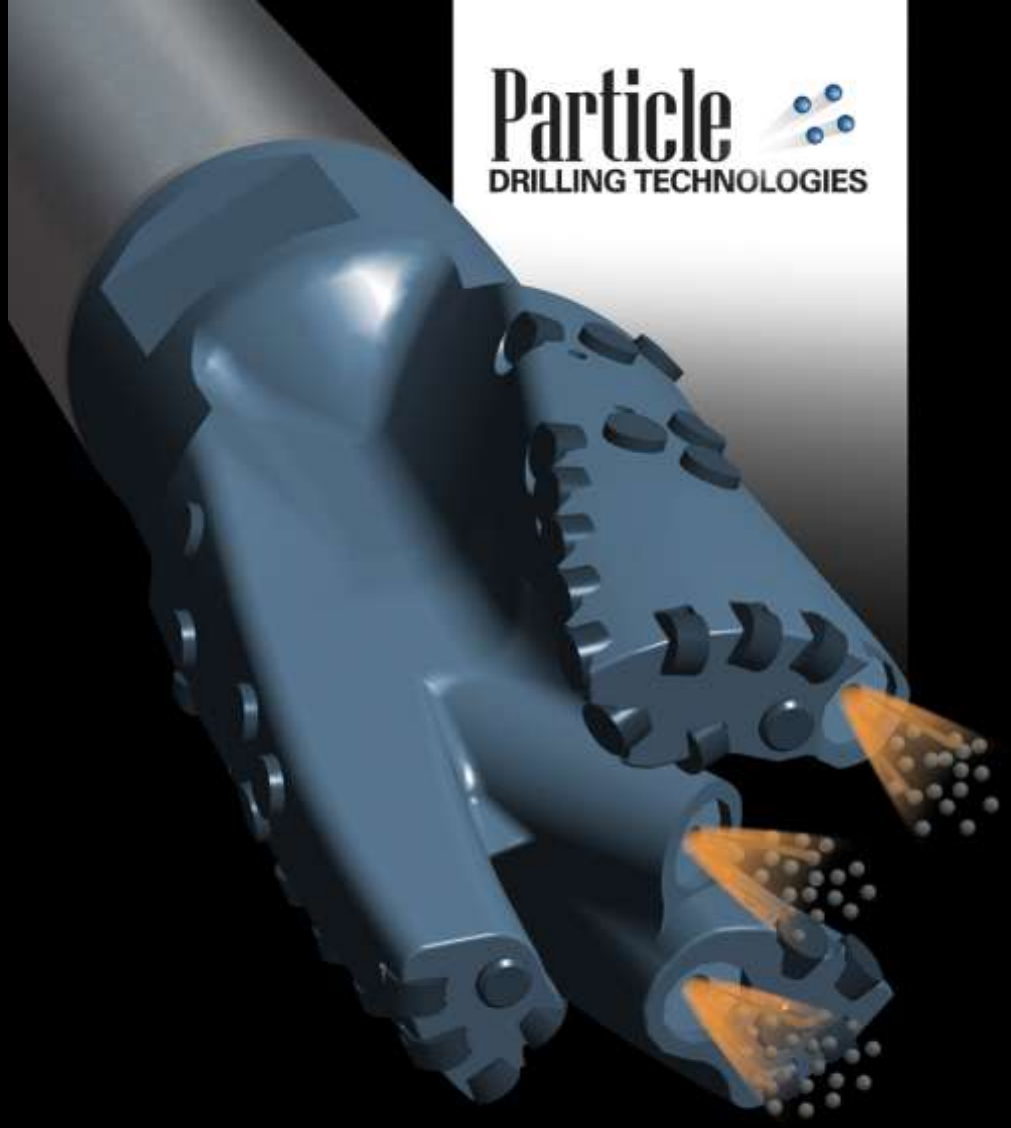


Particle Impact Drilling

Particle DRILLING TECHNOLOGIES

PDT Application Envelope

- Great Applications
  - Low daily footage due to:
    - Interbedded formations – hard to less hard or less hard to hard
      - Frequent trips for a bit “type” change
    - Hard rock (and/or) abrasive rock
    - Frequent trips for bit wear – short life
    - Anywhere Impreg Bits are run
    - Trouble maintaining verticality?
      - High WOB causing deviation
      - Formations dips or trends, crossing faults
      - Running motors or Rotary Steerable or VertiTrak or light weight
    - Drilling dynamics problems – Slip-Stick, Bit whirl
      - Poor BHA component reliability causing trips

