MetalMapper as a Risk Reduction Tool:
Lessons Learned from Prescribed Burn Preparation at Fort Ord, California

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The Team

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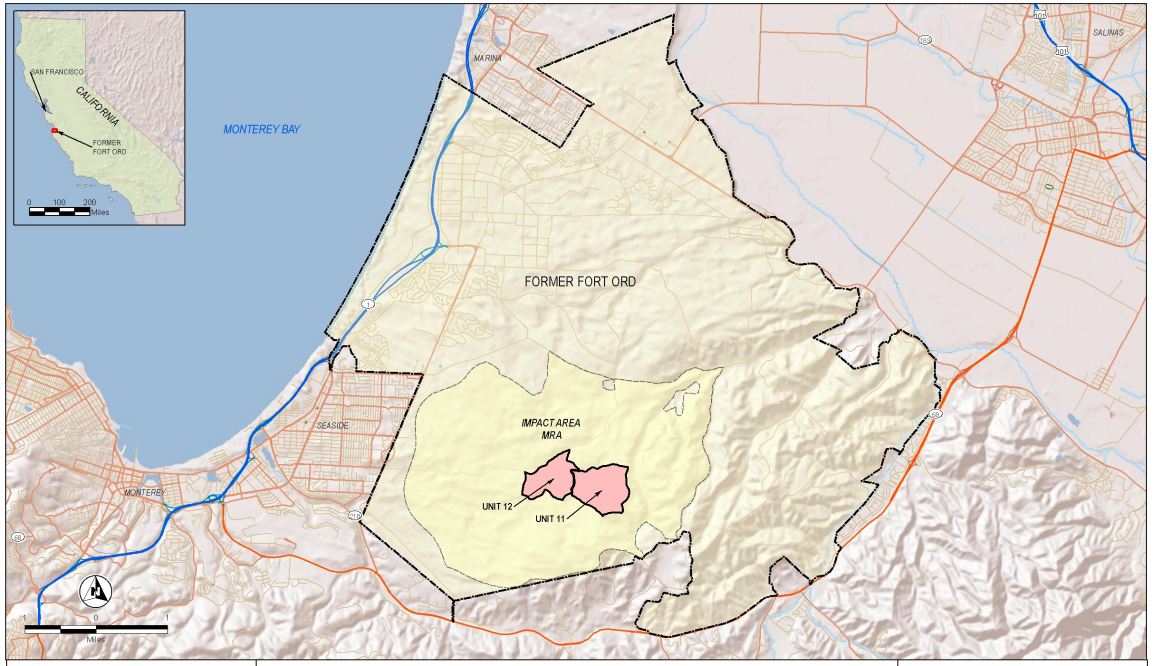
Background

Units 11 and 12 Location



Prescribed Burns at Fort Ord

- Prescribed burns at Fort Ord are part of the remedy for the Impact Area MRA
  - Vegetation clearance to support MEC removal actions
  - Periodic burning to maintain natural habitat
- Prescribed burns originally planned for Units 11 and 12 in 2011 were canceled due to the discovery of large MEC items on the ground surface
- Subsequent activities conducted in Units 11 and 12:
  - Vegetation cutting
  - Surface MEC removal
  - Digital geophysical mapping
- Prescribed burns rescheduled for fall of 2015

The Identified Risk

- USACE Safety identified the potential presence of 155mm projectiles and 8-inch projectiles remaining in the shallow subsurface as presenting a risk to prescribed burn personnel on the fuel breaks surrounding Units 11 and 12 during burn operations.

Risk Reduction Objective

- Reduce risk to prescribed burn personnel by removing large, near-surface MEC
- Targets of interest (TOI)
  - 155mm projectiles
  - 8-inch projectiles
  - Larger MEC (if present)
- Removal depth requirements
  - Outer Zone (within 436 feet of fuel breaks)
    - Removal of TOI to 2-foot depth
    - Reduce risk to burn personnel on perimeter fuel breaks
  - Inner Zone (greater than 436 feet from fuel breaks)
    - Removal of TOI to 1-foot depth
    - Reduce risk to support aircraft flying overhead

Risk Reduction Tasks

- Use EM61 detection data to select location for the classification survey
- Test pit and building the classification library
- IVS
- MetalMapper cued data collection
- Advanced geophysical classification analysis using UX-Analyze
- QC/QA plan
- Intrusive investigation

