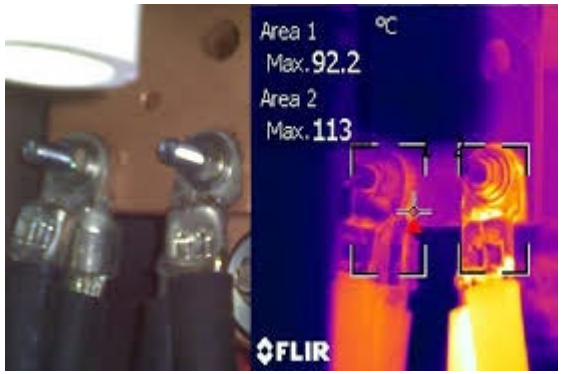
RSL ADVANCED LIGHTING TECHNOLOGIES

NSRP 2023 Panel Project 2019-477-04
DTS Integration into Electrical Plant Controls for Conditions Based Maintenance

FINAL REPORT & FOLLOW-ON EFFORTS

September 17, 2024



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NSRP
NATIONAL SHIPBUILDING RESEARCH PROGRAM™
Taking Shipbuilding and Repair to the Next Level

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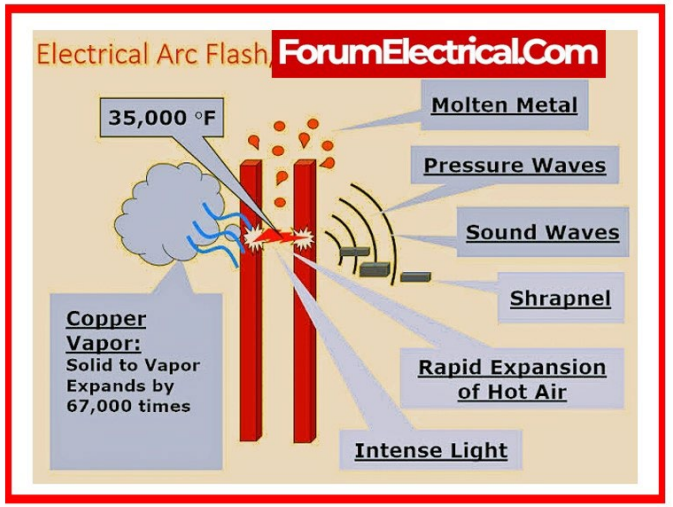
Problem Statement

1. **Potential of electrical system faults can not be predicted in real-time.**
   - Periodic open-door maintenance inspection of all connections are required every 6 to 12 months:
     - Putting personnel at risk of injury.
     - Maintenance costs an average of $3 million/year to surface fleet[1].

Increasing complexity of ship's electrical systems will make the problem worse.

2. **Faults are expensive!**
   - Arc faults average 8/yr throughout the U.S. Navy fleet switchboards and load centers [2].

   - Electrical fires cost $6 billion over past 12 years[3].
   - $3 million/year estimated cost arc fault repairs and availability delays.



3. **Current inspection technologies do not collect data to support Condition Based Maintenance (CBM)**

1) Based on avg. 15 switchboards per ship, 16 hrs. inspection, $ 80/hr., 157 surface combatants, 1 inspection per year.
2) J. Callen, Penn State Electro-Optics Center, "Distributed Temperature Sensing for Inspection of Electrical Panels on Navy Ships", NSRP Meeting, March 2017.
3) Naval Sea Systems Command Office of Corporate Communications, "NAVSEA establishes new group to improve industrial fire safety", December 6, 2021.

