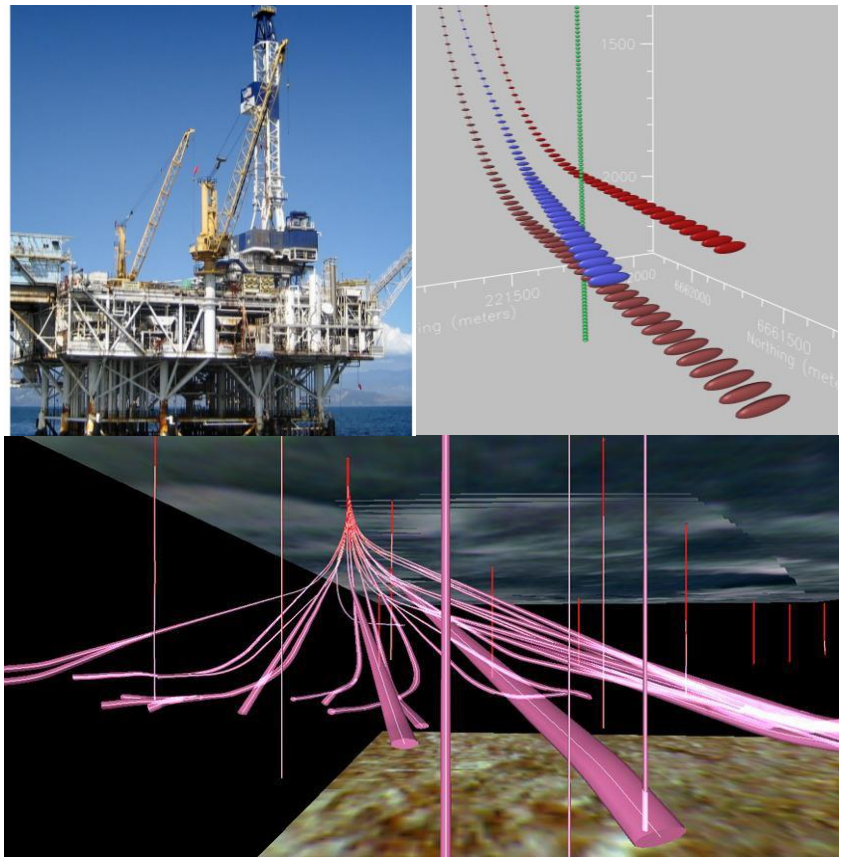

Recommendations for Improvements to Wellbore Surveying and Ranging Regulations

Presented at the

Public Technology Assessment Program (TAP) Forum

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Prepared for:
U.S. Department of Interior, Bureau of Safety and Environmental Enforcement

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Introduction

Study Objectives

- Improve BSEE's ability to understand the operational performance capabilities and limitations of downhole surveying and ranging tools, operational practices, and emerging technologies.
- Enhance BSEE's regulations related to wellbore surveying technology associated with surveying accuracy and survey management, as well as relief well/well interception operations.

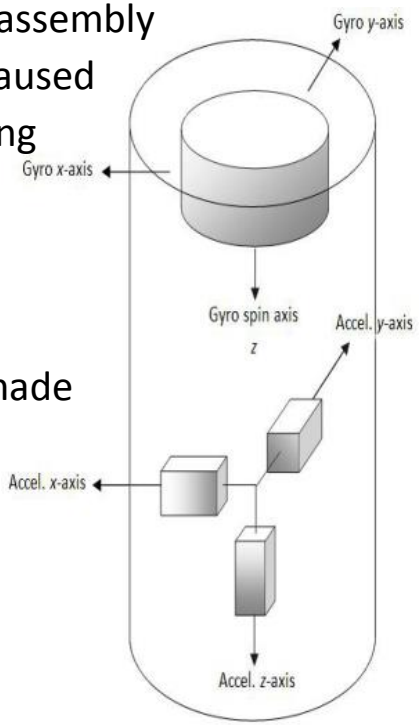
Methodology

- Developed an understanding of the current tools, technologies, and methods for wellbore surveying and ranging, as well as emerging technologies.
- Reviewed current industry best practices and state, federal, and international regulations related to wellbore surveying and ranging.
- Developed a list of potentially applicable regulatory areas and evaluate current BSEE regulations to identify gaps in regulations and guidance compared to best practice and other jurisdictions.
- Developed recommendations for improving and enhancing current BSEE regulations and guidance for wellbore surveying and ranging.

