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Application of Fiber Optic Technology for Well and Reservoir Management

(An Introduction to FO in the O&G Business)

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SPE Production & Operations Technical Committee

February 26th 2015

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Outline

- Introduction to Fiber Optics Sensing & Deployment
- Fiber Optics Applications Overview
- Application into Frac Diagnostics
- Fiber Durability and Survivability
- Data Challenges
- Closing Remarks & References

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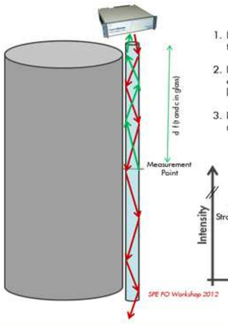
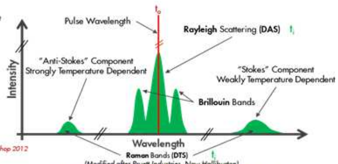
Fiber Optic Sensing & Deployment

Introduction to Fiber Optic Sensing



FO MEARURING STEPS

1. Interrogation box generated a light pulse that travels down the fiber at the speed of light in glass.
2. Local conditions at the different measuring points (MPs) such as temperature and pressure affect the glass changing its light transmission characteristics.
3. Light pulse with modulated signal is backscattered and recorded at interrogation box .

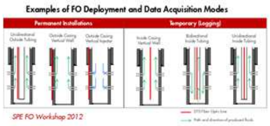


(Modified after Pruett Industries, Now Halliburton)

A DTS Primer for Oil & Gas Production Smolen J. and van der Spek A. 2003

FO Placement & Deployment

Examples of FO Deployment and Data Acquisition Modes



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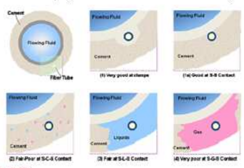
Thermal Coupling Scenario – FO Cables Cemented Behind Casing

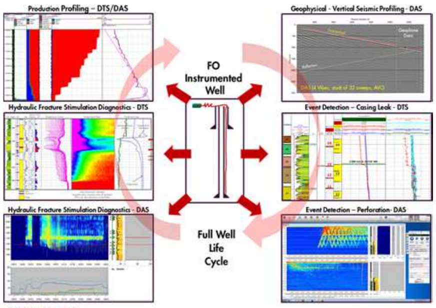


SPE 116182

- FO can be deployed in many different ways:
  - **Permanent**
    - Behind casing or outside tubing.
    - Continuous or episodal interrogation
  - **Temporary (logging)**
    - Wireline or coil tubing.
- FO placement is also important.
  - Certain applications require a particular type of fiber placement (for example: cemented behind casing deployment are required for frac diagnostics).
  - The quality of deployment can impact interpretation (for example: observed variation in thermal coupling for FO deployed behind casing can made DTS during HFS "noisy"). Sierra J. et. al. 2008 (**SPE 116182**)

Applications

FO Applications (*One FO Installation – Many Applications*)



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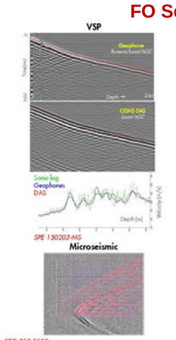
FO Seismic Applications

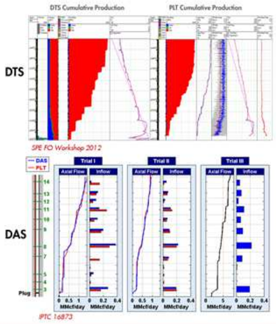


SPE 150203-MS

SEG-213-0182

- Koelman J.M.V.A. et. al. 2011 (**SPE 150203**) FO Geophysical Applications (VSP from DAS):
  - Comparison geophones, DAS and logs. Data clearly show first arrival and reflections and good similarity between log, geophones and DAS recorded velocities .
- Webster P. et. al. 2013 (**SEG-2103-0182**) Microseismic from DAS:
  - Comparison of microseismic event recorded via DAS (grey background) and geophones (red wiggles)
- Although DAS measurement might not reach the sensitivity and fidelity of state-of-art geophones, the low cost, simplicity and non-intrusiveness of FO "fit-for-purpose" geophysical application may still play important role in well reservoirs surveillance

