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More than just Penetration: Perforation Design for Naturally Completed and Stimulated Wells

John Hardesty, PE

Principal Research Engineer, GEODynamics, Inc.

john.hardesty@perf.com

Outline

- Introduction
- Perforation Performance Evaluation
  - Implications of Extrapolating from a Single Data Point
- Perforation Geometry
  - DP Perforation Geometry and Implications
  - BH Perforation Geometry and Implications
- Design and Field Applications
  - Natural Completions: Berea Sandstone
  - Overbalanced Sand Control: Castlegate Sandstone
  - Acidizing: Austin Chalk
  - Pre Frac: Mancos Shale
- Conclusion

API Section I: Unstressed Concrete

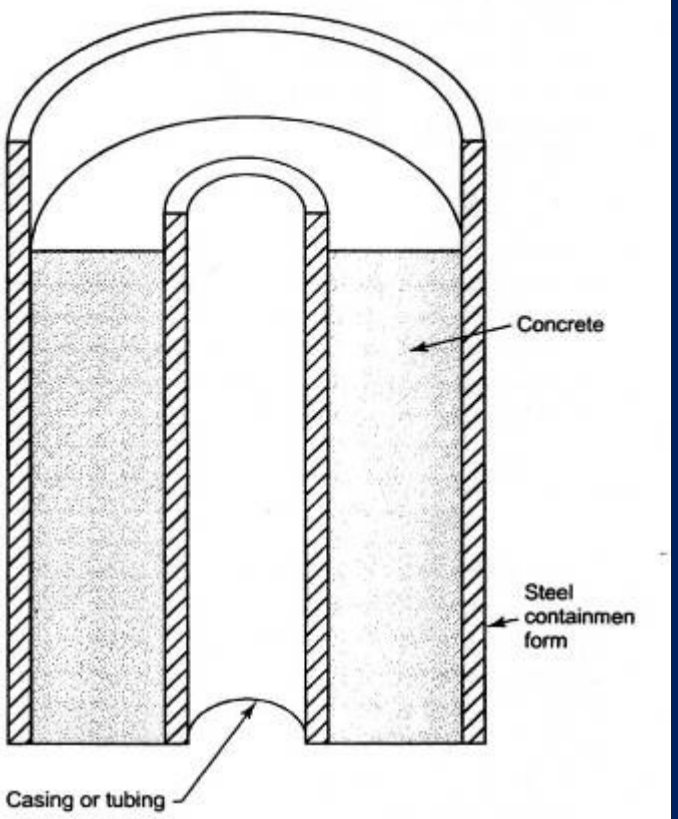


Figure 1—Example Concrete Target

- The API Section I Test is conducted by firing a representative gun section from the center of a poured cement target.
- This test can be registered with the API
- The targets and charges are aged 28 days prior to performing the test for registered data.

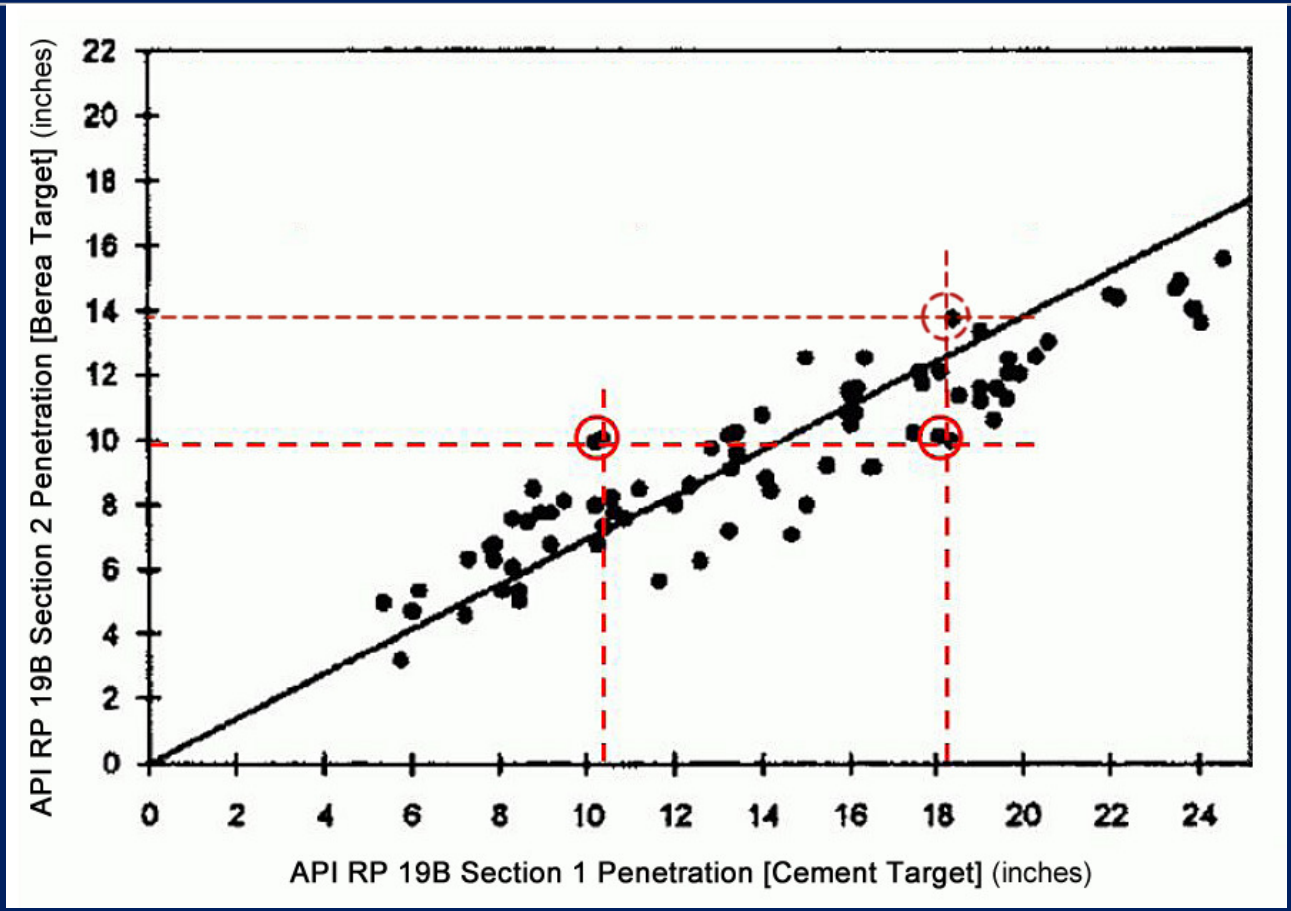
API Section I Test

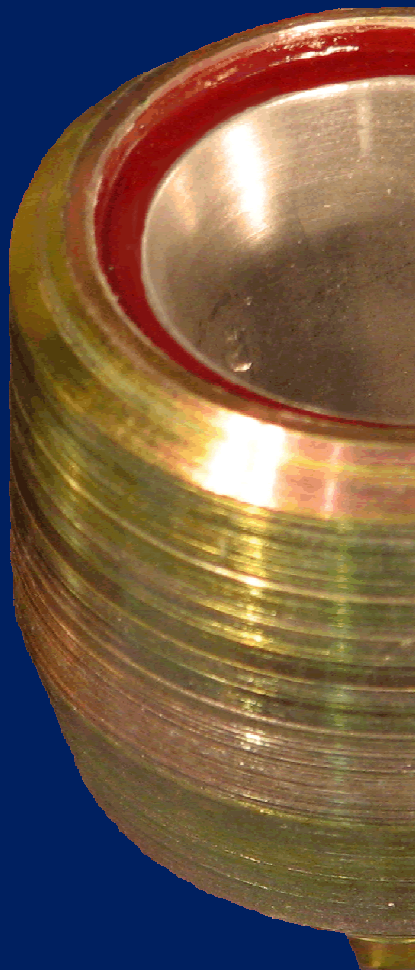
- The target must meet minimum specifications of construction, composition, and compressive strength.
- After the shot, the targets are split, and data collected on:
  - Hole Size
  - Penetration Depth
  - Debris
  - Burr Height of Casing

API Section I Test Considerations

- The test was originally designed to examine:
  - Interference
  - Charge Quality
  - Hole Size
- It has evolved to be the prime measurement of charge penetration performance as well.
- It is difficult to predict the down hole performance of a charge from its performance in an API Section I test.
- Performance increases in this test may not translate to performance increase in certain rock.