Particle DRILLING TECHNOLOGIES

PDT Application Envelope

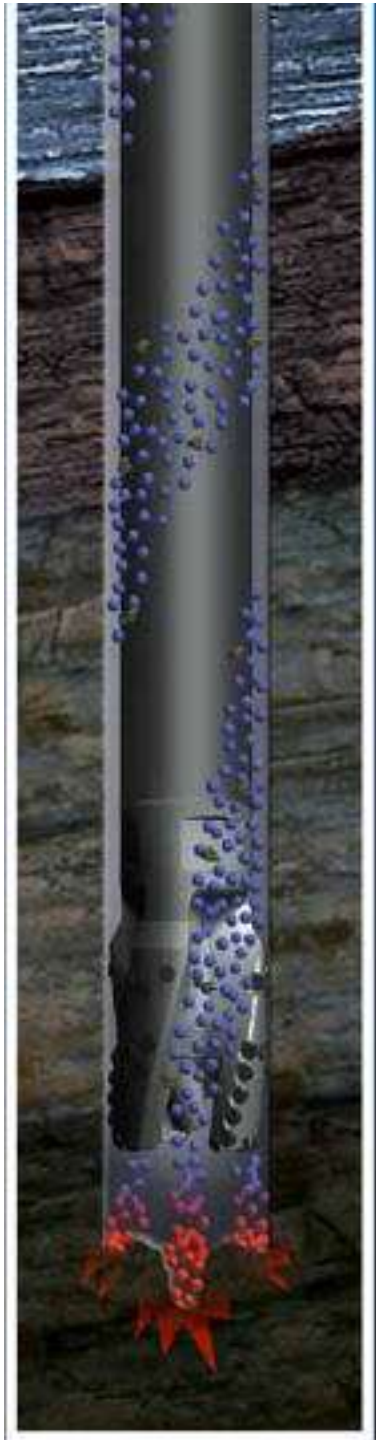
- Other Benefits to Consider
  - Will typically reduce drill string torque ~ 20%
  - Will reduce drill string wear in abrasive formations
  - Drills with no WOB or Torque at Bit
  - Will drill junk like lost cones
  - Will drill float and shoe equipment
  - The bit should last the entire interval
  - Works with any mud type with a YP > 16
- Other Factors to Consider
  - AV's are important returning shot to surface
  - Any LCM must be limited to shot sized additives
  - Flow line geometry can be important and may have to be jetted
  - Surface hydraulics must deliver 500 feet per second nozzle velocity

Particle
DRILLING TECHNOLOGIES

The Particle Impact Drilling system blasts away hard rock ahead of the bit with hardened steel particles which are accelerated through specially designed nozzles.

Drilling tests in Sierra White Granite show the rock is removed three to six inches ahead of the bit.

Zero weight on bit is required to achieve these results.



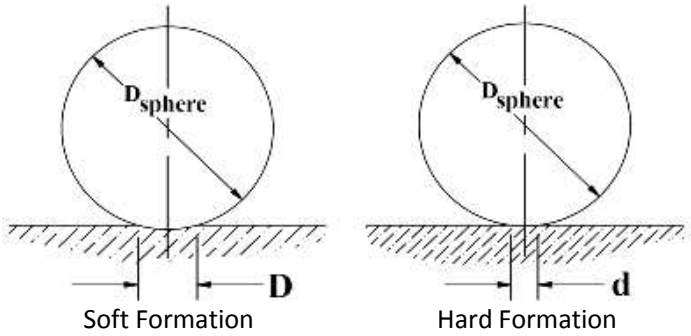
Particle Impact Drilling: The Science

The Particle Impact Drilling (PID) System:

- MV^2 - Mass Times Velocity Squared
- Removes hard rock by blasting it away with hardened steel particles entrained in the drilling fluid
  - Steel particles accelerate through the PID bit nozzles
    - Impacting the hard rock ~12 Million times per minute at 500 ft/sec nozzle velocity
  - The volume of steel particles required is relatively small at only 2-3% of total fluid volume

Particle Impact Drilling: Why It Works

- Particle impact force acts over the area of contact between the shot and the rock as shown below. This area is quite small because hard rock does not deform readily nor does the steel shot. As an example; assume the contact area based on a contact radius of 0.010" thereby yielding a contact area of 0.00008 square inches. A force of only 65 pounds is required to generate a 830,000 psi contact stress



- **Contact Area is a function of diameter squared: d^2**

$$AD >> Ad \qquad \frac{\pi D^2}{4} >> \frac{\pi d^2}{4}$$

- **Fracture propagation easier in harder material (higher comp strength = lower strain to failure)**
- **Contact stress is much greater in higher strength materials**
- **Smaller contact area and higher force due to a reduced time of contact**

Particle
DRILLING TECHNOLOGIES

PID Bits

Each bit diameter goes through rigorous testing to establish the optimum nozzle pattern for removing 100% of the formation in each hole size.

Test Bits

8-1/2” Bit Diameter

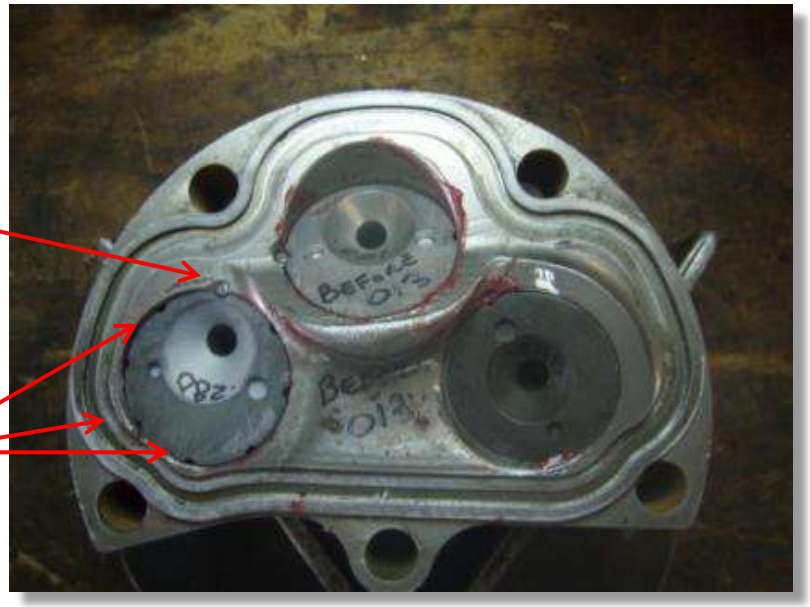
- Delivery System for Steel Particles
- Nozzles and Nozzle Protectors on Face
- No Formation Cutting Structures (PDC’s)
- Used for drilling test patterns to assure full bottom hole coverage of impacting particles
- Two-piece body design allows for multiple nozzle angle configuration changes with short turn-around time between tests

