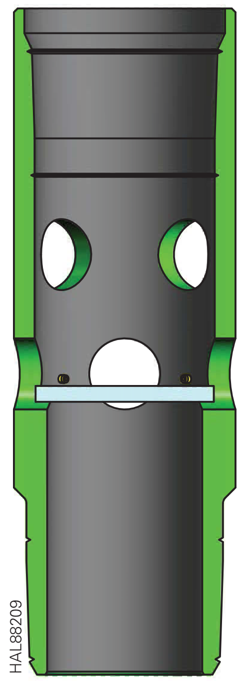
Features

- Allows debris to be circulated off the glass disk through the flow ports above the glass disk
- Acts as a perforated sub for circulating fluid displacement with nitrogen and swabbing
- Can be run with either a mechanical or pressure-actuated firing head

Operation

The FDA consists of a ported housing with a glass disk installed in the ID across the lower set of ports. The disk is not sealed; therefore, pressure can equalize across the glass. Any debris falling out of the tubing or fluid above the glass should land on the glass disk. This debris can be circulated off the disk, or if it is not a large amount, it will be displaced out the ports by the detonating bar falling through it.

Once the bar breaks through the disk, it should fall in clean fluid all the way to the firing head. In mud systems or wells with a known debris problem, the BIT is recommended in place of the FDA.



Fill Disk Assembly (FDA)

Fill Disk Assembly (FDA) Specifications

SAP No.	Thread Size and Type	Maximum OD in. (mm)	Minimum ID in. (mm)	Flow Area in.² (cm²)	Number of Ports	Tensile Strength lb (kg)	Makeup Length ft (m)	Material
102491867	API-NC50 Box-Pin	6.625 (168.275)	3.00 (76.2)	4.67 (30.13)	8	973,900 (441 754)	0.96 (0.29)	4140
102437150	2 7/8-6.40 TSH 511 Box-Pin	3.62 (91.95)	2.377 (60.376)	4.44 (28.65)	8	103,100 (46 765)	1.52 (0.46)	4140
102395030	2 7/8-7.80 VAM TOP®* Box-Pin	3.62 (91.95)	2.271 (57.683)	4.05 (26.13)	8	156,000 (70 760)	1.44 (0.44)	Nickel Alloy 925
102301618	4 1/2-13.50 VAM TOP Box-Pin	5.12 (130.048)	3.877 (98.476)	11.80 (76.13)	8	260,900 (118 342)	1.85 (0.56)	4140
102265364	4 1/2-12.60 JFEBEAR Box-Pin	4.93 (125.222)	3.85 (97.79)	11.6 (74.84)	8	89,400 (40 551)	2.0 (0.61)	13% Chrome
102034012	3 1/2-9.20 JEFBEAR Box × Pin	3.89 (98.806)	2.93 (74.422)	6.74 (43.48)	8	102,600 (46 539)	1.48 (0.45)	13% Chrome
101842680	4 1/2-17.00 TSH Blue Box × Pin	5.12 (130.048)	3.740 (94.996)	11.29 (72.84)	8	276,300 (125 328)	1.73 (0.53)	4140
101825692	4 1/2-13.50 VAM TOP Box × Pin	5.12 (130.048)	3.877 (98.476)	11.80 (76.13)	8	181,500 (82 327)	1.85 (0.56)	13% Chrome
101809440	3 1/2-9.20 VAM TOP Box × Pin	4.00 (101.6)	2.90 (73.66)	6.61 (42.65)	8	181,500 (82 327)	1.73 (0.53)	4140

Fill Disk Assembly (FDA) Specifications

SAP No.	Thread Size and Type	Maximum OD in. (mm)	Minimum ID in. (mm)	Flow Area in.² (cm²)	Number of Ports	Tensile Strength lb (kg)	Makeup Length ft (m)	Material
101807864	4 1/2-12.60 TSH Blue Box × Pin	5.12 (130.048)	3.91 (99.314)	12.05 (77.74)	8	251,900 (114 260)	1.78 (0.54)	4140
101778845	API-NC38 Box × Pin	5.00 (127.0)	2.438 (61.925)	4.67 (30.13)	8	483,300 (219 221)	1.17 (0.36)	4140
101717527	3 1/2-9.30 TSH CS Box × Pin	3.915 (99.441)	2.65 (67.31)	6.35 (40.97)	8	145,800 (66 134)	1.08 (0.33)	13% Chrome
101687181	4 1/2-17.00 TSH Blue Box × Pin	5.12 (130.048)	3.740 (94.996)	11.29 (72.84)	8	264,300 (119 884)	1.73 (0.53)	Nickel Alloy 925
101667802	3 1/2-9.20 JFEBEAR Box × Pin	3.89 (98.806)	2.93 (74.422)	6.74 (43.48)	8	147,500 (66 905)	1.74 (0.53)	4140
101601180	3 1/2-12.95 API EU Box × Pin	4.50 (114.3)	2.45 (62.23)	6.36 (41.03)	8	338,700 (153 632)	1.30 (0.4)	13% Chrome
101542231	4 1/2-12.60 VAM-FJL Box × Pin	4.56 (115.824)	3.85 (97.79)	11.6 (74.84)	8	81,600 (37 013)	1.7 (0.52)	13% Chrome
101435443	5 1/2-17.00 VAMTOP-HC Box × Pin	6.25 (158.75)	4.66 (118.364)	17.2 (110.97)	8	314,400 (142 609)	1.8 (0.55)	13% Chrome
101381727	4 1/2-12.75 TS-3SB Box × Pin	5.20 (132.08)	3.917 (99.492)	12.05 (77.74)	8	169,300 (76 794)	1.8 (0.55)	13% Chrome
101313229	5 1/2-17.00 TS-3SB Box × Pin	6.05 (153.67)	4.89 (124.206)	19.21 (123.94)	8	149,000 (67 585)	1.66 (0.51)	13% Chrome
101313133	3 1/2-9.30 TSH 3SB Box × Pin	4.252 (108.001)	2.982 (75.743)	7.16 (46.19)	8	141,600 (64 229)	1.2 (0.37)	13% Chrome
101302729	3 1/2-9.20 FOX-K Box × Pin	3.885 (98.679)	2.99 (75.946)	7.02 (45.29)	8	135,000 (61 235)	1.48 (0.45)	4140
101251365	4 1/2-12.60 VAM ACE Box × Pin	4.976 (126.39)	3.984 (101.194)	12.47 (80.45)	8	145,500 (65 998)	1.4 (0.43)	13% Chrome
101212820	4 1/2-12.75 TSH CS Box × Pin	5.00 (127.0)	3.865 (98.171)	11.7 (75.48)	8	204,500 (92 760)	1.5 (0.46)	4140
100005299	3 1/2 API-EU Box × Pin	4.19 (106.426)	3.00 (76.2)	8.61 (55.55)	8	216,200 (98 067)	0.7 (0.21)	4140
100005297	2 7/8 API-EU Box × Pin,	3.50 (88.9)	2.45 (62.23)	6.36 (41.03)	8	155,000 (70 307)	0.7 (0.21)	4140
100005295	2 3/8 API-EU Box × Pin	3.00 (76.2)	2.00 (50.8)	4.15 (26.77)	8	127,500 (57 833)	0.69 (0.21)	4140

*VAM TOP® and VAM® are registered trademarks of Vallourec Oil and Gas France.
All available sizes might not be included. Review Enterprise for a complete listing.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

Balanced Isolation Tool

The balanced isolation tool (BIT) assembly is used when either packer selection or well conditions preclude the use of a venting device. The BIT assembly replaces the fill disk assembly and is used in place of a perforated sub. The BIT helps prevent contamination of the fluid below it from the fluid above it. Debris or solids in the fluid above should not pass through the glass disk that is in the floating piston. The glass disk helps prevent debris from setting on the firing head. Pressure is balanced across the glass barrier through equalizing ports in the piston.

The BIT assembly is run between the firing head and packer. The recommended minimum distance from the BIT to the firing head is 30 ft (9.14 m).

Features

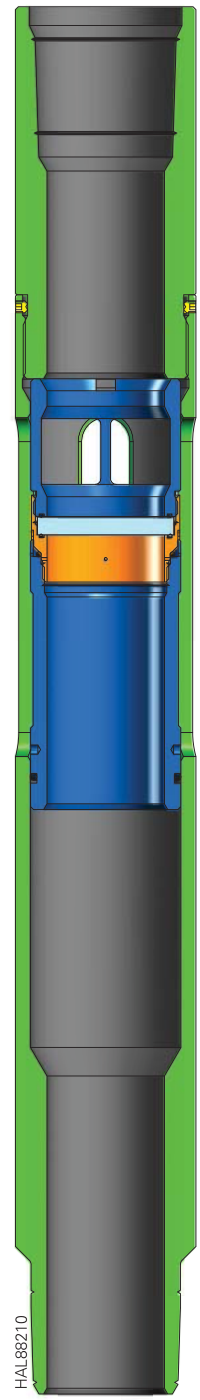
- Allows mud and debris to be circulated off the glass barrier through the flow ports above the glass barrier
- Allows displacement of the tubing with a lighter fluid or nitrogen before firing the guns
- Allows swabbing of the tubing to achieve differential pressure
- Allows stopping and circulating at any depth because flow ports are always open
- Can be run with either a mechanical or pressure-actuated firing head

Operation

The basic components of the BIT are a floating piston with a glass disk, a ported lower housing, and a top housing. The BIT is run with clean fluid below it.

The upward travel of the floating piston is limited by the bottom of the top sub. A pressure increase above the glass barrier causes the piston to move down and forces fluid below the glass barrier out of the bleeder ports. A pressure increase below the glass barrier forces the piston to move up or forces fluid out of the bleeder ports.

The piston moves up or down within its limits to help prevent the glass barrier from breaking. The glass barrier remains intact until the bar passes through it. As fluid enters or leaves the tubing through the ports, debris on the glass barrier is washed off.



Balanced Isolation Tool (BIT)

Balanced Isolation Tool Specifications

SAP No.	Thread Size and Type	Maximum OD in. (mm)	Minimum ID in. (mm)	Flow Area in.² (cm²)	Number of Ports	Tensile Strength lb (kg)	Makeup Length ft (m)	Material
102449418	API-NC38, Box-Pin	5.00 (127)	2.438 (61.925)	4.67 (30.13)	4	457,300 (207 428)	2.49 (0.76)	4140
120022203	1.900 API-EU Box × Pin	2.50 (63.5)	1.61 (40.894)	2.04 (13.16)	4	63,500 (28 803)	1.92 (0.59)	4140
102237812	2 7/8 API-EU Box × Pin	3.75 (95.25)	2.44 (61.976)	4.68 (30.19)	4	134,300 (60 917)	2.23 (0.68)	13% Chrome
102008098	2 7/8-6.40 TSH 511 Box × Pin	3.75 (95.25)	2.377 (60.376)	4.70 (30.32)	4	88,000 (39 916)	2.55 (0.78)	4140
101318220	2 3/8 API-EU Box × Pin	2.88 (73.152)	2.00 (50.8)	3.14 (20.26)	4	83,900 (38 056)	1.86 (0.57)	4140
100014323	2 7/8 API-EU Box × Pin	3.75 (95.25)	2.44 (61.976)	4.68 (30.19)	4	140,500 (63 730)	2.23 (0.68)	4140
100014322	2 3/8 API-EU Box × Pin	3.07 (77.978	2.00 (50.8)	3.14 (20.26)	4	117,200 (53 161)	1.98 (0.6)	4140
100156936	3 1/2 API-EU Box × Pin	4.25 (107.95)	3.00 (76.2)	7.07 (45.61)	4	213,000 (96 615)	2.21 (0.67)	4140
100156951	3 1/2 API-EU Box × Pin	4.25 (107.95)	3.00 (76.2)	Non-Ported		172,100 (78 063)	2.21 (0.67)	4140
100156947	2 7/8 API-EU Box × Pin	3.75 (95.25)	2.44 (61.976)	Non-Ported		155,600 (70 579)	2.23 (0.68)	4140
100156943	2 3/8 API-EU Box × Pin	3.10 (78.74)	2.00 (50.8)	Non-Ported		112,700 (51 120)	1.98 (0.6)	4140

EZ Pass™ Gun Hanger

The EZ Pass™ gun hanger runs in conjunction with the Halliburton modular gun system. This advanced design includes slips that stay retracted within the slip housing until the tool is set. After the perforating event, slips will return to the running position and the tool auto releases.