Reversed Charge Performance



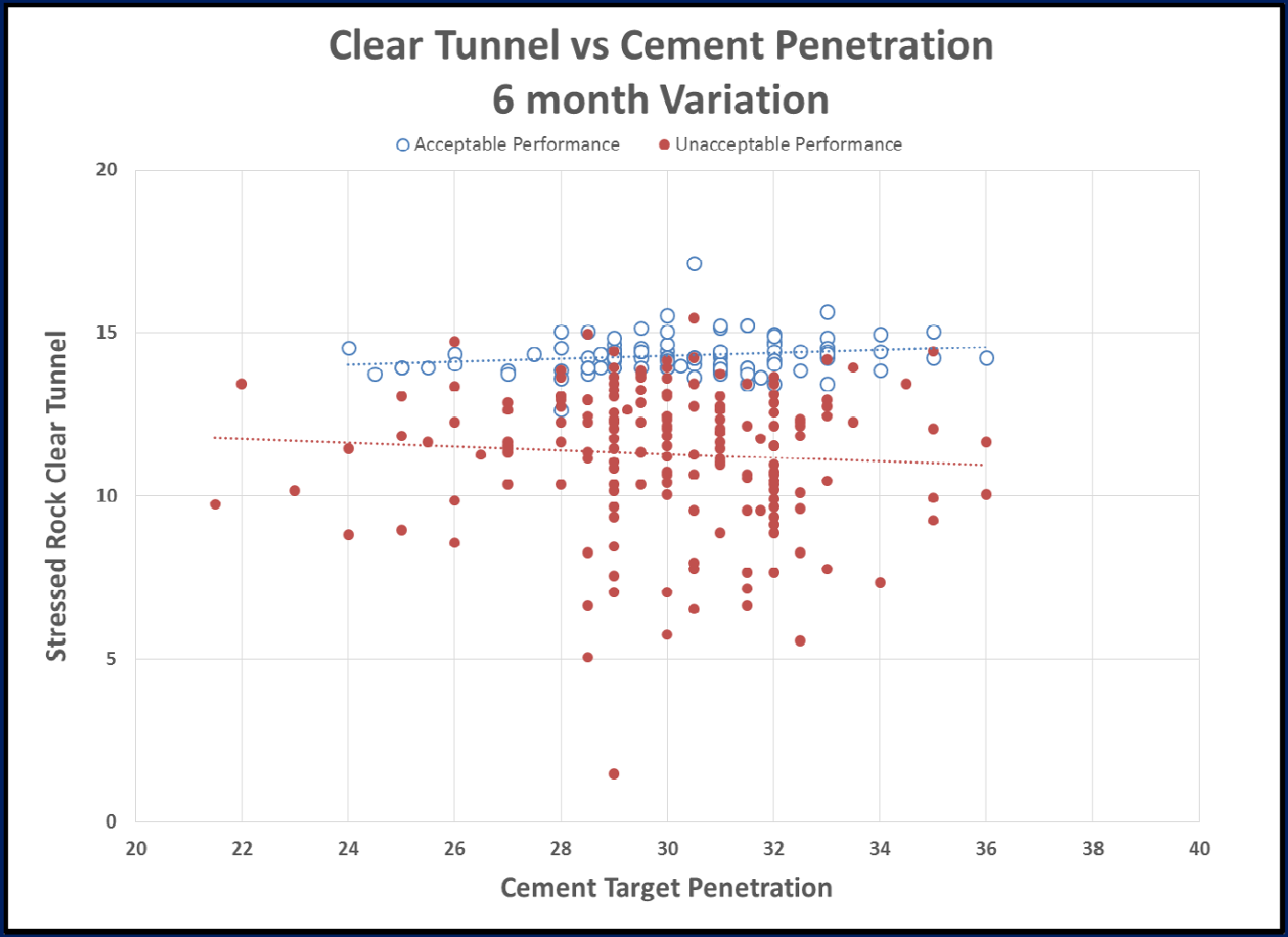


- Figure from SPE 27424, Ott, R.E. et al., "Simple Method Predicts Downhole Shaped-Charge Gun Performance." Nov 1994

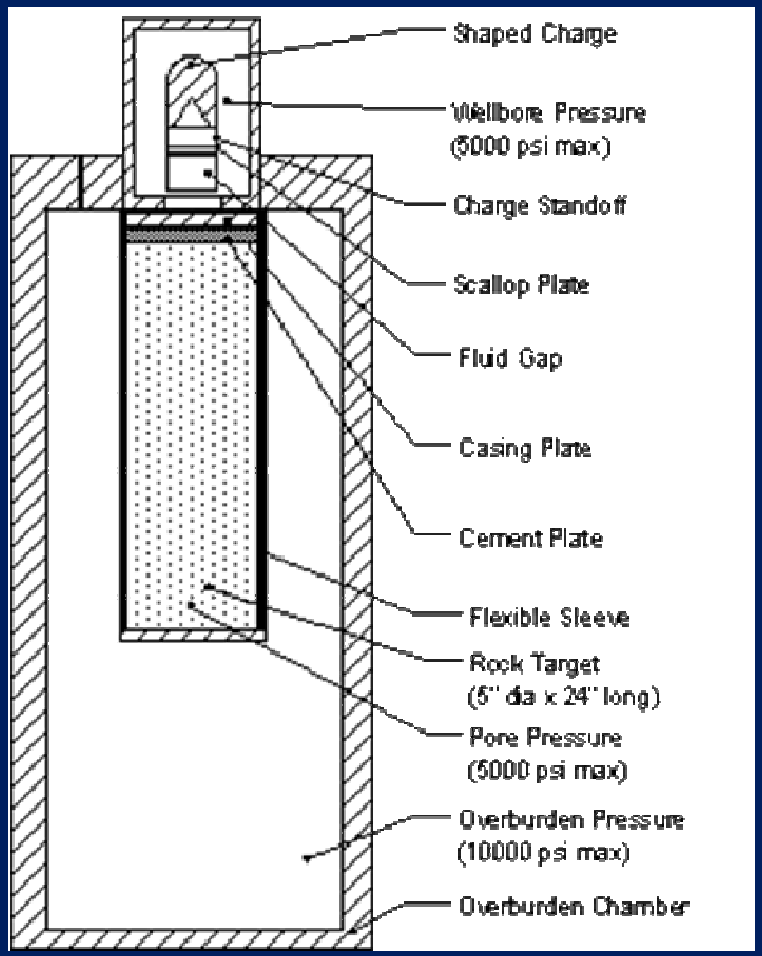
Other Implications - Examples

- Increased penetration in cement does not mean increased penetration in most other targets
  - 2X performance in cement translates to 90% performance in rock in comparative study…
- Single point data can not predict design dependent extrapolation
  - Dual String, or Triple String, or even Heavy Wall Casing
- Secondary characteristics not captured
  - Big Hole debris interaction with tapered cement tunnel
- Cement QC Performance vs Rock Performance
  - Periodic test during manufacturing is primary control of product produced

Perforation Performance Evaluation



Perforation Performance Evaluation

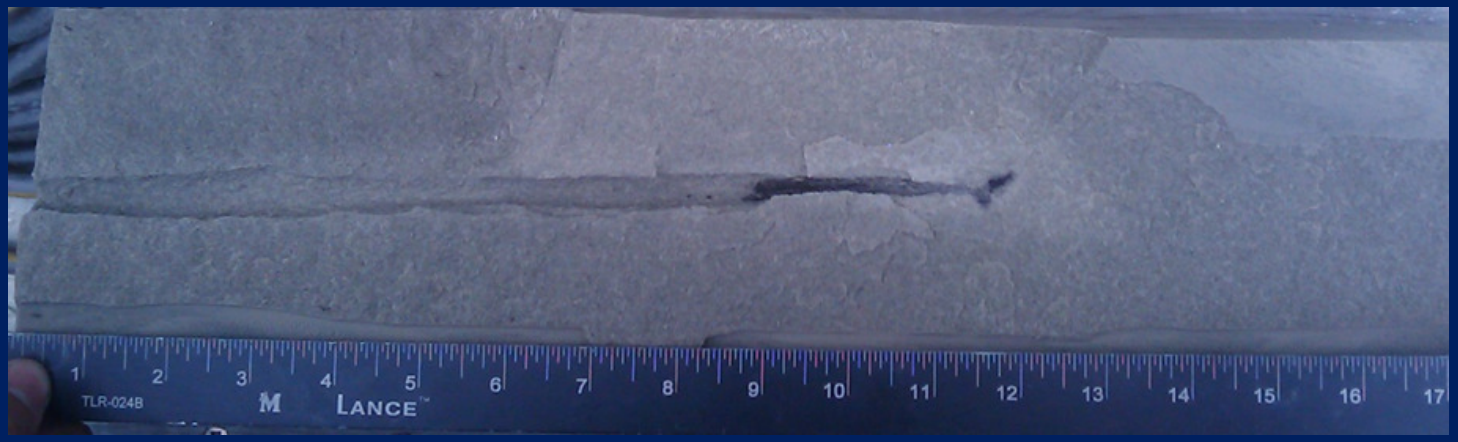


- Single Shot Flow Cell
  - Not Perfect Simulation
  - Does not represent near wellbore damage
  - Does not represent near wellbore stress state
  - Does not show perforation interaction
  - Improvement or reduction in performance does not necessarily mean same in field
- Still a very useful tool.

