Fracture Critical POD Process Validation

Active Project (2015 - 2017)

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Approved for public release.

Background

- Flaw detection capability is established for inspection systems and inspectors on the basis of Probability of Detection (POD). The commonly accepted metric for an adequate inspection system is as follows: for a minimum flaw size which is smaller than the critical defect being sought, there is 0.90 probability of detection with 95% confidence (90/95 POD).

- A number of issues with current processes exist and will be addressed:
  1. The existing OSMA POD data set, including flaw standard specimens, have been consolidated at WSTF. Specimens are available upon demand. A variety of materials, geometries, defects, and NDE methods are included spanning about 860 specimens.
     - ✓ Specimen storage procedures are inline with proposed best practices appendix.*
  2. In FY17 a centralized, searchable, and robust online database will be created to log and track POD specimens and results using agency mandated security and backup measures in line with ISO requirements.
  3. In FY18 a web-based service will be developed to enable analyses to be performed consistently across centers.

* Reference: Proposed NASA-STD-5009 Appendix, TEST SPECIMENS AND THEIR IDENTIFICATION, HANDLING, CLEANING, ETCHING AND REFURBISHMENT.

Anticipated Benefits

To NASA funded missions:

Although required and widely used to qualify inspection capabilities, the conduct of and tools for Probability of Detection (POD) analyses are not standardized for NASA and no system exists for cataloging POD data.

- If we know *a priori* that a data set is inadequate for providing acceptable multi-parameter Maximum Likelihood Estimate (MLE) of POD, then what direction is need to be given and satisfied to make the data set a viable data set for multi-parameter MLE.
- It's better to know this before, rather than after the analyses is done and you are trying validate a POD estimate that cannot be validated.

Approach

- Phase 0: Best practices appendices for POD and specimen storage (FY15)
  - First steps for the team's education in POD.
- Phase 1: Analyze the OSMA NDE POD Data Set (FY16)
  - Second step. Three studies completed, aided by Floyd Spencer. Reports in review.
- Phase 2: Create a centralized repository for POD specimens/ NDE capabilities essentially providing a living, backed-up, and encrypted table for NASA-STD-5009 via MAPTIS (FY17)
  - Phase 0 and 1 efforts informed team of database field and organization requirements.
- Phase 3: Develop and validate a web-based **analysis tool** standardizing analyses using the four common analysis algorithms:
  1. Multi-Parameter MLE
     a. Logistic Regression models (e.g. Logit and Probit) from MIL-HDBK-1823, NASA/TM–2014-218183 (April 2014).
     b. Add internal and external validation test for MLE estimates (draft coded into DOEPOD, but not released).
  2. Simple Binomial
     a. Method used by DOEPOD, and NASA Shuttle and Space Station Program estimate of POD.
     b. DOEPOD and DOEPOD's validation was critically reviewed by statistician Bill Meeker/ Iowa State.[1]
     c. NASA/TM–2014-218183 was critically reviewed, over a two year period by statisticians, Dr. William Q. Meeker of Iowa State University and Dr. Floyd W. Spencer of Sfhire, and Dr. William Vesely for NASA.
  3. Bayes Rule
  4. Receiver/Relative Operating Characteristics (ROC)
     a. ROC is a display technology that may be based on Binomial, MLE, or Bayes rule, etc.

Accomplishments

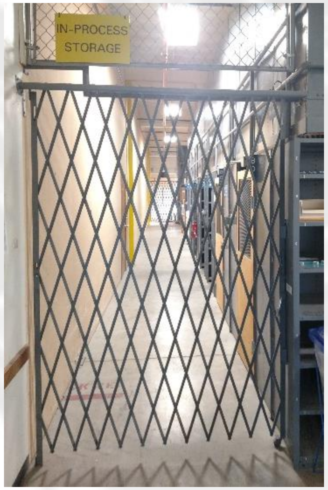
- Team assisted in review of NASA-STD-5009, proposing appendices for POD Best Practices (Appendix B) and an appendix governing sample storage (Appendix C). Language requiring method validation added to -5009.
- Publication of DOEPOD methodology. Version 1.2 and manual available. The software was licensed under non-disclosure to organization directly supporting DOT and to a business venture for other applications.
- **Phase 1:** About 70% of the specimens have been tested. All non-Adobe Version 9 files have been converted to MS Excel. Software glitch only allows Adobe 9 access to some inspector reports. Analysis and reports drafted for eddy current (ET), Level 3 (L3) Penetrant Testing (PT), and Level 4 (L4) PT.
- **Phase 2:** POD specimen database inclusion into MAPTIS via MSFC agreement began in FY17. Will poll Center POC's for specimens and studies to import.
  - Worked in parallel: OSMA flaw specimens relocated to WSTF, being checked for cleanliness, cataloged, and secured for agency distribution.
- **Phase 3:** Not started. MLE and DOEPOD methods will be included (proposed work for FY18 & FY19). Sets precedent as the first complex calculation modules added to MAPTIS. FY16 presentation to national NDE council drew interest in application independent and standardized calculator.

POD Studies

Phase 1: Progress in Analyzing the OSMA NDE POD Data Set

Specimen Sets

- About 860 metallic specimens were produced before 2011 with a selection of fatigue cracks, fastener hole cracks, lack of weld fusion, and electrical discharge machined (EDM) flaws at a cost of about $630,913. The metals used in this study are common throughout aerospace and include aluminum, titanium, nickel-chromium alloy, and stainless steel.
- NDE was performed on these specimens to augment the NASA NDE Data Book, which feeds into Table 1, NASA-STD-5009. Specimens were examined with x-ray radiographic testing (RT) under differing film densities, digital radiography (DR), ultrasonic testing (UT) (including phased array UT), ET (including automated methods), fluorescent PT (L3 & L4), magnetic particle testing (MT), and visual testing (VT). Three of about 60 POD analysis have been completed.




