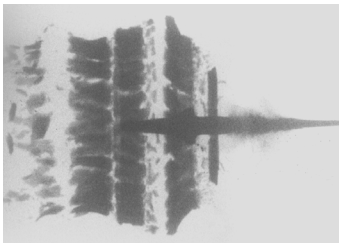
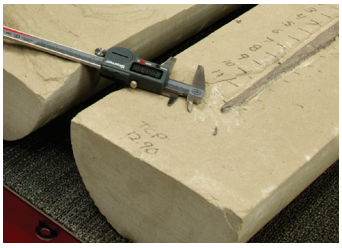
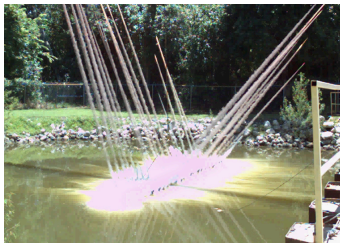
Perforating Center of Excellence

TESTING SERVICES OVERVIEW

JRC
JET RESEARCH CENTER®

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Jet Research Center (JRC) is the leader in energetic research and testing for the oil and gas industry. Since introducing jet perforators for completing oil and gas wells, JRC has led the industry in developing new energetic technologies. This is only possible through continuous investment in cutting-edge research and testing facilities. As a service to our industry, JRC provides access to these facilities in an effort to expedite the development, testing, and qualification of emerging technologies and products. The following is an overview of some of the testing services and facilities available.

API RP19B Testing

The American Petroleum Institute (API) publishes the Recommended Practice for the Evaluation of Well Perforators (RP19B). These testing recommendations, developed through working groups of industry-recognized subject matter experts, standardize testing procedures. Standardization is important to consistently and accurately evaluate performance results.

Section 1: Perforating System Testing at Ambient Condition

Section 2: Shaped Charge Performance in Stressed Sandstone

Section 3: Perforating System Testing at Elevated Temperature

Section 4: Shaped Charge Flow Performance at Reservoir Condition

Section 5: Perforating System Testing for Debris

Section 6: Perforating System Testing for Maximum Gun Swell

API RP19B | Section 1

The API RP19B Section I test method is used to evaluate shot-to-shot interference of shaped charges, casing hole size, and penetration into an unstressed cement target at a minimum compressive strength. The testing conditions and results are documented on a standard reporting template. The casing size is matched to the perforating gun diameter, and the surrounding cement target is matched to the expected depth of penetration. This testing is available as witnessed or unwitnessed. These tests are eligible to be registered and made public through API.

Test results include:

- Penetration depth into an unstressed cement target
- Casing hole diameter
- Casing burr height (protrusion from the inside casing or tubing wall)
- Charge performance variance

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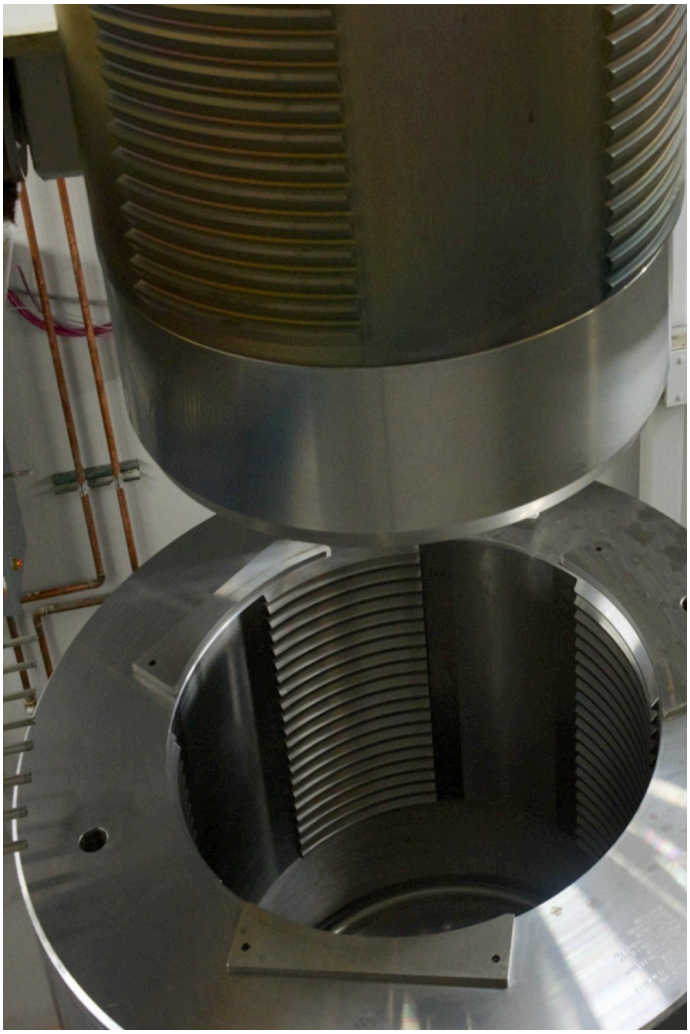
API RP19B | Section 2