FO Production Profiling Applications (Understanding Flow)



- DAS and DTS can be evaluated to determine production at the stage and PC level for single phase gas flow
  - DTS vs PLT comparison (Upper left)
  - DAS vs PLT comparison (Lower left)
- Although not identical FO results are comparable.
- van der Horst J. et. al. 2013 (**ICPT 16873**) FO production profiling advantages:
  - No subsequent well intervention is required to collect the data.
  - FO allows to observed production continuously and survey the entire well at the same time.
  - FO also provide a cost effective way to collect production data in some wells (when well configuration made acquisition difficult or cost prohibited (For example in Hz wells or after installing tubing)

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Application into Frac Diagnostics

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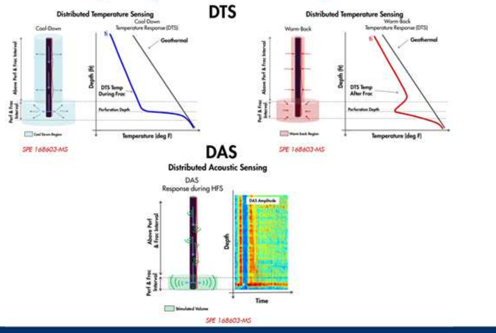
FO (DAS & DTS) Interpretation Basics: Hydraulic Fracturing



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DTS Movie

(vertical well)

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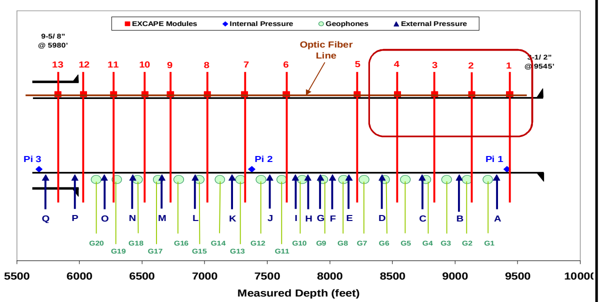
Horizontal Well Stimulation Diagnostics - SPE 118831

Barnett Shale Horizontal Instrumentation



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DTS Movie
(Horizontal well SPE 118831)

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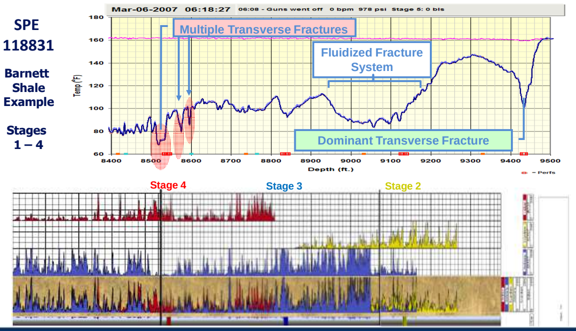
OF DTS Characterizes Stimulation Domain Variability

SPE 118831

Barnett Shale Example

Stages 1 – 4



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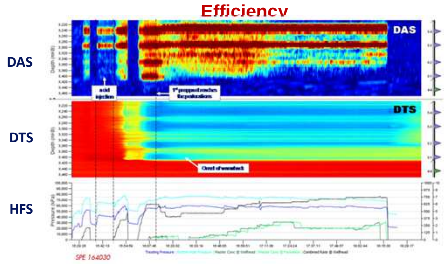
FO Frac Diagnostics: Stage and Perforation Cluster Efficiency



- Molenaar M. et. al. (2013) **SPE 164030**
  - Integration of DAS, DTS and HFS treatment data allow for a detail analysis of the stage and perforation clusters results on a CPnP Limited Entry completion in a horizontal well