Test Bits

- Several unique nozzle types for particle impact pattern testing
  - Straight
  - Various Angled Bore Nozzles
  - Straight Off-Center
- Test nozzles have grooves around the diameter
- Clocking pins allow for rotation to change the impingement location

Allows for thousands of potential nozzle configurations in a single test apparatus

6” Diameter External Nozzle View



6” Diameter Internal Nozzle View

Nozzle Alignment

Multiple tests are run with varied nozzle configurations until drilling tests show that 100% of the formation is being removed by the steel particles.

Based on hole size, the bit can now be manufactured with a definitive nozzle placement that assures all rock is being removed and hole diameter is being cut to gauge or just over gauge.

No weight on bit is run during drilling

Sierra White Granite 30,000 psi

Particle DRILLING TECHNOLOGIES

New Bit Sizes

Bit Size	# Nozzles
9 7/8	5 and 6
8 ¾	4
8 ½	4
6 ½	3
6	3

Progression of PID Surface Equipment

Catoosa – July '05

Components of the Hydraulic "frac pump" Injector System

Improved PID #1 – Feb '06

PID #1 at Gasco – April '06

PID #2 at EnCana – Sept '08

Particle DRILLING TECHNOLOGIES

Footprint

Fully Automated With Independent Power Generation Unit

Particle DRILLING TECHNOLOGIES

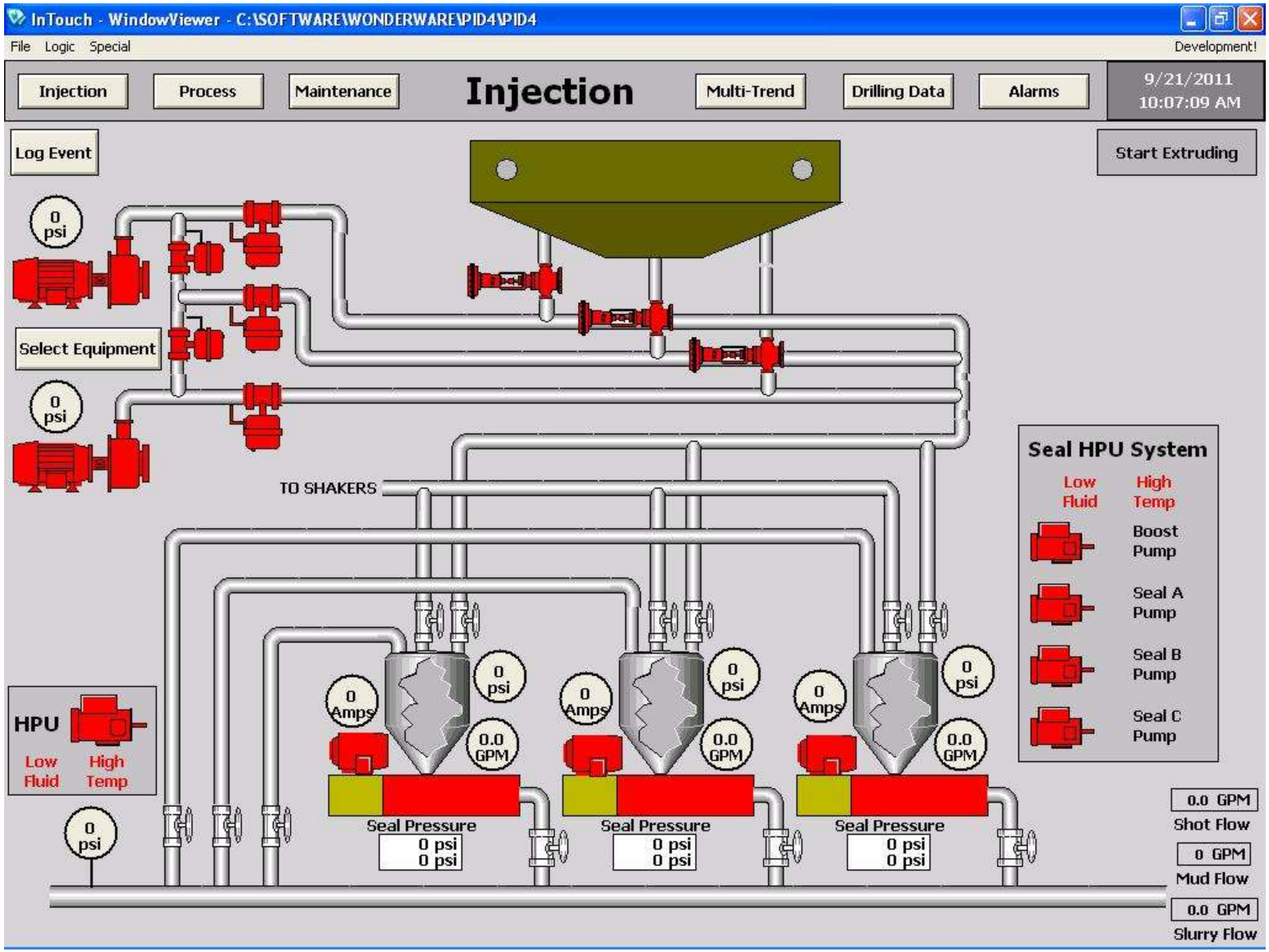
Particle Injection Unit