NSRP PROJECTS EVOLUTION - INSPECTION OF ELECTRICAL ASSETS

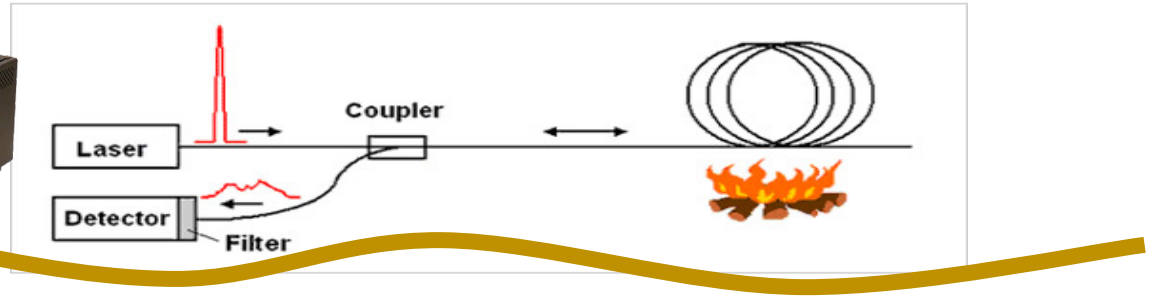
OBJECTIVES:

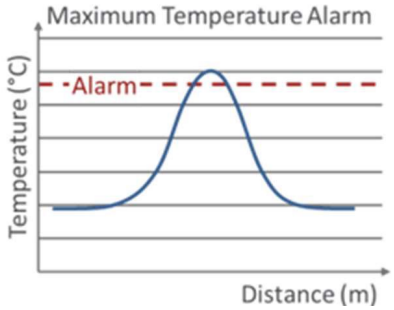
- Prevent damage due to loosened connections in switchboards (arcing).
- Reduce risk to personnel.
- Reduce maintenance costs.
- **Perform Condition Based Maintenance (CBM).**

- **2015 – PSU EOC**, HII-Ingalls, SUPSHIP GC: Reduce risk of inspection of MV Electrical panels by use of windows for IR thermal imaging.
- **2015 – RSL Fiber Systems** presents fiber optic Raman DTS at NSRP Electrical Technologies Panel mtg (San Diego).
- **2017 – PSU EOC**, HII-Ingalls, SUPSHIP GC: Evaluation of DTS for monitoring MV electrical panels.
- **2019*** – **Hepburn & Sons**, RSL FS: Raman DTS to monitor connections of Insulated Bus Pipe (IBP).
- **2020* – Hepburn & Sons**, RSL FS: Raman DTS to monitor IBP connections to equipment.
- **2023 – RSL Fiber Systems**, NAVSEA 05Z33, NSWC PD, BIW, PSU EOC: DTS Integration into Electrical Plant Controls.
- **2025** – RSL Fiber Systems,** NAVSEA 05Z33, NSWC DD, SUPSHIP GC, Austal USA, Ingalls Shipbuilding, PSU EOC: DTS Applications on U.S. naval vessel.
- **2025*** – RSL Fiber Systems,** NAVSEA 05Z33, NSWC PD, NSWC DD, Austal USA, PSU EOC: DTS Installation on U.S. naval vessel.

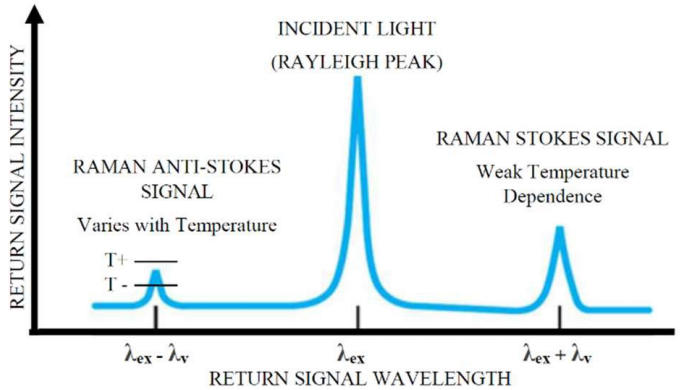
* NSRP Research Announcements
** Proposed 2025 NSRP Panel project
*** Proposed 2025 NSRP Research Announcement