Directional Survey and Ranging Tools

Directional Survey Tool Attributes vs. Tool Types (Magnetic & Gyroscopic)

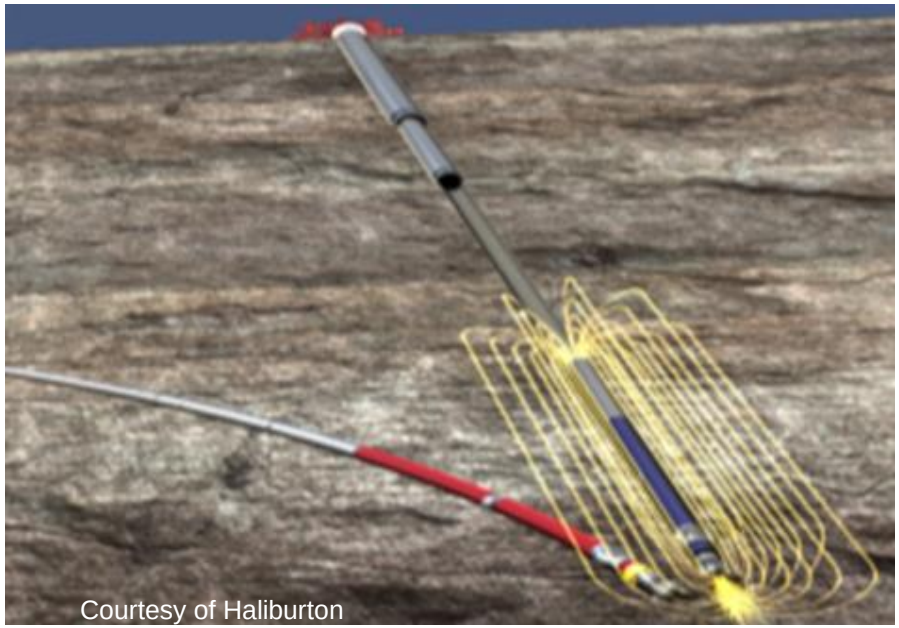
- **Sensors**
  - Accelerometers – measure inclination of borehole
  - Magnetometers – measure azimuth direction from magnetic north
  - Rate-sensing gyroscopes measure azimuth from earths spin rate
- **Tool Types**
  - MWD – makes measurements while drilling, part of the downhole tool assembly
  - Wireline – tools deployed on a heavy conductor cable while drilling is paused
  - Drop/Slickline – self-contained tools that can be dropped inside drillstring
- **Data Transmission/storage**
  - Mud pulse telemetry – information sent via mud pulses
  - Solid-state memory – data stored inside tool
  - Wireline telemetry transmitted up the cable while measurements are made
- **Power supply**
  - Turbine-generator – uses mud to drive power turbine
  - Battery
  - Wireline



Directional Survey and Ranging Tools

Ranging Tool Attributes

- Detects a cased borehole or other ferrous object and estimates the distance and direction to the object.
- Used for well intercepts (plug and abandon) and relief well drilling.
- Multiple ranging runs are made to locate, track, and intercept the target wellbore.
- Passive ranging tools measure distorted earth field and model interference caused by target; max range 40-80 feet.
- Active ranging tools measure AC field induced in target by tool; max range 70 – 200 feet.
- The attributes of the ranging tools were quite similar to their MWD system (magnetic sensor) counterparts.


Courtesy of Haliburton

Directional Survey and Ranging Tools

High Temperature Tools

- Four of the eight companies in the study offer high temperature magnetic survey tools which are capable of extended operation at temperatures greater than 350°F/176°C.
- These magnetic tools can also be used for ranging services, so they are capable of ranging in high temperature environments.
- No gyroscopic tools capable of extended operation at high temperatures were identified.

Future Technologies

- Directional survey and ranging technology is continually improving.
- The study identified one new tool, the adaptation of an acoustic logging tool to ranging applications, and a new approach to passive magnetic ranging as emerging tool technologies.
- The study also found that while the development of high temperature components for directional and gyroscopic tools is possible, it is largely dependent on the market demand, which does not currently support significant investment in these technologies.