Self-contained “Plug and Play” design allows for rig up in a matter of hours

Redundancy on primary components for added reliability

Particle DRILLING TECHNOLOGIES

Particle Injection Control System



Particle Injection Unit

Out to standpipe with particle entrained fluid

In from mud pumps with drilling fluid

A three valve manifold is located between the mud pumps and standpipe so that the system can be isolated from the rig circulating system. One line into the particle injection unit and one line out.

Three Valve Manifold

Particle Injection Unit can be easily isolated from drilling rig in a matter of minutes.

Particle Injection Unit

Particle
DRILLING TECHNOLOGIES

Particle Injection Unit

The Extruder loads a precisely controlled volume of particles into the drilling fluid

Particle Injection Unit

Extruder Valve Manifold

5” Manifold includes

- 4” Mud line in
- 4-1/16” ID skirted gate valve below each extruder
- 4” Mud Line to Standpipe
- Mud line Manifold 3 valves and 2 Tee’s

Particle Extractor / Recovery Unit

Mud from the flow line is diverted to the large diameter extractor where velocity is reduced and steel particles are separated and pumped to the process unit

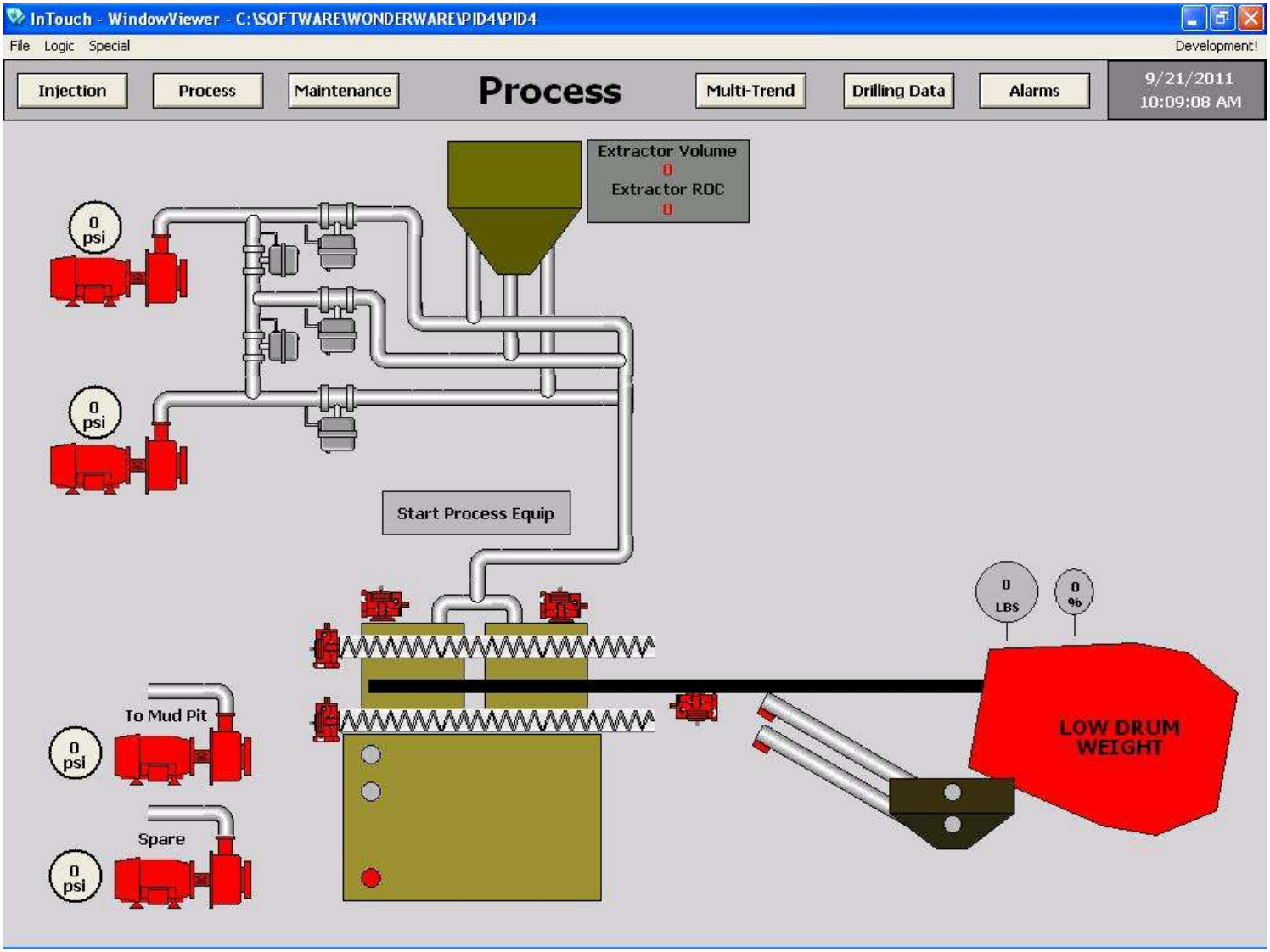
* Used only in cases where gas is present to prevent particles from flowing to gas buster