Specimen Sets – maintained by WSTF, available for PODs / recerts

Aluminum Plates with Fatigue Cracks

Box #1: AIA-1 to -16

Box #2: AIA-19 to -46

Box #3: AIA-47 to -74

Box #4: AIA-75 to -102

Titanium Plates with Fatigue Cracks

Box #5: AIT-1 to -16

Box #6: AIT-18 to -38

Box #7: AIT-39 to -59

Box #8: AIT-60 to -80

Box #9: AIT-81 to -101

Inconel Plates with Fatigue Cracks

Box #10: AII-1 to -16

Box #11: AII-18 to -33

Box #12: AII-34 to -50

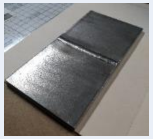
Box #13: AII-51 to -68

Box #14: AII-69 to -85

Box #15: AII-86 to -101

Aluminum Flat Plate w/ LOF Welds

Box #16: BIA-1 to -6



Box #17: BIA-18L to 39L

Box #18: BIA-40L to 61L

Titanium Flat Plate w/ LOF Welds

Box #19: BIT-1 to 16

Box #20: BIT-18 to 38(7)

Box #21: BIT-40 to 61

Inconel Welds w/ EDM Notches

Box #22: BII-18 to 22, 24-25, & 27-37

Welds w/ EDM Notches (SS, Al, Ti)