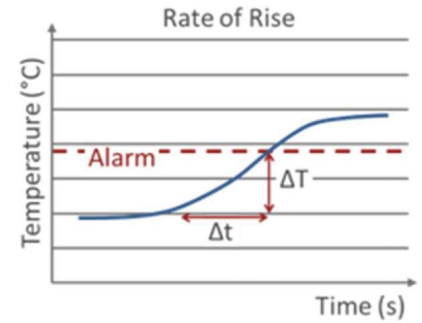
Fiber Optic Distributed Temperature Sensing

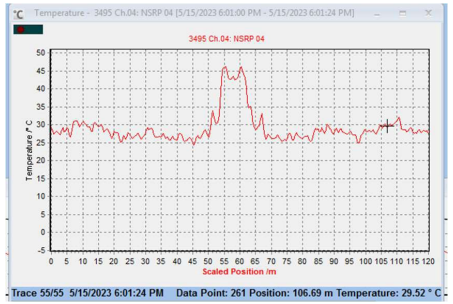


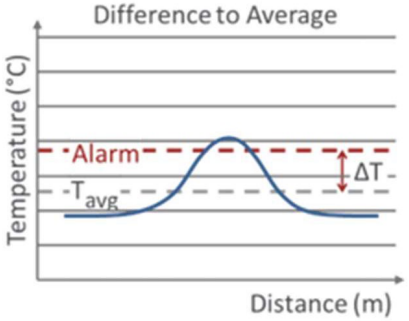


- Based on Raman Scattering.
- **Entire fiber is the sensing unit** – up to,000's of programmable zones per fiber channel.
- Temperature rise of 0.1°C
- Spatial Resolution down to 50 cm.
- Zones can overlap and encompass multiple zones.
- Multiple warnings / alarms can be set in each zone.
- Standard MM 50/125, 62.5/125 or SM fiber.
- Up to 30 Km MM, 40 Km SM - real time monitoring across entire length.









DTS Technology Advantage

- **Existing Smoke and Corona Detectors**
  - Identify fault(s) once they become critical limiting time to remediate.
  - Do not provide exact location of requiring the open-door inspection of all connections.

- **Detection via Raman Scattering DTS**
  - Monitors temperature in real-time using entire length of the fiber.
  - Enables personnel to detect faults, isolate location, determine severity and define action.
  - Collects historical data for further analysis and prediction of potential future events.

- **DTS Technology at a readiness TRL 9**
  - Used commercially in applications such as fire detection, data centers, machinery.
  - DTS sensing assembly viability proven by 3 NSRP projects.
  - ***Can be ready for full shipboard implementation w/in 3 years (2 yrs. RA + 1 yr. Qualification).***

- **NSRP Technology Investment Plan (TIP/SIP 7.3) Focus Areas**
  - Enhance occupational health, safety;
  - Implement new inspection and maintenance processes;
  - Improve early condition assessments and prognostic monitoring tools to support condition-based maintenance and structural health.