Particle DRILLING TECHNOLOGIES

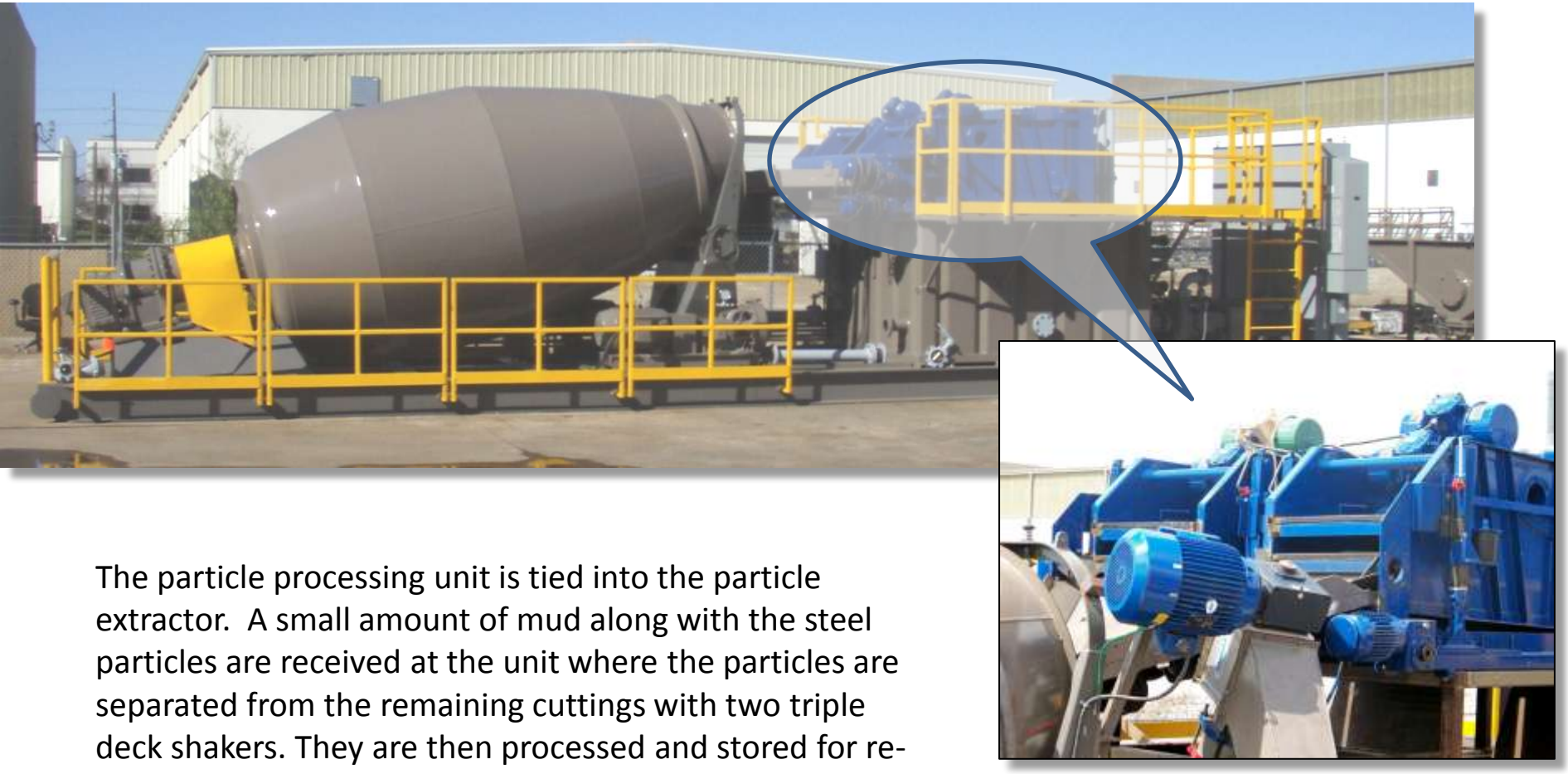
Particle Processing Unit

- 96,000 lb. drum capacity (keeps shot agitated)
- Load Pin Rollers front and rear
- Integral Motive Pumps
- Particle Hopper (not shown)
- Tandem Triple Deck Shakers
- Collapsible Cat Walks
- Control Panel Integral