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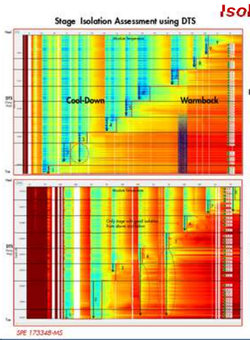
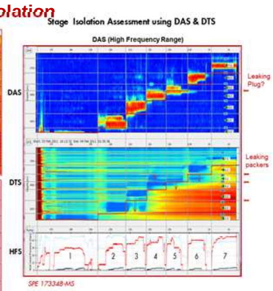
FO Frac Diagnostics: Stage and Perforation Cluster Isolation





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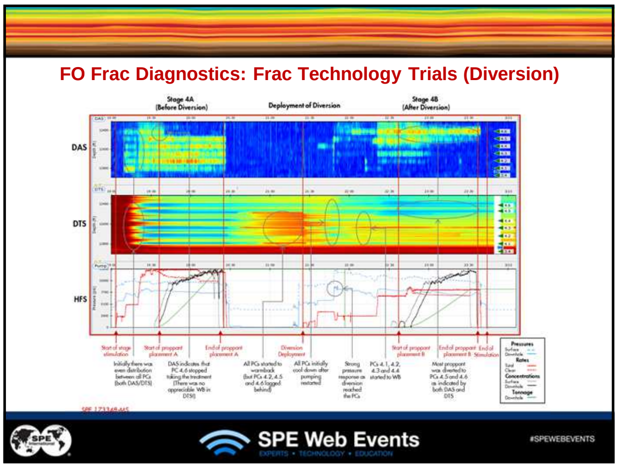
FO Frac Diagnostics: Frac Technology Trials (Diversion)
Stage 4A (Before Diversion)
Deployment of Diversion
Stage 4B (After Diversion)
DAS
DTS
HFS
Start of stage stimulation
Start of proppant placement A
End of proppant placement A
Diversion Deployment
Start of proppant placement B
End of proppant placement B
End of Stimulation
Initially there was even distribution between all PCs (both DAS/DTS)
DAS indicates that PC 4.6 stopped taking the treatment (There was no appreciable WB in DTS)
All PCs started to warmback (but PCs 4.2, 4.5 and 4.6 lagged behind)
All PCs initially cool down after pumping restarted
Strong pressure response as diversion reached the PCs
PCs 4.1, 4.2, 4.3 and 4.4 started to WB
Most proppant was diverted to PCs 4.5 and 4.6 as indicated by both DAS and DTS
Pressures
Rates
Concentrations
Tonnage
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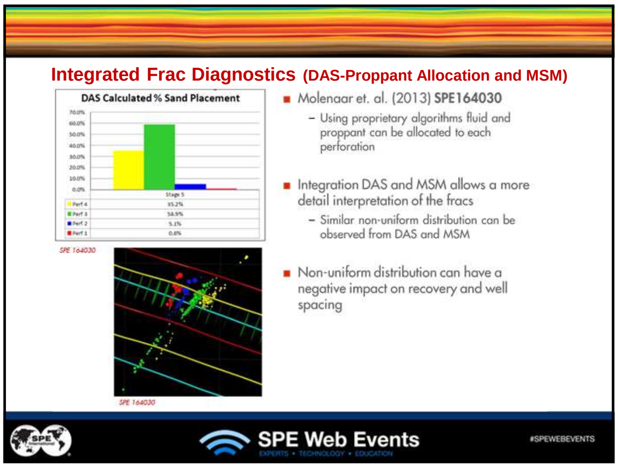
Integrated Frac Diagnostics (DAS-Proppant Allocation and MSM)
DAS Calculated % Sand Placement
Stage 5
Perf 4 35.2%
Perf 3 58.9%
Perf 2 5.1%
Perf 1 0.8%
SPE 164030
SPE 164030
Molenaar et. al. (2013) SPE164030
– Using proprietary algorithms fluid and proppant can be allocated to each perforation
Integration DAS and MSM allows a more detail interpretation of the fracs
– Similar non-uniform distribution can be observed from DAS and MSM