Box #23: BIS-18 to 27, 29-30, & 32-37

Box #24: BIA-18 to -37

Box #25: BIT-18 to -37

Inconel Tubes with Fatigue Cracks

Box #26: CII1-1 to 16

Box #27: CII1-17 to 33

Stainless Tubes with Fatigue Cracks

Box #28: CIS1-1 to 3, 9-16, & 18-20

Box #29: CIS1-21 to 39

Stainless Tubes with LOF Welds

Box #30: CIS2-1 to 17

Box #31: CIS2-18 to 33

Inconel Tubes with Fatigue Cracks

Box #32: CI1-1L to 16L

Box #33: CI1-18L to 39L

Box #34: CI1-40L to 61L

Inconel Tubes with LOF Welds

Box #35: CIS1-18L to 33L

Box #36: CIS1-40L to 61L

Box #37: CIS1-62L to 83L

Stainless Tubes with LOF Welds

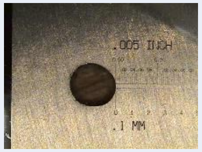
Box #38: CIS2-18L to 33L

Box #39: CIS2-40L to 61L

Box #40: CIS2-62L to 83L

Cracked Fastener Holes, Aluminum

Box #41: DIA-1 to 16



Box #42: DIA-18 to 31

Box #43: DIA-32 to 46

Box #44: DIA-47 to 61

Cracked Fastener Holes, Titanium

Box #45: DIT-2 to 17

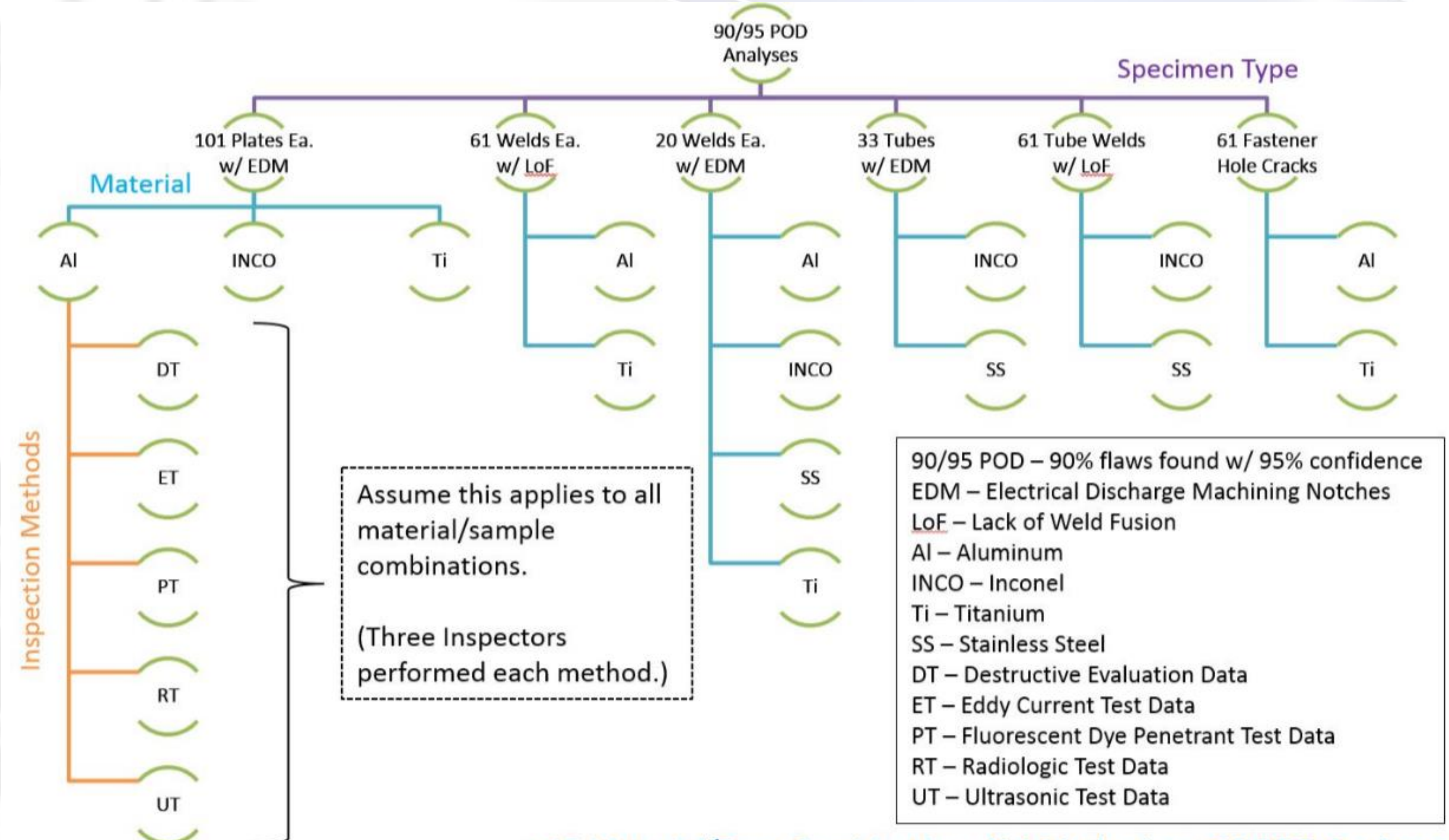
Box #46: DIT-18 to 31

Box #47: DIT-32 to 46

Box #48: DIT-47 to 61

Box1 and Box2 are radiographs

Inspection Data Produced



>15 Material/Type Combinations X 4 Methods = **>60 POD Analyses**

MAPTIS

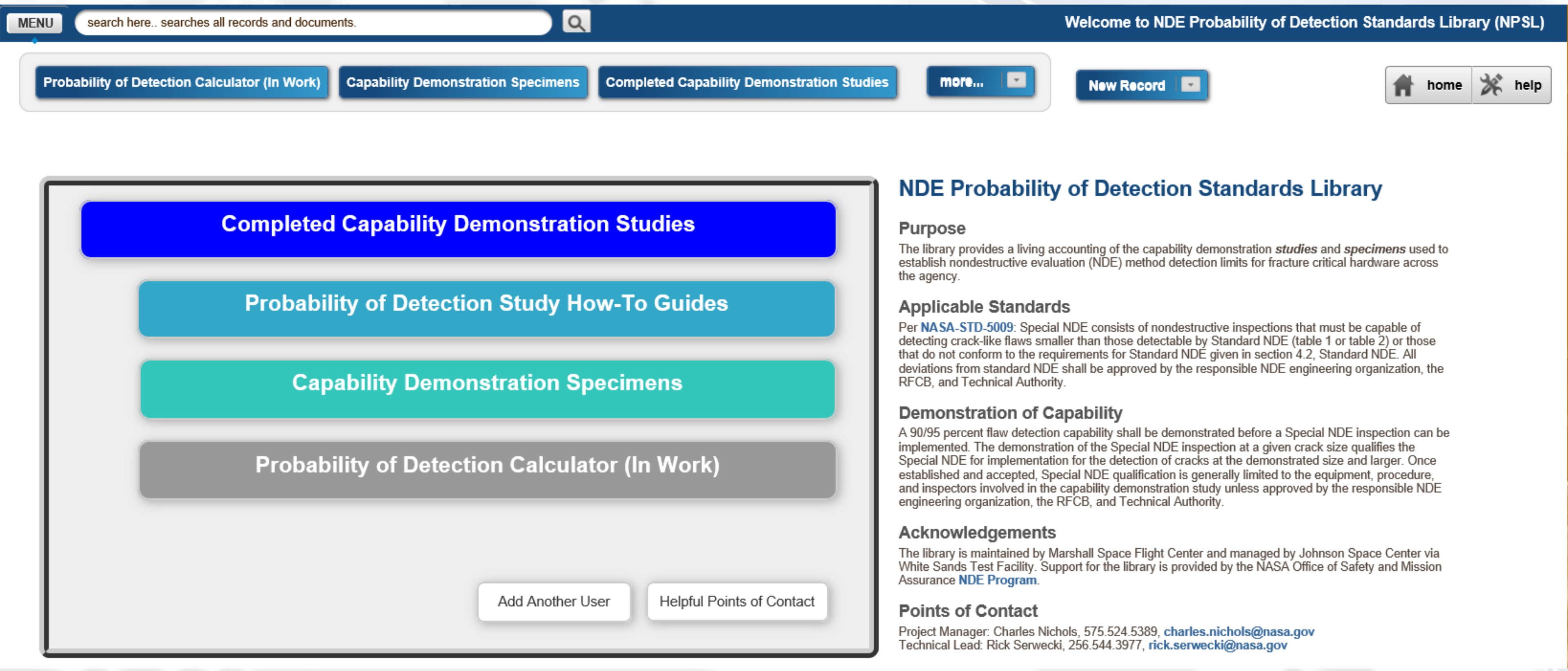
MATERIALS AND PROCESSES TECHNICAL INFORMATION SYSTEM

NDE POD Standards Library

Phase 2: Creates a centralized repository for POD specimens/ NDE capabilities essentially providing a living, backed-up, and encrypted table for NASA-STD-5009 via MAPTIS.