Survey Lifecycle Elements

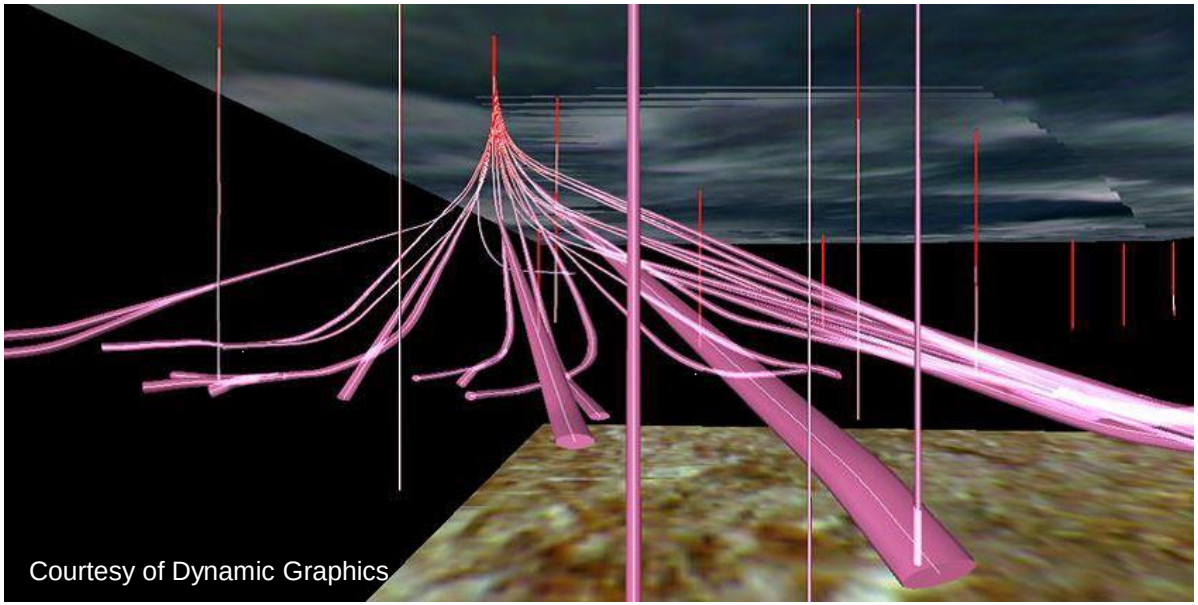
The Survey Lifecycle includes the operational and management activities associated with wellbore surveys and includes the following elements:

- Wellbore and Directional Survey Planning
- Survey Operations
- Data Management
- Corrections and Tool Error Models (Uncertainty)
- Survey Quality Control and Survey Management