If desired, the hanger can be fished with a standard pulling tool and retrieved from the well.

Features

- Running and setting procedures are similar to common bridge plugs and sump packers — uses standard setting equipment
- Can be set in larger ID after running through restrictions
- Retrievable and redressable
- Can be configured to auto-release or stay set after gun detonation
- Can be deployed on wireline, tubing, or coiled tubing
- One size sets in multiple casing ranges

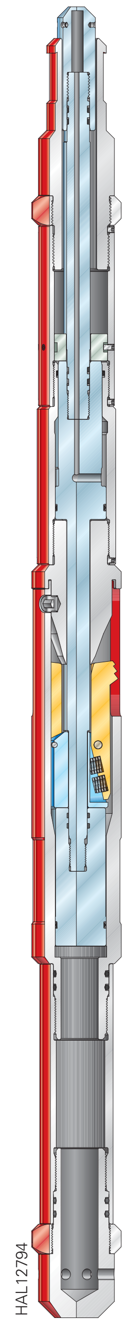
Operation

The EZ Pass gun hanger can be run independently or attached to the gun system.

If the gun hanger is deployed and positioned similar to a wireline-set permanent or sump packer, the same power charge-type setting tools are used to set the hanger. After the setting tool is removed from the wellbore, the guns can be deployed as individual modules or as a complete assembly and are stacked on top of the hanger.

A releasing tool is needed to release the hanger and can be run on the bottom of the perforating assembly. When activated, the releasing tool fires a shaped charge and breaches the top of the hanger. This process allows the gun weight to be transferred to the inner mandrel, placing the hanger in the releasing position and forcing the slips away from the casing.

The EZ Pass gun hanger is designed with a 2.75 fishing neck and can be fished with a standard pulling tool. The slips will retract into the ID of the tool and help allow it to be retrieved through a wellbore restriction.



EZ Pass™ Gun Hanger

EZ Pass™ Gun Hanger Specifications

Casing Size and SAP No.	Casing Weights* lb	Casing ID* Range in. (cm)	Tool Maximum OD (Slips Retracted) in. (cm)	Maximum Operating Pressure psi (bar)	Minimum Operating Pressure psi (bar)	Temperature Rating °F (°C)	Tensile Rating lb (kg)	Collapse Pressure psi (bar)	Maximum Overall Length ft (m)	Maximum Gun Weight lb (kg)	Weight lb (kg)
4 1/2 12067518	N/A	4.408 to 3.826 (11.19 to 9.72)	3.50 (8.89)	18,000** (1241)	500 (34.5)	400 (204.4)	56,000 (25 401)	19,300 (1331)	5.1 (1.55)	30,000 (13 600)	116 (52.6)
5 1/2 101315538	20/23/26	4.778 to 4.548 (12.14 to 11.55)	4.125 (10.5)	20,000** (1450)	500 (34.5)	400 (204.4)	56,000 (25 401)	20,000 (1450)	5.1 (1.55)	30,000 (13 600)	165 (74.8)
7 101321131	29/32/35	6.184 to 6.004 (15.70 to 15.25)	5.375 (13.65)	20,000** (1450)	500 (34.5)	400 (204.4)	56,000 (25 401)	21,700 (1496)	5.1 (1.55)	30,000 (13 600)	180 (81.7)

*Recommended
**Maximum operating pressure based on hydrostatic pressure and applied gun weight.
The EZ Pass™ hanger does not have minimum ID or burst pressure requirements.
NOTE: The EZ Pass gun hanger is designed with specific features to enhance its retrievability; however, because of the uncertainty of the wellbore conditions created by the perforating event, the retrieval of this tool cannot be ensured.
All available sizes might not be included. Review Enterprise for a complete listing.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

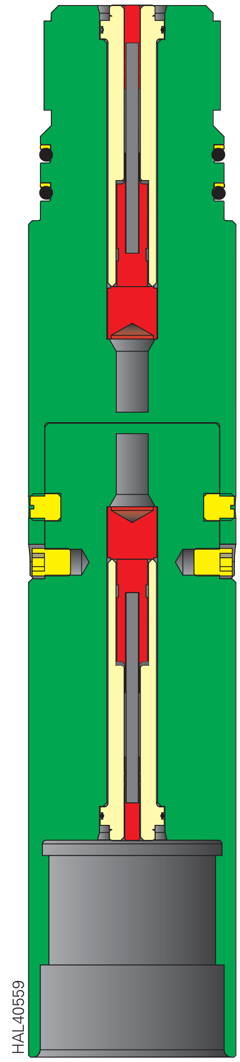
EZ Pass™ Gun Hanger Releasing Tool

SAP No.	Maximum OD in. (cm)	Maximum Operating Pressure psi (bar)	Temperature Rating	Makeup Length ft (m)	Top Connection	Tensile Rating lb (kg)	Load Rating lb (kg)
101365350	3.5 (8.89)	23,000 (1586)	Determined by explosives	2.68 (0.817)	3 3/8-in. Gun	82,400 (37 376)	45,400 (20 593)

Emergency Release Assembly

The emergency release assembly runs in conjunction with the automatic-release gun hanger assembly. When deploying the gun hanger on tubing or drillpipe, the emergency release is run between the gun hanger and guns to serve as a weak point in case the hanger gets stuck while running in the hole. Pulling or jarring on the pipe causes the emergency release assembly to shear, allowing retrieval of the guns and tubing from the well.

When deploying the gun hanger on wireline, the rope socket typically acts as the weak point.



Emergency Release Assembly

Emergency Release Assembly Specifications

SAP No.	OD Size in. (mm)	No. Shear Screws	Temperature Rating	Pressure Rating psi (bar)
101201127	3 3/8 (85.73)	8 steel shear screws rated at 5,600 lb per screw	Determined by explosives	25,000 (1724)

All available sizes might not be included. Review Enterprise for a complete listing.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

Annular Pressure Firer-Control Line Vent

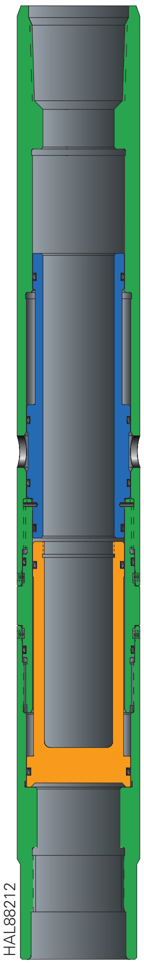
The annular pressure firer-control line (APF-C) vent isolates the tubing from annulus fluid or pressure. The vent is actuated by rathole pressure after the perforating assembly is detonated. It then provides a flow path for the formation fluid into the tubing string.

Features

- Ideal for highly deviated or horizontal wells
- Requires minimal pressure to operate
- Eliminates nitrogen displacement or swabbing the tubing string to achieve desired underbalance

Operation

The APF-C vent is run directly on top of the APF-C firing head. When the perforating assembly is detonated, gun pressure shifts an actuating piston into a power piston. This shift opens the flow ports to the tubing.



Annular Pressure-Control Line (APF-C) Vent

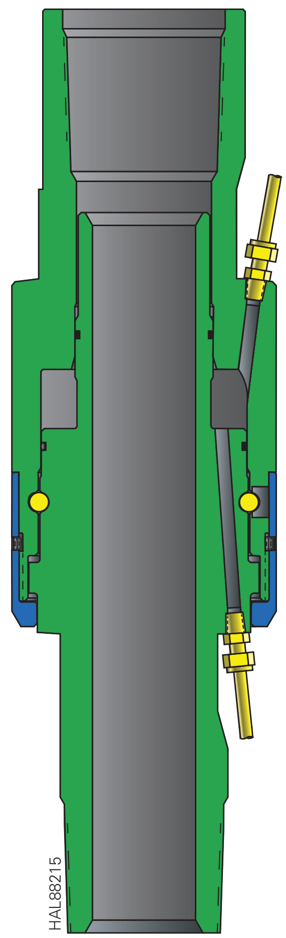
Annular Pressure-Control Line (APF-C) Vent Specifications

SAP No.	Thread Size and Type in. (mm)	Maximum OD in. (mm)	Minimum ID in. (mm)	No. and ID of Ports in. (mm)	Flow Area in.² (cm²)	Makeup Length ft (m)	Maximum Operating Pressure psi (bar)	Tensile Strength lb (kg)	Burst Pressure psi (bar)	Collapse Pressure psi (bar)
120038049	2 3/8 (60.33) EUE 8 Rd Box × 2 7/8 (73.03) 6P Acme Box	3.38 (85.85)	Non-fullbore	4 at 1.0 (25.4)	2.63 (16.97)	2.37 (0.72)	20,000 (1380)	150,000 (68 000)	22,000 (1515)	22,000 (1515)
101016565	2 7/8 (73.03) EUE 8 Rd Box × 2 7/8 (73.03) 6P Acme Box	3.88 (98.55)	Non-fullbore	5 at 1.0 (25.4)	3.93 (25.34)	2.43 (0.74)	20,000 (1380)	170,000 (77 000)	15,000 (1035)	15,000 (1035)

All available sizes might not be included. Review Enterprise for a complete listing.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

Annular Pressure-Control Line Swivel Sub

When run in conjunction with the annular pressure-control line (APF-C) firing head, the APF-C swivel sub provides a swivel point between the guns and packer when it is desired to have the guns rotate freely as when orienting shots in a deviated well.



APF-C Swivel Sub

Features

- Compatible with APF-C firing head and control line
- Can be run anywhere between the packer and the firing head
- Transmits pressure through the control line while rotating

Operation

The APF-C swivel is made up in the string between the packer and the firing head. A section of control line is made up from the packer to the top of the swivel. A second section of control line is made up from the bottom of the swivel to the APF-C firing head. Annulus pressure is transmitted from the packer, through the swivel to the firing head.

Annular Pressure-Control Line (APF-C) Swivel Sub Specifications

SAP No.	Thread Size and Type in. (mm)	Maximum OD in. (mm)	Minimum ID in. (mm)	Tensile Strength lb (kg)	Operating Load Limit Rating lb (kg)	Burst Pressure psi (bar)	Collapse Pressure psi (bar)	Makeup Length ft (m)
101230619	2 7/8 EU 8rd Box × Pin	5.13 (130.30)	2.0 (50.8)	200,000 (90 718)	36,000 (16 329)	N/A*	N/A*	1.3 (0.39)

*The APF-C swivel sub is not designed to operate with differential pressure.
All available sizes might not be included. Review Enterprise for a complete listing.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

Annular Pressure-Control Line Tubing Release

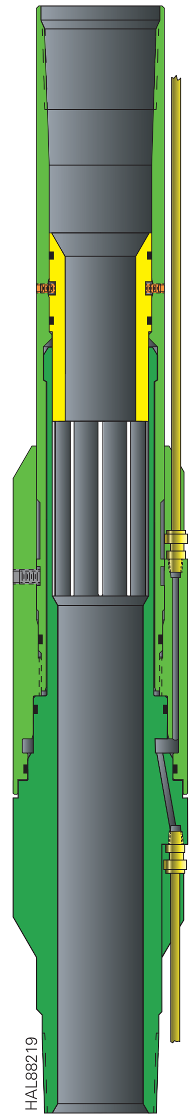
The 2 7/8-in. annular pressure-control line tubing release (APF-C TR) assembly provides a mechanical method of releasing the APF-C firing head and VannGun® assembly from the tubing string.

Features

- Releasing the gun assembly opens the tubing for other tools, such as production logging, testing, and treating
- Low-cost method to release gun assembly
- Uses off-the-shelf shifting tools
- No time limit on dropping the gun assembly
- Leaves perforations uncovered and helps eliminate flow restriction

Operation

The APF-C TR is run between the APF-C firing head and the 7- or 9 5/8-in. annulus pressure transfer reservoir (APTR). The control line for the APF-C is attached to the control line housing, which transfers the pressure through the APF-C TR and out the finger sub to a second control line. The second control line transfers the pressure down to the APF-C firing head. Releasing can be accomplished by using a standard Halliburton or Garret shifting tool.