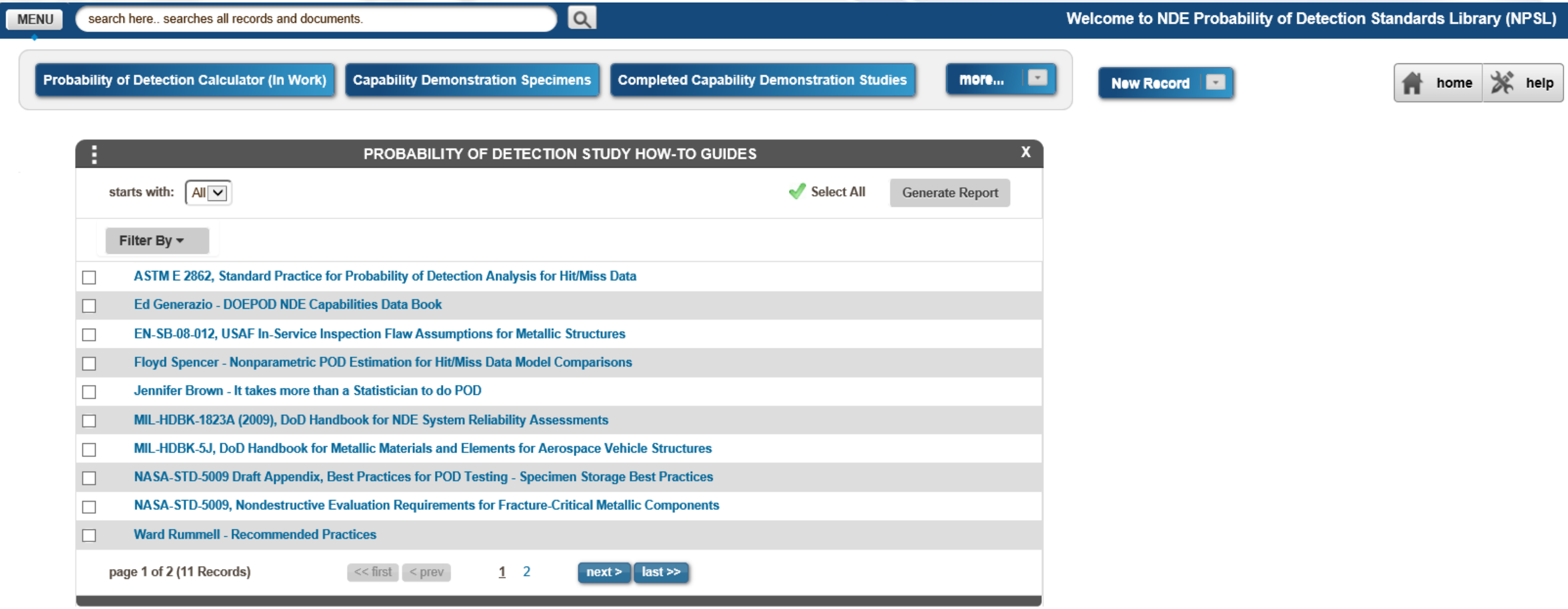
Also logs Phase 1 specimens for agency support and dissemination.