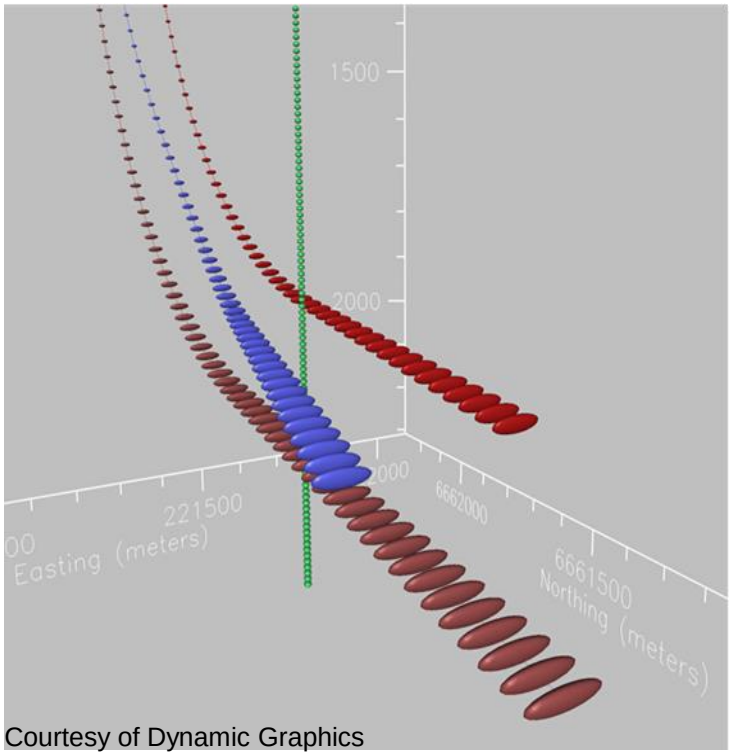
Survey Lifecycle Elements

Wellbore and Directional Survey Planning

- Wellbore planning is an iterative process that requires understanding the capabilities of the directional survey tools, as well as the corrections applied to raw data and the source and magnitude of uncertainties for each measurement.
- Includes anti-collision (AC) analysis and planning. Most operators consider AC a Safety Critical Element that requires enhanced QC procedures and approvals.
- Planning is integrally linked with all the other elements of the Survey Lifecycle



Survey Lifecycle Elements



Courtesy of Dynamic Graphics

Survey Operations

- Directional measurements are made and interpreted in real time to steer the bit and avoid obstacles (other wells).
- Safe and accurate drilling requires adherence to proper tool calibrations and the application of corrections to account for influences on direction and depth measurements.
- Calculating the uncertainty of the wellbore location is a key component in interpreting the directional survey location. Accurate calculation of uncertainty is critical for safety.
- Important aspects of operations include tool check and calibration, survey station frequency/interval, tool checks while operating, and integrating multiple surveys into a single definitive survey.

Survey Lifecycle Elements

Data Management

- Occurs across the survey lifecycle and is a key component to ensuring the safe and efficient drilling of offshore wells.
- Completed survey data report includes the definitive data on wellbore position (x, y, and z coordinates), along with header information. This is generally the data set provided to regulatory agencies for the permanent record.
- Survey data components include all the information that are used to generate the final wellbore position including the raw data. Some of this is submitted to regulators.

(Def Survey)

Report Date:	November 05, 2015 - 01:42 PM	Survey / DLS Computation:	Minimum Curvature / Lubinski
Client:	BP	Vertical Section Azimuth:	64.610 ° (Grid North)
Field:	Fall ATW Training Field	Vertical Section Origin:	3.361 m, 3.551 m
Structure / Slot:	A Structure / 9	TVD Reference Datum:	Rotary Table
Well:	A9 Well	TVD Reference Elevation:	68.300 m above MSL
Borehole:	A9 OH	Seabed / Ground Elevation:	100.000 m below MSL
UWI / API#:	Unknown / Unknown	Magnetic Declination:	-0.480 °
Survey Name:	A9 Keeper + MWD ft	Total Gravity Field Strength:	1000.9965mgn (9.80665 Based)
Survey Date:	April 10, 2012	Gravity Model:	DOX
Tort / AHD / DDI / ERD Ratio:	91.965 ° / 1493.290 m / 5.715 / 0.527	Total Magnetic Field Strength:	49951.532 nT
Coordinate Reference System:	UTM Zone 31N - WGS84, Meters	Magnetic Dip Angle:	70.120 °
Location Lat / Long:	N 56° 10' 40.52341", E 3° 27' 36.36214"	Declination Date:	April 10, 2012
Location Grid N/E Y/X:	N 6225977.520 m, E 528563.380 m	Magnetic Declination Model:	BGGM 2011
CRS Grid Convergence Angle:	0.3822 °	North Reference:	Grid North
Grid Scale Factor:	0.99961001	Grid Convergence Used:	0.3822 °
Version / Patch:	2.8.572.0	Total Corr Mag North->Grid North:	-0.8622 °
		Local Coord Referenced To:	Structure Reference Point