DTS IMPLEMENTATION OBJECTIVE - DATA ANALYTICS

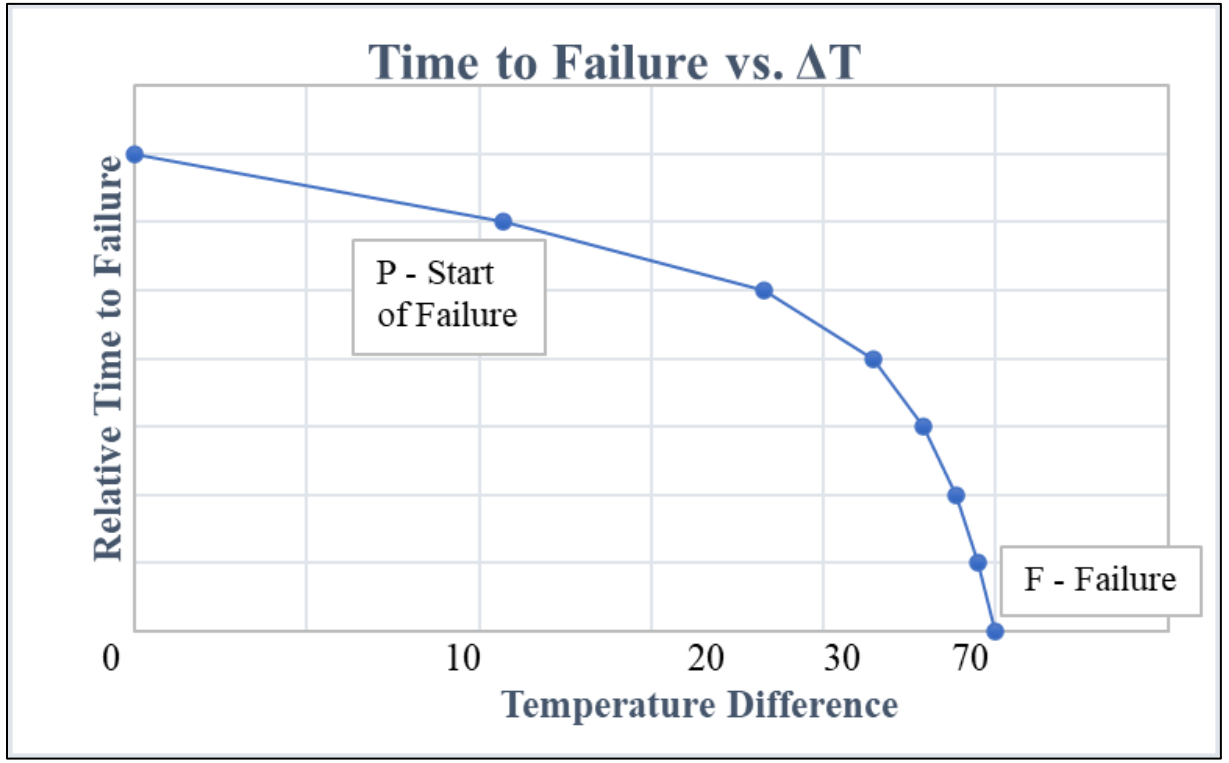
CONDITION BASED MAINTENANCE

Define Prevention – Failure (P-F) curve for LV, MV, and HV electrical panels from data collected by DTS system.

Priority	Temp Rise or ΔT	Operational Assessment	Severity Code	Action
1	≥ 70°C	Failure Imminent	****	Equipment should be secured immediately and not operated until repairs are complete.
2	40°C to < 70°C	Failure Almost Certain	***	Equipment should be secured if operating conditions permit otherwise monitored until corrective action can be taken.
3	20°C to < 40°C	Failure Possible	**	Corrective action should be taken as soon as feasible.
4	5°C to < 20°C	Performance Degraded	*	Corrective action should be taken at next scheduled routine maintenance period or as schedule permits.
	< 5°C	N/A	N/A	No corrective action required; note for future reference.