NDE Probability Standards Library NPSL) Database – Main Menu

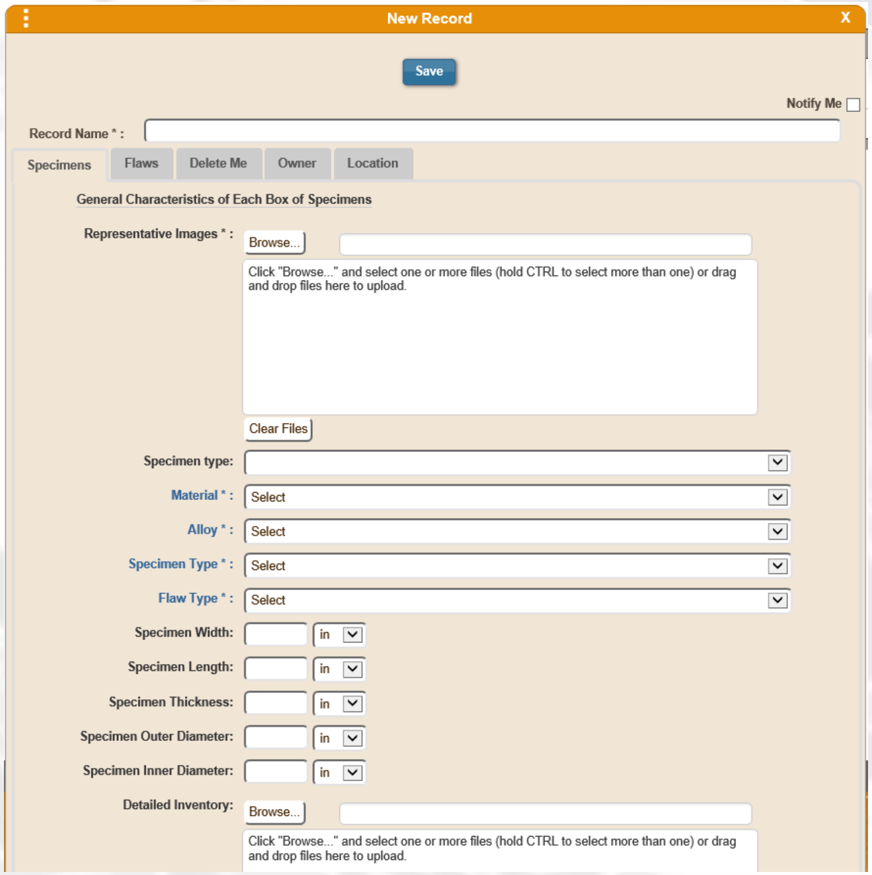


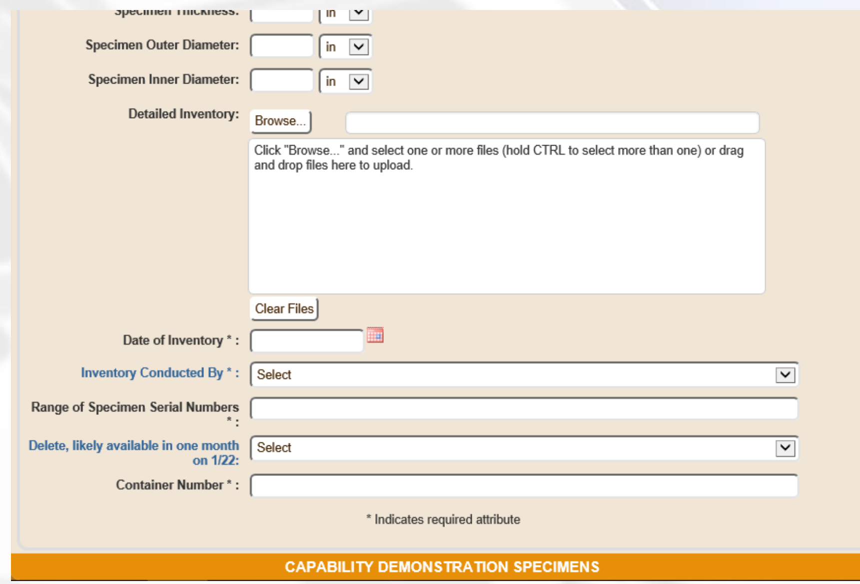
Under Construction. Likely to go live in June:
https://maptis.ndc.nasa.gov/Athena/ViewRecords.aspx?pk=32

NPSL Database – How-To Guides (Draft)



NPSL Database – POD Specimens (Draft)





NPSL Database – POD Studies (Draft)

New Record X

Save

Notify Me

Record Name * :

Capability... | Certified ...

NDE Capability Demonstration Study

Location: Select

NDE Method: Select

Material * : Select

Alloy * : Select

Files & Report * : Browse...

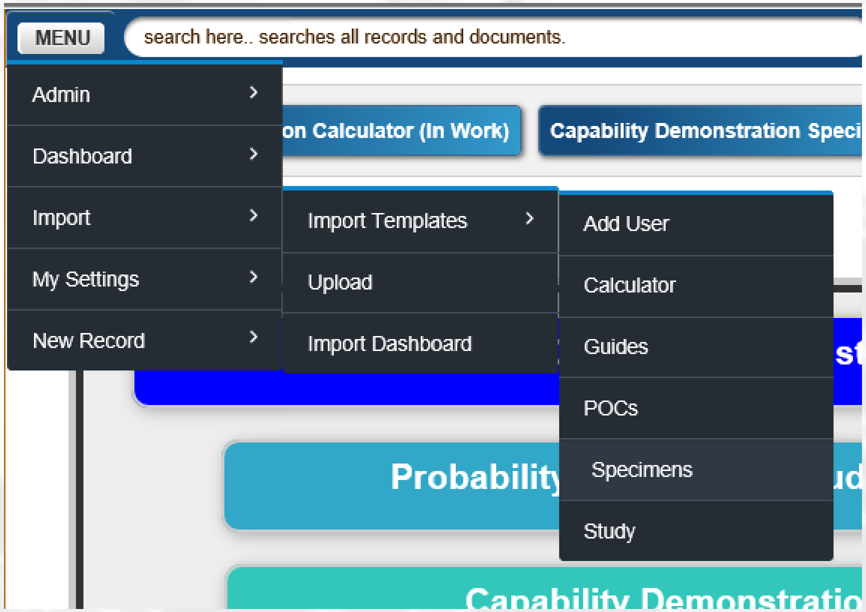
Click "Browse..." and select one or more files (hold CTRL to select more than one) or drag and drop files here to upload.