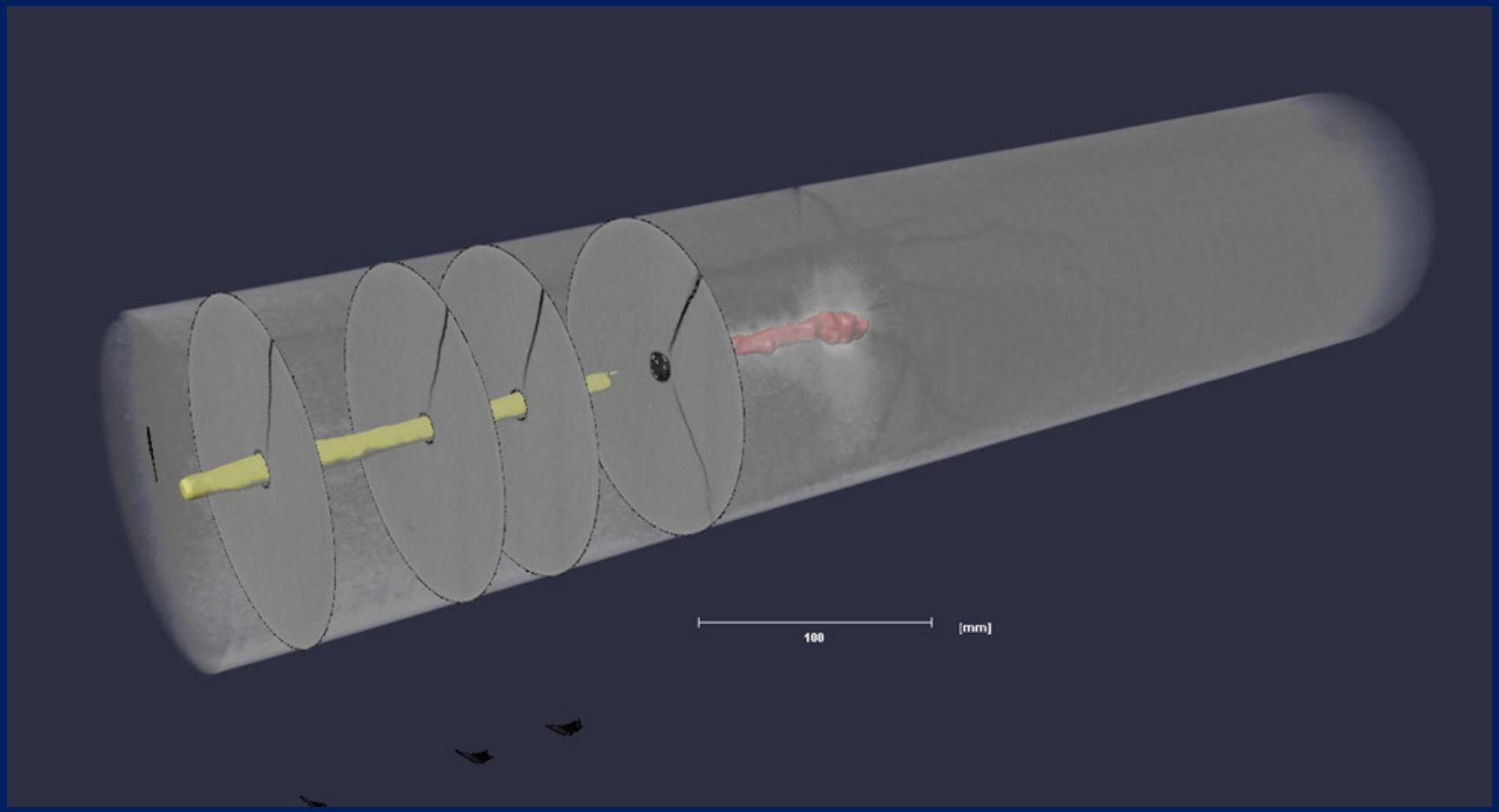
The Industry is Making Progress!

- API RP 19B Section 4 Revised and Approved
  - Highlights sources of Experimental Error
  - Adds new ways to analyze results
  - Enables more uniform testing between companies
- API RP 19B Section 2: Under Revision
  - Wide Involvement
  - Draft Standard: New Performance Metric
  - New Registered and Witnessed Test
  - Still Concentrating on Penetration Only – No Analysis
  - Currently Evaluating necessary Equipment Specifications