APF-C Tubing Release (APF-C TR)

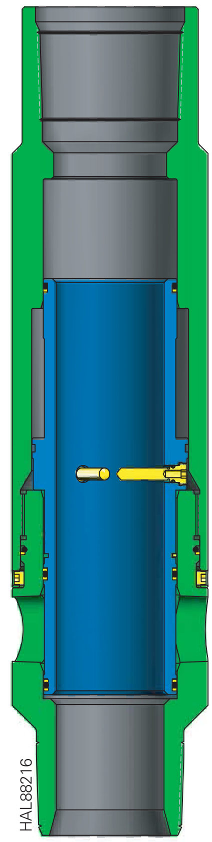
Annular Pressure Control Line Tubing Release (APF-C TR) Specifications

SAP No.	Upper Thread Size and Type	Lower Thread Size and Type	Makeup Length ft (m)	Maximum OD in. (mm)	Minimum ID in. (mm)	Tensile Strength lb (kg)	Burst Pressure psi (bar)	Collapse Pressure psi (bar)
87921	2 7/8 (73.03) EUE 8RD Box	2 7/8 (73.03) EUE 8RD Pin	2.24 (0.68)	4.62 (117.35)	Latch sizes: 1.88 (47.75), 2.125 (53.98), or 2.25 (57.15)	120,000 (54 431)	12,000 (827)	11,000 (758)

All available sizes might not be included. Review Enterprise for a complete listing.

Bar Pressure Vent

The bar pressure vent (BPV) is designed to achieve a differential pressure between the formation and tubing string. It helps to safely allow a differential pressure in wells with existing open perforations or in unperforated wells. The BPV is an internal sliding-sleeve tool actuated by pressure in the tubing. It is run between the packer and the guns.



Bar Pressure Vent (BPV)

Features

- Offers an inexpensive way to create the necessary underbalance
- Allows the hole to be totally contained at the wellhead before the surge
- Allows the sleeve to lock in place once the port is opened
- Can be run with any packer
- Does not rely on tubing manipulation (Hydrostatic pressure in the tubing is the only force required.)

Operation

The BPV comprises a ported housing and a sliding sleeve. The sliding sleeve is isolated from the tubing pressure by a break plug with a hollow center.

The BPV activates when the detonating bar is dropped through the tubing, shearing the hollow break plug. This action allows the pressure in the tubing to force the sleeve upward, uncovering the ports. A lock ring locks the sleeve open. The detonating bar continues downward to strike the firing head. If the vent must be opened before dropping the detonating bar, dropping a special tube opens the vent without firing the guns. When the bar is dropped, it passes through the tube and fires the guns.

Bar Pressure Vent (BPV) Assemblies

SAP No.	Thread Size and Type in.	Maximum OD in. (mm)	Minimum ID in. (mm)	No. and ID of Ports in. (mm)	Flow Area in. ^{2} (cm^2)	Maximum Operating Pressure psi (kPa)	Minimum Operating Pressure psi (kPa)	Maximum Differential Pressure psi (kPa)	Burst Pressure psi (kPa)	Collapse Pressure psi (kPa)	Tensile Strength lb (kg)	Makeup Length ft (m)
101201951	2 3/8 EUE 8RD Box × Pin	3.06 (77.72)	1.50 (38.10)	4 1.0 (25.4)	1.77 (11.40)	17,000 (117 211)	1,000 (6895)	8,000 (55 185)	17,200 (118 590)	17,200 (118 590)	109,100 (49 487)	1.3 (0.40)
100155788	2 3/8 EUE 8RD Box × Pin	3.63 (92.20)	1.90 (48.26)	4 1.0 (25.4)	2.84 (18.32)	15,000 (103 421)	1,000 (6895)	8,000 (55 185)	16,600 (114 453)	15,000 (103 421)	117,400 (53 252)	1.3 (0.40)
100010328	2 7/8 EUE 8RD Box × Pin	3.88 (98.55)	2.25 (57.15)	4 1.3 (28.70)	3.98 (25.68)	15,000 (103 421)	1,000 (6895)	8,000 (55 185)	19,000 (131 000)	16,300 (112 385)	122,300 (55 474)	1.60 (0.49)
102012494	2 7/8-6.4 TSH 511 Box × pin	3.88 (98.55)	2.25 (57.15)	4 1.3 (28.70)	3.98 (25.68)	15,000 (103 421)	1,000 (6895)	8,000 (55 185)	19,000 (131 000)	15,700 (108 248)	100,000 (45 359)	1.94 (0.59)
100155789	3 1/2 EUE 8RD Box × Pin	5.00 (127)	2.75 (69.85)	4 1.75 (44.45)	5.97 (38.52)	15,000 (103 421)	1,000 (6895)	8,000 (55 185)	15,000 (103 421)	15,000 (103 421)	349,900 (158 712	1.57 (0.48)
101244650	3 1/2-9.3 TSH CS Box × Pin	5.00 (127)	2.75 (69.85)	4 1.75 (44.45)	5.97 (38.52)	15,000 (103 421)	1,000 (6895)	8,000 (55 185)	15,100 (104 111)	12,300 (84 806)	269,400 (122 198)	1.79 (0.55)

All available sizes might not be included. Review Enterprise for a complete listing.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

Below-Packer Vent Device

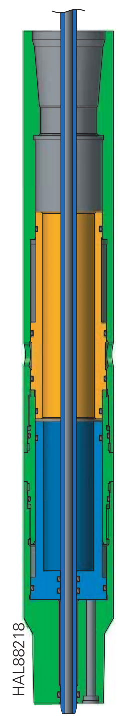
The below-packer vent device (BPVD) was developed for use with the annulus-pressure crossover assembly (APCA). Surface pressure applied to the annulus is transmitted through the APCA to a closed chamber below the BPVD and above a pressure-responsive firing head. The BPVD can be set to work before or after the perforating assembly is detonated.

Features

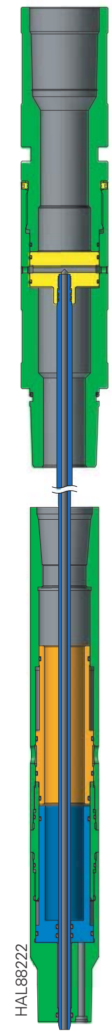
» Does not require tubing hydrostatic pressure to operate
» Operates in highly deviated wells
» Can be used in wells with low formation pressure
» Eliminates nitrogen requirements
» Helps allow maximum underbalance
» Compatible with several types of firing heads
» Helps provide reliable and accurate pressure response

Operation

To open the BPVD, a predetermined annulus pressure is transmitted through the APCA to below the BPVD. This pressure then ruptures a disk in the lower housing of the BPVD. An actuating piston then forces the venting sleeve away from the production ports. This action establishes communication with the tubing string.



Below-Packer Vent



Below-Packer Vent Device (BPVD)

Below-Packer Vent Device (BPVD) Specifications

SAP No.	Thread Size and Type in. (mm)	Maximum OD in. (mm)	Minimum ID in. (mm)	Makeup Length ft (m)	No. and ID of Ports in. (mm)	Maximum Operating Pressure psi (bar)	Minimum Operating Pressure psi (bar)	Tensile Strength lb (kg)	Burst Pressure psi (bar)	Collapse Pressure psi (bar)
100155787	2 3/8 (60.33) EUE 8RD Box × Pin	3.38 (85.85)	Non-fullbore	2.32 (0.71)	4 at 1.0 (25.4)	15,000 (1035)	1,000 (69)	150,000 (68 000)	25,000 (1725)	22,000 (1515)
100014176	2 7/8 (73.03) EUE 8RD Box × Pin	3.88 (98.55)	Non-fullbore	2.26 (0.69)	5 at 1.0 (25.4)	15,000 (1035)	1,000 (69)	170,000 (77 000)	25,000 (1725)	25,000 (1725)

All available sizes might not be included. Review Enterprise for a complete listing.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

Maximum Differential Bar Vent

The maximum differential bar vent (MDBV) assembly is run between the perforating guns and the packer. After the packer is set, the opening of the vent creates communication between the tubing and the rathole. The vent is opened by breaking the plug inside the tool and allowing the sleeve to uncover the ports. Running the MDBV allows the operator to run the tubing in the well with no hydrostatic pressure in the tubing.

Features

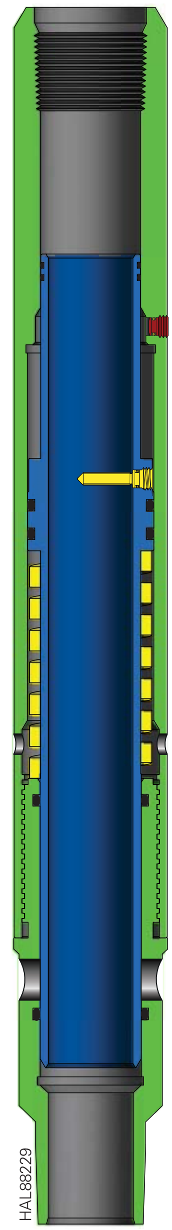
- Operates with a minimum amount of fluid in the tubing
- Helps allow maximum differential pressure when perforating in low-pressure formations
- Does not depend on tubing hydrostatic pressure to operate
- Assisted mechanically by an operating spring to help ensure full and complete opening
- Can be used in wells with open perforations to achieve an underbalance when guns are fired to add new perforations

Operation

The maximum differential bar vent is held closed by a chamber of silicone fluid, which keeps a spring compressed. When the silicone fluid is released from the chamber, the spring extends and opens the vent. Once the break plug is broken, the silicone fluid drains into the tubing.

The MDBV will open with up to 1,000 psi (68.95 bar) in the tubing, regardless of rathole pressure. If there is more than 1,000 psi (68.95 bar) in the tubing, and there is uncertainty about the rathole pressure, consider the bar pressure vent instead of the MDBV.

If the vent must be opened before dropping the detonating bar, dropping a special tube will open the vent without firing the guns. When the bar is dropped, it will pass through the tube and fire the guns.



Maximum Differential Bar Vent (MDBV)

Maximum Differential Bar Vent (MDBV) Specifications

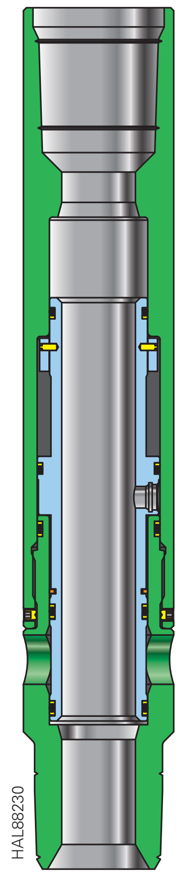
SAP No.	Thread Size and Type in. (mm)	Maximum OD in. (mm)	Minimum ID in. (mm)	No. and ID of Ports in. (mm)	Flow Area of Ports in.^{2} (cm^2)	Makeup Length ft (m)	Temperature Rating (Limited by Silicone Fluid) °F (°C)	Tensile Strength lb (kg)	Burst Pressure psi (bar)	Collapse Pressure psi (bar)
100005291	2 3/8 (60.33) EUE 8RD Box × Pin	3.36 (92.20)	2.0 (50.80)	5 at 1.0 (25.40)	3.92 (25.29)	2.29 (0.70)	350 (176)	221,000 (100 200)	19,500 (1345)	16,500 (1135)
100005294	2 7/8 (73.03) EUE 8RD Box × Pin	3.88 (98.55)	2.2 (57.15)	4 at 1.13 (28.70)	4.01 (27.87)	2.39 (0.73)	350 (176)	231,000 (104 700)	19,000 (1310)	13,000 (895)
100156853	3 1/2 (88.9) EUE 8RD Box × Pin	4.50 (114.30)	2.7 (69.85)	4 at 1.75 (44.45)	9.58 (61.81)	2.75 (0.84)	350 (176)	245,000 (111 000)	14,000 (965)	14,000 (965)

All available sizes might not be included. Review Enterprise for a complete listing.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

Pressure-Operated Vent

The pressure-operated vent (POV) is designed to achieve a differential pressure between the formation and tubing string and provide a way to open the vent and test the packer before the guns are fired.

When the guns are positioned and the packer is set, the predetermined amount of fluid is added to the tubing. Adding the fluid into the tubing causes the POV to open and creates the proper pressure differential before firing. Nitrogen can also be used with or in place of the fluids to obtain the necessary hydrostatic pressure in the tubing.