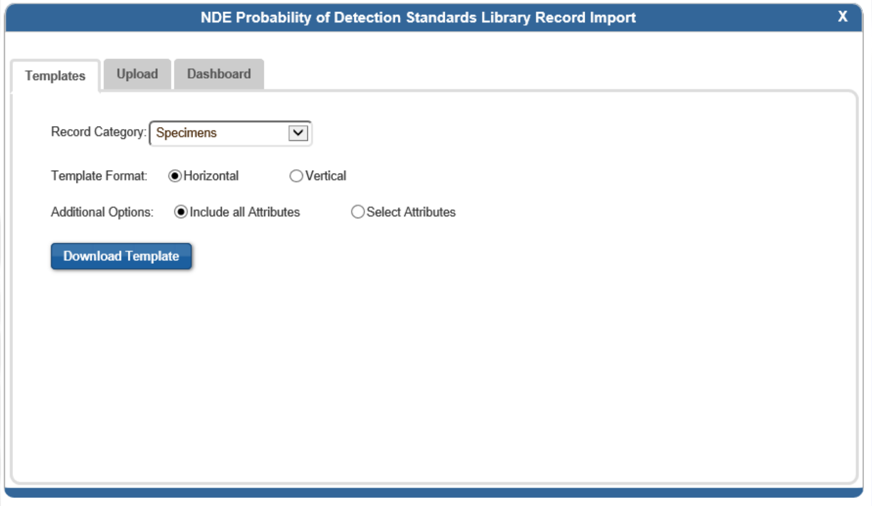
Clear Files

* Indicates required attribute

COMPLETED CAPABILITY DEMONSTRATION STUDIES

NPSL Database – Upload Templates

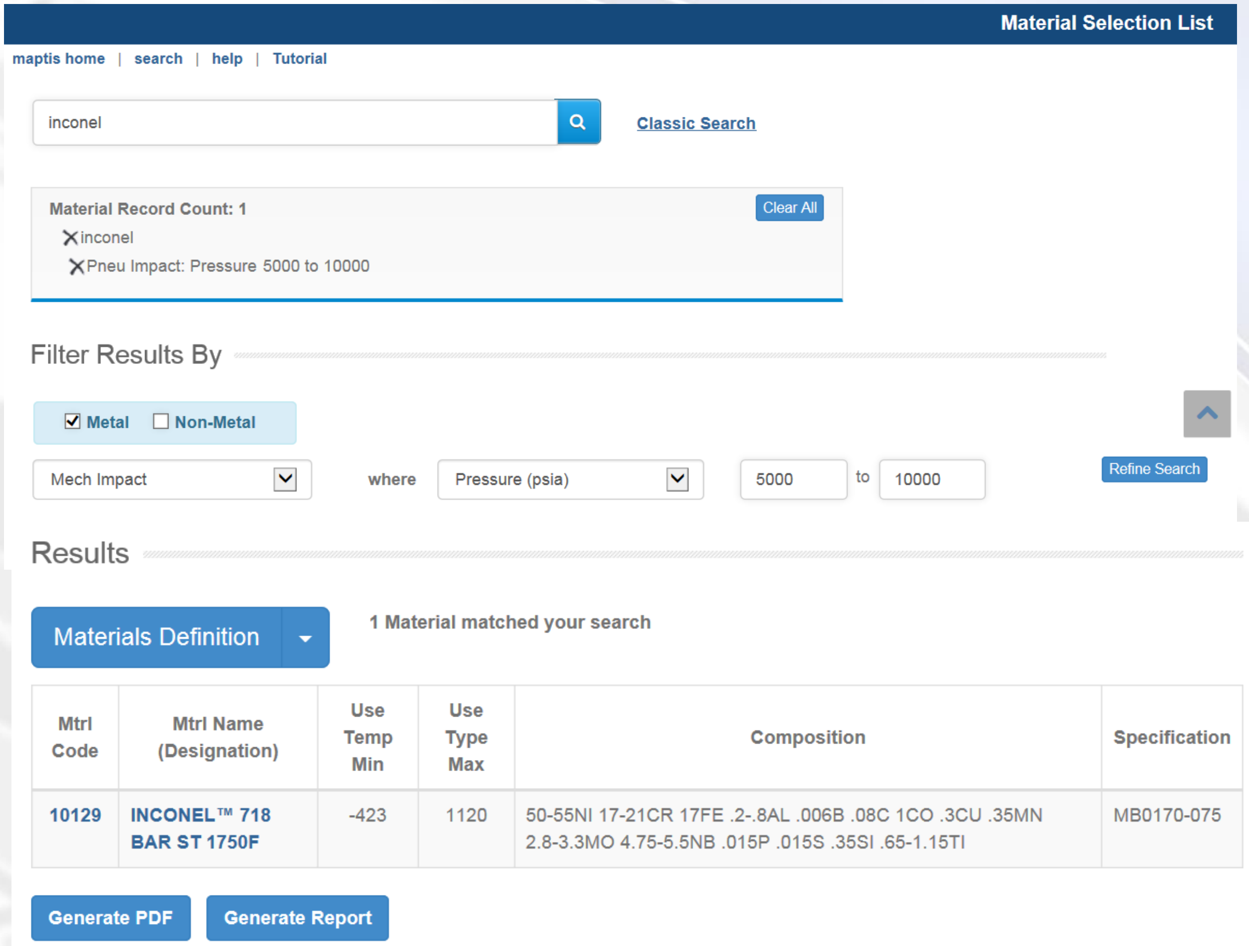




Results in a MS Excel spreadsheet laid out to enable rapid, batched uploads.

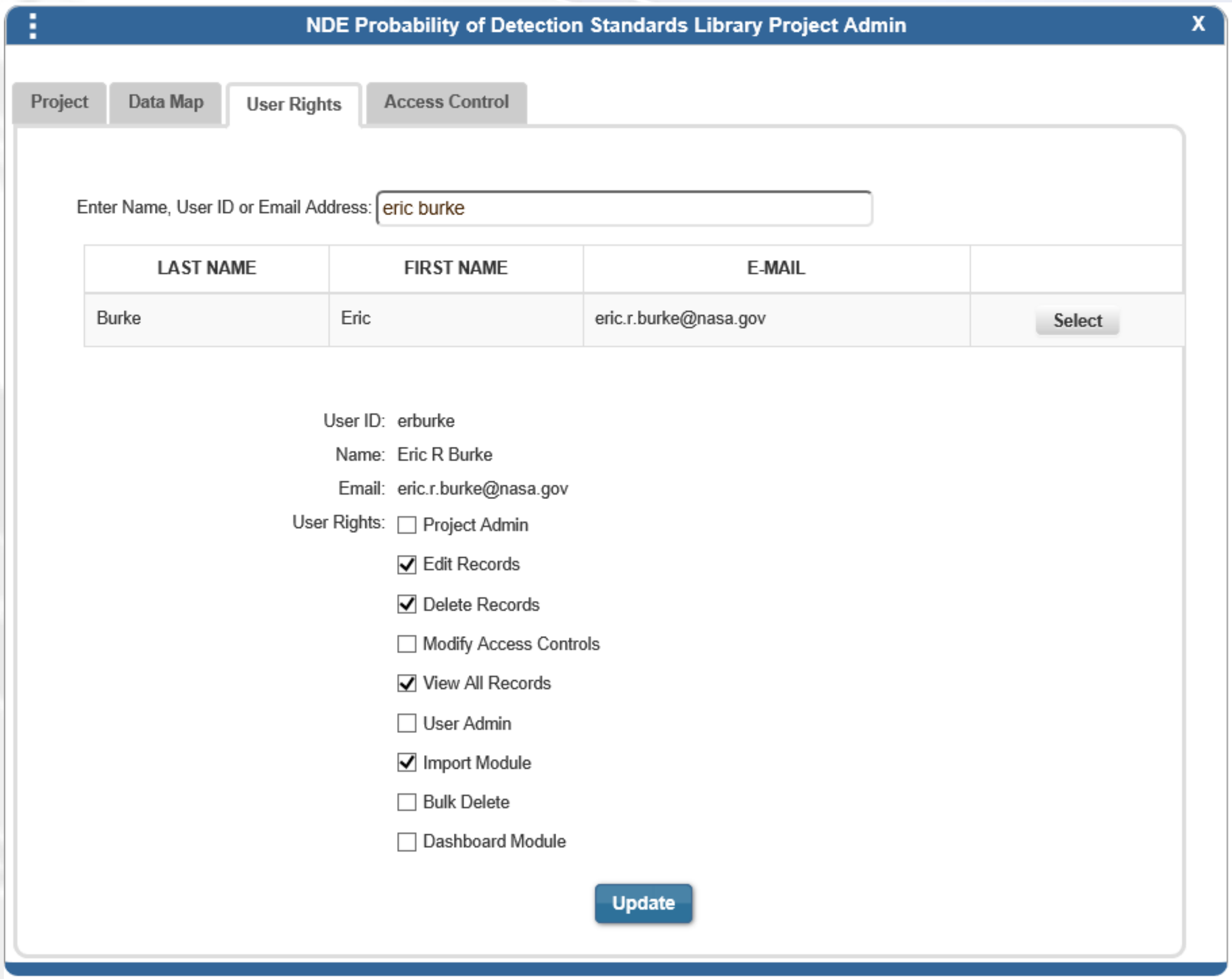
Users can just copy > paste into the appropriate column from existing tables.