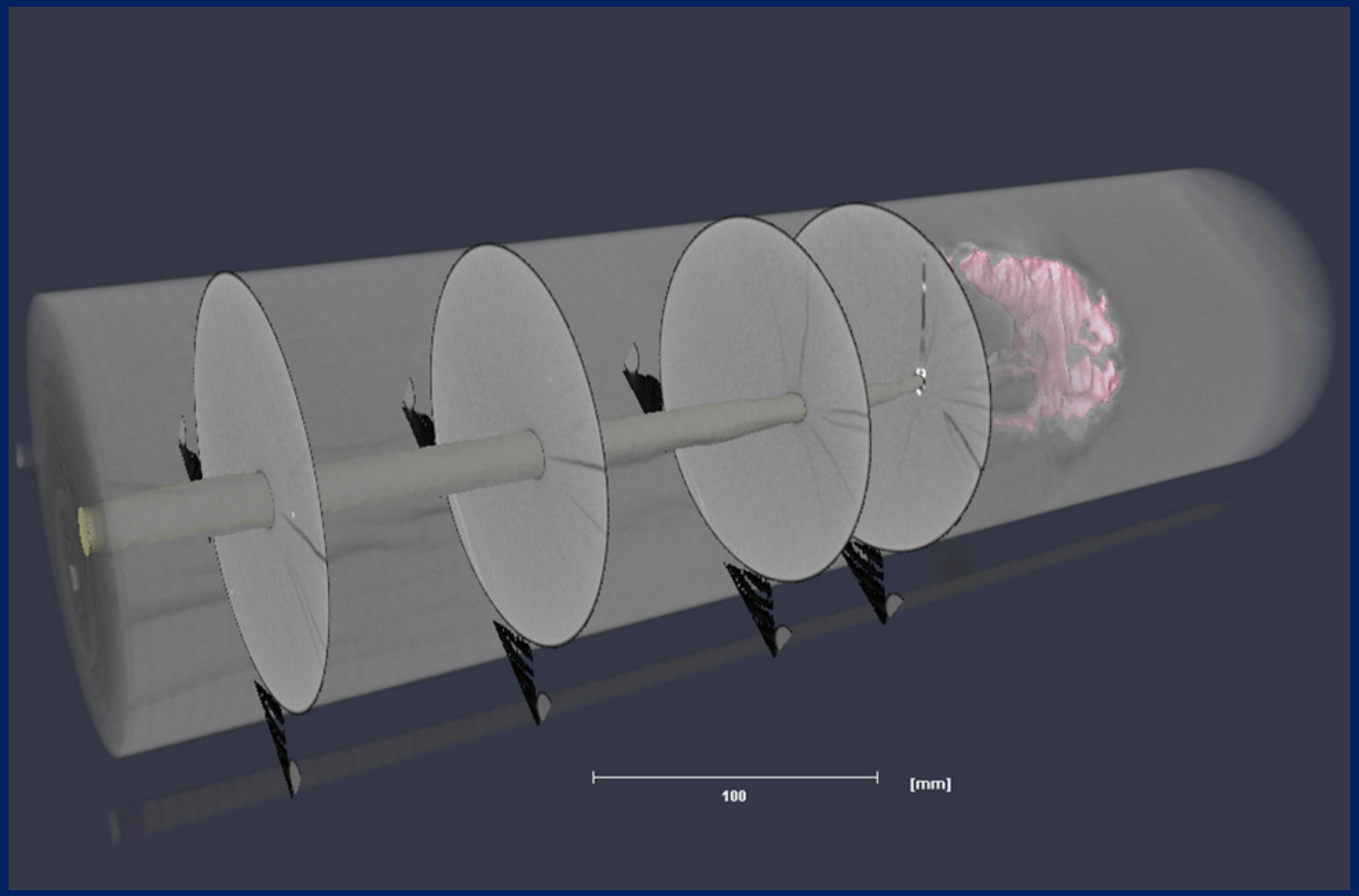
Perforation Geometry – DP Charges



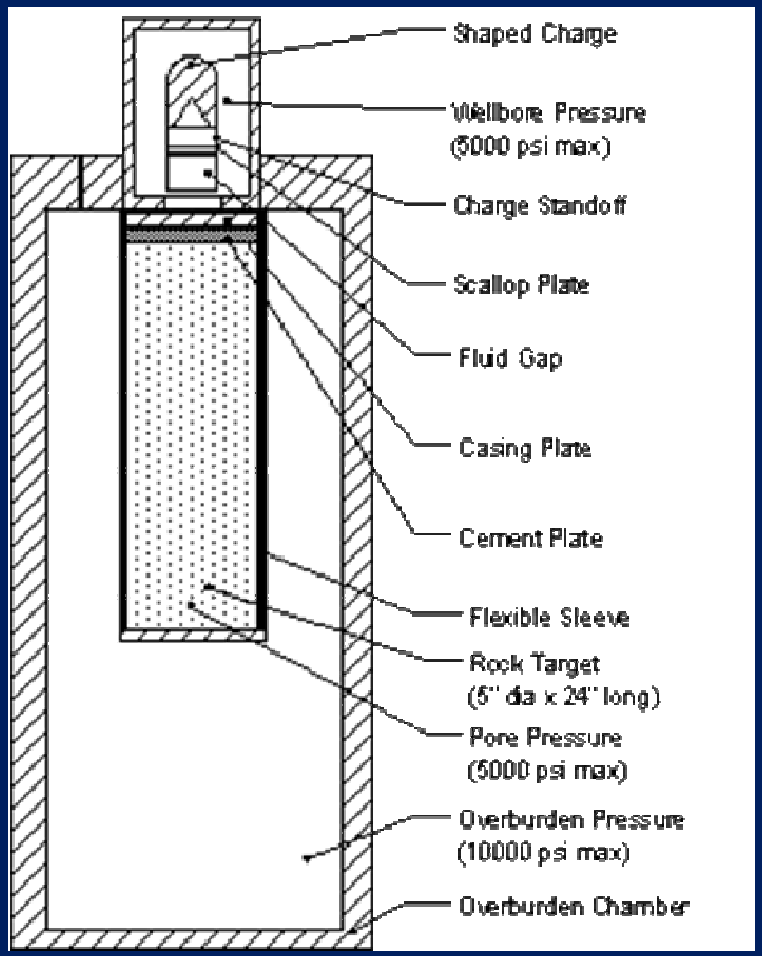
Permeability Map, Conventional Tunnel



Permeability Map, Reactive Tunnel

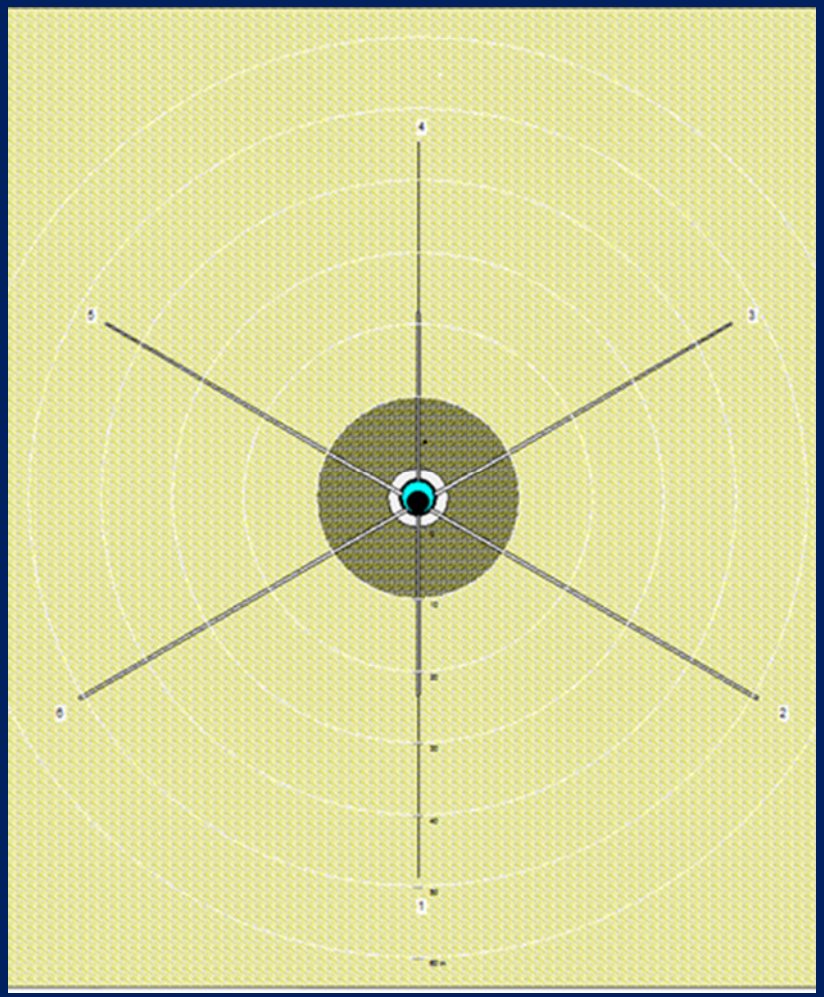


Perforation Geometry – DP Charges



- 15g HMX Conventional
- API RP 19B 35.1”
- Berea Sandstone
  - 100-150 mD
  - 19% porosity
  - 7000 psi UCS
- Typical Penetration:
  - 8-9 inches

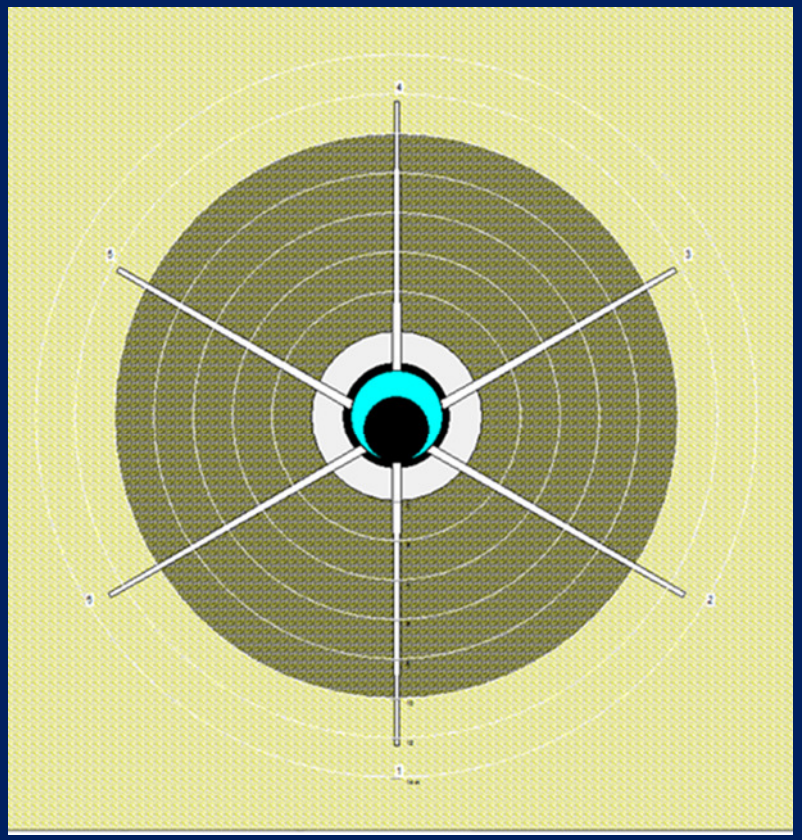
Perforation Performance Evaluation



- 22.7 g Charge
- API Cement 39.02”
- 8” Borehole
- 10” Damage Radius

- Perforations Far Field
- Assumed Open

Perforation and Well Geometry



- Perforations Near WB
- Interaction of perforation geometry with near wellbore geometry
- Improved perforation may not improve some wells
  - (too much or too little damage)
- Critical for others

Perforation Geometry – DP Charges

- Other Considerations
  - Dual String – Plugging in second string
  - Gun plugging which alters dynamic surge
  - Heterogeneous Formation: Plugging in the hard layers
  - Where does the fluid enter (acid) or exit the formation?
- Other Lithology
  - Carbonate: Shorter tunnels. Narrower Tunnels. More Opportunity for plugging.
  - Shale: In some cases much shorter than expected. Open tunnel a primary function of charge design, and not of perforating balance.

Perforation Geometry BH Charges

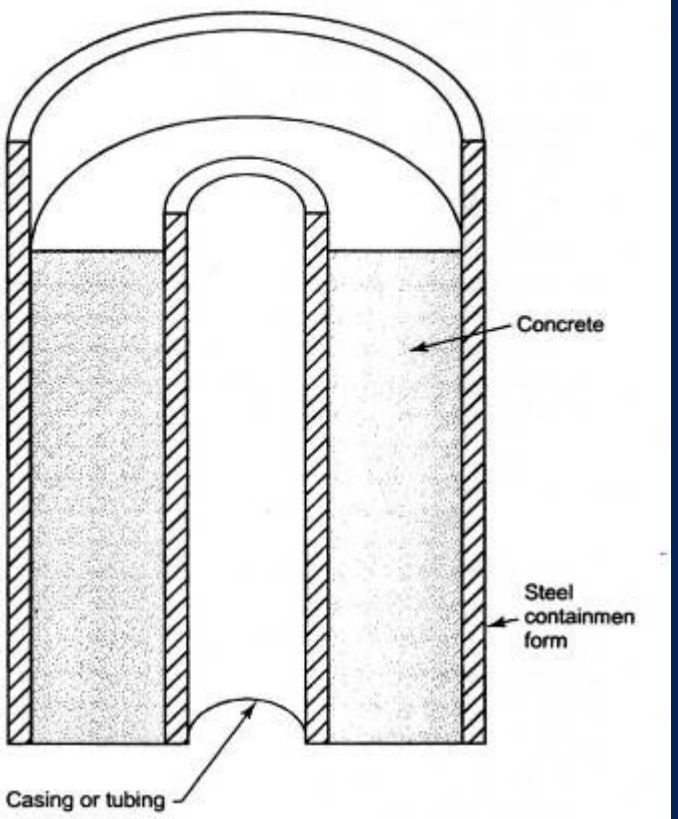


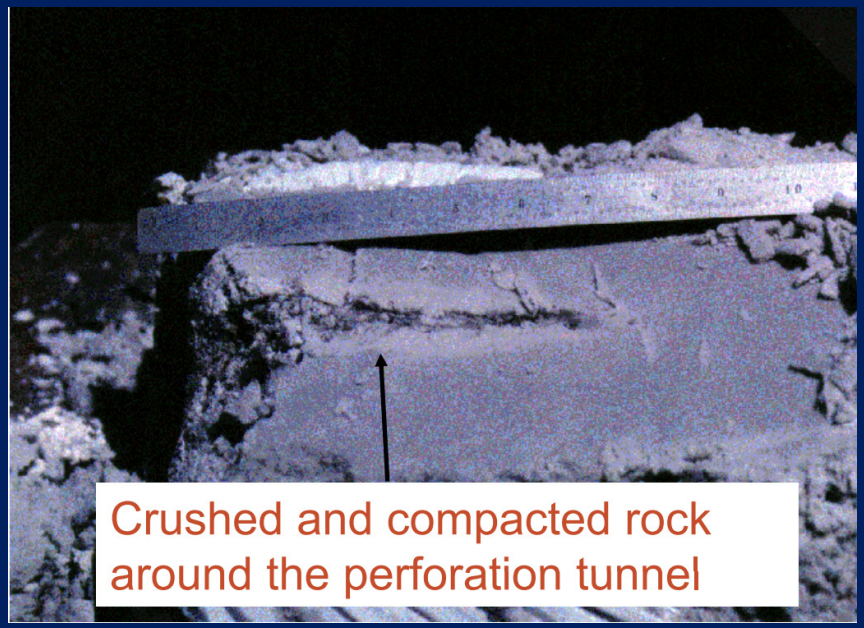
Figure 1—Example Concrete Target

- Back to the Section 1 Test
- Maximize Area Open to Flow (Square Inches/Foot) in Standard Casing Only
- Standard Casing is L-80 Grade, and thinner than most modern applications
- Extrapolation is used by software to predict down hole performance.