The API RP19B Section 2 test is designed to evaluate a shaped charge's performance in stressed sandstone. The sandstone target is cored to a diameter of 4 in. or 7 in., depending upon the shaped charge's explosive mass. The core is placed inside a specially designed test fixture where a uniform confining stress is applied to the core. The core is perforated with a single shaped charge through a representative gun, scallop, wellbore fluid gap, casing plate, and a simulated cement sheath.

Test results include:

- Penetration depth into a stressed rock target
- Faceplate (casing) hole diameter



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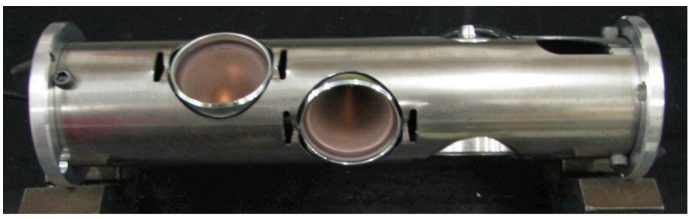
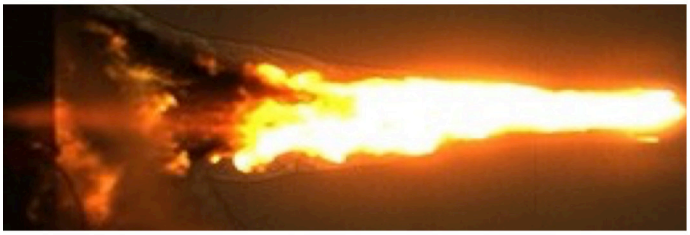
API RP19B | Section 3

The API RP19B Section 3 test is used to evaluate perforating system performance at elevated temperatures. This test characterizes a system's function, reliability, and performance degradation (if any) at elevated temperature. These tests are typically conducted in pairs: one at elevated temperature and a second test at ambient temperature as a benchmark. Tests may incorporate elevated pressure to further verify the operational rating of the system.

Test results include:

- Penetration depth into steel target of each shaped charge
- Faceplate (casing) hole diameter from each shaped charge
- Faceplate hole roundness
- Time/temperature profile





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API RP19B | Section 4

The API RP19B Section 4 test is designed to provide a measure of flow performance of a perforation into stressed rock-simulating, reservoir-specific downhole conditions. This test allows for reservoir or analog rock to be used, and reservoir pressure applied with a desired wellbore pressure differential (under/overbalance). This test method most accurately evaluates downhole perforator performance.

Test results include:

- Total core penetration depth into stressed reservoir rock at downhole conditions
- Debris-free penetration depth into stressed reservoir rock at downhole conditions
- Faceplate (casing) hole diameter
- Inflow performance of perforation tunnel

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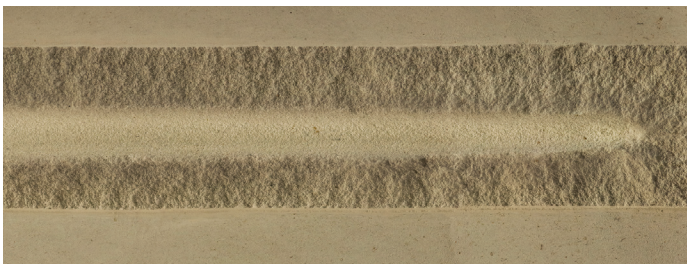

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API RP19B | Section 5

The API RP19B Section 5 test is designed to quantify the amount of debris that exits a perforating gun upon detonation, and also identify and quantify the debris remaining in the gun that is small enough to potentially exit the gun assembly when removing the system from the well. The test consists of detonating a perforating gun assembly, then collecting the produced and recovered debris. The debris is sorted and quantified by debris particle size.

