

# EVALUATION OF RISK AND POSSIBLE MITIGATION SCHEMES FOR PREVIOUSLY UNIDENTIFIED HAZARDS

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# Previously Unidentified Hazards

- ✍ Orbiter is docked at the International Space Station (ISS)
  - ✍ Un-commanded firing of the reaction control system (RCS) jets » damage or loss of Orbiter and ISS.
- ✍ One proposed scenario:
  - ✍ Arcing in the 28 VDC heater circuit wire transfers enough power to open fuel/ox valve.

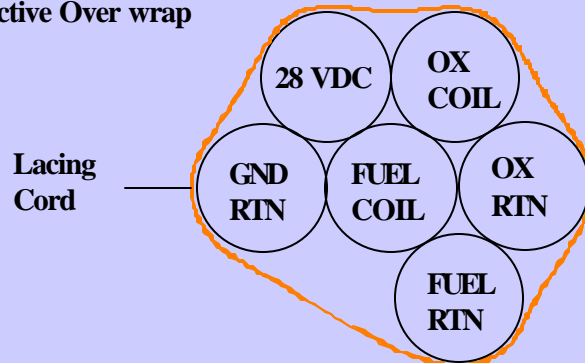
# Goal of These Experiments

- ✍ Possibility of arcing causing an un-commanded firing of the RCS jets.
- ✍ Effectiveness of different segregation methods.
- ✍ The goal was not to examine the probability of an arc track event occurring.