Perforation Geometry BH Charges

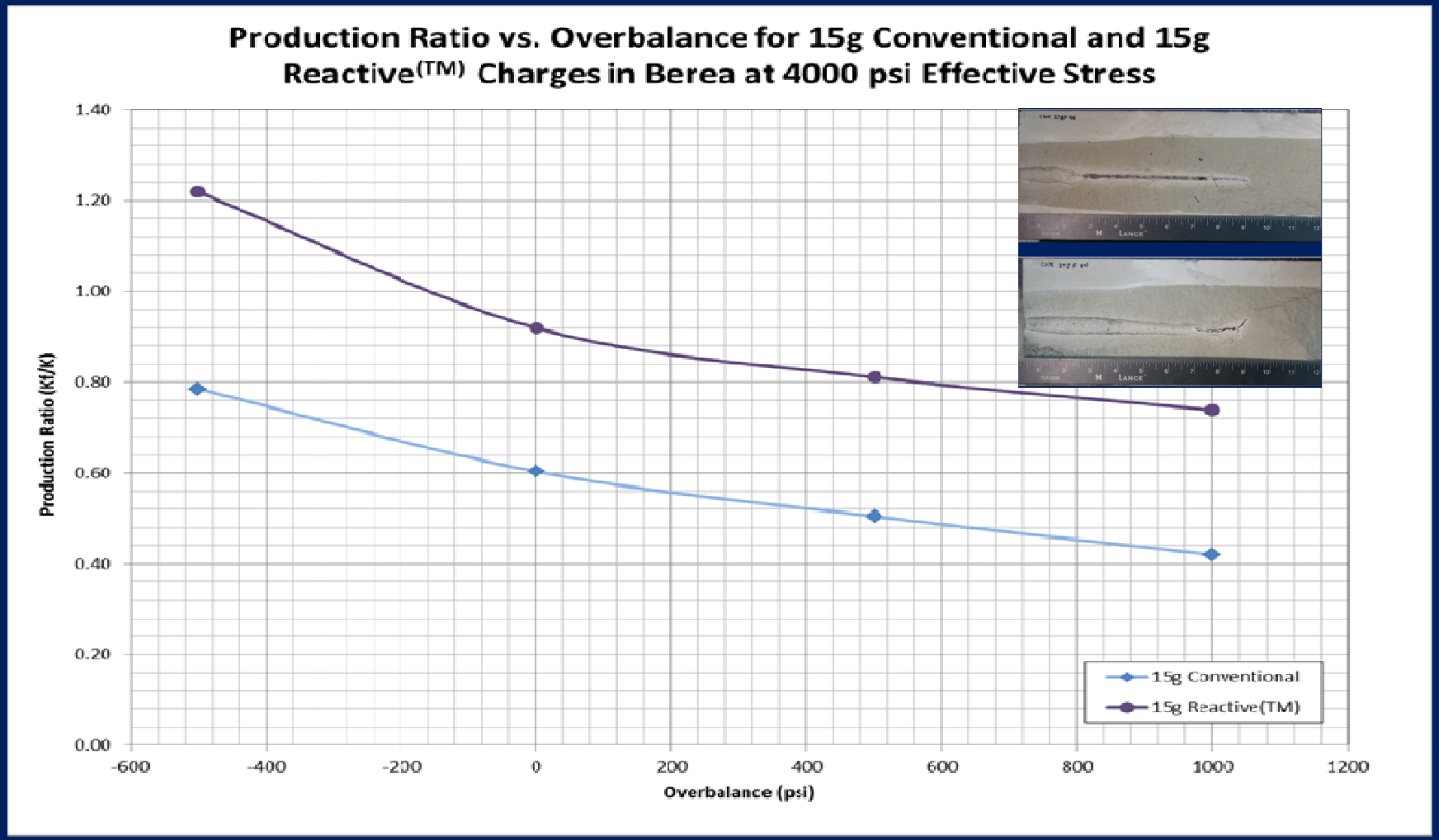
- Translation to Heavy Wall Casing is Design Dependent
  - In one instance heavy wall performance exceeds that in thin wall casing
- Design For Heavy Wall Casing
  - Publish performance in both standard casing and heavy wall casing
  - Two data point design allows for better prediction
  - Superior charges translate across all applications

Perforation Geometry BH Charges



- Affected area much larger in diameter than hole size
- Crushed sand can form an effective injection plug
- In lab, plug can be broken down, fluidized without fracture

Berea Sandstone Flow Performance



Laboratory Evaluation: Berea Sandstone

- Flow Performance is 55% to 76% superior to the conventional charge at every balance condition.
- Reactive Charge at 1000 psi overbalance performed equivalently to the conventional charge at 500 psi underbalance.
- With slight underbalance, the reactive perforation tunnel flow performance surpasses 1.0 Production Ratio.

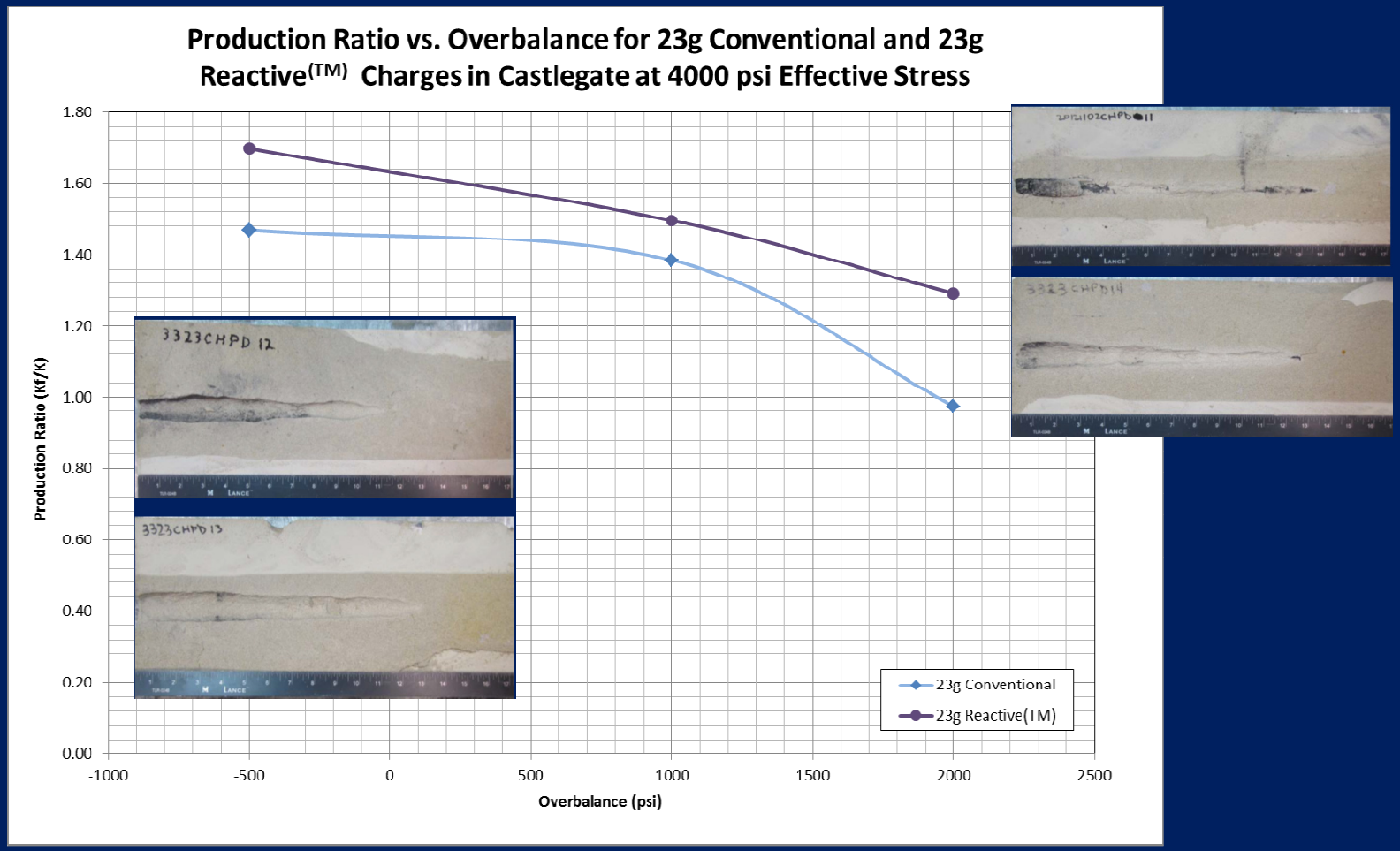
Field Applications • Shoot and Produce

- Wells in which no stimulation is required
- Success = increased productivity
- Bonus = reduced cost, complexity, risk
  - Eliminate underbalance, release rig (TCP to W/L)
- Examples:
  - Thailand • +50% initial productivity based on performance of appraisal wells perforated with premium system
  - Pakistan • 3x productivity of previous best-in-field well
  - North Sea • Equivalent productivity with 1 run vs. 3 runs