Pressure-Operated Vent (POV)

Features

- Allows the vent to be opened without the guns being fired
- Allows the packer to be tested before the guns are fired
- Fills tubing automatically when run with the Vann™ circulating valve
- Can be run with mechanical or pressure-actuated firing heads
- Useful in highly deviated wells
- Compatible with other packers

Operation

The POV consists of a ported housing, a sliding sleeve, and a set of shear pins. The sleeve is held in the closed position by a variable number of shear pins. The pins are isolated from annular pressure and are only exposed to the tubing hydrostatic. The POV will open when the proper amount of hydrostatic pressure is applied to the shear pins. The amount of hydrostatic necessary to open the POV depends on how many shear pins are installed in the tool. When the pins shear, the hydrostatic pressure forces the sleeve upward, which uncovers the flow ports. The sleeve is then locked into the open position.

Pressure-Operated Vent (POV) Specifications

SAP No.	Thread Size and Type in. (mm)	Maximum OD in. (mm)	Minimum ID in. (mm)	No. and ID of Ports in. (mm)	Total Flow Area in.² (cm²)	Makeup Length ft (m)	Maximum Operating Pressure psi (bar)	Minimum Operating Pressure psi (bar)	Maximum Differential Pressure psi (bar)	Tensile Strength lb (kg)	Burst Pressure psi (bar)	Collapse Pressure psi (bar)
101297298	2 3/8 (60.33) EUE 8RD Box × Pin	3.06 (77.72)	1.50 (38.10)	4 at 1.0 (25.40)	1.77 (11.40)	1.30 (0.40)	20,000 (1380)	1,000 (69)	8,000 (550)	140,000 (63 400)	24,000 (1655)	20,000 (1380)
100014177	2 3/8 (60.33) EUE 8RD Box × Pin	3.63 (92.20)	1.90 (48.26)	4 at 1.0 (25.40)	3.14 (20.27)	1.30 (0.40)	15,000 (1035)	1,000 (69)	8,000 (550)	146,000 (66 200)	18,000 (1240)	22,000 (1515)
100014178	2 7/8 (73.03) EUE 8RD Box × Pin	3.88 (98.55)	2.25 (57.15)	4 at 1.13 (28.70)	3.98 (25.65)	1.40 (0.43)	15,000 (1035)	1,000 (69)	8,000 (550)	160,000 (72 500)	19,000 (1310)	17,000 (1170)
100014179	3 1/2 (88.90) EUE 8RD Box × Pin	5.0 (127.0)	2.75 (69.85)	4 at 1.75 (44.45)	5.94 (38.32)	1.57 (0.48)	15,000 (1035)	1,000 (69)	8,000 (550)	400,000 (181 400)	22,000 (1515)	18,000 (1240)

All available sizes might not be included. Review Enterprise for a complete listing.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

Vann™ Circulating Valve

The Vann™ circulating valve can be used as a fill-up valve or as a circulating valve for displacing well fluids before setting a packer. After the fluid is displaced, the operator applies pressure to the tubing or annulus to rupture a disk and close the Vann circulating valve.

Features

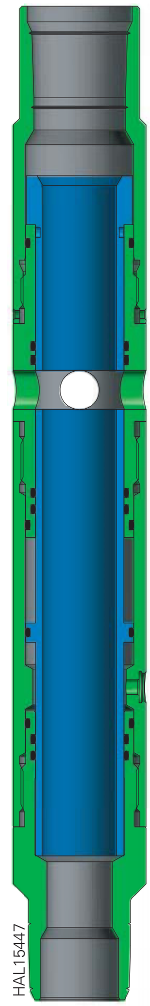
- Can be used as a circulating and shutoff valve
- Often run with other venting or production devices
- Economical and reusable

Operation

The Vann circulating valve consists of a ported housing, a sliding sleeve, and a rupture disk, which must be ordered separately. The sliding sleeve, which has two air chambers, is open while the tool is run in the hole.

The rupture disk is available for different pressure ratings as needed. The amount of hydrostatic pressure required to actuate the Vann circulating valve depends on the rupture disk rating.

Once the disk ruptures, the hydrostatic pressure enters the lower air chamber through the ruptured disk, forcing the sliding sleeve upward to cover the flow ports. Operating pressure can be pump pressure-applied after the Vann circulating valve is at the bottom of the well or applied by hydrostatic pressure when the tool is run in the hole.



Vann™ Circulating Valve

Vann™ Circulating Valve Specifications

SAP No.	Thread Size and Type in. (mm)	Maximum OD in. (mm)	Minimum ID in. (mm)	No. and ID of Ports in. (mm)	Flow Area of Ports in.² (cm²)	Makeup Length ft (m)	Maximum Operating Pressure psi (bar)	Minimum Operating Pressure psi (bar)	Tensile Strength lb (kg)	Burst Pressure psi (bar)	Collapse Pressure psi (bar)
101015372	2 3/8 (60.33) EUE 8RD Box × Pin	3.38 (85.85)	1.875 (47.62)	4 at 1.0 (25.4)	3.14 (20.26)	1.96 (0.60)	15,000 (1035)	1,000 (69)	225,000 (102 000)	22,000 (1515)	18,000 (1250)
120038456	2 7/8 (73.03) EUE 8RD Box × Pin*	4.65 (188.11)	2.12 (53.85)	6 at 1.0 (25.4)	4.71 (30.39)	3.25 (0.99)	15,000 (1035)	1,000 (69)	392,000 (177 700)	20,000 (1380)	18,000 (1250)

*Optional 2 7/8-IF and 3 1/2-IF connections.
All available sizes might not be included. Review Enterprise for a complete listing.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

Automatic Release

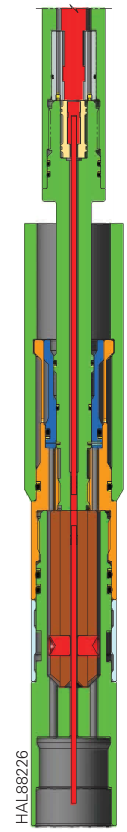
The automatic release (AR) allows the perforating guns to drop immediately after firing.

Features

- Can be used with most mechanical and pressure-actuated firing heads
- Allows for immediate release of the guns
- Leaves the tubing fully open after the guns are released
- Eliminates the need to run wireline to shift the guns
- Reduces the chance of the guns sticking because of debris

Operation

The AR allows for dropping the perforating guns after they are fired. The guns can be fired either mechanically or by pressure. The releasing device is actuated by the pressure generated outside the perforating guns upon detonation, so the guns are released as soon as they fire.



Automatic Release (AR)

Automatic Release (AR) Firing Head Assemblies

SAP No.	Description	Firing Head	Material	Top Thread	Type
100005226	2 3/4 AR Model II-D, 2 3/8 API-EU Box	Model II-D	4140 Low Alloy Steel	2 3/8 API-EU	Standard
100005225	2 3/4 AR Mechanical Firing Head, 2 3/8 API-EU Box	Mechanical	4140 Low Alloy Steel	2 3/8 API-EU	Standard
102520340	3 3/8 AR 4-13.20 API-NU Box, 2 3/4 Gun Pin × 3 3/8 Gun Box		4140 Low Alloy Steel	4-13.20 API-NU	Standard
102453650	3 3/8 AR 4 1/2-13.50 VAM TOP® Box, Pressure Isolated Latch	Model II-D	4140 Low Alloy Steel	4 1/2-13.50 VAM TOP	Pressure Isolated Latch
102361405	3 3/8 AR 2 1/2 TDF, 4 1/2-12.60 VAM TOP Box, Pressure Isolated Latch	2 1/2 TDF	4140 Low Alloy Steel	4 1/2-12.60 VAM TOP	Pressure Isolated Latch
102320037	3 3/8 AR 2 1/2 TDF, 4 1/2-12.60 VAM TOP Box	2 1/2 TDF	4140 Low Alloy Steel	4 1/2-12.60 VAM TOP	Standard
102302016	3 3/8 AR 2 1/2 TDF, 4 1/2-12.60 VAM TOP Box	2 1/2 TDF	4140 Low Alloy Steel	4 1/2-12.60 VAM TOP	Standard
102273110	3 3/8 AR 2 1/2 TDF, 4 1/2-12.60 JFEBEAR™ Box, Super 13% Chrome Housings, Pressure Isolated Latch	2 1/2 TDF	Super 13% Chrome/ 4140 Low Alloy Steel	4 1/2-12.60 JFEBEAR	Pressure Isolated Latch
102269011	3 3/8 AR Model III-D, 4 1/2-12.60 JFEBEAR Box, Super 13% Chrome Housings, Pressure Isolated Latch	Model III-D	Super 13% Chrome/ 4140 Low Alloy Steel	4 1/2-12.60 JFEBEAR	Pressure Isolated Latch

Automatic Release (AR) Firing Head Assemblies

SAP No.	Description	Firing Head	Material	Top Thread	Type
102262175	3 3/8 AR 2 1/2 TDF, 4 1/2-12.60 JFEBEAR Box, 13% Chrome Housing	2 1/2 TDF	13% Chrome/4140 Low Alloy Steel	4 1/2-12.60 JFEBEAR	Standard
102255962	3 3/8 AR 2 1/2 TDF, 3 1/2-9.20 JFEBEAR Box, 13% Chrome Housing	2 1/2 TDF	13% Chrome/4140 Low Alloy Steel	3 1/2-9.20 JFEBEAR	Standard
102196128	3 3/8 AR Vann™ Jet Stinger, 4 1/2-12.60 VAMTOP Box, 13% Chrome Housing	Wireline Retrievable	13% Chrome/4140 Low Alloy Steel	4 1/2-12.60 VAMTOP	Standard
102024037	3 3/8 AR 1 11/16 Hydraulic Actuator Firing Head, 2 7/8 API-EU Box	1 11/16 Hydraulic Actuator	41XX Low Alloy Steel	2 7/8 API-EU	
101989958	3 3/8 AR Vann Jet Stinger, 4 1/2-12.60 JFEBEAR Box, 13% Chrome Housing	Wireline Retrievable	13% Chrome/4140 Low Alloy Steel	4 1/2-12.60 JFEBEAR	Standard
101842753	3 3/8 AR Model II-D, 4 1/2-17.00 TSH Blue® Box	Model II-D	4140 Low Alloy Steel	4 1/2-17.00 TSH Blue	Standard
101827136	3 3/8 AR Model II-D, 4 1/2-13.50 VAMTOP Box, 13% Chrome Housing	Model II-D	13% Chrome/4140 Low Alloy Steel	4 1/2-13.50 VAMTOP	Standard
101792927	3 3/8 AR Model III-D, Pressure Isolated Latch, 4 1/2-12.60 TSH-Blue Box	Model III-D	4140 Low Alloy Steel	4 1/2-12.60 TSH-Blue	Press Isolated Latch
101727826	3 3/8 AR Model II-D, 3 1/2-9.30 TSH CS® Box, 13% Chrome Housing	Model II-D	13% Chrome/4140 Low Alloy Steel	3 1/2-9.30 TSH CS	Standard
101723718	3 3/8 AR 2 1/2 TDF, 3 1/2-9.30 TSH CS Box, 13% Chrome Housing	2 1/2 TDF	13% Chrome/4140 Low Alloy Steel	3 1/2-9.30 TSH CS	Standard
101711837	3 3/8 AR 2 1/2 TDF, 3 1/2-9.30 TSH CS Box	2 1/2 TDF	4140 Low Alloy Steel	3 1/2-9.30 TSH CS	Standard
101702230	3 3/8 AR Model II-D, 3 1/2-9.20 Fox™-K Box	Model II-D	4140 Low Alloy Steel	3 1/2-9.20 Fox-K	Standard
101701744	3 3/8 AR 2 1/2 TDF, 3 1/2-9.20 Fox-K Box	2 1/2 TDF	4140 Low Alloy Steel	3 1/2-9.20 Fox-K	Standard
101696923	3 3/8 AR Model II-D, 4 1/2-17.00 TSH Blue Box, Nickel Alloy 925 Housing, AFLAS®	Model II-D	Nickel Alloy 925/4140 Low Alloy Steel	4 1/2-17.00 TSH Blue	Standard
101636732	3 3/8 AR Model II-D, 4 1/2-12.60 VAMTOP Box, 13% Chrome Housing, AFLAS	Model II-D	13% Chrome/4140 Low Alloy Steel	4 1/2-12.60 VAMTOP	Standard
101629343	3 3/8 AR 2 1/2 TDF, 4 1/2-12.75 TSH 3SB™ Box, AFLAS	2 1/2 TDF	4140 Low Alloy Steel	4 1/2-12.75 TSH 3SB	Standard
101481657	3 3/8 AR 2 1/2 TDF, 4 1/2-12.75 TSH 3SB Box, 80 kpsi 41XX Low Alloy Steel Housing	2 1/2 TDF	41XX Low Alloy Steel	4 1/2-12.75 TSH 3SB	Standard
101436502	3 3/8 AR Vann Jet Stinger, 5 1/2-17.00 VAMTOP-HC Box, 13% Chrome Housing	Wireline Retrievable	13% Chrome/4140 Low Alloy Steel	5 1/2-17.00 VAMTOP-HC	Standard
101418579	3 3/8 AR 3 1/2 API-EU Pin, Mechanical Firing Head	Mechanical	4140 Low Alloy Steel	3 1/2 API-EU	Standard
101393016	3 3/8 AR 2 1/2 TDF, 5 1/2-15.50 VAMTOP Box, 13% Chrome Housing, AFLAS	2 1/2 TDF	13% Chrome/4140 Low Alloy Steel	5 1/2-15.50 VAMTOP	Standard
101393013	3 3/8 AR 2 1/2 TDF, 4 1/2-12.60 VAMTOP Box, 13% Chrome Housing, AFLAS	2 1/2 TDF	13% Chrome/4140 Low Alloy Steel	4 1/2-12.60 VAMTOP	Standard
101383884	3 3/8 AR Model III-D, 4 1/2-12.75 TSH 3SB Box, 13% Chrome Housing	Model III-D	13% Chrome/4140 Low Alloy Steel	4 1/2-12.75 TSH 3SB	Standard
101382883	3 3/8 AR 2 1/2 TDF, 4 1/2-12.75 TSH 3SB Box, 13% Chrome Housing	2 1/2 TDF	13% Chrome/4140 Low Alloy Steel	4 1/2-12.75 TSH 3SB	Standard
101357918	3 3/8 AR 2 1/2 TDF, 5 1/2-15.50 VAMTOP Box, 13% Chrome Housing	2 1/2 TDF	13% Chrome/4140 Low Alloy Steel	5 1/2-15.50 VAMTOP	Standard
101357916	3 3/8 AR 2 1/2 TDF, 4 1/2-12.60 VAMTOP Box, 13% Chrome Housing	2 1/2 TDF	13% Chrome/4140 Low Alloy Steel	4 1/2-12.60 VAMTOP	Standard
101313282	3 3/8 AR Model II-D, 3 1/2-9.30 TSH 3SB Box, 13% Chrome Housing	Model II-D	13% Chrome/4140 Low Alloy Steel	3 1/2-9.30 TSH 3SB	Standard
101313281	3 3/8 AR 2 1/2 TDF, 3 1/2-9.30 TSH 3SB Box, 13% Chrome Housing	2 1/2 TDF	13% Chrome/4140 Low Alloy Steel	3 1/2-9.30 TSH 3SB	Standard