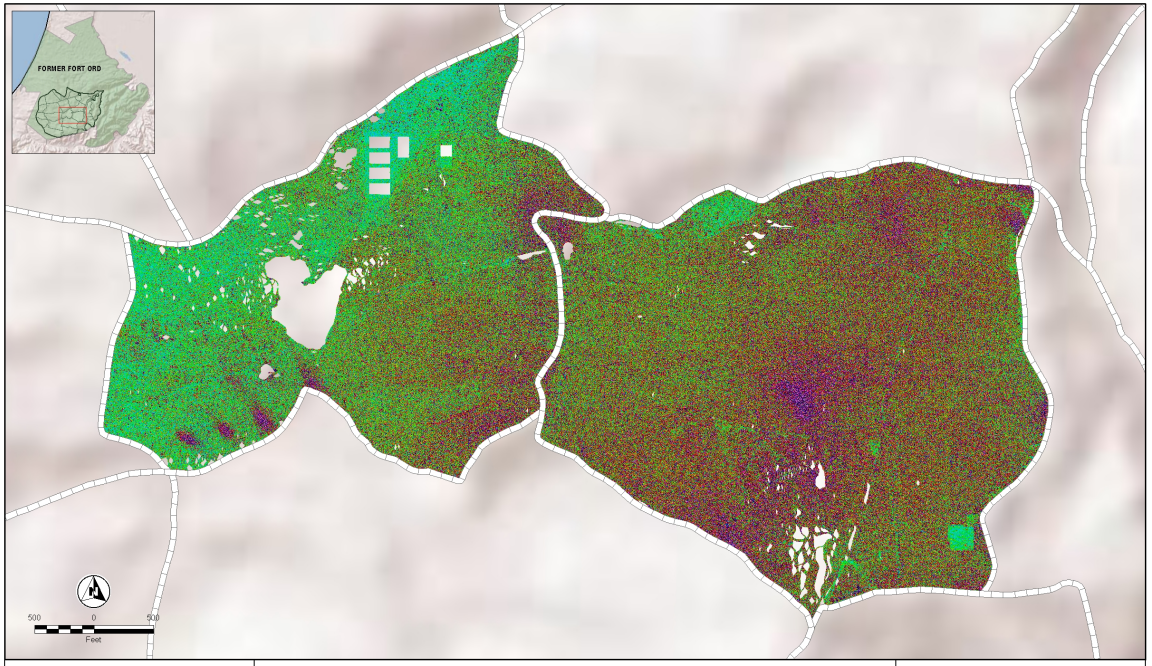
CB&I ESTCP Demonstration

- Primary Objective:
  - Demonstrate whether large munitions such as 155mm and 8-inch projectiles at depths to 2 feet can be confidently classified within a challenging high metallic anomaly density background.
- Secondary Objectives:
  - Demonstrate whether large munitions at depths to 4 feet can be confidently classified within a challenging high metallic anomaly density background.
  - Demonstrate if smaller munitions such as 40mm projectiles can be confidently classified within the range of high background conditions.

ESTCP Demonstration Results and Conclusions

- 2,804 unique cued locations
  - 35 total TOI 1 (100%)
  - 361 total TOI 2 (350/361 = 97%)
- Achieving primary objective (large TOI to 2-feet) = EASY!
- Achieving secondary objective 1 (large TOI to 4-feet) = DIFFICULT but DOABLE!
- Achieving secondary objective 2 (all TOI to depth of detection) = CLOSE, but NOT POSSIBLE!
  - Moving forward, need to address depth vs. signal strength vs. anomaly density issues
  - Removal action vs. risk reduction