Process System Control



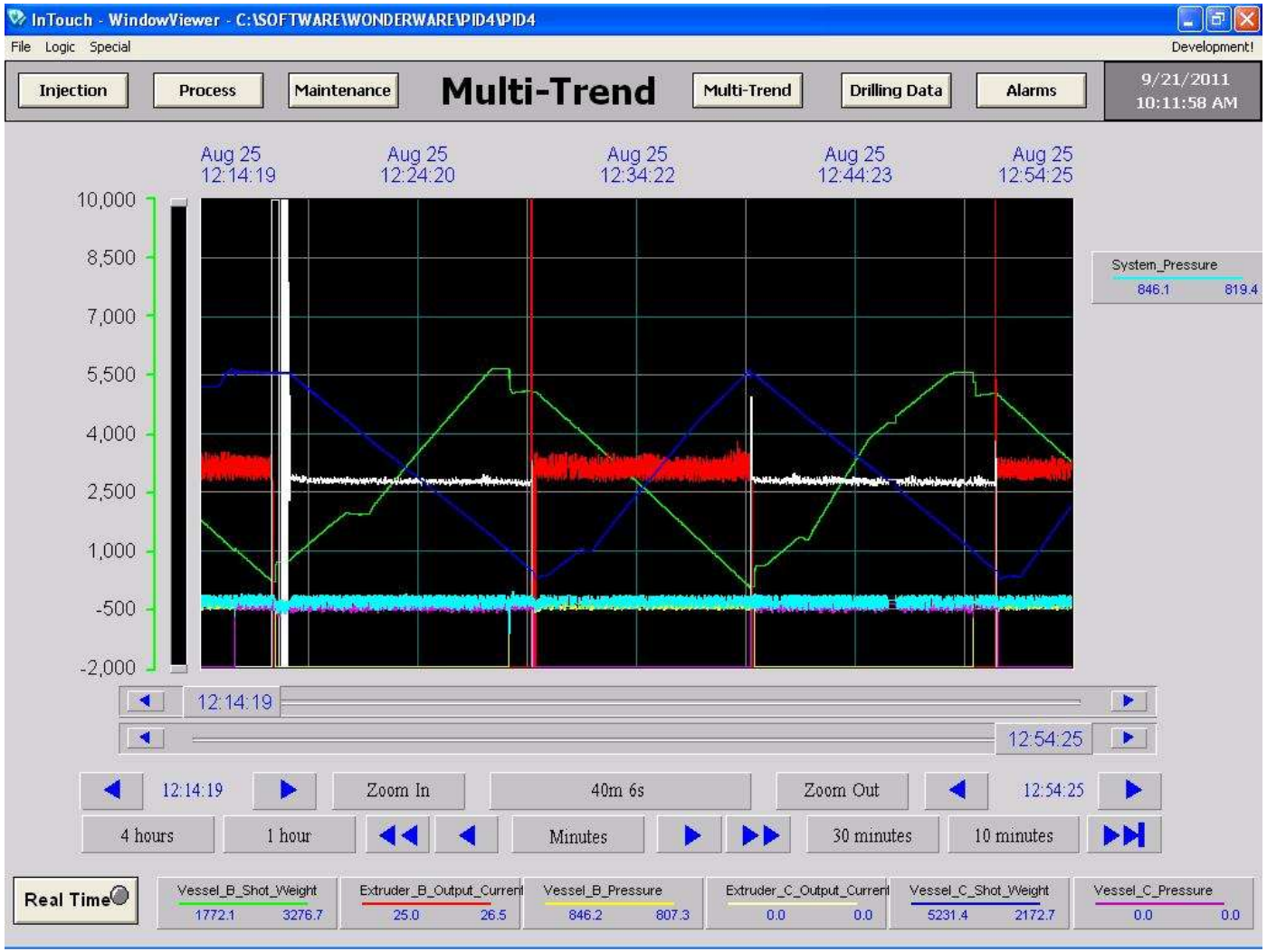
Particle Processing Unit



The particle processing unit is tied into the particle extractor. A small amount of mud along with the steel particles are received at the unit where the particles are separated from the remaining cuttings with two triple deck shakers. They are then processed and stored for re-circulation into the system.