Test results include:

- Volume and weight of debris from detonation
- Volume and weight of debris from rolled gun assembly
- Debris particle size distribution through 8 sieve sizes

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API RP19B | Section 6

The API RP19B Section 6 test is designed to quantify the amount of gun body swell for a given perforating system. The test consists of a fully loaded perforating gun assembly of no less than 4 ft in length being detonated inside a designated casing section. The detonated gun assembly is then measured and recorded. The gun assembly can also be drifted after detonation to qualify passing through wellbore restrictions. The test can be conducted dry or in fluid.

Test results include:

- Maximum Pre-Shot OD
- Maximum Post-Shot OD
- Average Perforator Swell Percent
- Go/No-Go Diameter Drift

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Advanced Testing

JET RESEARCH CENTER'S ADVANCED PERFORATING FLOW LAB (APFL)

To better satisfy our clients' testing needs and to continue development of industry-leading perforating and completion solutions that maximize reservoir inflow performance, JRC has expanded its testing capabilities with an award-winning Advanced Perforating Flow Laboratory. The lab houses multiple leading-edge testing vessels with inflow monitoring and evaluation technologies, allowing the study of deviated and horizontal completions, high- and ultrahigh-temperature reservoirs, high- and ultrahigh-pressure reservoirs, unconsolidated reservoirs, oil and gas reservoirs, extreme pressure differentials, and chemical intervention treatments. No other facility in the world comes close to the advanced capabilities of JRC's APFL.

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Jet Research Center's Advanced Perforating Flow Laboratory (APFL) was awarded the Hart Energy's Meritorious Award for Engineering Innovation.

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ENHANCED API 19B SECTION II, IV TESTING

Conventional API RP19B Section II & IV testing uses nominal confining pressures. Using the full capabilities of the Advanced Perforating Flow Laboratory (APFL) at Jet Research Center, perforator performance can now be simulated at exact downhole conditions, matching true reservoir and wellbore pressures, confinement stress, perforation orientation, and wellbore temperature. The capabilities of our advanced testing vessels, testing techniques, and instrumentation are truly unmatched within the oil and gas industry. Our advanced vessel capabilities include:

Rotating Perforation

180° Flow Vessel

» Maximum Pore Pressure: 5,000 psi

» Maximum Overburden: 10,000 psi

» Temperature: Ambient

» Core Size: 9 in. x 48 in. (22.9 cm x 121.9 cm)

High Pressure/Ultrahigh Temperature

Flow Vessels

» Maximum Pore Pressure: 20,000 psi

» Maximum Overburden: 25,000 psi

» Temperature: 400°F/204°C

» Core Size: 12 in. x 48 in. (22.9 cm x 121.9 cm)