Comments	MD (m)	Incl (°)	Azim Grid (°)	TVD (m)	VSEC (m)	NS (m)	EW (m)	DLS (°/30m)	Northing (m)	Easting (m)	Latitude (N/S ° ' ")	Longitude (E/W ° ' ")
	3048.00	16.46	60.11	2629.79	1428.17	613.47	1294.85	0.52	6226587.39	529854.18	N 56 10 59.96	E 3 28 51.46
	3077.00	16.88	60.32	2657.57	1436.47	617.60	1302.07	0.44	6226591.52	529861.39	N 56 11 0.10	E 3 28 51.88
	3105.00	16.46	60.40	2684.39	1444.48	621.57	1309.05	0.45	6226595.49	529868.37	N 56 11 0.22	E 3 28 52.28
	3134.00	15.28	59.14	2712.29	1452.38	625.56	1315.90	1.27	6226599.48	529875.22	N 56 11 0.35	E 3 28 52.68
	3171.00	15.78	58.76	2747.94	1462.24	630.67	1324.39	0.41	6226604.59	529883.70	N 56 11 0.51	E 3 28 53.18
	3189.00	16.67	59.33	2765.22	1467.24	633.26	1328.70	1.51	6226607.17	529888.02	N 56 11 0.60	E 3 28 53.43
	3216.00	17.32	58.20	2791.04	1475.09	637.35	1335.45	0.81	6226611.26	529894.76	N 56 11 0.73	E 3 28 53.82
	3244.00	17.71	57.64	2817.74	1483.46	641.83	1342.59	0.46	6226615.74	529901.90	N 56 11 0.87	E 3 28 54.24
	3261.00	17.98	58.20	2833.92	1488.64	644.60	1347.01	0.56	6226618.50	529906.31	N 56 11 0.96	E 3 28 54.49
Interpolation	3194.00	16.79	59.11	2770.01	1468.68	634.00	1329.94	0.81	6226607.91	529889.25	N 56 11 0.62	E 3 28 53.50 E 3 27 41.81

Survey Lifecycle Elements

Corrections and Tool Error Models

- Prior to interpretation, MWD survey data can be corrected to minimize the effects of distorted or changing local magnetic fields, magnetic interference from tools, and tool alignment. Depth is corrected for pipe stretch. This reduces wellbore position uncertainty.
- Tool error models use tool- and well-specific information to quantify the uncertainty of the wellbore positon in three dimensions (azimuth, inclination, and depth).
- Directional survey tools make measurements at discrete depths, often 100 or more feet apart, and are combined (or integrated) using accepted calculations (normally minimum radius-of-curvature) to create continuous representations of wellbore position.

Corrections
BHA Sag (tool misalignment)
Natural magnetic field anomalies (local)
Short sub magnetic interference
Pipe Stretch

Survey Lifecycle Elements

Survey Quality Control and Survey Management

- Quality control procedures occur throughout the survey lifecycle and must be implemented to ensure the wellbore positon and uncertainty estimates are truly representative of the actual conditions.
- The most powerful quality control procedure for wellbore positon is to run two different survey tools over the same interval and analyze the variability. Ideally the tools would be based on different measurement systems, normally magnetic and gyro.
- Survey management includes a broad range of services applied to improve the usability and accuracy of wellbore survey data throughout the survey lifecycle. Can be performed by the operator or third party.

Best Practices

Across the survey lifecycle components we identified:

- More than 25 industry best practices for directional surveying
- Six industry best practices for relief and intercept well surveying
- Best practices are derived primarily from the ISCWSA documents
- SPE publications also document many of these best practices

ISCWSA is currently preparing American Petroleum Institute (API) Recommended Practice (RP) 78 for Wellbore Surveys, expected to be completed in late 2016. It will include many of these best practices.

Industry Steering Committee for Wellbore Survey Accuracy (ISCWSA)
ISCWSA is a voluntary industry organization formed in 1995 whose mission is to produce and maintain standards for the industry relating to wellbore survey accuracy, set standards for terminology and accuracy specifications, and, establish a standard framework for modelling and validation of tool performance.

Regulations

Scope

- Regulations on wellbore surveying, collision avoidance, survey accuracy, survey management, and relief well/well intersection operations
- State and federal jurisdictions in the U.S., as well as international jurisdictions

Observations

- All existing requirements reviewed were oriented towards specific defined requirements (e.g., frequency of measurements) or specific data elements to be collected or reported.
- None of the jurisdictions reviewed identify high temperature environments as a unique condition that requires separate treatment in regulation.
- U.S. state and federal regulations are, in general, badly dated with respect to technology application for survey quality and data management.
- None of the regulations identified rely on industry standards for detailed practices.
- The more detailed approaches often include regulatory reference to more specific guidance, which then becomes *defacto* requirements as a result of the approvals process.