Particle DRILLING TECHNOLOGIES

We Track and Monitor All Trends



Particle DRILLING TECHNOLOGIES

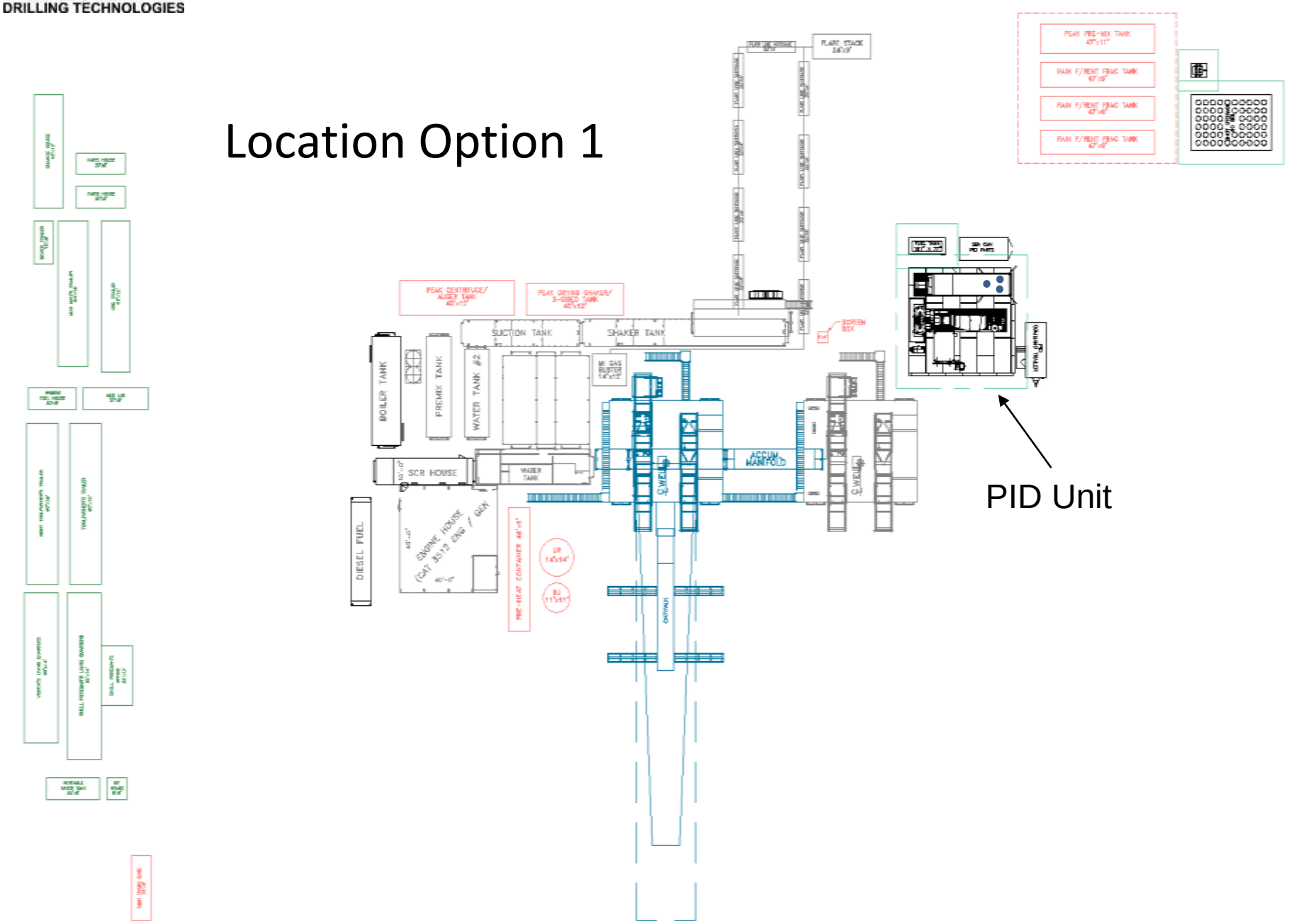
Extensive 24 Hour Testing

Gallons	194,710
Hours	229
Shot Weight - Lbs./Gallon	38.4
Total Pounds Injected	7,476,864
Drum Capacity	95,000
Drum Turns	79
Maximum Shot Rate	21
Average shot Rate	14.1