Table from MIL-STD-2194*

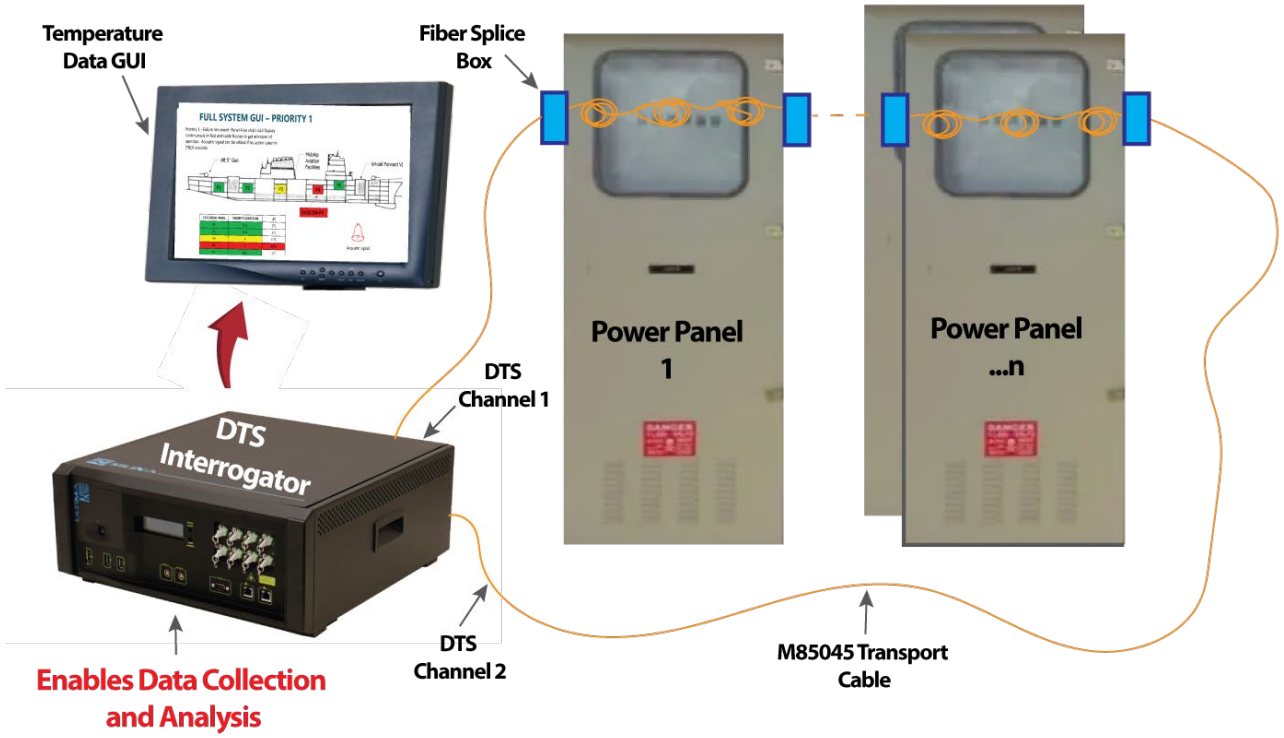
(*) Obsolete but same table used in other MIL STD documents.



NOTE: Graph for illustrative purpose only. Not based on actual data.

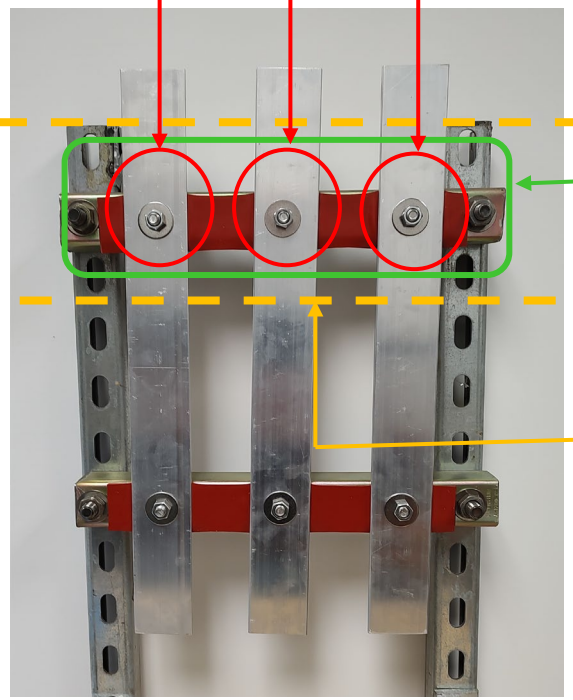
Application to Shipboard Panels

- **Use the entire Length of Fiber** to senses temperature in real time.
  - Absolute temperature (T) of cables to busbar connections.
  - $\Delta T/\Delta t$ of connections.
  - ΔT between connections of three phase busbars.