Ultrahigh Pressure

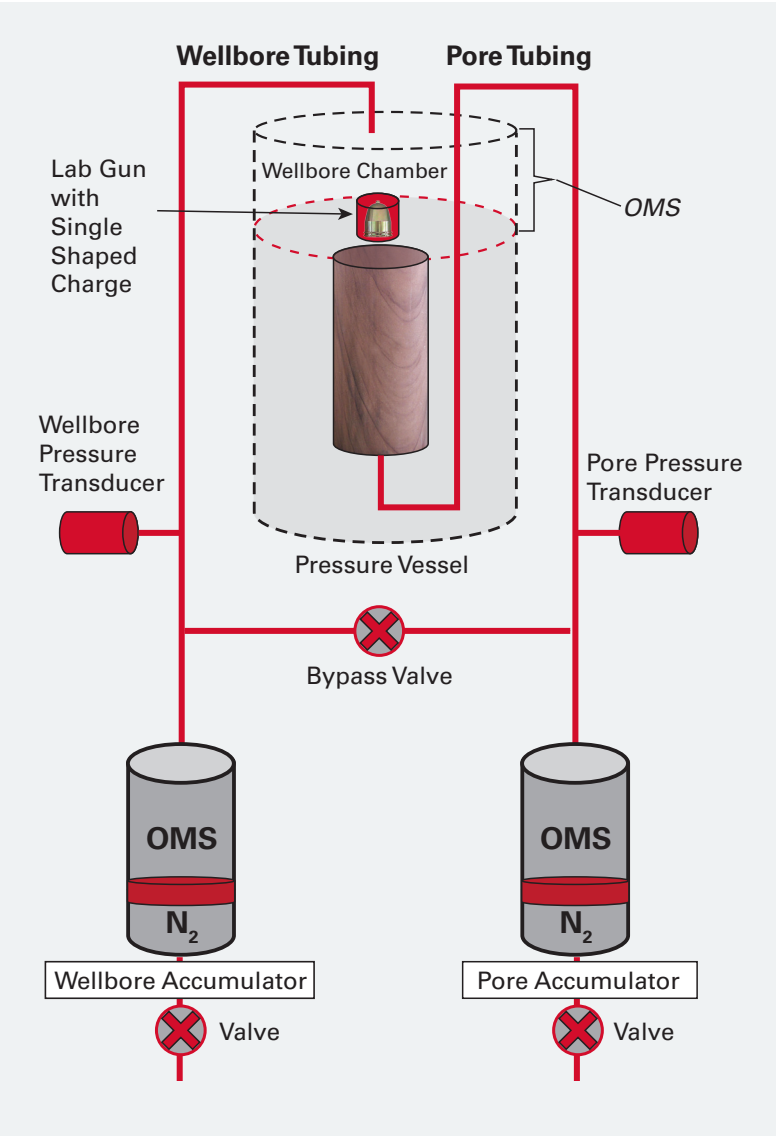
Perforation Flow Vessel

» Maximum Pore Pressure: 40,000 psi

» Maximum Overburden: 50,000 psi

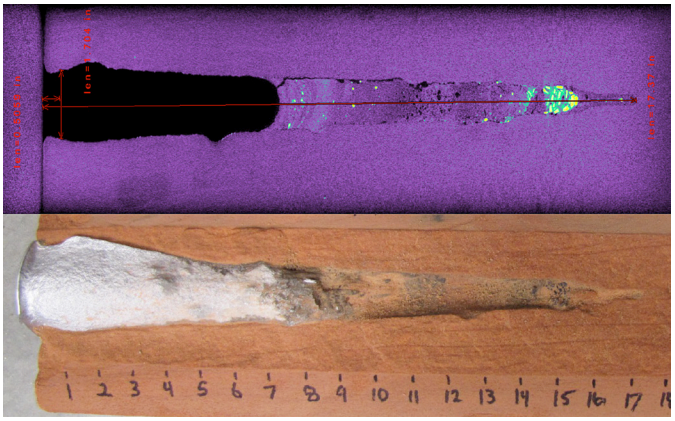
» Temperature: Ambient

» Core Size: 12 in. x 48 in. (22.9 cm x 121.9 cm)



SECTION II PLUS

Plus testing is an advancement to traditional API RP19B Section II testing. It is a collaborative effort between JRC's APFL team, our clients' needs, and the specific perforating scenario. These tests are designed to control the dynamic-pressure response to better match the wellbore-pressure transients created during perforating. Through better testing and evaluation of dynamic underbalance/overbalance pressures, these tests can help identify the optimum perforating system and evaluate how dynamic pressures can significantly influence perforation-tunnel geometry, resulting in enhanced production.