Assumed ROP	50
Extrapolated Footage Drilled	11,450

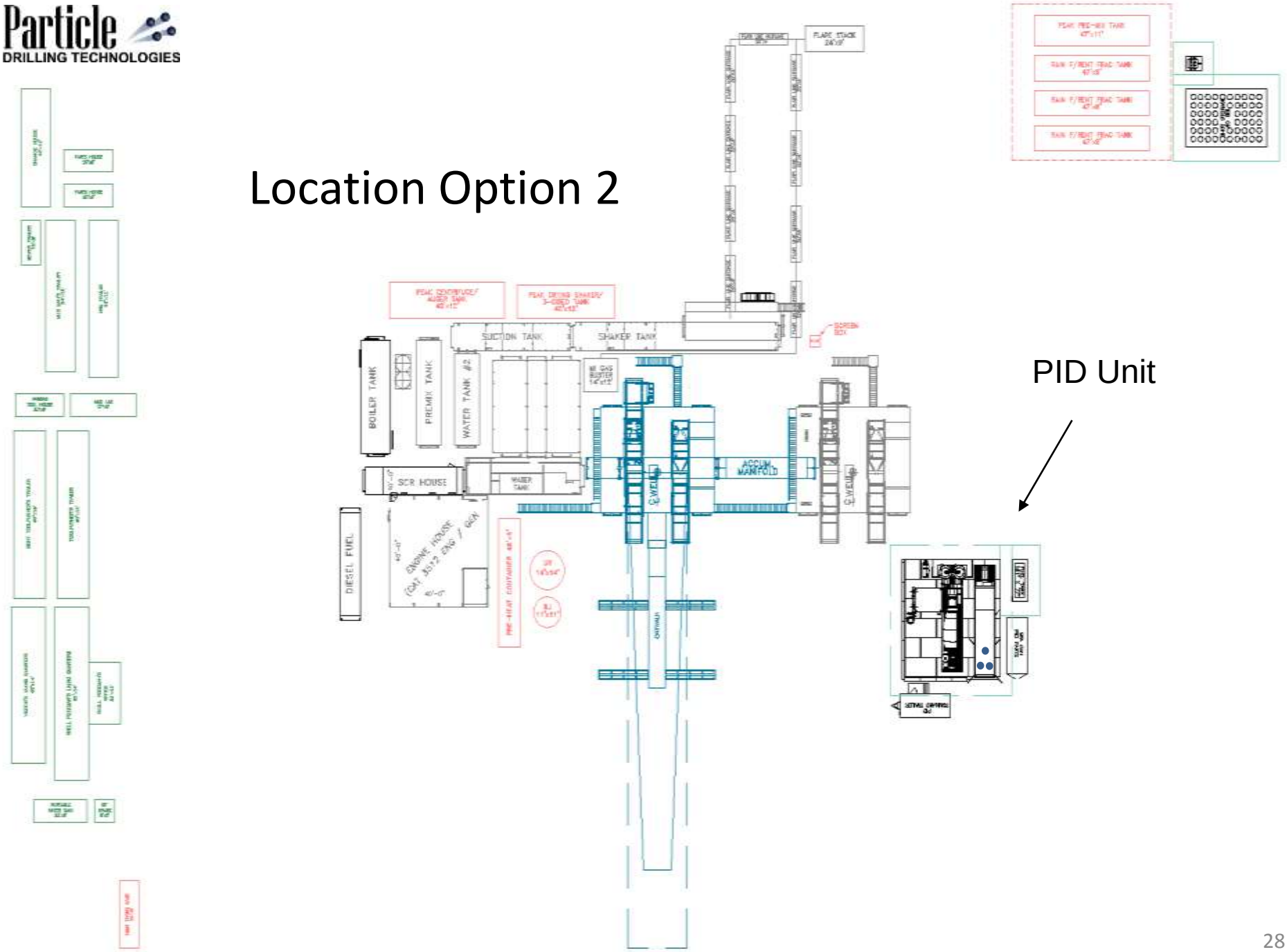
Particle
DRILLING TECHNOLOGIES

Location Option 1



Particle
DRILLING TECHNOLOGIES

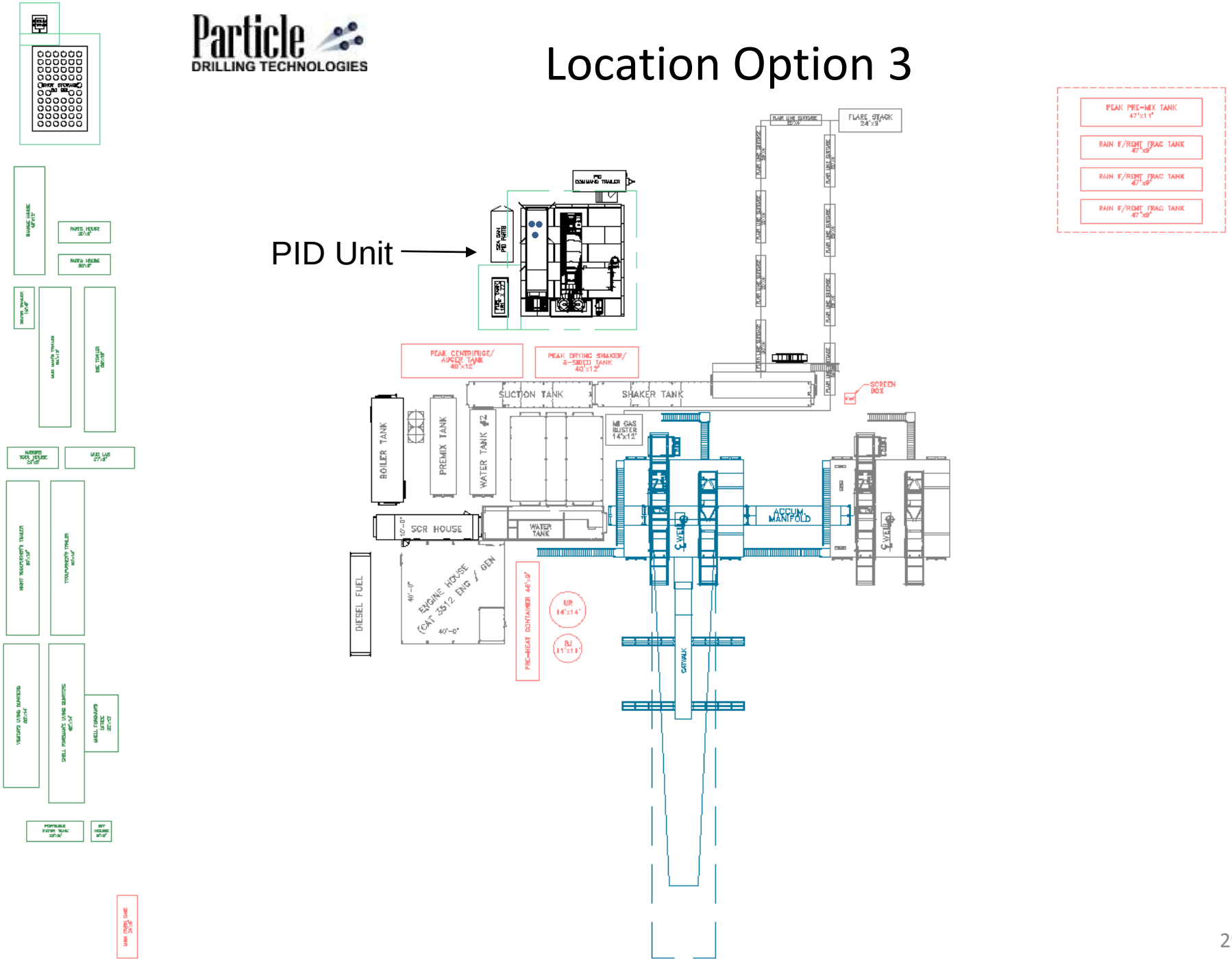
Location Option 2



PID Unit

Particle DRILLING TECHNOLOGIES

Location Option 3



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