- **Single DTS interrogator can monitor multiple panels.**
- Recorded temperature data can be split into up to 000's **programmable zones** per fiber channel.
- Multiple **warnings/alarms** can be set in each zone to alert to temperature deviations.
- **Single interrogator** with 10,000's zones or **multiple interrogators** with 1,000's zones for redundancy.

EXAMPLE – DEMO OF 3 PH. PANEL



Zones 1, 2, 3: Individual Connections
Temperature of Each Connection (T)
Rate of Temperature Change (ΔT/Δt)

Zone 4: Three Phase Busbars (3)
Difference in Temperature between Three Connections (ΔT)

Zone 5: Entire Panel (all Busbars + Connections)
Temperature within entire Panel (T)
Difference in Temperature (ΔT)
Rate of Temperature Change (ΔT/Δt)

ZONE #	ZONE NAME	START	END	MONITORING	Pre-Alarm @ Temp	Alarm @ Temp
1	Connection 1	76.7	78.7	Min & Max T, ΔT/Δt	> 50°C & ΔT/Δt > 5/60	> 80°C & < 10°C
2	Connection 2	71.6	73.6	Min & Max T, ΔT/Δt	> 50°C & ΔT/Δt > 5/60	> 80°C & < 10°C
3	Connection 3	66.2	68.7	Min & Max T, ΔT/Δt	> 50°C & ΔT/Δt > 5/60	> 80°C & < 10°C
4	Busbars 1-2-3	66.2	78.7	ΔT between C1, C2, and C3	Δ>10°C	Δ>25°C
5	Full Panel	20	120	T, ΔT, ΔT/Δt in Panel	> 50°C, > 5/60, & Δ>10°C	> 80°C, > 10/60, & Δ>25°C

2023 NSRP PANEL PROJECT

DTS Integration into Electrical Plant Controls

Project 2019-477-004

Detect → Isolate → Determine Severity → Define Action

Monitor temperature of connections in U.S. Navy ships' Medium Voltage (MV = 4,160 VAC) electrical panels in real time to detect loosening connections and prevent arc flashing by collecting and providing actionable data.

TASKS

1. Methodology to secure the fiber optic sensors to the electrical connections.
2. Configure the GUI to display actionable Condition Based Maintenance data collected by the DTS.
3. Create baseline guidelines and specifications to qualify and implement DTS on Navy vessels.
4. **Provide baseline for project to finalize development and qualify DTS system for panels monitoring.**

TEAM MEMBERS

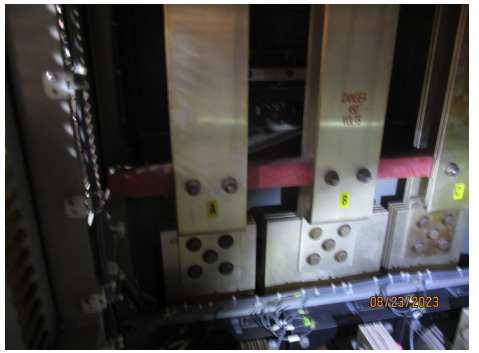
- Prime/Lead: RSL Fiber Systems, LLC
- Team Members: Penn State University – ARL, General Dynamics – Bath Iron Works, DV7 Engineering, Silixa, NAVSEA 05Z33, NSWCPD.
- Program Technical Representative: Jason Farmer, Ingalls Shipbuilding.