# Bundle Configurations (Slide 1 of 2)

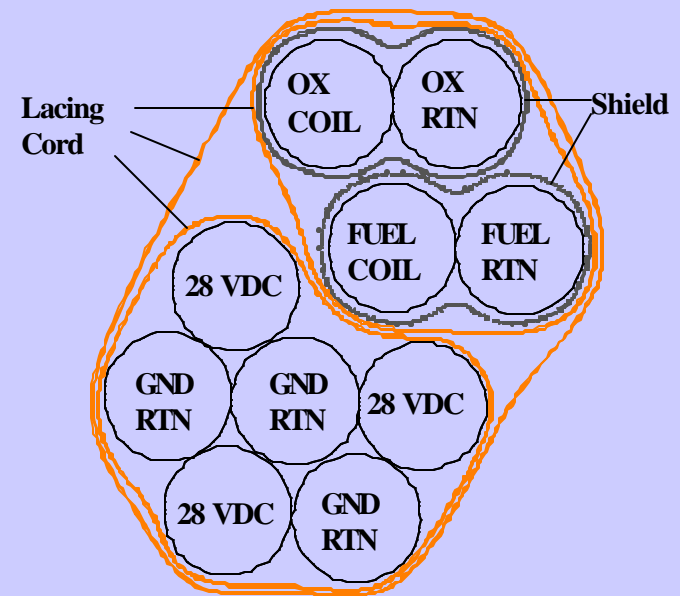
## Configuration 1: 1 Power Circuit

Fuel/Ox Wires: Twisted Quad  
No Protective Over wrap



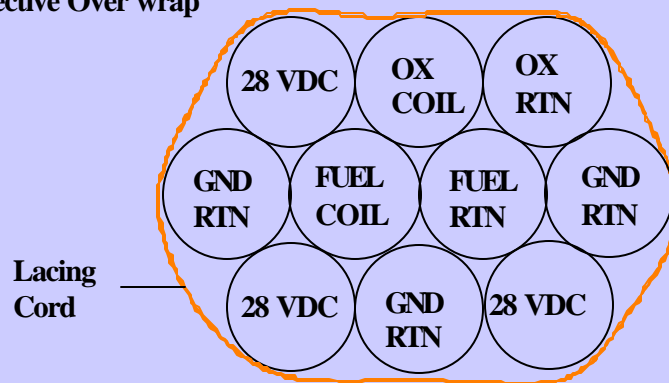
## Configuration 2: 3 Power Circuits

Fuel/Ox Wires: 2 Shielded Twisted Pair  
No Protective Over Wrap



## Configuration 1: 3 Power Circuits

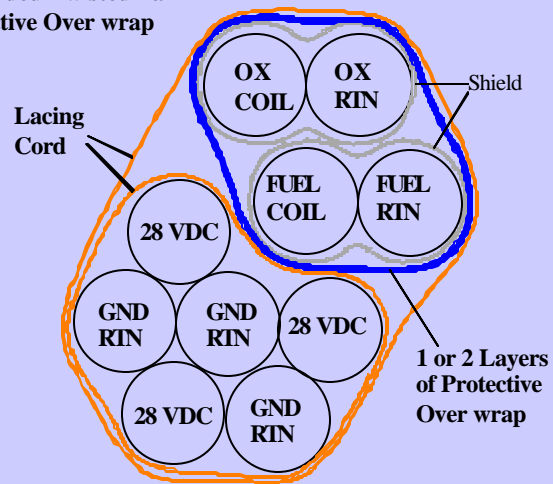
Fuel/Ox Wires: Twisted Quad  
No Protective Over wrap