Automatic Release (AR) Firing Head Assemblies

SAP No.	Description	Firing Head	Material	Top Thread	Type
101313059	3 3/8 AR 5 1/2-17.00 TSH 3SB Pin, 13 Chrome Housing, 3 3/8 Gun Pin Crossover	Not Specified	13% Chrome/4140 Low Alloy Steel	5 1/2-17.00 TSH 3SB	Standard
101313025	3 3/8 AR Model II-D, 5 1/2-17.00 TSH 3SB Pin, 13 Chrome Housing	Model II-D	13% Chrome/4140 Low Alloy Steel	5 1/2-17.00 TSH 3SB	Standard
101294470	3 3/8 AR 2 1/2 TDF, 3 1/2 API-EU Pin	2 1/2 TDF	4140 Low Alloy Steel	3 1/2 API-EU	Standard
101213155	3 3/8 AR Model II-D, Pressure Isolated Latch, 4 1/2-12.75 TSH CS Box	Model II-D	4140 Low Alloy Steel	4 1/2-12.75 TSH CS	Pressure Isolated Latch
101205564	3 3/8 AR Model II-D, Pressure Isolated Latch, 3 1/2 API-EU Box	Model II-D	4140 Low Alloy Steel	3 1/2 API-EU	Pressure Isolated Latch
100156106	3 3/8 AR Model II-D, 3 1/2 API-EU Pin	Model II-D	4140 Low Alloy Steel	3 1/2 API-EU	Standard
100155754	3 3/8 AR Model III-D, 2 7/8 API-EU Box	Model III-D	4140 Low Alloy Steel	2 7/8 API-EU	Standard
100155751	3 3/8 AR 2 1/2 TDF 3 1/2 API-EU Pin	2 1/2 TDF	4140 Low Alloy Steel	3 1/2 API-EU	Standard
100014158	3 3/8 AR 2 1/2 TDF, Pressure Isolated Latch, 2 7/8 API-EU Box	2 1/2 TDF	4140 Low Alloy Steel	2 7/8 API-EU	Pressure Isolated Latch
100010045	3 3/8 AR Mechanical Firing Head, Pressure Isolated Latch, 2 7/8 API-EU Box	Mechanical	4140 Low Alloy Steel	2 7/8 API-EU	Pressure Isolated Latch
100005236	3 3/8 AR Mechanical Firing Head, 3 1/2 API-EU Pin	Mechanical	4140 Low Alloy Steel	3 1/2 API-EU	Standard
100005235	3 3/8 AR 2 1/2 TDF, 2 7/8 API-EU Box	2 1/2 TDF	4140 Low Alloy Steel	2 7/8 API-EU	Standard
100005234	3 3/8 AR Model II-D, 2 7/8 API-EU Box	Model II-D	4140 Low Alloy Steel	2 7/8 API-EU	Standard
100005233	3 3/8 AR Mechanical Firing Head, 2 7/8 API-EU Box	Mechanical	4140 Low Alloy Steel	2 7/8 API-EU	Standard

All available sizes might not be included. Review Enterprise for a complete listing.
VAM TOP® is registered Trademark of Vallourec Oil and Gas France.
JFEBEAR™ is a trademark of Hunting Energy Services.
TSH Blue® and TSH CS® are registered trademarks of TenarisHydril;TSH 3SB™ is a trademark of TenarisHydril.
Fox™ is a trademark of Hunting Energy Services.
AFLAS® is a registered trademark of the Asahi Glass Co., Ltd.

Automatic Release (AR) Firing Head Specifications

SAP No.	Maximum OD in. (mm)	ID After Release in. (mm)	Makeup Length ft (m)	Maximum Operating Pressure psi (bar)[1]	Minimum Operating Pressure psi (bar)[2]	Maximum Differential Pressure psi (bar)	Tensile Strength lb (kg)[3]	Pressure Isolated Latch
100005226	2.88 (73.152)	2.125 (53.975)	2.04 (0.62)	17,600 (1213)	1,500 (103)	2,200 (152)	10,200 (4627)	
100005225	2.88 (73.152)	2.125 (53.975)	2.04 (0.62)	17,600 (1213)	1,500 (103)	2,200 (152)	10,200 (4627)	
102520340	4.750 (120.65)	3.660 (92.964)	2.39 (0.73)	15,440 (1064.55)	1,500 (103)	6,800 (468.84)	85,700 (38 873)	
102453650	5.07 (128.78)	3.775 (95.885)	3.08 (0.94)	8,000 (551.58)	1,500 (103)	6,000 (413.68)	85,600 (38 828)	Yes
102361405	5.07 (128.78)	3.775 (95.885)	2.98 (0.91)	9,150 (630.87)	7,000 (482.63)	7,650 (527.45)	85,700 (38 873)	Yes
102320037	4.925 (125.781)	3.67 (93.218)	2.39 (0.73)	17,800 (1227.26)	7,000 (482.63)	6,800 (468.84)	85,700 (38 873)	
102302016	4.925 (125.781)	3.67 (93.218)	2.39 (0.73)	17,800 (1227.26)	7,000 (482.63)	6,800 (468.84)	85,700 (38 873)	
102273110	4.925 (125.781)	3.67 (93.218)	2.39 (0.73)	17,800 (1227.26)	7,000 (482.63)	6,800 (468.84)	85,700 (38 873)	Yes
102269011	5.07 (128.78)	3.775 (95.885)	3.08 (0.94)	8,000 (551.58)	1,500 (103)	7,650 (527.45)	85,700 (38 873)	Yes

Automatic Release (AR) Firing Head Specifications

SAP No.	Maximum OD in. (mm)	ID After Release in. (mm)	Makeup Length ft (m)	Maximum Operating Pressure psi (bar)[1]	Minimum Operating Pressure psi (bar)[2]	Maximum Differential Pressure psi (bar)	Tensile Strength lb (kg)[3]	Pressure Isolated Latch
102262175	4.913 (124.79)	3.682 (95.523)	2.22 (0.68)	17,800 (1227.26)	7,000 (482.63)	6,800 (468.84)	85,700 (38 873)	
102255962	3.890 (98.806)	2.958 (75.133)	1.99 (0.61)	17,800 (1227.26)	7,000 (482.63)	7,500 (517.11)	53,300 (24 176)	
102196128	4.925 (125.781)	3.67 (93.218)	2.39 (0.73)	17,800 (1227.26)	1,500 (103.42)	6,800 (468.84)	85,700 (38 873)	
102024037	3.38 (85.852)	1.595 (40.513)	5.95 (1.81)	13,000 (896.32)	3,200 (220.63)	7,000 (482.63)	44,400 (20 139)	
101989958	4.913 (124.79)	3.682 (95.523)	2.22 (0.68)	17,800 (1227.26)	1,500 (103.42)	6,800 (468.84)	85,700 (38 873)	
101842753	5.114 (129.90)	3.682 (95.523)	2.14 (0.65)	17,800 (1227.26)	1,500 (103.42)	6,800 (468.84)	85,800 (38 918)	
101827136	4.983 (126.57)	3.682 (95.523)	2.14 (0.65)	17,800 (1227.26)	1,500 (103.42)	6,800 (468.84)	85,700 (38 873)	
101792927	5.07 (128.778)	3.775 (95.885)	2.68 (0.82)	8,000 (551.58)	500 (34.47)	7,800 (537.79)	87,500 (39 689)	Yes
101727826	3.92 (99.568)	2.92 (74.168)	1.99 (0.61)	17,800 (1227.26)	1,500 (103.42)	6,500 (448.16)	46,600 (21 137)	
101723718	3.915 (99.441)	2.92 (74.168)	1.99 (0.61)	17,800 (1227.26)	7,000 (482.63)	6,500 (448.16)	46,600 (21 137)	
101711837	3.915 (99.441)	2.92 (74.168)	1.99 (0.61)	17,800 (1227.26)	7,000 (482.63)	7,500 (517.11)	53,300 (24 176)	
101702230	3.883 (98.628)	2.999 (76.175)	1.99 (0.61)	17,800 (1227.26)	1,500 (103.42)	7,500 (517.11)	53,300 (24 176)	
101701744	3.885 (98.679)	2.999 (76.175)	1.99 (0.61)	17,800 (1227.26)	7,000 (482.63)	7,500 (517.11)	53,300 (24 176)	
101696923	5.114 (129.90)	3.682 (95.523)	2.14 (0.65)	17,800 (1227.26)	1,500 (103.42)	6,800 (468.84)	85,800 (38 918)	
101636732	4.952 (125.781)	3.67 (93.218)	2.38 (0.37)	17,800 (1227.26)	1,500 (103.42)	6,800 (468.84)	85,700 (38 873)	
101629343	4.909 (124.689)	3.682 (95.523)	2.18 (0.66)	17,800 (1227.26)	7,000 (482.63)	6,800 (468.84)	85,700 (38 873)	
101481657	5.201 (132.105)	3.67 (93.218)	2.38 (0.37)	13,000 (896.32)	7,000 (482.63)	6,800 (468.84)	85,700 (38 873)	
101436502	6.25 (1.58.75)	4.70 (119.38)	2.39 (0.73)	17,800 (1227.26)	1,500 (103.42)	4,700 (324.05)	106,100 (48 126)	
101418579	3.78 (96.012)	3.001 (76.225)	3.78 (96.012)	17,800 (1227.26)	1,500 (103.42)	7,500 (517.11)	53,300 (24 176)	
101393016	5.957 (151.308)	4.70 (119.38)	2.39 (0.73)	17,800 (1227.26)	7,000 (482.63)	4,700 (324.05)	106,100 (48 126)	
101393013	4.952 (125.781)	3.67 (93.218)	2.38 (0.73)	17,800 (1227.26)	7,000 (482.63)	6,800 (468.84)	85,700 (38 873)	
101383884	5.201 (132.105)	3.67 (93.218)	2.38 (0.73)	8,000 (551.58)	250 (17.24)	6,800 (468.84)	85,700 (38 873)	
101382883	5.201 (132.105)	3.67 (93.218)	2.38 (0.73)	13,000 (896.32)	7,000 (482.63)	6,800 (468.84)	85,700 (38 873)	
101357918	5.957 (151.308)	4.70 (119.38)	2.39 (0.73)	13,000 (896.32)	7,000 (482.63)	4,700 (324.05)	106,100 (48 126)	
101357916	4.952 (125.781)	3.67 (93.218)	2.38 (0.73)	13,000 (896.32)	7,000 (482.63)	6,800 (468.84)	85,700 (38 873)	
101313282	4.252 (108.001)	2.999 (76.175)	1.99 (0.61)	13,000 (896.32)	1,500 (103.42)	6,500 (448.16)	46,600 (21 137)	
101313281	4.252 (108.001)	2.999 (76.175)	1.99 (0.61)	13,000 (896.32)	7,000 (482.63)	6,500 (448.16)	46,600 (21 137)	
101313059	5.81 (147.574)	4.703 (119.456)	1.83 (0.56)	17,800 (1227.26)	1,500 (103.42)	4,700 (324.05)	106,100 (48 126)	
101313025	5.81 (147.574)	4.703 (119.456)	1.83 (0.56)	13,000 (896.32)	1,500 (103.42)	4,700 (324.05)	106,100 (48 126)	