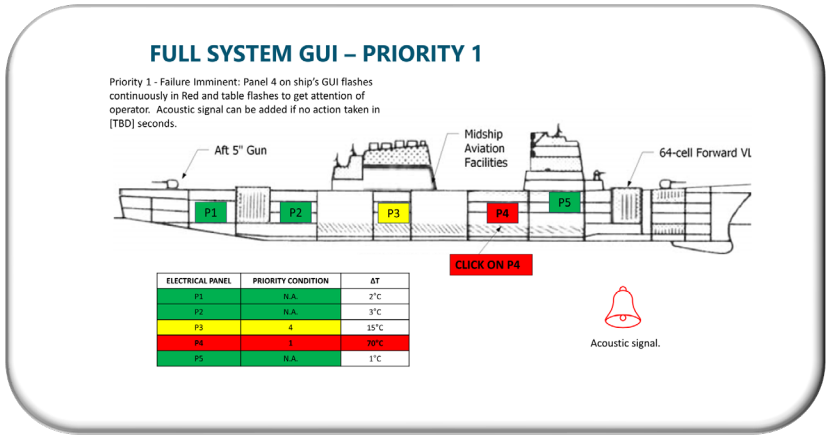
ROI

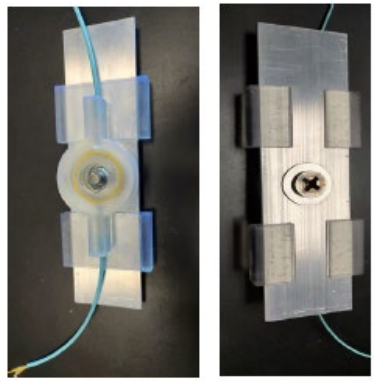
- **Reduce labor costs** by eliminating the need to perform thermal imaging and troubleshooting on energized panels.
- **Eliminate the safety hazards** involved in visually inspecting energized electrical panels.
- **Eliminate the risk of fire** and conductors' damage resulting from loose electrical connections.
- Constant monitoring of bolted connection temperatures will alert to early occurrence, **prevent unexpected failures**, reduce troubleshooting time and eliminate the need to make temperature measurements on an energized panel.

2023 NSRP DTS PROJECT SUMMARY

- Four (4) Hands-On System Demonstrations + one (1) On Ship Visit.
  - **Dedicated processor & display** to simplify cybersecurity requirements.
  - **LV panels (450 VAC)** candidate for DTS → many on ships w/ faults most common.
  - **Install assemblies after power cables** to prevent damage.
- Molded assemblies' shapes to **attach without straps**.
  - **90°C Max normal operation and 120°C Max excursions**.
    - NSRP 2019-477-03 Cable Jacket Panel Project identified materials.
- Developed outline for Graphical User Interface.
- Developed outline for DTS Implementation → system **configuration, installation, commissioning, and maintenance**.
- Baseline for follow-on projects:
  - PP: Identification of additional DTS applications.
  - RA: installation of DTS on naval vessel.