# Bundle Configurations (Slide 2 of 2)

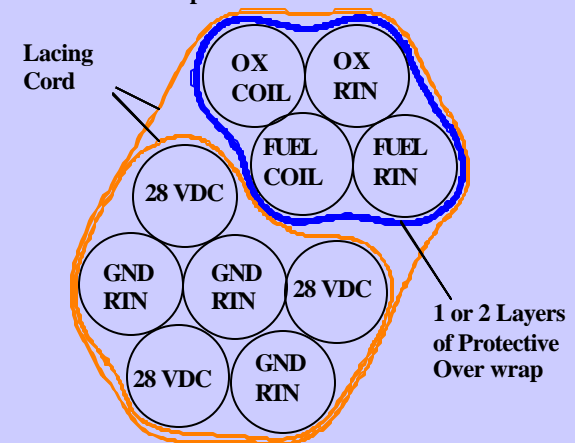
## Configuration 3: 3 Power Circuits

Fuel/Ox Wires: 2 Shielded Twisted Pair  
1 or 2 Layers of Protective Over wrap

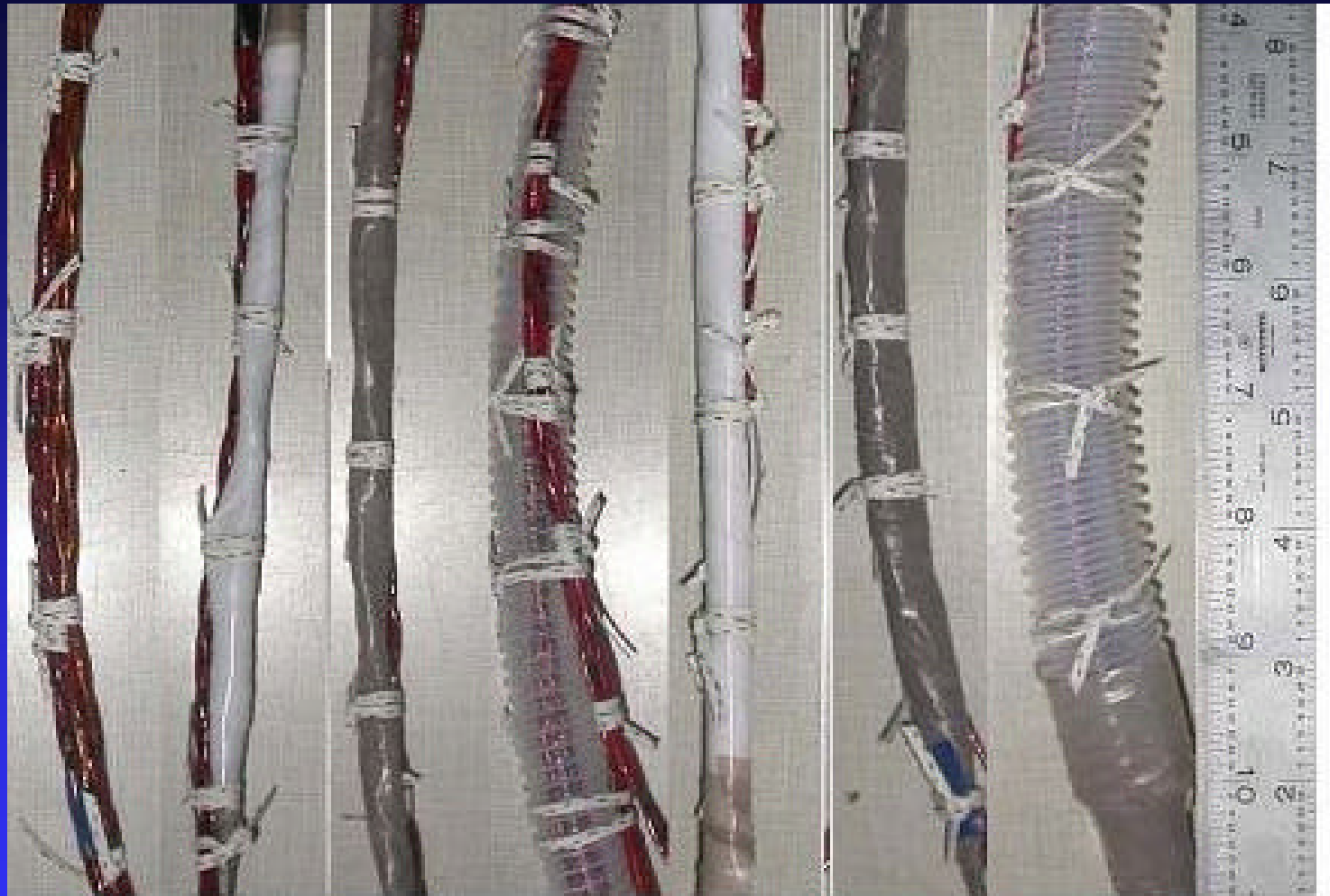


## Configuration 4: 3 Power Circuits

Fuel/Ox Wires: 2 Twisted pair  
1 or 2 Layers of Protective Over wrap



# Specimens with Various Protection Configurations



Shielded  
Twisted Pair  
No Protection

1 Layer  
PTFE Wrap

1 Layer  
Mystik  
(3 wraps)

1 Layer  
Convolute

2 Layers  
PTFE Wrap

2 Layers  
Mystik

2 Layers  
Convolute

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# Twenty-nine Different Test Configurations