Field Applications • Re-Perforation

- Generally a tough task for perforators
  - Effective stress increases as reservoir pressure drops
  - Hard to apply underbalance with open perforations etc.
- Success = increased productivity
- Examples:
  - UK • 30x productivity after re-perforation (best in field)
  - USA • 10x productivity … more than 2x the increase seen re-perforating offset wells with conventional systems
  - USA • 10x increase in gas well production after re-perforation … already shot twice with premium DP system

Castlegate Sandstone Flow Performance



Laboratory Evaluation: Castlegate

- Flow Performance is 6% to 59% superior to the conventional charge at every balance condition.
- Optimized Reactive Charge provided a PR of 0.92 at overbalance condition.
- Conventional charge produced deeper tunnels, however reactive design produces cleaner perforations, with better side wall condition.

Field Applications • Low Strength Rock

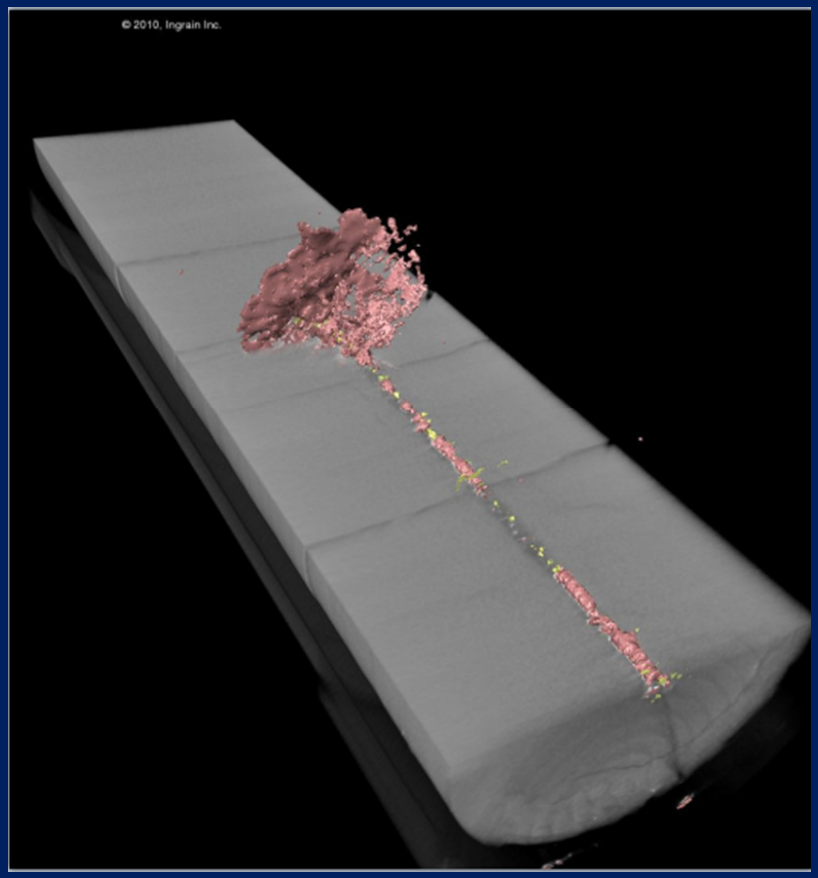
- Success = reduce TSS at same/higher rate due to greater number of open tunnels and reduced flux rate
- Example:
  - Oman • Well produced 2x gross liquids of comparable offsets but only 10% of the field average sand rate
  - North Sea • Excellent Performance on High Perm Injection Wells

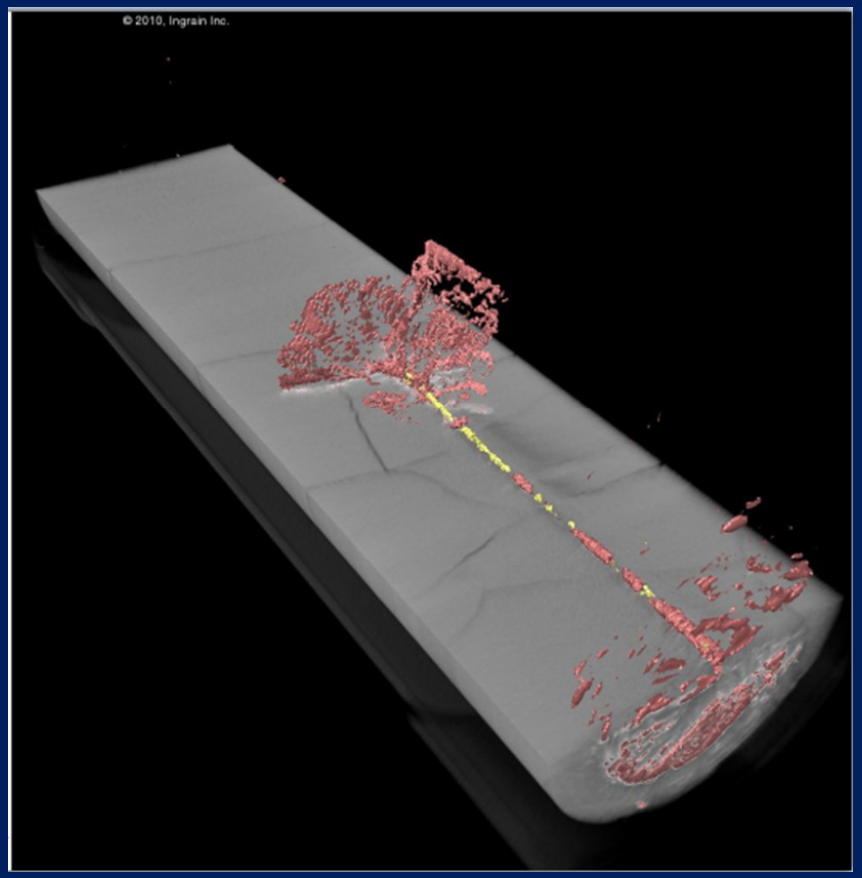
Matrix Acidizing
Reactive Charges-23 gm Load
Needs 1/6 of Acid to break through