Non-uniform distribution can have a negative impact on recovery and well spacing
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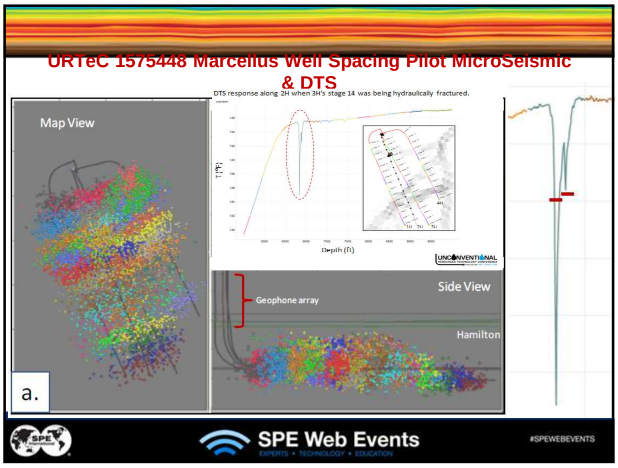
URTeC 1575448 Marcellus Well Spacing Pilot MicroSeismic & DTS
DTS response along 2H when 3H's stage 14 was being hydraulically fractured.
T (°F)
Depth (ft)
1H 2H 3H 4H
UNCONVENTIONAL RESOURCES TECHNOLOGY CONFERENCE
Map View
Side View
Geophone array
Hamilton
a.
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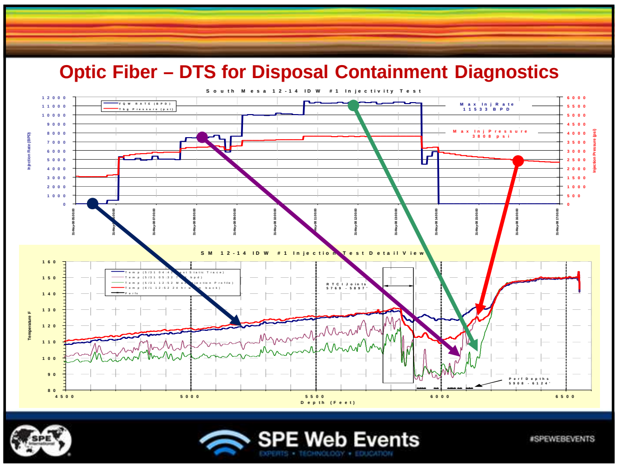
Optic Fiber – DTS for Disposal Containment Diagnostics
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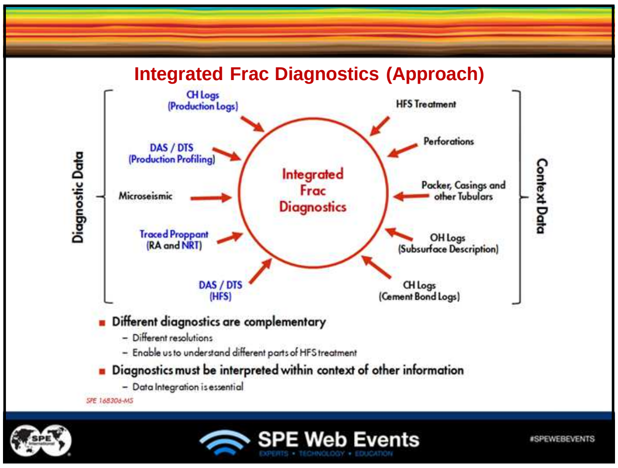
Integrated Frac Diagnostics (Approach)
Diagnostic Data
Context Data
CH Logs (Production Logs)
HFS Treatment
DAS / DTS (Production Profiling)
Perforations
Microseismic
Integrated Frac Diagnostics
Packer, Casings and other Tubulars
Traced Proppant (RA and NRT)
OH Logs (Subsurface Description)
DAS / DTS (HFS)
CH Logs (Cement Bond Logs)
Different diagnostics are complementary
Different resolutions
Enable us to understand different parts of HFS treatment
Diagnostics must be interpreted within context of other information
Data Integration is essential
SPE 168306-MS
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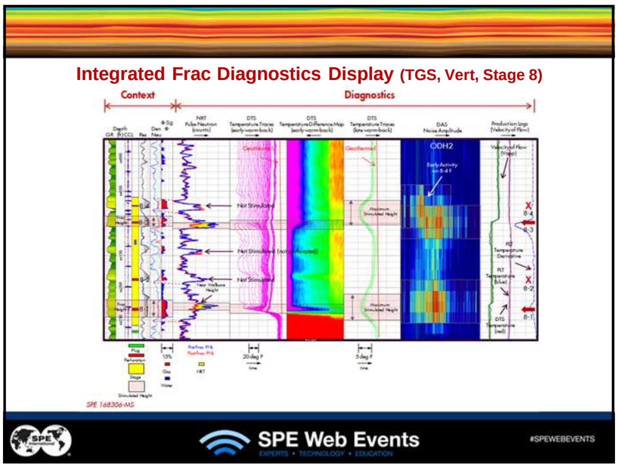
Integrated Frac Diagnostics Display (TGS, Vert, Stage 8)
Context
Diagnostics
SPE 168306-MS
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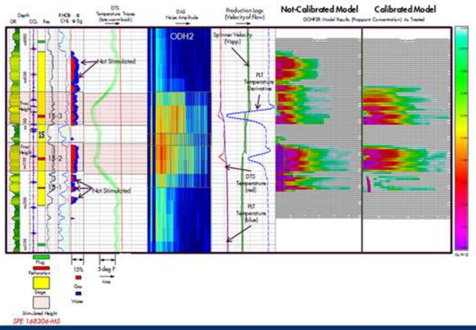
Integrated Frac Diagnostics and Modeling (TGS, Vert, Stage 15)