Automatic Release (AR) Firing Head Specifications

SAP No.	Maximum OD in. (mm)	ID After Release in. (mm)	Makeup Length ft (m)	Maximum Operating Pressure psi (bar)[1]	Minimum Operating Pressure psi (bar)[2]	Maximum Differential Pressure psi (bar)	Tensile Strength lb (kg)[3]	Pressure Isolated Latch
101294470	3.78 (96.012)	3.001 (76.225)	1.74 (0.53)	13,000 (896.32)	7,000 (482.63)	7,500 (517.11)	53,300 (24 176)	
101213155	4.92 (124.968)	3.815 (96.901)	2.79 (0.85)	8,100 (558.47)	1,500 (103.42)	7,600 (524.00)	87,500 (39 689)	Yes
101205564	4.50 (114.3)	2.910 (73.914)	2.73 (0.83)	13,000 (896.32)	1,500 (103.42)	8,000 (551.58)	53,300 (24 176)	Yes
100156106	3.78 (96.012)	3.001 (76.225)	1.74 (0.53)	13,000 (896.32)	1,500 (103.42)	7,500 (517.11)	53,300 (24 176)	
100155754	3.38 (85.852)	2.72 (69.088)	1.92 (0.59)	8,000 (551.58)	1,500 (103.42)	6,300 (434.37)	44,400 (20 139)	
100155751	3.78 (96.012)	3.001 (76.225)	1.74 (0.53)	13,000 (896.32)	7,000 (482.63)	7,500 (517.11)	53,300 (24 176)	
100014158	3.38 (85.852)	2.527 (64.186)	5.00 (1.52)	7,900 (544.68)	7,000 (482.63)	7,700 (530.90)	38,700 (17 554)	Yes
100010045	3.38 (85.852)	2.527 (64.186)	2.75 (64.186)	7,900 (544.68)	500 (34.47)	7,700 (530.90)	38,700 (17 554)	Yes
100005236	3.78 (96.012)	3.001 (76.225)	1.74 (0.53)	13,000 (896.32)	1,500 (103.42)	7,500 (517.11)	53,300 (24 176)	
100005235	3.38 (85.852)	2.625 (66.675)	4.51 (1.37)	13,000 (896.32)	7,000 (482.63)	6,300 (434.37)	44,400 (20 139)	
100005234	3.38 (85.852)	2.72 (69.088)	1.92 (0.59)	13,000 (896.32)	1,500 (103.42)	6,300 (434.37)	44,400 (20 139)	
100005233	3.38 (85.852)	2.72 (69.088)	1.92 (0.59)	13,000 (896.32)	1,500 (103.42)	6,300 (434.37)	44,400 (20 139)	

All available sizes might not be included. Review Enterprise for a complete listing.

Notes:
[1]The maximum operating pressure is based on an open system; a closed system will be less. Check Enterprise for closed system ratings.
[2]The minimum pressure required to shift the latch in a standard ARFH is 1,500 psi. In an ARFH with an isolated latch, minimum pressure is 500 psi. The minimum pressure listed in this table is either for the latch or the firing head, whichever is greater. (e.g., ARFH with a 2 1/2-in. TDF shows a minimum pressure of 7,000 psi. This is based on the minimum number of shear pins (8) called out for the TDF.)
[3]The tensile rating will be reduced depending on the weight of the gun string below it. Check Enterprise for calculations.

Mechanical Tubing Release

The mechanical tubing release (MTR) provides operators with the option of keeping or releasing the VannGun® assembly from the tubing string. The MTR is usually run above the firing head and below the production ports below the packer. A standard shifting tool is used to operate the release mechanism in the MTR.

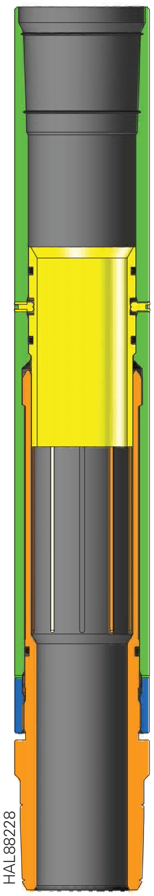
Features

- Frees the tubing for other tools and operations, such as logging, production testing, and treating
- Provides a low-cost way to release the gun assembly
- Uses standard off-the-shelf shifting tools
- Does not have a time limit on dropping the gun assembly
- Leaves perforations uncovered to eliminate flow restrictions

Operation

The MTR consists of three main components: the upper housing, a lower finger release sub, and a latch. The latch retains the finger release sub in the housing. To operate the MTR, the user must do the following:

1. Select the proper shifting tool and run it into the hole on slickline through the MTR.
2. Pick back up to engage the latch and lightly jar the latch four or five times.
3. Go back down to verify the release of the VannGun assembly.



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Mechanical Tubing Release (MTR)

Mechanical Tubing Release (MTR) Specifications

SAP No. (Without Latch)	Thread Size and Type in. (mm)	Maximum OD in. (mm)	Minimum ID (Latch Size) in. (mm)	Tensile Strength lb (kg)	Burst Pressure psi (bar)	Collapse Pressure psi (bar)	Makeup Length ft (m)
100005286	2 3/8 (60.33) EUE 8RD Box × Pin	3.06 (77.22)	1.50 (38.10) 1.63 (41.40) 1.81 (45.97) 1.88 (760)	111,500 (50 576)	12,000 (825)	10,000 (690)	1.50 (0.46)
100005281	2 7/8 (73.03) EUE 8RD Box × Pin	3.38 (85.85)	1.88 (47.75) 2.13 (53.98) 2.25 (57.15)	111,500 (50 576)	12,000 (825)	11,000 (760)	1.63 (0.50)
100005284	3 1/2 (88.9) EUE 8RD Box × Pin	3.95 (100.33)	2.25 (57.15) 2.75 (69.85)	111,500 (50 576)	11,000 (760)	10,000 (690)	1.88 (0.57)

Mechanical Tubing Release (MTR) Specifications

SAP No. (Without Latch)	Thread Size and Type in. (mm)	Maximum OD in. (mm)	Minimum ID (Latch Size) in. (mm)	Tensile Strength lb (kg)	Burst Pressure psi (bar)	Collapse Pressure psi (bar)	Makeup Length ft (m)
101236790	5 (127) 15 lb (6.8 kg) New VAM® Box × Pin	5.59 (142.01)	3.69 (93.68)	111,500 (50 576)	12,000 (825)	11,000 (760)	3.60 (1.10)
101435633	5 1/2-17.00 VAM TOP® HC Box × Pin Threads, 13 Chrome	6.50 (165)	4.313 (110)	168,000 (76 200)	6,800 (469)	5,000 (345)	4.7 (1.4)
101398862	4 1/2-12.6 VAM TOP Threads, 13 Chrome	5.50 (140)	3.562 (90)	107,000 (48,500)	6,300 (434)	6,000 (414)	4.1 (1.25)
101399826	5 1/2-15.5 VAM TOP Threads, 13 Chrome	6.50 (165)	4.313 (110)	168,000 (76,200)	6,400 (441)	4,000 (276)	4.8 (1.46)
101327124	4 1/2-12.6 VAM ACE Box × Pin, 13 Chrome	5.50 (140)	3.562 (90)	107,000 (48,500)	6,300 (434)	6,000 (414)	4.1 (1.25)

*VAM® and VAM TOP® are registered trademarks of Vallourec Oil and Gas France.

Mechanical Tubing Release (MTR) Shifting Tool and Key Number

Latch Size in. (mm)	Tool No. SAP No.	Key No. SAP No.	Key Maximum Exp. OD in. (mm)	Key Minimum OD in. (mm)
1.50 (38.10)	42 BO 245 101059081	42 B 818 101282505	1.64 (41.65)	1.49 (37.85)
1.625 (41.28)	42 BO 121 12005796	42 B 80 101059269	1.89 (48.006)	1.62 (41.148)
1.81 (45.97)	42 BO 117 101059064	42 B 37 101059122	2.076 (52.73)	1.75 (44.45)
	42 BO 237 101059079	42 B 681 101059193	2.156 (54.76)	1.69 (42.93)
1.88 (47.75)	42 BO 116 100008775	42 B 153 101059090	2.108 (53.569)	1.84 (46.74)
	42 BO 117 101059064	42 B 37 101059122	2.076 (52.73)	1.750 (44.45)
	42 BO 237 101059079	42 B 681 101059193	2.156 (54.76)	1.69 (42.93)
2.25 (57.15)	42 BO 118 100008776	42 B 287 101059109	2.592 (65.837)	2.156 (54.762)
2.125 (53.98)	42 BO 159 101015719	42 B 387 101059133	2.49 (63.25)	1.97 (50.04)
2.75 (69.85)	42 BO 146 100009659	42 B 349 101059118	3.156 (80.16)	2.718 (69.037)
3.69 (93.73)	42 BO 238 101010057	42 B 707 101059204	4.15 (105.41)	3.67 (93.218)
3.562 (90)	101399752	101399753		
4.313 (110)	101399109	101399113		

All available sizes might not be included. Review Enterprise for a complete listing.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

Pressure-Actuated Tubing Release

The pressure-actuated tubing release (PATR) separates the guns from the tool string when mechanical or slickline devices are not desirable. When separated, the guns drop off of the production tubing. Once the guns drop away, other tools and operations have no restrictions through the end of the tubing. In fact, the housing attached to the string has a greater ID than the tubing.

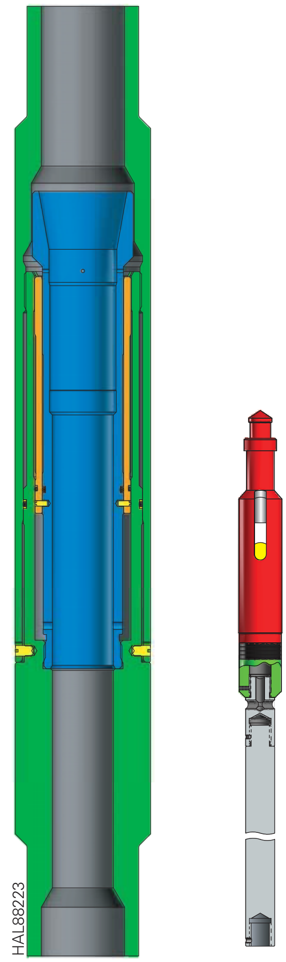
Features

- Tubing string left fully open
- Ideal for use in remote areas where wireline is expensive or unavailable
- Ideal for situations in which wireline can cause a safety hazard
- Access to the wellbore provided for production logging tools
- Particularly suited for releasing guns before stimulation treatments

Operation

The PATR comprises four main components: an upper housing, lower finger release sub, inner sleeve, and retaining latch. The PATR is pressure balanced until the standing valve is dropped into the inner sleeve.

Tubing pressure is applied to shear the retaining pins in the latch. Once the latch is shifted, the finger release sub with the sleeve releases from the housing and drops the perforating assembly into the rathole.