| Test #       | Harness Config # | # Heater Circuits | Fuel/Ox Wire | Protection Schemes |                 | Circuit Protection (fuse rating) |
|--------------|------------------|-------------------|--------------|--------------------|-----------------|----------------------------------|
|              |                  |                   |              | 1st Layer (Bottom) | 2nd Layer (Top) |                                  |
| N264 1-5     | 1                | 1                 | Twist Quad   | NA                 | NA              | 15 A                             |
| N264 6-10    | 1                | 3                 | Twist Quad   | NA                 | NA              | 15 A                             |
| N264 11-15   | 2                | 3                 | 2 Sh/Tw/Pair | NA                 | NA              | 15 A                             |
| N264 16-20   | 3                | 3                 | 2 Sh/Tw/Pair | PTFE Wrap          | None            | 15 A                             |
| N264 21-25   | 3                | 3                 | 2 Sh/Tw/Pair | Mystik             | None            | 15 A                             |
| N264 26-30   | 3                | 3                 | 2 Sh/Tw/Pair | Convolute          | None            | 15 A                             |
| N264 31-35   | 3                | 3                 | 2 Sh/Tw/Pair | PTFE Wrap          | PTFE Wrap       | 15 A                             |
| N264 36-40   | 3                | 3                 | 2 Sh/Tw/Pair | PTFE Wrap          | Mystik          | 15 A                             |
| N264 41-45   | 3                | 3                 | 2 Sh/Tw/Pair | PTFE Wrap          | Convolute       | 15 A                             |
| N264 46-50   | 3                | 3                 | 2 Sh/Tw/Pair | Mystik             | PTFE Wrap       | 15 A                             |
| N264 51-55   | 3                | 3                 | 2 Sh/Tw/Pair | Mystik             | Mystik          | 15 A                             |
| N264 56-60   | 3                | 3                 | 2 Sh/Tw/Pair | Mystik             | Convolute       | 15 A                             |
| N264 61-65   | 3                | 3                 | 2 Sh/Tw/Pair | Convolute          | PTFE Wrap       | 15 A                             |
| N264 66-70   | 3                | 3                 | 2 Sh/Tw/Pair | Convolute          | Mystik          | 15 A                             |
| N264 71-75   | 3                | 3                 | 2 Sh/Tw/Pair | Convolute          | Convolute       | 15 A                             |
| N264 76-80   | 4                | 3                 | 2 Tw/Pair    | PTFE Wrap          | None            | 15 A                             |
| N264 81-85   | 4                | 3                 | 2 Tw/Pair    | Mystik             | None            | 15 A                             |
| N264 86-90   | 4                | 3                 | 2 Tw/Pair    | Convolute          | None            | 15 A                             |
| N264 91-95   | 4                | 3                 | 2 Tw/Pair    | PTFE Wrap          | PTFE Wrap       | 15 A                             |
| N264 96-100  | 4                | 3                 | 2 Tw/Pair    | PTFE Wrap          | Mystik          | 15 A                             |
| N264 101-105 | 4                | 3                 | 2 Tw/Pair    | PTFE Wrap          | Convolute       | 15 A                             |
| N264 106-110 | 4                | 3                 | 2 Tw/Pair    | Mystik             | PTFE Wrap       | 15 A                             |
| N264 111-115 | 4                | 3                 | 2 Tw/Pair    | Mystik             | Mystik          | 15 A                             |
| N264 116-120 | 4                | 3                 | 2 Tw/Pair    | Mystik             | Convolute       | 15 A                             |
| N264 121-125 | 4                | 3                 | 2 Tw/Pair    | Convolute          | PTFE Wrap       | 15 A                             |
| N264 126-130 | 4                | 3                 | 2 Tw/Pair    | Convolute          | Mystik          | 15 A                             |
| N264 131-135 | 4                | 3                 | 2 Tw/Pair    | Convolute          | Convolute       | 15 A                             |
| N264 136-140 | 1                | 1                 | Twist Quad   | NA                 | NA              | 10 A                             |
| N264 141-145 | 1                | 3                 | Twist Quad   | NA                 | NA              | 10 A                             |