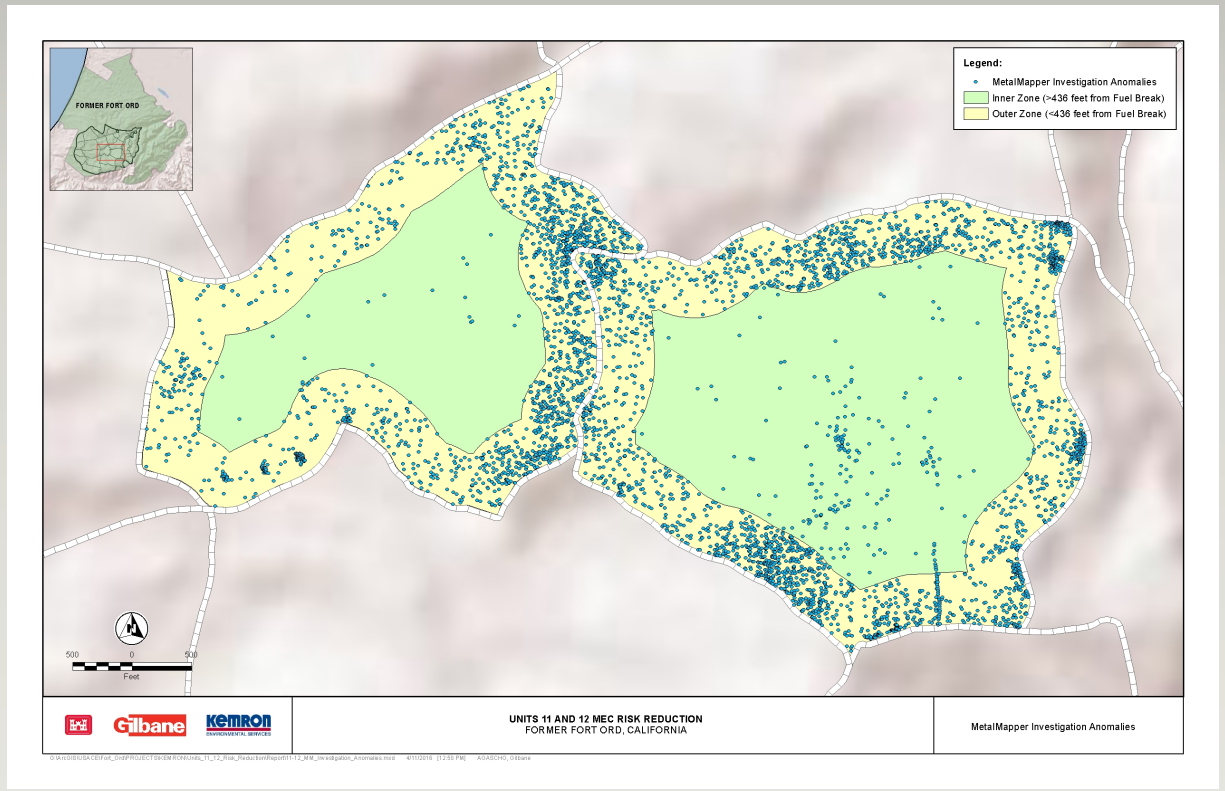
Digital Geophysical Mapping



Subsurface Anomalies

- Approximately 550,000 anomalies in existing EM61 detection data
- Detection threshold adjusted for large TOI using Naval Research Laboratory EM61 response data to determine minimum response of a 155mm projectile at the required removal depths:
  - Outer Zone (2 feet below ground surface) – EM61 channel 3 response values of 114mV or greater
  - Inner Zone (1 foot below ground surface) – EM61 channel 3 response values of 446mV or greater
- Conservative response thresholds by design
- Resulted in identification of 4,625 subsurface anomalies potentially related to large TOI above the risk reduction removal depths

MetalMapper Investigation Anomalies



Risk Reduction Plan

- Cued MetalMapper survey to model and classify each of the selected anomalies
  - TOI – likely to be large MEC items (155mm projectiles, 8-inch projectiles)
  - Non-TOI – highly-likely to be something other than TOI
- TOI – removed prior to burn operations
- Non-TOI – left in place
- Cannot Analyze (targets where the acquired data does not support a confident classification decision) removed prior to burn operations

Risk Reduction Activity Results

Library Validation

- Initial library was used, validation performed to determine if additional entries can be added to the library
- Cluster analysis performed
- Selected 22 analyst calibration digs
  - 6 for TOI threshold verification
  - 13 from unknown clusters
  - 2 for Parameter Space (size-decay) verification
- Updated initial library with excavation results
  - 3 – 155mms for ranked dig list
  - 18 other munitions (non-TOI)
- Library Validation is a separate task from Classification Validation