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Durability & Survivability

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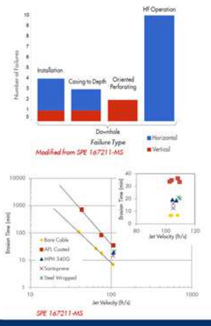
FO Failures – Onshore Installations



- Kate Bateman et.al. (2013) **SPE 167211-MS**
- Large dataset (35 installations since 2005)
  - 85% collected information during hydraulic fracturing
  - Only 35% survived to gather production data
- Four downhole failures modes:
  - Installation / Casing to Depth / Orienting Perforating & Hydraulic Fracturing Operations
- Oriented Perforating
  - Only observed in vertical wells
  - Proper use of oriented tools and developments best practices can minimized risk significantly
- HF Operations
  - Only in horizontal well
  - Erosion is the root cause of most failures during HF ops
- Laboratory Tests
  - Erosion risk increase as function of rate and time
- Adherence established procedures and best practices has helped to reduce the risk
  - Failure during HF ops remains a concern

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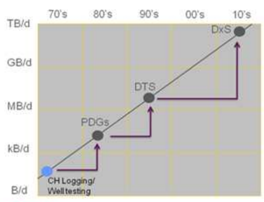
Data Challenges

Data Volume & Storage



IPTC 14629-MS

- Koelman J. et.al. (2011) **IPTC 14629-MS**
- Explained the challenges associated with permeant surveillance and distributed sensing in particular (DxS)
  - Trendline of doubling data rates every 1.5 years (a hundred-fold increase every 10 years)
  - DxS application can generate TB/d
  - Compounded by several applications generating data some times simultaneously from the same FO deployment
- What to do:
  - Data reduction and effective exception-based surveillance is the key.
    - Store "event-rich" data only

Data Handling & Interpretation

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- Data Handling
  - Most data manipulation interpretation today is done via software not specifically designed for handling FO data.
  - Integration requires moving data across multiple applications and the ability of co-display relevant raw and interpreted data.
- Data Interpretation
  - There is no "off-the-shelf" solutions (**perseverance is essential**)
  - Interpretation requires a multifunctional and multidisplinary approach.
  - Need to establish and implement workflows, standards and best practices.
  - Need to identify, modify or develop systems and software for the transmission, storage, display, interpretation and integration of FO data.