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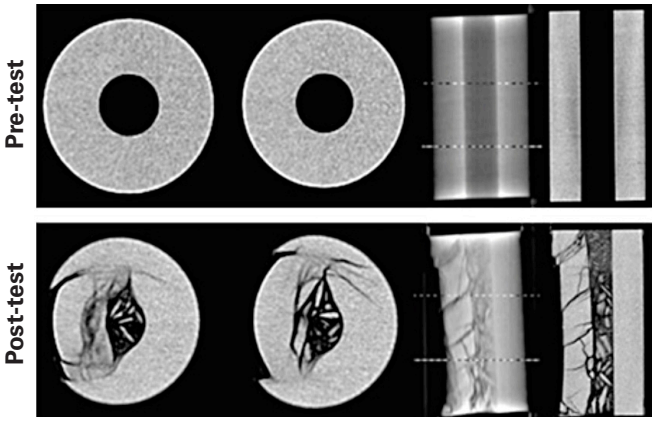

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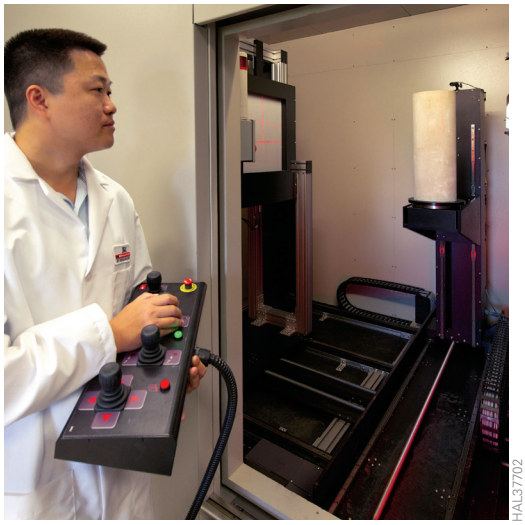
ADVANCED COMPUTERIZED TOMOGRAPHY (CT) CORE SCAN

Advanced core scanning allows unmatched inflow analysis and provides advanced understanding of perforation-tunnel geometry and potential flow profile. This technology can also be useful for component and material investigation and for critical quality control.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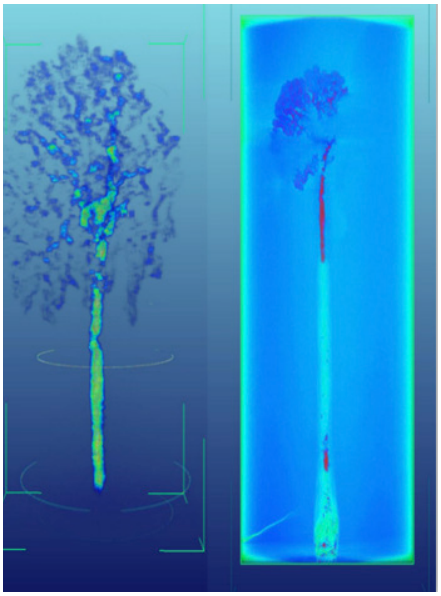
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Operational Testing

Well completions and interventions can present unique challenges. Making the best operational decisions sometimes requires definitive answers on how a perforating or cutter system may perform, occasionally in nonstandard conditions. JRC is positioned to deliver these answers with a dedicated team of testing professionals. We're ready to perform fast, accurate, and representative testing to provide the answers needed for making the best operational decisions.

Whether it's identifying perforator performance through multiple casing strings, understanding perforator penetration through unique completion jewelry, gun swell in a dry gas well for a through-tubing recompletion, performance degradation due to higher than anticipated reservoir temperature, or casing cutter performance – JRC has the expertise to deliver the answers you need!

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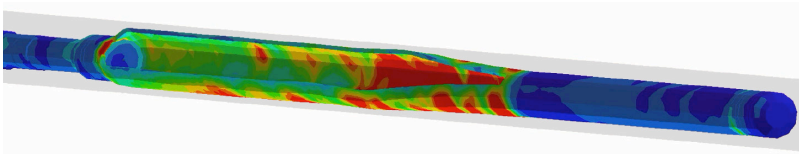

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COUPON PERFORMANCE EVALUATION

This test series typically includes three separate shaped charge detonations, allowing for statistical certainty of the tested charge's performance. Coupon tests can be used to understand relative penetration into a cement target, but are mainly used to identify casing-hole size and charge's performance consistency. Multiple casing strings can be evaluated, and at different standoffs, with this type of test. Tests are performed using L-80 or customer-specified coupon targets.