Pressure-Actuated Tubing Release (PATR) *Standing Valve*

Pressure-Actuated Tubing Release (PATR) Specifications

SAP No.	Thread Size and Type in. (mm)	Maximum OD in. (mm)	Minimum ID Before Release in. (mm)	Minimum ID After Release in. (mm)	Standing Valve OD in. (mm)	Makeup Length ft (m)	Tensile Strength lb (kg)	Burst Pressure psi (bar)	Collapse Pressure psi (bar)
100156751	2 3/8 (60.33) EUE 8RD Box × Pin	3.38 (85.85)	1.63 (41.40)	2.31 (58.67)	1.76 (44.70)	1.73 (0.53)	90,000 (40 800)	10,000 (670)	9,000 (620)
100156744	2 7/8 (73.03) EUE 8RD Box × Pin	3.75 (95.25)	1.812 (46.02)	2.828 (71.83)	1.86 (47.24)	1.72 (0.52)	120,000 (54 400)	10,000 (670)	10,000 (670)
101015385	3 1/2 (88.9) EUE 8RD Box × Pin	4.19 (106.43)	1.812 (46.02)	3.5 (88.90)	1.86 (47.24)	1.71 (0.52)	130,000 (58 900)	10,000 (670)	10,000 (670)

All available sizes might not be included. Review Enterprise for a complete listing.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

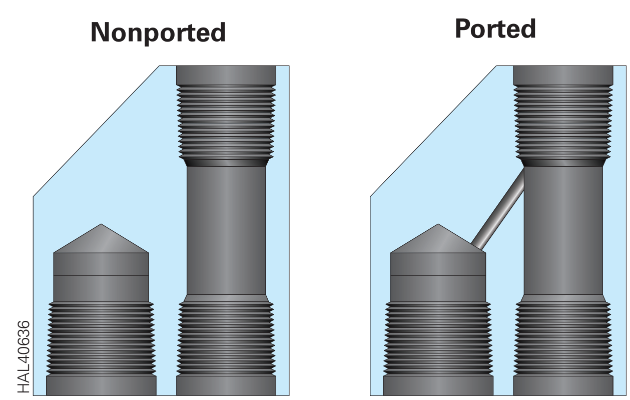
Y-Block Assembly

The Y-block assembly is used in dual completions and single selective completions to attach or hang guns from the long string.

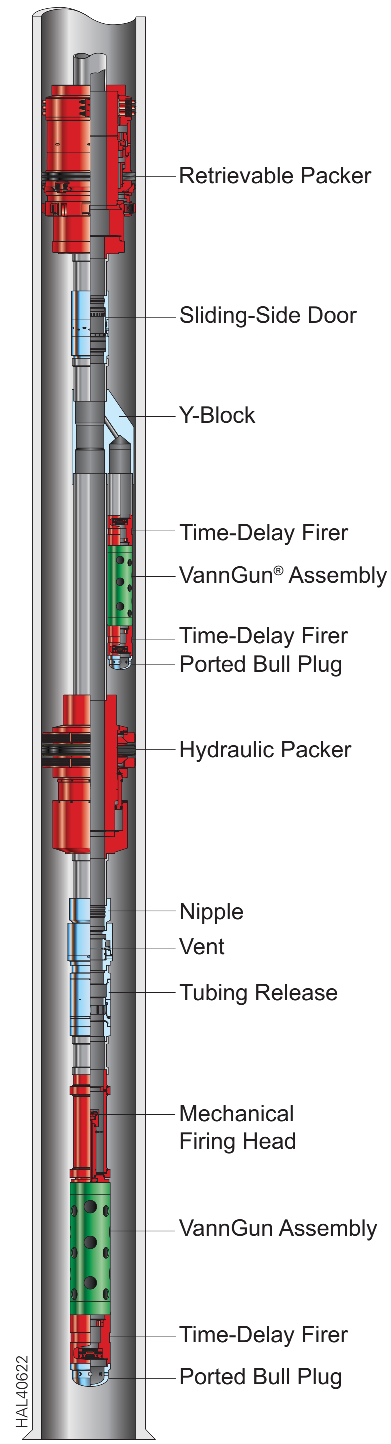
In single selective completions, this installation is run either for selectively shooting and testing two zones or for production when the application requires the option of producing two zones separately through one tubing string.

In dual completions, the assembly allows for the elimination of the tail pipe between the dual packer and the gun.

The Y-block assembly is available as a ported or nonported assembly. The ported Y-block allows guns to be fired upon applying pressure to the long string. In the nonported assembly, there is no communication between the long string and the short string.



Y-block assemblies are custom made according to the casing ID, the tubing size and type, and the gun size. Consult your local Halliburton representative for ordering information.



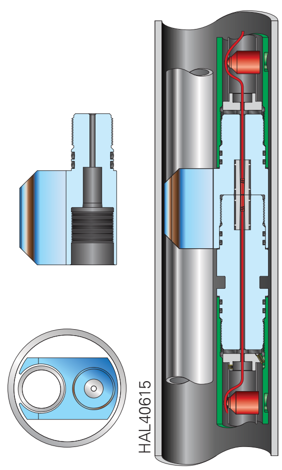
Y-Block Assembly

Gun Guides

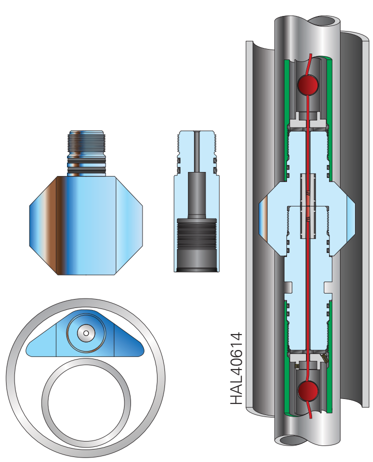
Halliburton developed gun guides to maintain the proper orientation of guns attached to the short string in a dual completion. The gun orientation must be maintained so that the charges shoot away from the long string. Gun guides are also used with Y-blocks in dual-string and single-string completions.

There are two types of gun guides. The delta-shaped or dual gun guide can be used when the casing ID is the same from top to bottom. If the casing at the top of the well is larger, then the wraparound guide must be used. The wraparound type can also be used in the wellbores with the same ID top to bottom.

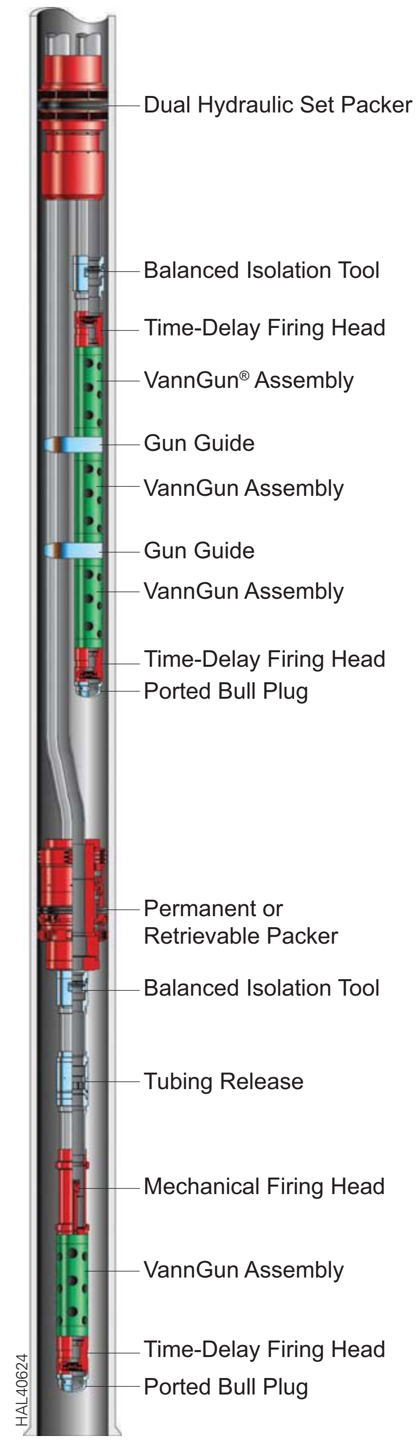
Guides are available for most of the smaller size guns [3 3/8 in. (85.73 mm) and smaller] that are typically run on the short string side of a dual completion.



Dual Completion with Wraparound Gun Guide



Dual Completion with Dual Gun Guide



Dual Completion with Gun Guide

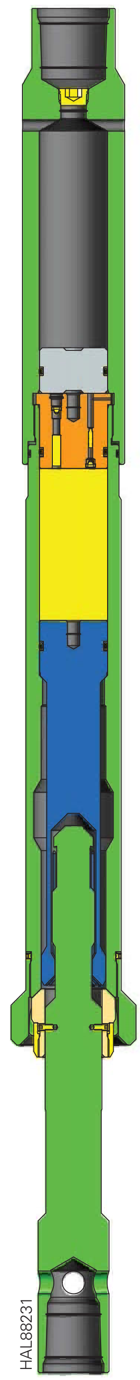
Hydraulic Metering Release Tool for STPP™-GH Single-Trip System Tool

The hydraulic metering release tool is one component of the single-trip system that allows operators to perforate and frac pack a zone of interest in a single trip.

Numerous safety and economic benefits accompany this capability. These benefits become even more profound as well parameters become more severe. The ever-present goal is to reduce completion capital expenditure and maximize net present value.

Features

- Save rig time with reduced pipe trips for faster completions
- Minimize fluid loss and formation damage
- Minimize associated well control risks
- Perforate under- or overbalanced
- Perform the sand control option most suitable for your well (frac pack, high-rate water frac pack, gravel pack)
- Complete deep, hot zones where fluid loss pills are ineffective



Hydraulic Metering Release Tool

Hydraulic Metering Release Assembly (Low Temperature)

Upper Thread Size and Type	Lower Thread Size and Type	Overall Length in. (cm)	Maximum OD in. (cm)	Effective OD* in. (cm)	Temperature Rating °F (°C)	Tensile Rating lb (kg)	Maximum Slackoff Weight on Tool lb (kg)	Minimum Slackoff Weight on Tool lb (kg)	Redressable	Weight lb (kg)
2 7/8 EU-RD	N/A	45.47 (115.49)	4.5 (11.43)	4.5 (11.43) 5.5 (13.97) 7.5 (19.05)	200 (93.33)	97,700 (44 315)	30,000 (13 607)	13,600 (6168)	Yes	156.46 (70.96)

*Effective OD of the tool is dictated by the OD of the skirt to be used.
**Maximum weight on gun hanger = gun weight + slackoff weight on hydraulic release tool.
***The tool is assembled with four shear screws of 3,400 lb each.
All available sizes might not be included. Review Enterprise for a complete listing.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

Hydraulic Metering Release Assembly (High Temperature)

Upper Thread Size and Type	Lower Thread Size and Type	Overall Length in. (cm)	Maximum OD in. (cm)	Effective OD* in. (cm)	Temperature Rating °F (°C)	Tensile Rating lb (kg)	Maximum Slackoff Weight on Tool lb (kg)	Minimum Slackoff Weight on Tool lb (kg)	Redressable	Weight lb (kg)
2 7/8 EU-RD	N/A	45.47 (115.49)	4.5 (11.43)	4.5 (11.43) 5.5 (13.97) 7.5 (19.05)	200 to 350 (93.33 to 148.88)	97,700 (44 315)	30,000 (13 607)	13,600 (6168)	Yes	156.46 (70.96)

*Effective OD of the tool is dictated by the OD of the skirt to be used.
**Maximum weight on gun hanger = gun weight + slackoff weight on hydraulic release tool.
***The tool is assembled with four shear screws of 3,400 lb each.
All available sizes might not be included. Review Enterprise for a complete listing.
These ratings are guidelines only. Check Enterprise for verification of ratings, or contact the TCP Technology Department.

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Appendix

Frequently Asked Questions and Answers

General

Which is better—underbalanced/dynamic underbalanced or balanced perforating?
It depends on completion objectives and well conditions.Laboratory experiments and field observations have proven time and again that when designed properly, lower perforation skin is achieved through underbalanced/dynamic underbalanced perforating. The concept of underbalanced/dynamic underbalanced perforating is to create a large pressure differential between the wellbore and reservoir when the guns are fired to instantaneously move fluid through the newly created perforation tunnels. This fluid movement is what helps remove crushed formation material and residual shaped charge debris, resulting in more efficient perforations. When proper underbalance/dynamic underbalance pressure is not achieved, either because of operational issues or lack of sufficient formation pressure, the result can be perforations that are not cleaned up completely, leading to reduced injectivity or higher pressure drawdown for production. In some cases in which balanced perforating is the only option, it might be necessary to perform some type of remedial step, such as acidifying or fracturing to stimulate the near-wellbore area.