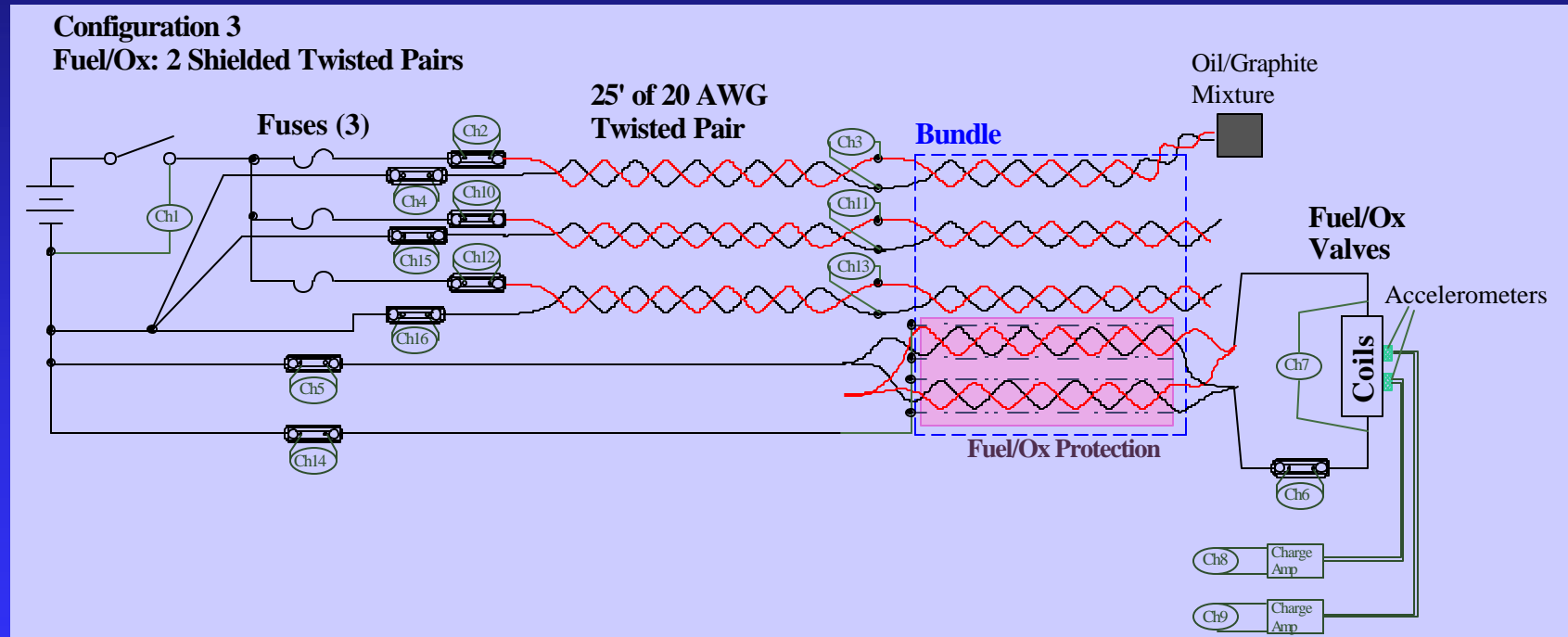
# Detection of Fuel/Ox Valve Opening and Damage to Fuel/Ox Wire

- ✍ Detection of the opening of the Fuel/Ox valve:
  1. Audible clicking sound of valve solenoids.
  2. Accelerometer measurements.
  3. Coil voltage and current measurements indicating that the coil was at or above the operational threshold.
  
- ✍ Damage to the specimen and Fuel/Ox wire:
  1. Coil Voltage and Current Measurements (including Shield current measurements).
  2. Fuel/Ox Wire Damage (Visual and wet dielectric voltage withstand (DVW) test).
  3. Breach of Protection Layers (Visual Examination).