Top Three Recommendations

1. **Strengthen the well planning/permitting process by including specific requirements for a wellbore directional survey program and written plan. Relief well planning should also be strengthened to include a ranging plan.**

2. **Enhance the role of quality control during directional survey operations and data management by providing specific minimum standards for ensuring accurate and reliable data are collected and reported.**

3. **BSEE can use the API Recommended Practices (RP) for Wellbore Survey (API 78) as a starting point for technical requirements. If the RP is referenced in a regulation, BSEE should include in the regulation all specific items for which BSEE feels it needs to go beyond the RP.**

The complete set of recommendations can be found in the report on the BSEE TAP website at:

https://www.bsee.gov/research-record/tap-761-wellbore-survey-technology

Top Three Recommendations

1. **Strengthen the well planning/permitting process by including specific requirements for a wellbore directional survey program and written plan. Relief well planning should also be strengthened to include a ranging plan.**
   - The operator must develop and submit a written wellbore survey program that identifies each directional survey tool or tool type to be used for each section of the wellbore, and the rationale for selection.
   - The plan must address the specific conditions expected to be encountered in the proposed well(s), and identify how the operator will comply with the wellbore survey regulations.
   - Clearly identify if any part of the well will be drilled under high temperature conditions (350°F or greater) and incorporate the effects of high temperature into equipment selection for any data collection activity.
   - The APD must include a statement of certification from the well planner indicating that the plan was developed in accordance with best industry practices, includes a collision avoidance analysis, and reflects the safety and environmental conditions anticipated in the drilling of the well.

Top Three Recommendations

2. **Enhance the role of quality control during directional survey operations and data management by providing specific minimum standards for ensuring accurate and reliable data are collected and reported.**
   - Operators must ensure that all survey tools are calibrated in accordance with their standard calibration procedures.
   - Operators must provide written certification that the directional survey data they are submitting accurately represents the wellbore trajectory and uncertainty and conforms to the calibration standards and operational procedures set forth by the MWD/directional survey company, and best industry practice.
   - Operators should apply the most appropriate tool error model (instrument performance model) and other data quality improvement methods to minimize the uncertainty of the borehole location at each survey point. All corrections and tool error models shall be documented.
   - In situations where the precise location of a borehole is important, the use of redundant surveys, with both magnetic and gyro-based tools, should be considered. (i.e., where wells are present nearby and may create a collision hazard, high dogleg severity sections, obstacle avoidance, or small driller's target).

Top Three Recommendations

3. **BSEE can use the API Recommended Practices (RP) for Wellbore Survey (API 78) as a starting point for technical requirements. If the RP is referenced in a regulation, BSEE should include in the regulation all specific items for which BSEE feels it needs to go beyond the RP.**
   - ISCWSA is an industry organization with a mission to improve wellbore survey accuracy. Members are experts in the field and represent a diverse group of tool manufacturers, service companies, independent consultants, and operators.
   - Based on the preliminary outline for the RP, many of the technical recommendations in this report will be addressed in the RP.
   - Since the RP will not be a required API Standard, but rather a recommended practice it will be based on the use of “should” statements not “shall” statements. Key elements of API RP 78 could be defined in regulation, or stipulated as review criteria in BSEE’s review approach to drilling plan applications.

Future Needs and Research

- **Documenting Definitive Surveys:** Currently a one-way process: operator/service company submits survey to BSEE and there is no confirmation or feedback from BSEE. Consider changing to two-way process: following completion of well/project and receipt of the definitive survey(s), BSEE could review and send what has been identified as the definitive survey(s) back to the operator for confirmation.
- **High Temperature Tool R&D:** Current market for surveying, steering, and ranging tools capable of operating at high temperatures is episodic and unpredictable, and justifying the investment needed to develop such tools is difficult. Explore ways to provide incentives to accelerate the R&D and/or testing of such tools or components (like MEMS-based rate gyros).
- **Better Decision Making/Human Factors:** The application of human factors has led to better decision-making and safer operations in many industries. It can facilitate the development and acceptance of processes and interactive tools that improve dynamic decision-making. Industry could explore the use of human factors in other applications to learn how it might best be applied to decisions made while drilling.

Future Needs and Research

- **Engaging with Industry:** ISCWSA, through its affiliation with SPE, is currently drafting a set of API Recommended Practices for Wellbore Surveying that are expected to be completed in late 2016. The practice covers survey planning, anti-collision analysis, databases, corrections, tool error models, and quality control. The Technical Workgroup is open to all and offers an opportunity for BSEE to engage directly with industry experts to facilitate integration of the API RP with new guidance and regulations.

Questions?

Thank You!

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