Key Thresholds for Classification

- Verification digs were performed on each of these key thresholds that were used
- Library match statistic
  - Category 1 High Confidence TOI
  - Category 2 Cannot Decide
  - Category 2 Cannot Decide, Low Signal
  - Category 3 Non-TOI below library match statistic threshold or outside limits on decay, size and signal amplitude
- Cannot Analyze
  - Inversion failed or cannot extract reliable betas
  - Poor Fit Coherence
  - Unreasonable depth
  - High Chi2
- Modeled depth limit was set at 2m below the sensor, well below the planned removal depth

Classification Results

- 4,625 anomalies investigated with MetalMapper
- 589 anomalies identified for intrusive investigation and removal
  - 22 analyst calibration digs
  - 567 ranked classification digs
    - Category 0 (Cannot Analyze): 38
    - Category 1 (High-Confidence TOI): 306
    - Category 2 (Cannot Decide): 223
- 4,036 anomalies (87.3%) classified as Category 3 (Non-TOI)

Classification Recovery Summary

Category	Quantity Recovered	Correctly Classified as TOI	% Correctly Classified	Category 0	Category 1	Category 2
8-inch Projectile	2	2	100	0	2	0
155mm Projectile	235	235	100	0	224	11
QA Seed	24	24	100	3	21	0
QC Seed	35	35	100	0	32	3

Category 0 = Cannot Analyze

Category 1 = High-Confidence TOI

Category 2 = Cannot Decide

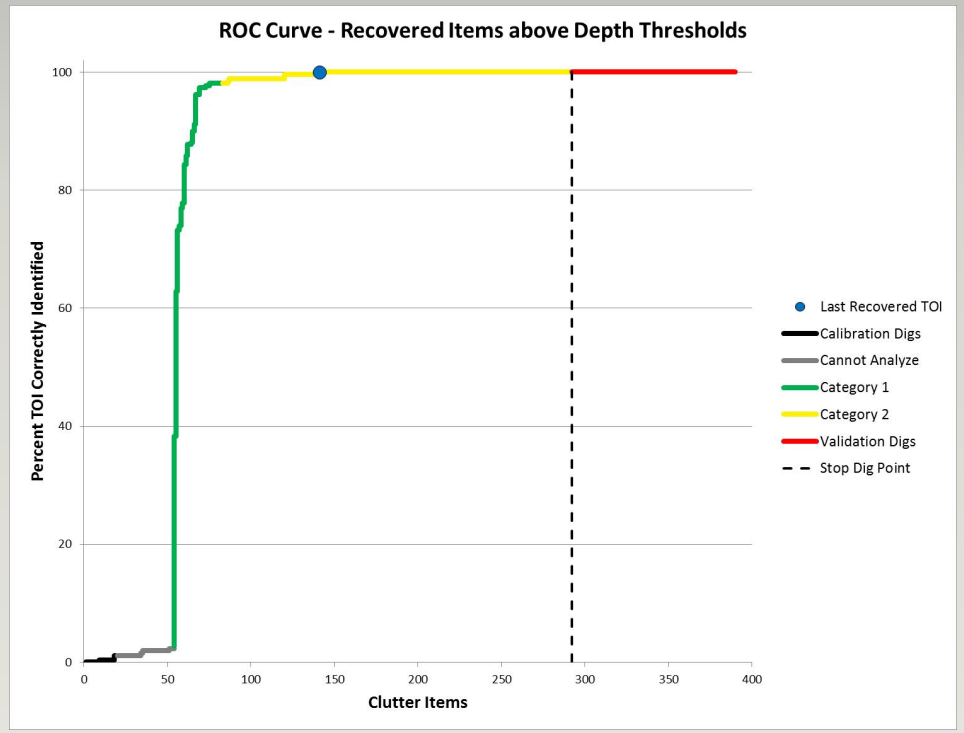
Recovered TOI

- 296 TOI were recovered from the 589 Calibration, Category 0, Category 1, and Category 2 intrusive investigations:
  - 2 8-inch projectiles
    - MEC: 2
    - MD: 0
  - 235 155mm projectiles
    - MEC: 17
    - MD: 218
  - 35 QC seed items (large ISOs)
  - 24 QA seed items (large ISOs and 155mm projectiles)
- 36 of the TOI were recovered below the 1- and 2-foot depth thresholds

Verification/Validation Investigations

- 99 Category 3 targets (High-Confidence Non-TOI) selected for intrusive investigation, as described in the Data Validation Plan
  - 38 library match threshold verification targets
  - 11 cluster verification targets
  - 25 goodness of fit (chi-square) verification targets
  - 25 QA validation targets
- No TOI were recovered from the verification and validation investigations.