NPSL Database – Search & Reporting Features



Example: Material Selection Database, Link: https://maptis.ndc.nasa.gov/matsel/

NPSL Database – Access Controls



Schedules/Milestones

- ✓ FY15: Inventory all data; identify and fill gaps, should they exist. Provide a Best Practices appendix to NASA-STD-5009. Include recommendations for long-term sample storage.
- ✓ FY16-17: Analyze and log the following NNWG POD standards –*NDE Methods: UT, RT, ET, & PT*. Not practical to accomplish in one year under given resources.
  - About 60 studies would need to be performed. Three studies were wrapped up.
    - ~101 flat plates with fatigue cracks (Al, INCO, & Ti)
    - 61 plate weld specimens with lack of fusion (Al & Ti)
    - 20 plates welded with an EDM notch specimens (Al, INCO, SS & Ti)
    - ~33 1” or 2” tubes welded with an EDM notch (INCO, SS)
    - ~61 1” or 2” tubes welded with lack of fusion (INCO & SS) and
    - 61 fastener hole crack specimens (Al & Ti)
- ❑ FY17+: Alpha test/approve NPSL entry and query capabilities. Create a platform-independent POD analysis tool Extract, interpret, and integrate macros from DOEPOD into NPSL.
    - Code in MLE as presented in NASA/TM–2014-218183, April 2014.
    - Add internal and external validation test for MLE estimates (these have been draft coded into DOEPOD, but not released).
- ❑ Proposed for FY18-19: Test and approve NPSL entry and query capabilities. Create a platform-independent POD analysis tool
    - Code in MLE as presented in NASA/TM–2014-218183, April 2014.
    - Add internal and external validation test for MLE estimates (these have been draft coded into DOEPOD, but not released).

Customers

NASA Infusion

1. Having a central catalog of POD studies provides a number of benefits: tracking POD study values across a wide variety of parameters to establish precedence via a living database, auditable sources for POD studies and inspector certs, alerting Center reps to looming inspector recertification expiration (2-year certs per NASA-STD-5009), the ability to learn how other Centers qualify NDE, etc.
2. Once Center surveys are completed, the database will serve as a centralized NASA library for locating the specimens and resources needed to perform capability demonstration studies. As these specimens can be very expensive to produce, collaboratively sharing resources and reducing duplicated efforts has the potential for saving programs and agency NDE practitioners thousands of dollars each year.
3. Later, addition of a POD calculator to the database will reduce the practice of using multiple tools across NASA to run estimations.

U.S. Air Force

- Though the necessary validation, security protocols, and database population will take some time, the project team wishes to make NPSL accessible by agency partners across the country. This is unprecedented. There is some USAF interest in an updated database based on Berens and Hovey POD v3 implementing MIL-HDBK-1823, but this has not yet come to pass.

U.S. Navy

- NASA collaboration through NAVSEA/NUWC is a possibility on some submarine work, however the USAF remains the most prolific user of POD throughout the U.S. military.