Conventional

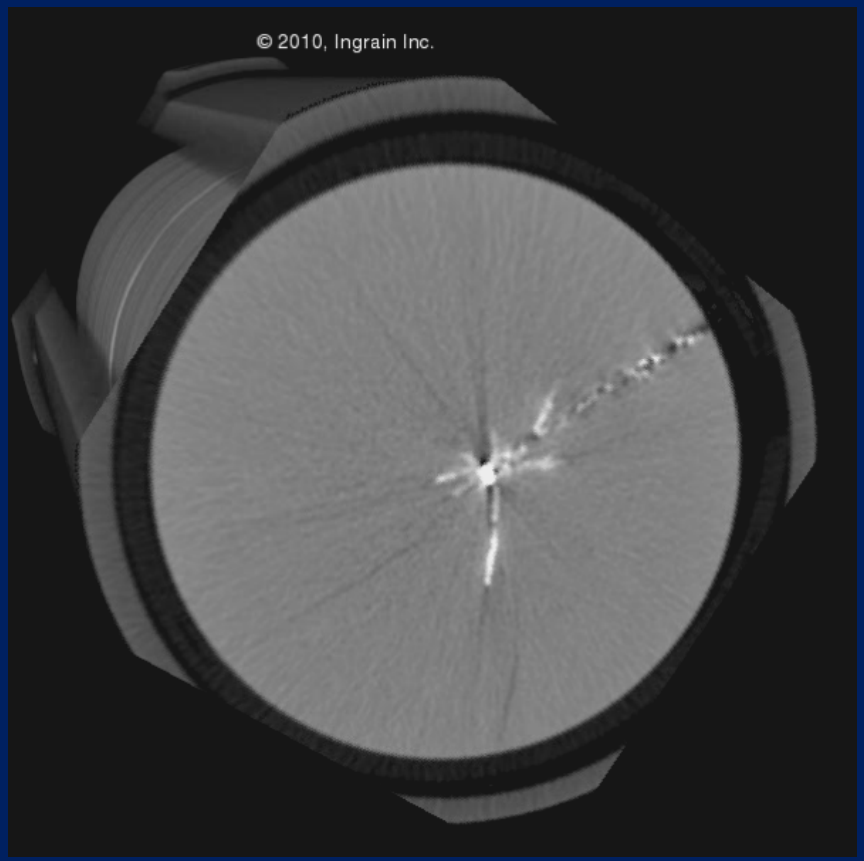
Reactive

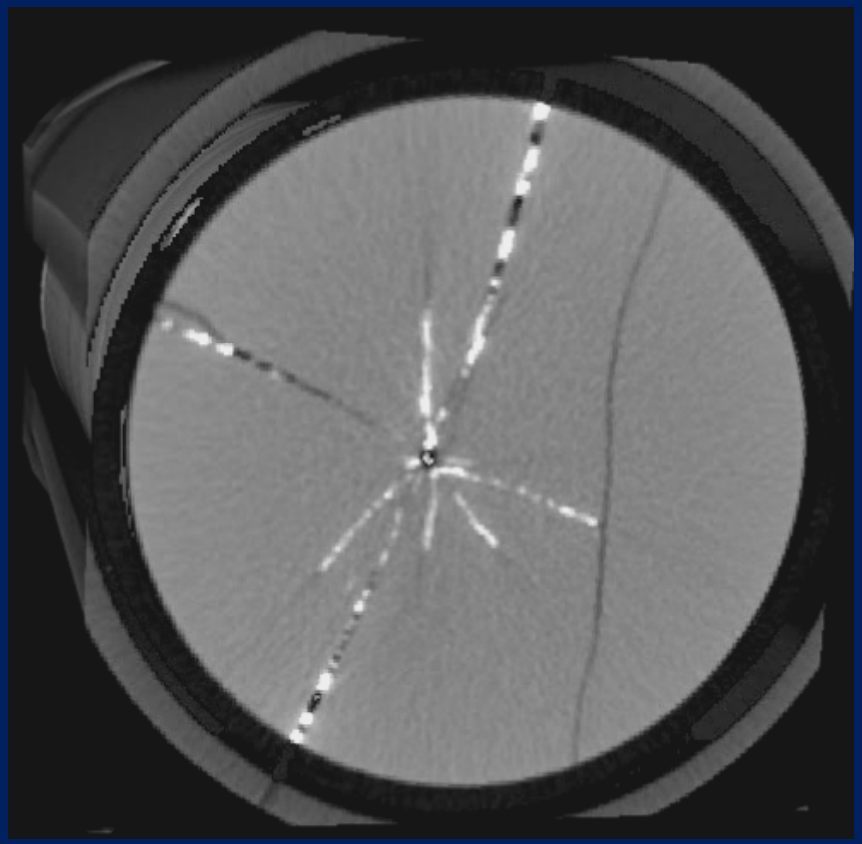
CT Scans, Mancos Shale, 23g XEH Charges



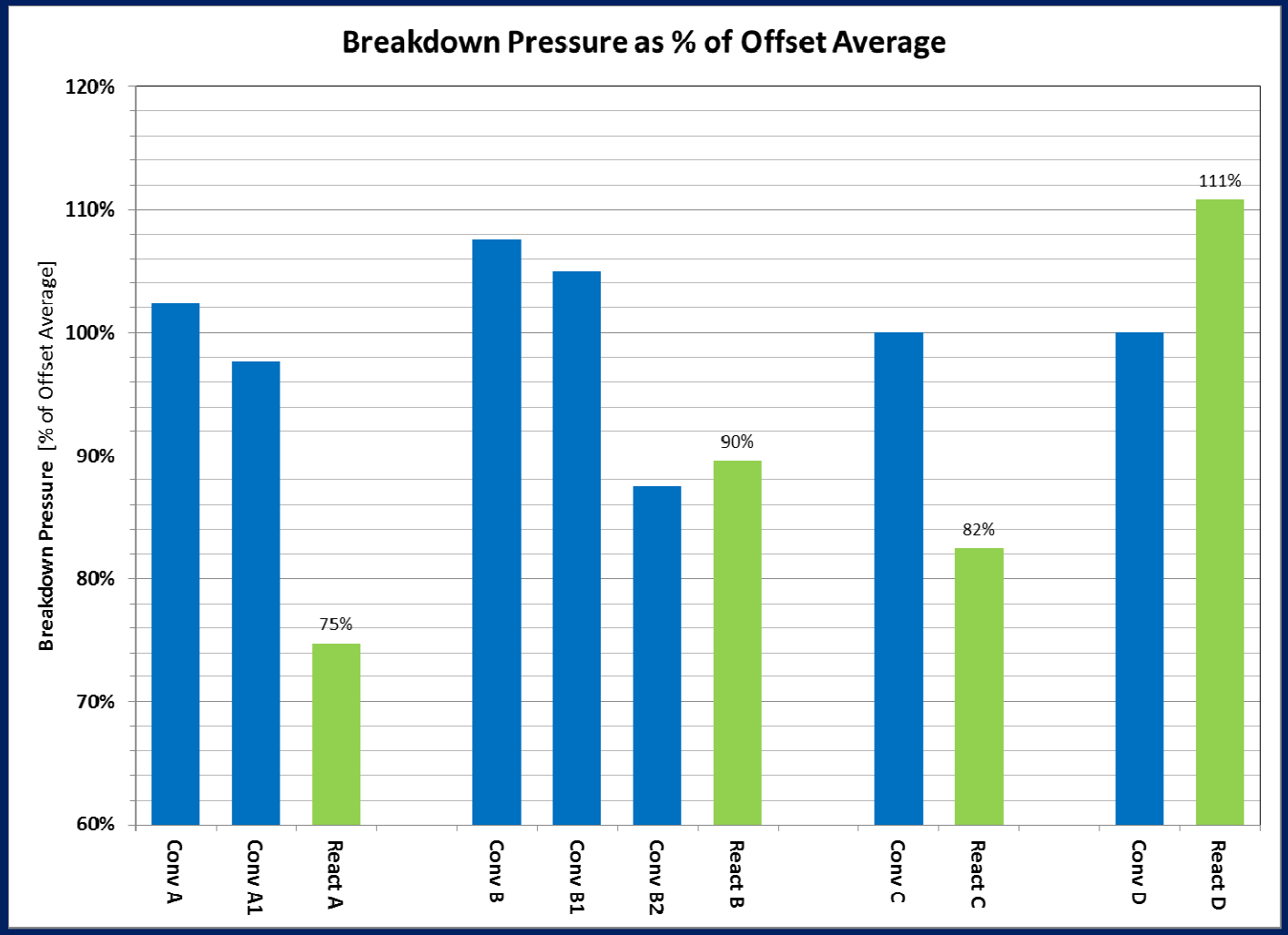


CT Scans, Mancos Shale, 23g XEH Charges

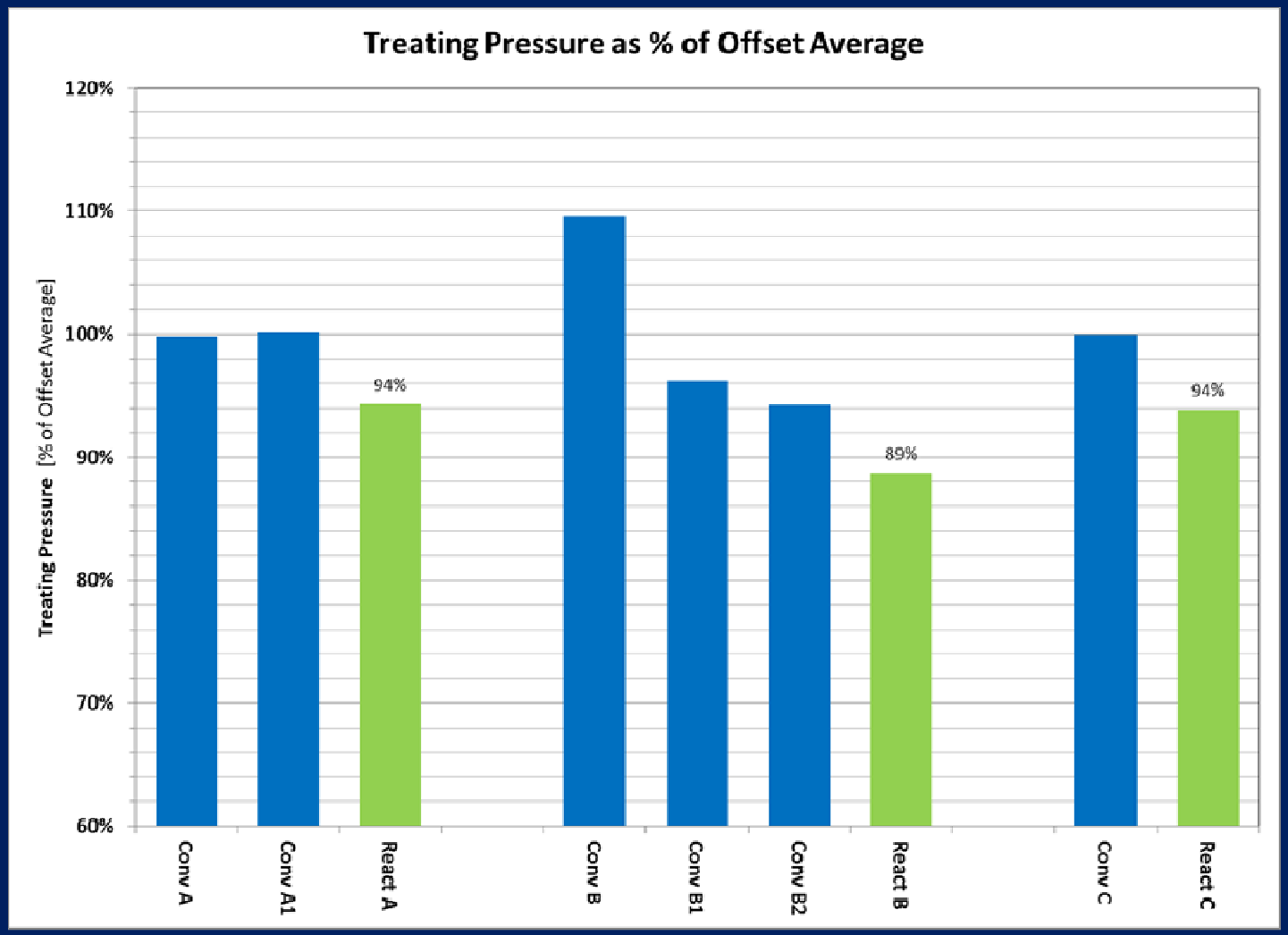




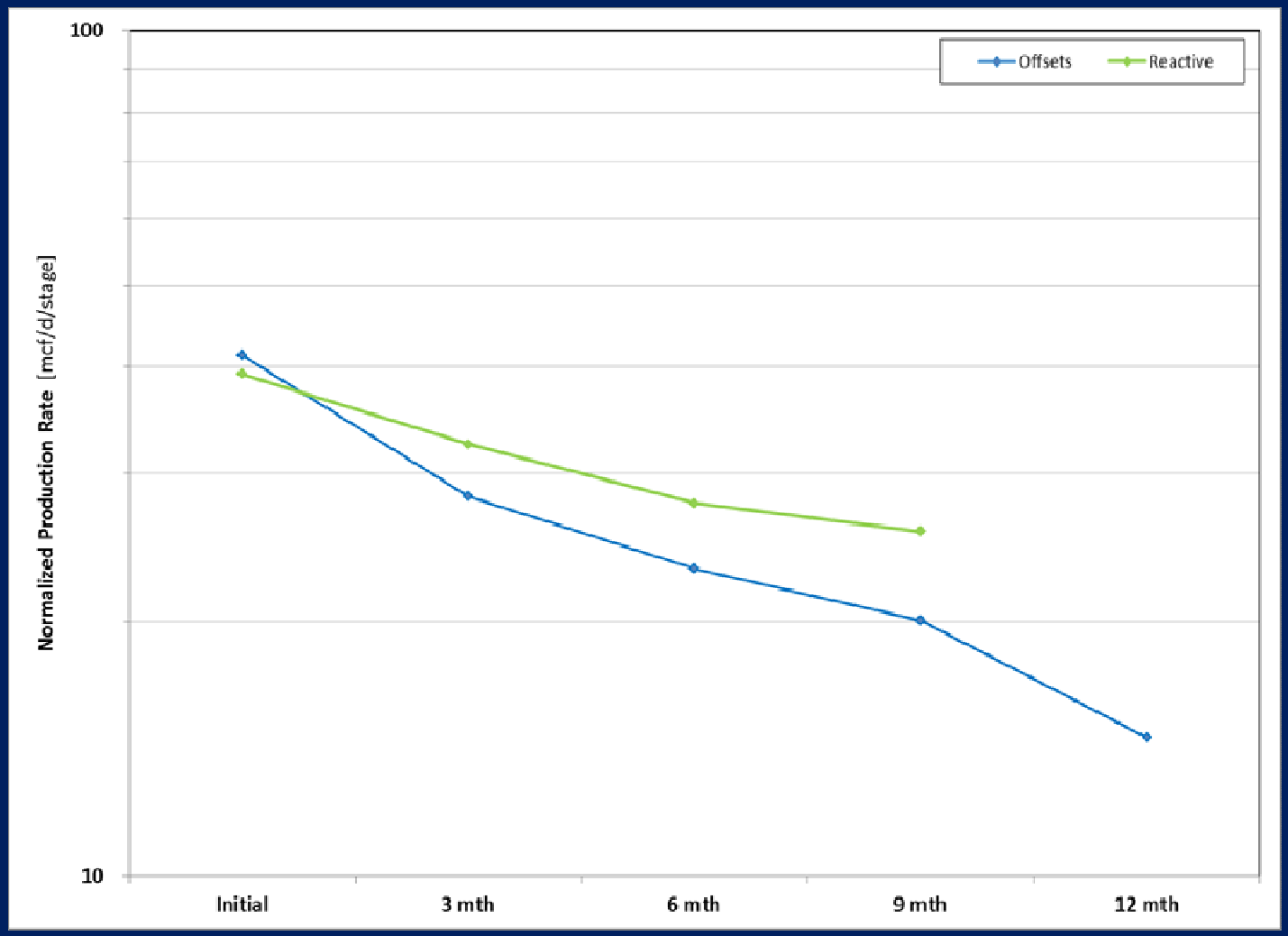
Field Results – Breakdown Pressure Red



Field Results – Treating Pressure Reduction



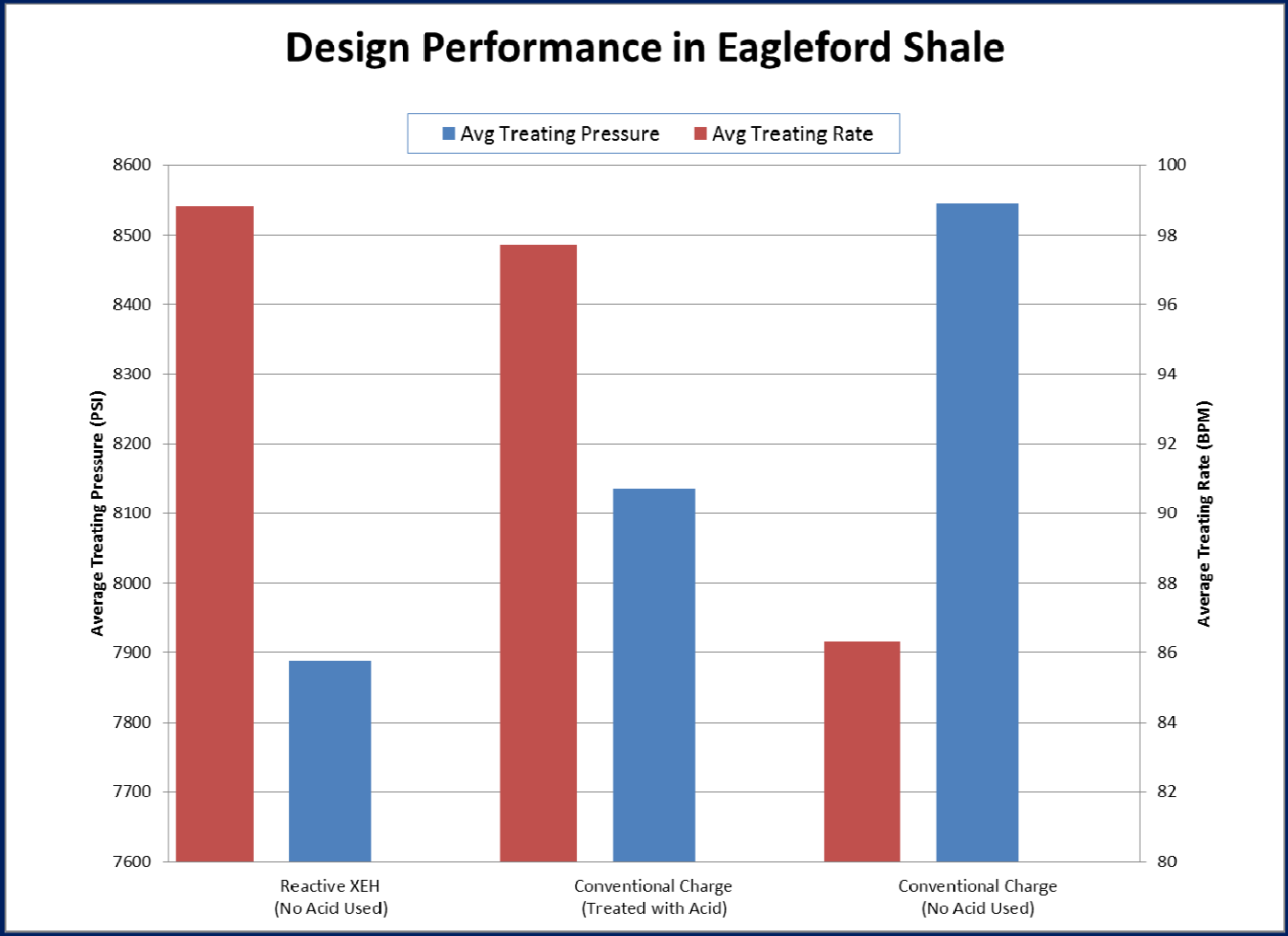
Field Results – Productivity Improvements



Field Results – Offset Comparison

- 4 Offset Groups
- 13% to 29% Reduction in Breakdown Pressure
- 6% to 15% Reduction in Treatment Pressure
- Improvement in Early Productivity Decline

Field Results: Eagleford Shale



Thank you!

For more: SPE144167, SPE 116226, SPE 122174, SPE 125901

John Hardesty

Principal Research Engineer, GEODynamics, Inc.

john.hardesty@perf.com