ROC Curve


ROC Curve - Recovered Items above Depth Thresholds
Percent TOI Correctly Identified
100
80
60
40
20
0
0
50
100
150
200
250
300
350
400
Clutter Items
Last Recovered TOI
Calibration Digs
Cannot Analyze
Category 1
Category 2
Validation Digs
Stop Dig Point

Lessons Learned

Lessons Learned

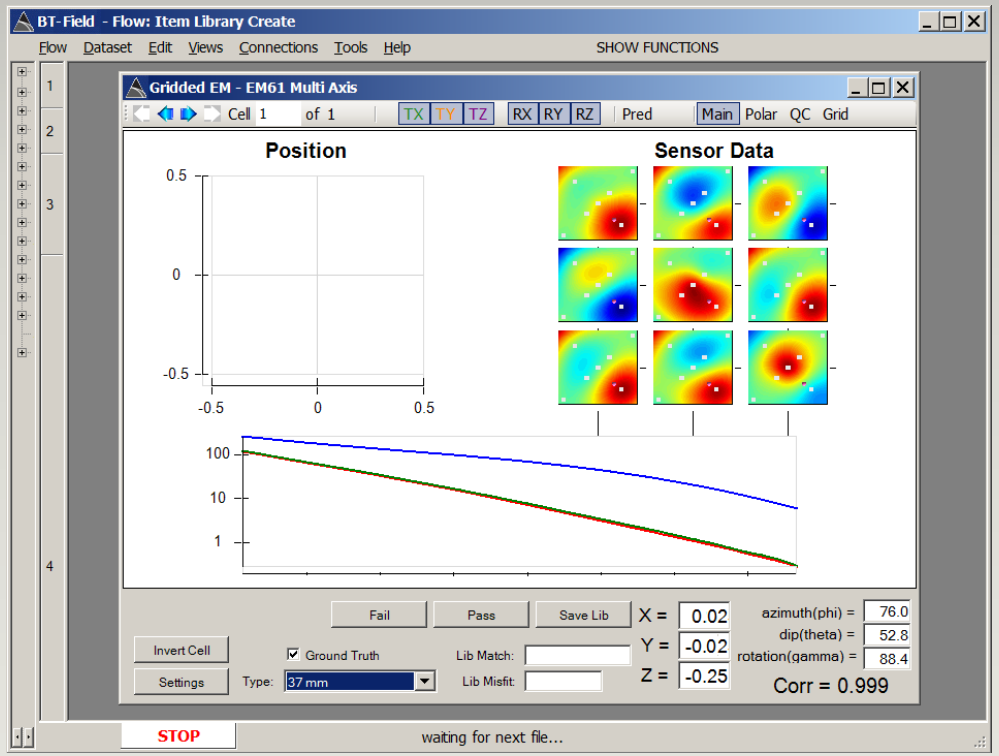
- Positioning accuracy with IMU
- In-field inversion software
- Single-point data spikes
- Tow vehicle interference
- Long time range setting
- 25ms classification library
- Cultural feature information and detection data availability
- Goodness of fit evaluation

Positioning Accuracy with IMU

- The incorporation of an IMU on the MetalMapper results in increased accuracy in positioning the sensor compared to the EM61 array that was used for the detection survey
- The MQO was adjusted as follows: For readings with a combined roll-pitch greater than 9, a measurement must be acquired with the center of the array <23.5 inches from the flag location
- Review of intrusive results for consistency with predicted sources resulted in an increase in the allowable distance from the MetalMapper sensor array at which large sources could be classified with high confidence