Another alternative to underbalanced/dynamic underbalanced or balanced perforating is extreme overbalance perforating. This technique involves pressuring the wellbore with nitrogen above the fracture gradient of the formation to initiate perforation breakdown and mild fracturing near the wellbore. This method is particularly effective when the reservoir pressure is insufficient to effectively surge the perforations clean.

Your Halliburton representative can provide an analysis of the factors affecting your well.

How is the optimum underbalance/dynamic underbalance to yield clean perforations determined?
Maximum underbalance/dynamic underbalance without sand production can be estimated based on the density of the shales above and below the sand or on sonic travel time. Minimum underbalance/dynamic underbalance can be estimated using the Halliburton perforating tool kit (HPTK).

Should the well be flowed after perforating?
Yes, in most cases, to:

- Remove perforation debris before gravel packing
- Gather reservoir data including drawdown, effective permeability, skin damage, and productivity index
- Collect reservoir examples for analysis

What volume should be flowed back after perforating?
One gallon per perforation is often used as a guide for backflow volumes.

How important is centralizing the guns when a gravel pack will be run?
Extremely. The guns must be centralized to provide uniform hole sizes around the casing and to maximize charge performance. Total flow area can be increased as much as 25% by centralizing the guns.

How much casing damage does perforating cause?
Studies show cemented 7- and 9 5/8-in. casing can be perforated with phased shot densities up to 12 spf with a 0.76-in. hole without reducing crush resistance.

How much performance is lost when charge time and temperature rating is exceeded?
Charges begin to degrade immediately after time and temperature limits are exceeded. However, there is no way to quantify the degree of loss without testing the specific charges under identical conditions.

Halliburton time and temperature charts are based on data from tests on explosives that performed at maximum levels after exposure to time and temperature.

How much does shooting out of scallop reduce performance?
Testing of deep-penetrating (DP) charges indicates a performance reduction of 10 to 15% depending on charge and gun size.

When should backup firing heads be included in the perforating string?
Any time you want to minimize the risk of a misrun.

How can stuck guns be retrieved?
Several options are available.

Include jars in the TCP work string in areas where stuck guns are common. Maximum pull on the string and jarring usually frees the guns.

Make a chemical cut in the tubing below the packer to retrieve the packer and accessory tools. Then, an overshot/washpipe can be run so the fish can be washed over and retrieved.

Halliburton normally includes a safety joint in the perforating string. It separates above the stuck packer allowing the accessory tools to be retrieved. Then, an overshot or spear and jars can be used to jar the packer and guns free.

A safety joint can also be run below the packer. It allows the accessory tools to be pulled. Then, an overshot or a pin can be run in with jars.

What can be learned when gauges are run with the TCP string?
If the well is perforated underbalanced/dynamic underbalanced and surged, Halliburton FasTest® service can analyze the data and produce reservoir pressure and permeability estimates.

How can fluid loss be controlled when killing the well?
The Halliburton multiposition OMNI™ valve can be closed after perforating to hold completion fluids in the work string. A fluid loss pill can also be spotted across the formation after cycling the OMNI valve to its reversing position by applying annulus pressure.

Should 3 3/8-in. guns be run in 4 1/2-in. casing?
Though this is done frequently, usually without problems, Halliburton recommends only gun sizes that can be washed over with standard washover pipe in any particular casing size.

How compatible are the different Halliburton explosives types?
Halliburton uses four standard explosive types — RDX, HMX, HNS, and PYX. Tests show they are compatible with almost all configurations.

Any time more than one type of explosive is used in a system, the entire system will have a time and temperature rating equivalent to the lowest rated explosive.

StimGun™ System FAQs

How effective is the StimGun™ technique?
The procedure usually has a 95% success ratio as a perforation breakdown tool. As a standalone stimulation tool, it usually has a 45 to 50% success rate.

Can the StimGun assembly be used in horizontal wells?
Yes. The procedure has been quite successful in horizontal wells. Standard perforation breakdown treatments, such as the Powr*Perf™ and PerfStim™ processes are limited by the amount of energy that can be delivered through the tubing. They are impractical treatments for long intervals. However, StimGun sleeves provide the energy at the perforations so long intervals can be treated effectively.

Can the StimGun service be used with limited-entry perforating?
No. A minimum of 4 spf and at least 2 ft of perforations and a minimum of 3 ft of StimGun sleeve are required for a successful StimGun service. Otherwise, insufficient pressure is generated. The system is not compatible with limited-entry type perforating or 0° shot phasings.

What are the StimGun sleeve temperature limits?
Standard sleeves can be used at temperatures up to 250°F (52°C). High-temperature sleeves can be used up to 360°F (182°C).

Can StimGun sleeves be used in acid?
Yes. The sleeves are not acid reactive.

What sleeve sizes are available?
Sleeves are available for all VannGun® Assembly tools.

How much fluid should be run above the StimGun tool?
The sleeves require 500-psi hydrostatic pressure to help ensure proper burn. Fluid, not gas (nitrogen), should be used.

What can be learned by running the high-speed recorder?
The recorder monitors the StimGun sleeve's burn and pressure regime. The pressure, acceleration, and strain data it records can be analyzed by the PulsFrac™ system and compared with the model's preliminary output.

The data and results can be valuable in future completion design work.

Is gun centralization important?
Yes. When running the StimGun assembly, it is necessary to protect sleeves from damage. The StimGun sleeves are similar to PVC piping and are very brittle. Therefore, the recommendation is to run a StimGun retaining collar top/bottom of each 3-ft sleeve in addition to gun centralization.

What are the primary applications for the Powr*Perf™ system?
The system is excellent for cleaning up near-wellbore skin in low-pressure reservoirs with good permeability.

It is also an excellent choice for reservoirs with adjacent water or gas zones.

The service can also develop data for prefrac evaluations by fracturing the reservoir and producing fluid samples. Shots can be oriented to the fracture plane, enhancing the value of the data gathered. In some cases, the data has shown the reservoir is not viable, saving costs associated with additional treatments.

The service should not be considered a standalone treatment in reservoirs with less than 2-md permeability.

What criteria are used to choose between an underbalanced/dynamic underbalanced TCP job and a Powr*Perf™ systems job?
In general, if the reservoir has good permeability and sufficient reservoir pressure, it is a candidate for a natural (underbalanced) completion. If information from offset wells and/or charts from the Halliburton perforating tool kit (HPTK) brochure indicate reservoir pressures are not sufficient, the well should be considered a Powr*Perf system candidate.

What special equipment is required to run a Powr*Perf system job?
Standard equipment for Powr*Perf system jobs includes the Halliburton wellhead isolation tool, pop off valves to protect the annulus, and packers rated for at least 5,000-psi differential. A Halliburton nitrogen pumper usually is the only pumping equipment required.

Are special tubulars required?
No. The Powr*Perf system was designed to be an integral part of the completion string. In the vast majority of cases, standard Oil Country Tubular products can be used. Pressure can be held on the backside to reduce differential across the tubing. The Halliburton wellhead isolation tool protects topside equipment.

What rules of thumb can be used in designing a Powr*Perf system job?
A fluid column of no more than 300 ft should be run in the tubing above the Powr*Perf guns. Marathon studies show friction losses become excessive with higher fluid levels. The fluid can be acid, brine, produced fluids, etc., or any fluid that is compatible with the formation.

The pressure gradient should be a minimum of 1.4 psi/ft — regardless of the reservoir's frac gradient. This gradient helps overcome frictional losses and helps rectify frac gradient miscalculations.

Marathon studies show pressure gradients of 100 to 200% over the frac gradient produce the best results. More is better whenever possible with this process.

The Powr*Perf process does not require additional pumping. However, Halliburton often recommends pumping one tubing volume of nitrogen after the guns fire to energize the formation, aiding in dislodging debris from low-pressure reservoirs.

What is the maximum interval length that can be effectively treated with the Powr*Perf process?
The current practical limit is 60 to 70 ft. According to industry studies, lower sections of longer intervals do not benefit because of large pressure drops.

What ratio of Powr*Perf carrier to perforated interval should be used?
For the smaller 3 1/8- and 3 3/8-in. OD carriers, a 2:1 ratio should be used. For 4- and 4 1/2-in. OD carriers, a 1:1 ratio is sufficient.

What is the minimum shot density and phasing for Powr*Perf system jobs?
The Powr*Perf service requires a minimum of 6 spf and 60° phasing. The 6 spf increases flow area to the wellbore while 60° phasing aligns more perforations with natural frac planes. This minimum configuration eliminated tortuosity, screenouts, and reduced horsepower requirements.

Should deep-penetrating or big hole charges be used?
Halliburton currently recommends deep-penetrating (DP) charges. Results from several jobs using big hole (BH) charges were unsatisfactory. Studies indicate BH charges can create more fines, which inhibit fluid injection and might not be desirable for extreme overbalance.

Why is sintered bauxite used?
Bauxite offers excellent erosive qualities and high density. In tests at the velocities achieved in Powr*Perf service, frac sand shatters at the formation face.

What fluid velocities are produced during a Powr*Perf treatment?
Fluid velocities of 3,000 ft/sec and flow rates equivalent to 140 bbl/min per perforation occur at the moment of detonation. All tubing fluid evacuates in less than 5 seconds.

DrillGun™ System FAQs

What advantages does the drillable gun system offer?
The system eliminates a wireline perforating trip during squeeze cementing operations. The squeeze-perforating DrillGun™ tool and cement retainer are run in a single trip. This system also allows squeeze cementing in underbalanced/dynamic underbalanced conditions. Jobs can be run with clear fluids instead of drilling fluids, which can create costly disposal issues. The gun's design incorporates a pressure-activated, shear-sleeve firing head. The system can be configured to isolate the rathole from firing pressure when required.

What materials are used in the gun's construction?
The gun and firing head are made entirely of aluminum, which is very easy to drill.

What cement retainer is used?
The system includes the Halliburton field-proven cement retainer EZ Drill® SVB (EZSVB) packer.

AutoLatch™ Gun Connector FAQs

Are special blowout preventers required for the AutoLatch™ Connector?
No. The only requirement is the spacing between the blowout preventer (BOP) rams fit the linear dimensions of the connector. If required, spacer spools can be inserted between the BOP rams.

Does the AutoLatch Connector need to be centralized in the BOP stack?
Yes. BOP rams must close equally on the stinger seal area for the retrieving tool to properly latch to the top of the stinger. The running tool must also be centralized in the BOP stack.

What section lengths can be run?
It depends on the equipment available to build the riser section. Halliburton has deployed single 22-ft gun sections and sections of up to three 22-ft guns.

Can pressure-actuated firing heads be used or should only ball drop firing heads be used?
Either type firing head can be used. However, extreme care must be taken when running pressure-actuated firing heads. Well pressures and well return must be constantly monitored.

In an emergency, can BOP shear rams be closed on the gun?
No, never close the shear rams on guns. Even when the guns have been fired, it cannot be determined if all explosive materials have been detonated until the gun is out of the hole. However, if the situation requires, the Christmas tree's high shear ram can be closed.

How much right-hand torque can be applied to break out a gun section?
Maximum torque is limited by the guns to 6,000 ft/lb.

What if a gun section will not break out?
If the optional backup release sub is included in the string, rotating to the right will back off the sub. Then, an overshot can be run. Once it latches, and the connection is tested, the string is pulled up to the next seal sub in the seal slip.

How is a gun broken out should the sealed initiator develop a leak?
A short-catch overshot and grapple is used. The procedure does require more time, but gun sections can continue to be retrieved under pressure.

What if multiple sealed initiators begin to leak?
Simply continue retrieving gun sections using the short-catch overshot.

What if the BOP leaks?
If the connection is not already made and the leak is not dramatic, connect with the short-catch overshot and lower guns below the Christmas tree. Close and test the lower pipe ram, then repair the leaking ram. If the leak is serious, contingency procedures are followed.

Which inserts work best in the seal/slip rams with the ratchet gun connector?
Stewart-Stevenson inserts with straight slips work well.

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StimGun™ is a trademark of Marathon Oil Company and licensed by Halliburton.

PerfStim™ is a trademark of Oryx Energy Company. It is patented by Oryx and licensed by Halliburton.

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