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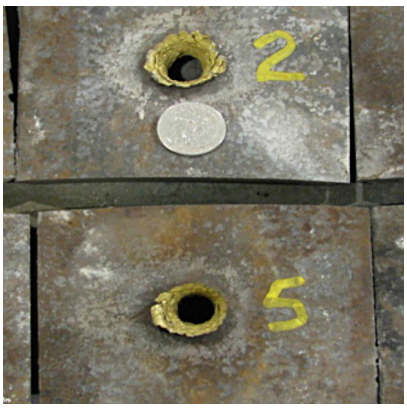
THERMAL TESTING PERFORATING COMPONENT OR EQUIPMENT COMPONENT

Thermal testing is important to evaluate the degradation of perforating components exposed to elevated temperatures. Each test is specifically designed to achieve the specific data point required, whether it is a single-component pass/fail or full system performance with swell and penetration at extended temperature exposure. Our capability for thermal explosive testing includes:

» 3 ovens rated to: 700°F / 371°C, 26 in. x 20 in. x 36 in. capacity

» 1 oven rated to: 600°F / 315°C, 12 in. x 12 in. x 120 in. capacity



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SYSTEM PERFORMANCE EVALUATION – BARREL TEST

A barrel test is performed by detonating a loaded perforating gun assembly inside a cemented segment of casing placed inside a standard steel barrel. This single test is commonly performed to evaluate shot-to-shot interference, obtain casing hole and gun scallop size from all phasing planes, casing and gun burr height, and maximum gun swell. Penetration is not measured during a barrel test. Tests are performed using L-80 or customer-specified casing. Multiple casing strings can be evaluated. The test setup is similar to a Section I test, but the outer cement target is minimized since penetration results are not obtained, saving time and reducing testing cost.


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DROP TESTING

System survivability test from shock or drop. Drop test is typically performed for equipment survival. Test is a 30-ft drop onto a steel plate.


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PIPE RECOVERY (JET CUTTER/DRILL COLLAR SEVERING TOOL)

Testing of any Jet Cutter or Drill Collar Severing Tool can be performed in various environmental conditions (tension, compression, fluids, etc.). These tests are designed to evaluate a cut or no-cut for a single environmental condition.


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MECHANICAL SYSTEM TESTING (PRESSURE/TEMPERATURE)

Mechanical system testing is an integral step in qualifying any downhole tool or perforating system prior to operating in a wellbore. JRC's extensive testing capabilities provide the foundation for developing and qualifying industry-leading technologies for the most extreme environmental conditions.

JRC currently houses four separate test vessels capable of pressure and temperature testing simultaneously and values beyond ultra HP/HT ratings.

These vessels are capable of evaluating explosive and nonexplosive systems.


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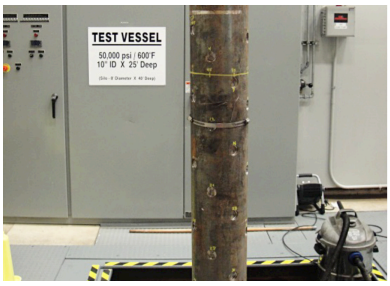
Ultra HP/HT Vessel	50,000 psi	600˚F	10-in. ID X 25-ft deep
Ultra HP/HT Vessel	40,000 psi	500˚F	6-in. ID X 8-ft deep
Ultra HP Vessel	30,000 psi	ambient	6-in. ID X 15-ft deep
HP/HT Vessel	20,000 psi	400˚F	7.5-in. ID X 13.5-ft deep



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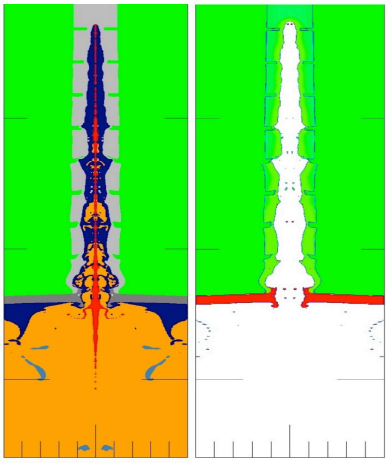
CUSTOMIZED TEST

Our team of engineers and technicians stand ready to work closely with our clients to develop and conduct any testing program. Customized testing is our specialty, and we pride ourselves in the ability to obtain needed data and operational information to enable better decisions that lead to lower risk and higher return on investment.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