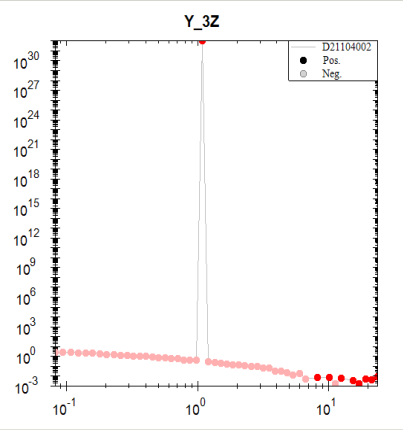
In-Field Inversion Software

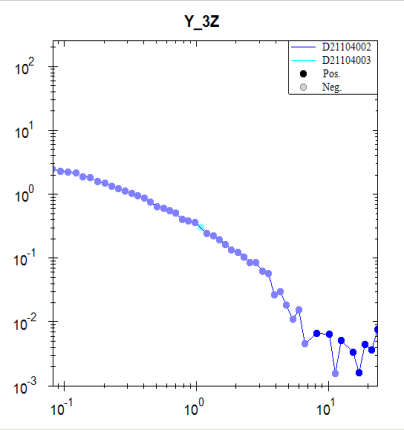
- Onboard inversion software (BT-Field) proved to be very useful
- Assisted with navigation to flag locations
- Provided immediate feedback on positional accuracy
- Greatly reduced the amount of recollection requested by data analysts

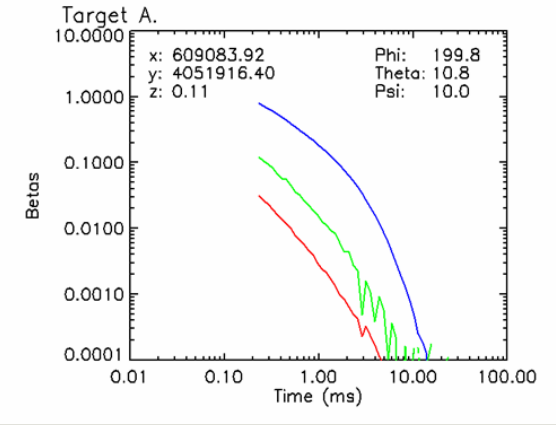


Single-Point Data Spikes

- Removal of sporadic high magnitude single point data spikes from the data with a non-linear filter







Tow Vehicle Interference

- Tow vehicles have different influence on the noise level of the data
- The effect is minimal compared to the signal response of large sources but should be evaluated and considered for future projects with different objectives and TOI lists

Long Time Range Setting

- Use of the long time range setting was beneficial for classification of large sources in high density environments
- The standard 8.3ms time range is good for measuring data from small TOI, but it also allows the EM response of small clutter items to remain in the measured data
- The large TOI for the this risk reduction activity allowed us to extend the measured time range to 25ms, providing the benefit of eliminating much of the response from the high density of small non-TOI clutter while retaining the response from larger metallic items, including potential TOI

25ms Classification Library

- Prior to the start of this project the 25ms MetalMapper munitions signature library was very limited
- Test pit measurements were therefore performed to ensure the initial library was large enough for good classification results
- Initial library from IVS and Test Pit
  - Representative samples of expected TOI at the site
  - 155mm, 8 inch, Large ISO
  - Contained 44 entries with measurements of test items at different depths and orientation
- After cluster analysis and analyst calibration digs added 3 TOI and 18 non-TOI to the library used for final classification

Cultural Features and Detection Data

- Documentation of culture features should be made available to data analysts
- Detection data was not available to analysts during data verification to ensure the locations of QC and QA seeds remained blind to the data analysts

Goodness of Fit Evaluation

- On the preliminary ranked list (prior to calibration digs), a seed item was not properly classified
- Investigation revealed that the target was in a localized area of very high metallic clutter
- The amplitude-normalized goodness of fit measure in the initial classification routine failed to indicate that the measured data could not be adequately modeled
- Analysis of the un-normalized chi-square measure of goodness of fit to the model was added to the classification routine
- Anomalies with chi-square values greater than 8,000 were classified as Cannot Analyze and thus intrusively investigated and removed

Conclusions

Risk Reduction Outcome

- Used advanced geophysical classification to remove large MEC in the shallow subsurface from a heavily contaminated impact area that presented a risk to prescribed burn personnel during burn operations
- Remediation options:
  - Full subsurface MEC remediation: 550,000 digs
  - EM61 amplitude discrimination: 4,625 digs
  - MetalMapper classification: 589 digs
- Successfully met the project objectives and reduced the risk identified by USACE Safety with over 99% reduction in the initial EM61-detected anomalies in the ground (85% of the MetalMapper investigations)
- Completed the risk reduction activity on schedule for Units 11 and 12 to be ready for prescribed burn operations

Questions

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