Products

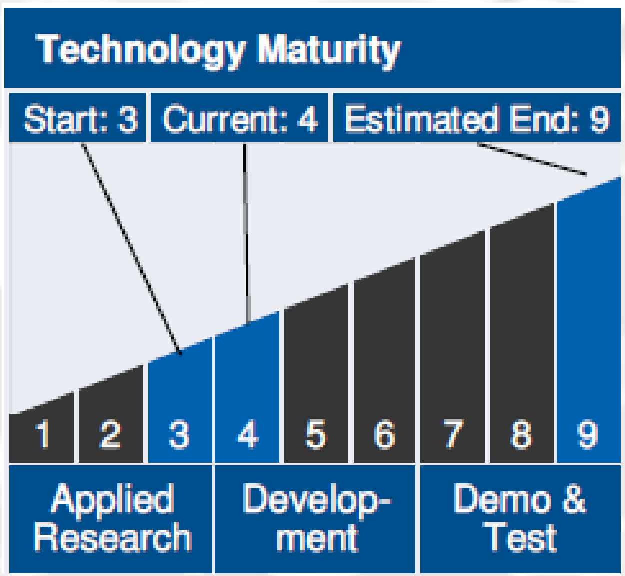
Publications

1. Binomial Test Method for Determining Probability of Detection Capability for Fracture Critical Applications (http://ntrs.nasa.gov/search.jsp?R=20110015149)
2. Directed Design of Experiments for Validating Probability of Detection Capability of NDE Systems (DOEPOD), NASA TM 2015-218696 (http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20150013987.pdf)
3. Interrelationships Between Probability of Detection Methodologies, NASA/TM–2014-218183 (http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20140005337.pdf)
4. NASA DOEPOD NDE Capabilities Data Book, NASA TM 2015-218770 (http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20150013943.pdf)
5. OSMA's NDE Program Published Capabilities Data Book, OSMA Website

Patents

1. US Patent 8108178, Directed Design of Experiments for Validating Probability of Detection Capability of a Testing System (http://www.anypatents.com/patents/US8108178)

Metrics



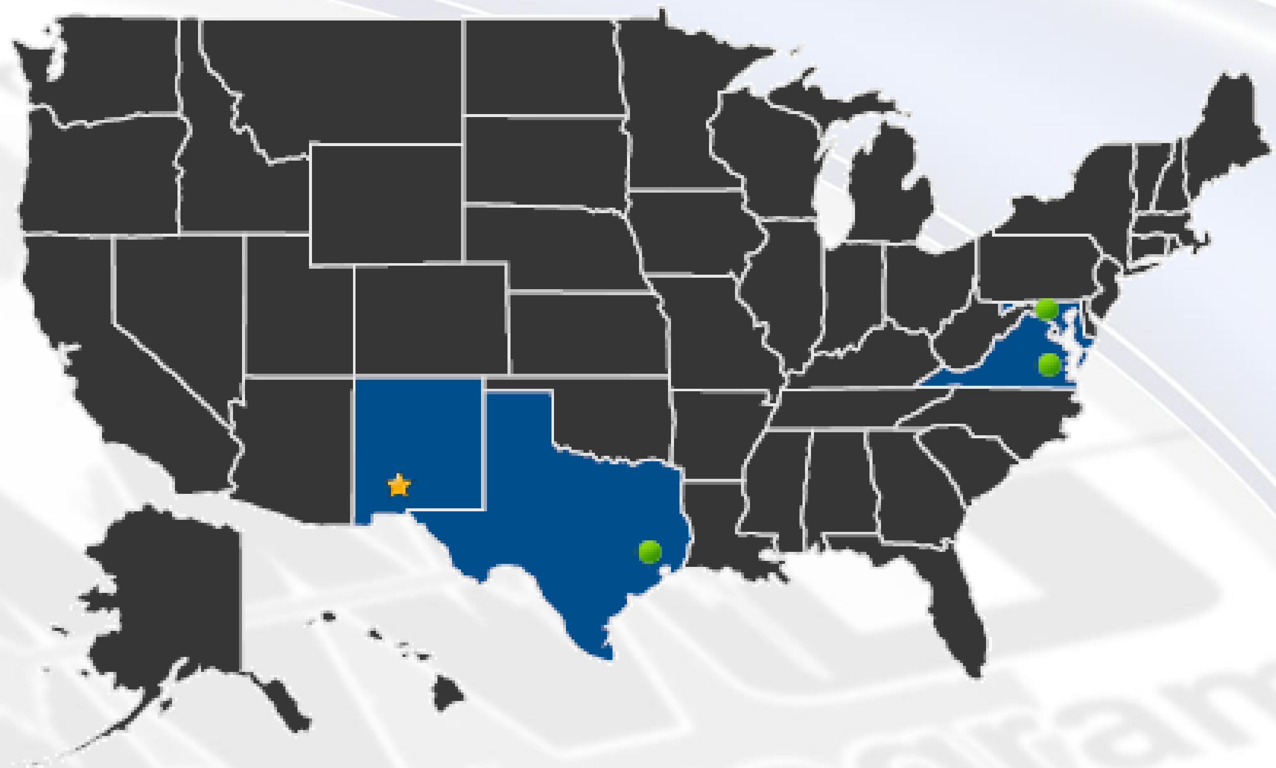
Technology Areas

Materials, Structures, Mechanical Systems and Manufacturing (TA 12)

- Nondestructive Evaluation Sensor and Method (TA 12.4.5.1)

Cross-Cutting (no content) (TA 12.5)

U.S. WORK LOCATIONS AND KEY PARTNERS



U.S. States With Work

Lead Center:
White Sands Test Facility

Supporting Centers:

- Goddard Space Flight Center
- Johnson Space Center
- Langley Research Center

Acknowledgements

- Ed Generazio: DOEPOD
- Bill Prosser: training
- Ajay Koshti: training
- Ward Rummel: POD methods
- Floyd Spencer: POD analyses
- Jordan Wladyka: PL
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- Laura Cerecerez
- Sandy Montoya
- Jess Waller: best practices
- Jill George
- Justin Jones: archiving
- Brad Parker
- Judy Corbett: NPSL
- Ken Hodges: -5009
- Jennifer Petry
- Eric Burke
- John Aldrin
- Jennifer Brown: POD statistical methods
- Mike Suits: -5009
- Ben Henrie & Teresa Miller: MAPTIS

Q & A

- For further information, refer to the following report:

  Link: https://techport.nasa.gov/view/32921

- Point of Contact:

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