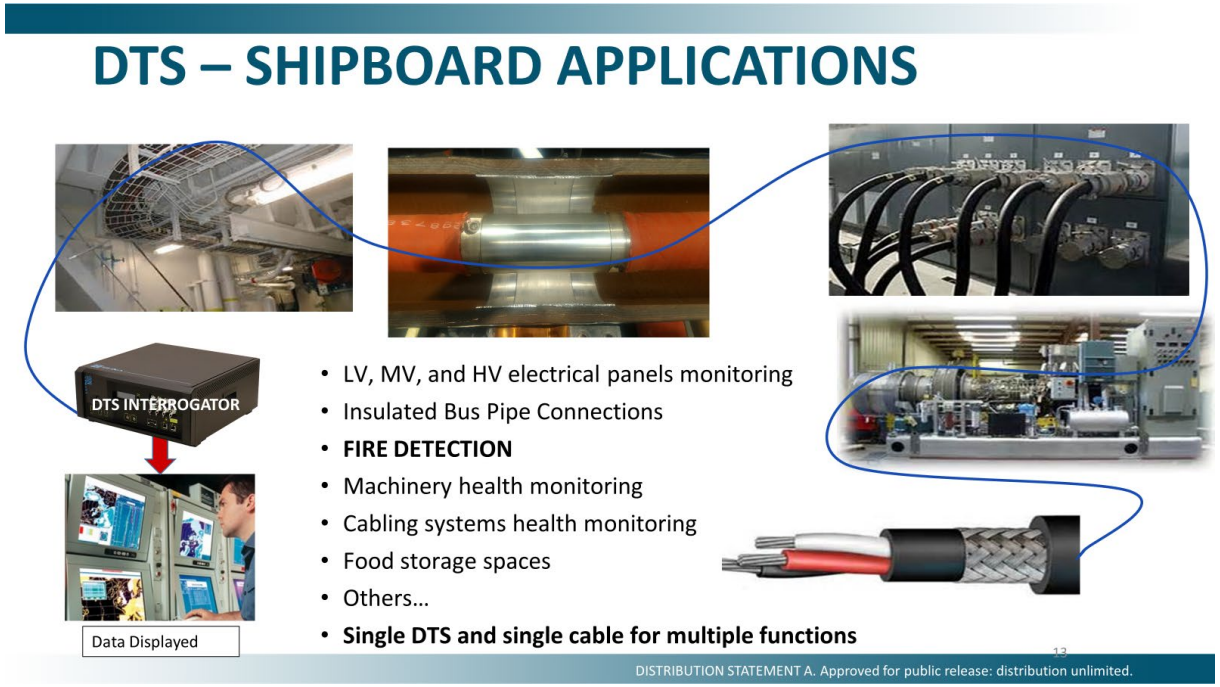






TECHNOLOGY TRANSFER

- Presented at **MFPT 2023**
  [Co-Authors: G. Tomasi, C. Nemarich]
- Presented at **SNAME SMC 2023**
  [Co-Authors: G. Tomasi, C. Nemarich and R. DeLoge]
- Presented at **ShipTech 2024**
  [Co-Authors: G. Tomasi, C. Nemarich and R. DeLoge]
- **Hands-on demonstration** at HII-NAVSEA CHENG meeting [G. Tomasi, C. Nemarich]
- Paper to be Published in **ASNE Journal** [Co-Authors: G. Tomasi, C. Nemarich, B. Whaley, and R. DeLoge]



Proposed Follow-on 2025 NSRP Projects:

- *Panel Project to **investigate other applications** for DTS.*
- *Research Announcement to **install DTS on an in-service naval vessel**.*

NSRP RA - INSTALLATION OF DTS ON NAVAL VESSEL FOR ELECTRICAL PLANT MONITORING

PHASE 1

Task 1 – Finalize Configuration of the Sensing Assemblies

- Attachment methods & Materials

Task 2 – Determine optimal Configuration of the DTS Hardware

- Single unit with 10,000's zones vs. multiple units w/fewer zones.

Task 3 – Configure the Monitoring Software and Graphical User Interface

Task 4 - System Installation on DDG 51 land-based facility in Philadelphia.

- Define methods, configuration, and operation for on-ship Install.
- Baseline for Ship Change Document (SCD) for Temp Alt.

Task 5 – Training

- Train AITs and Navy personnel in DTS installation and maintenance.

PHASE 2

Task 6 – Installation Planning

- Generate SCD for the Temp Alt.
- Finalize ship for install, identify location of equipment, GUI, warnings/alarms.

Task 7 – Installation

- Install and verify functioning of DTS system.
- Map sensing zones, program alarms, perform system check.

Task 8 – Operation on Navy Ship

- Make modifications as required based on feedback from ship's personnel .

Task 9 – Generate a Document Defining the DTS System Requirements

- Hardware, Qualification testing, Installation procedures.
- System set up, validation, acceptance testing, repair, and maintenance procedures.

Qualification and Full-Scale Implementation

NSRP PP - INVESTIGATION OF APPLICATIONS OF DTS ON NAVAL VESSELS

- Use lessons learned on the DTS integration project 2019-477-004 as baseline.
  - Use questions / feedback from demonstrations and technology transfer activities.
- Investigate other applications where temperature detection may identify problems / issues.
  - Determine if Raman DTS is optimal or other sensing technology may be used.
- Determine how Raman DTS can be adapted to the application.
  - Evaluate system requirements, modifications, suitability of utilizing existing assets (example: fiber network).
  - Outline future efforts to implement DTS for the application.

QUESTIONS?

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