Closing Remarks & References

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Closing Remarks

- Many FO applications already exist & new ones are being developed
  - Near Wellbore Stimulation Distribution
    - Completion Effectiveness, incl' Limited Entry Evaluation
    - Stage Isolation & Communication Evaluation
    - Overflush Evaluation
  - Production Inflow Profiling
  - Strain / Compaction Monitoring
  - MicroSeismic from DAS: Far-Field Geometry Characterization
  - Far-Field Interference Diagnostics via Intersection with Fiber
  - Disposal Well Diagnostics – Enables License to Operate
- Complementary Value from Integration with other Diagnostic Methods
- FO has potential for broader application within O&G industry but many challenges remain
  - Application Cost and Durability
  - Data Handling and storage
  - Interpretation and Integration are Still Evolving
- Industry collaboration is essential

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References

- Sierra J. et. al. 2008 (**SPE 116182**) Production Profiling and Frac Diagnostics
- Huckabee P. 2009 (**SPE 118831**) Frac Diagnostics, Production Profiling, Disposal Diagnostics
- Holley E.H. et al 2010 (**SPE 136565**) Frac Diagnostics and Integration
- Mestayer J. et. al. 2011 (**SEG Annual Meeting**) Geophysical Applications
- Molenaar M. et. al. 2011 (**SPE 140561**) Frac Diagnostics
- Koelman J.M.V.A et. al. 2011 (**IPTC14629**) FO Applications
- Koelman J.M.V.A et. al. 2012 (**SPE 150203**) FO Applications
- Molenaar M. et. al. 2012 (**SPE 152981**) Frac Diagnostics
- Molenaar M. et. al. 2013 (**SPE 164030**) Frac Diagnostics
- van der Horst J. et al 2013 (**IPTC 16973**) Production Profiling & Flow Characterization
- Bateman K. et. al. 2013 (**SPE 167211**) FO Failures
- Webster P. et. al. 2013 (**SEG-2013-0182**) Geophysical Applications (MSM)
- Ugueto G. A. et. al. 2014 (**SPE 168603**) Frac Diagnostics and Integration
- van der Horst J. et al 2014 (**IPTC 17528**) Production Profiling & Flow Characterization
- in't Panhuis P. et. al. 2014 (**SPE 170917-MS**) Production Profiling
- Ugueto G. A. et al. 2015 (**SPE 173348-MS**) Frac Diagnostics
- Richards J. et. al. 2015 (**SPE 173440-MS**) Production Profiling

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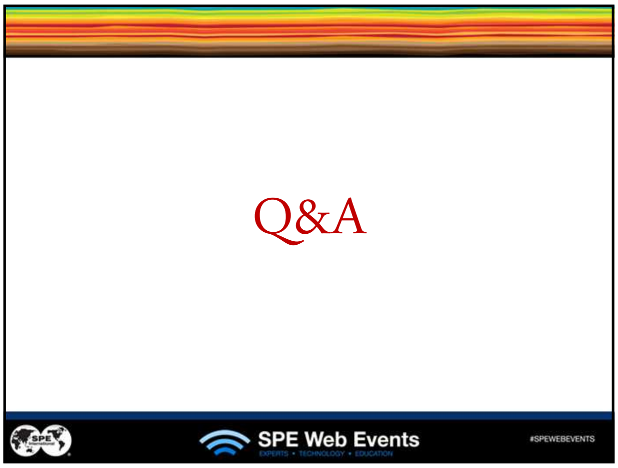
Q&A
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