# Harness Configuration 3: 3 Heater Circuits

## Fuel/Ox: 2 Shielded Twisted Pairs

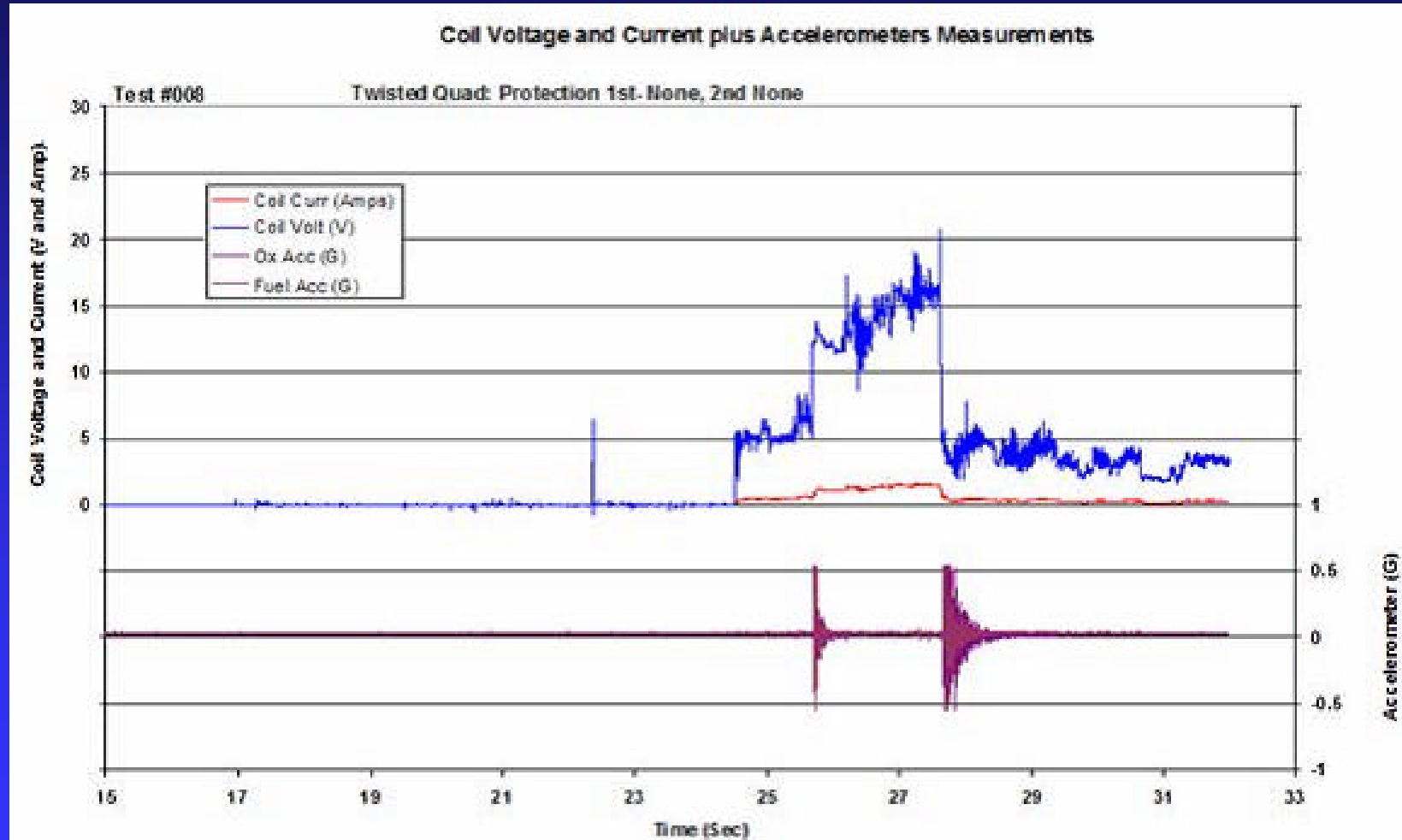


# Test N264-008



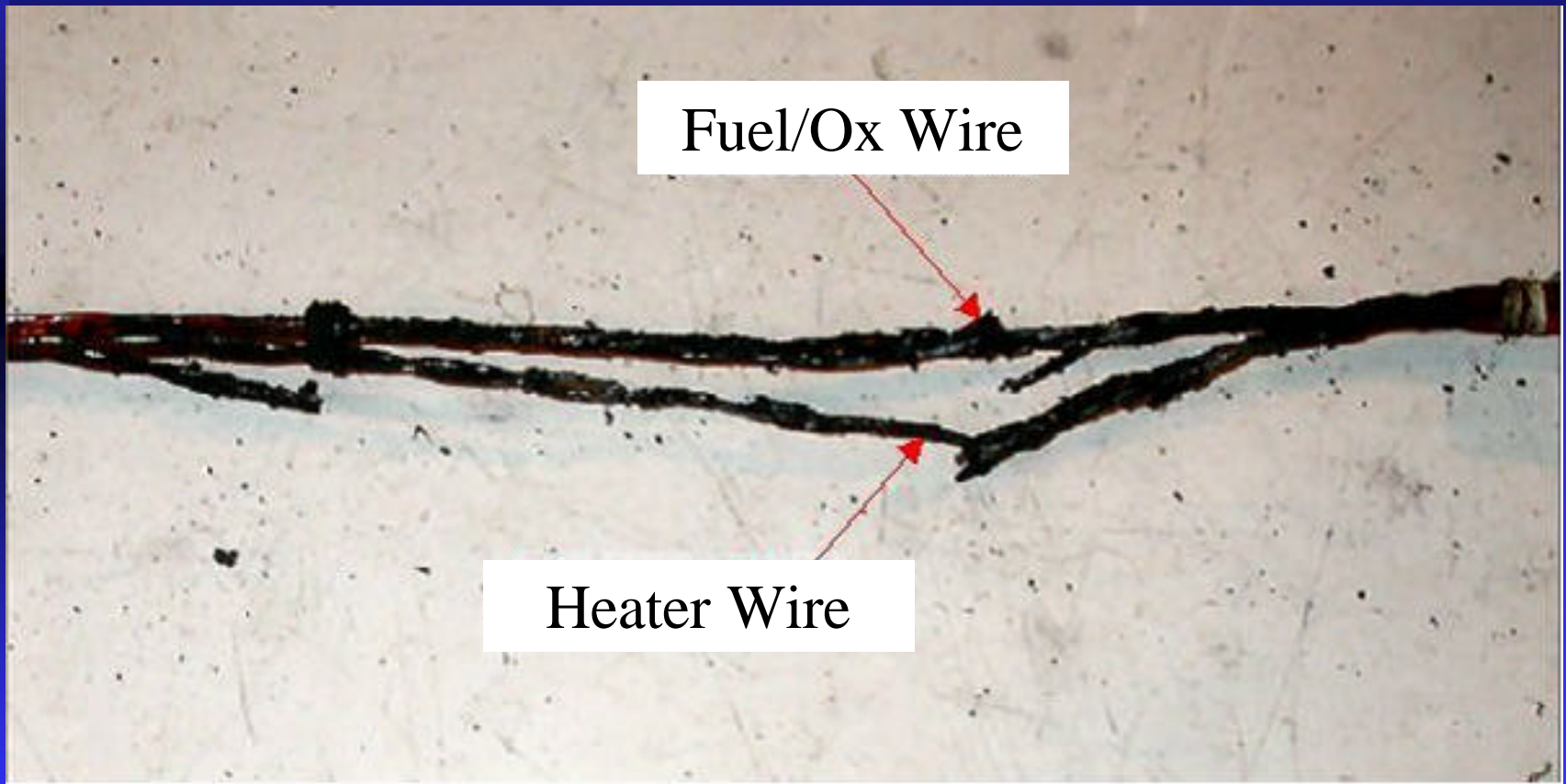
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# Test N264-008: Coil Voltage and Current plus Accelerometer Measurements



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## N264-008: Post Test: No segregation (15 A fuse)



# Close-up of Damage to Fuel/Ox Twisted Quad Wire (N264-002)



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## Worst Case Results for Protected Fuel/Ox Wire

- Specimen 264-076: 1 layer PTFE over twisted pair
- No coil voltage or current
- Wires passed wet DVW test



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# Summary of Test Results

| Test #       | Harness Config# | # Heater Circuits | Fuel/Ox Wire | Protection Schemes |                 | Circuit Protection (fuse rating) | Audible Click Valve Opened | Accelerometer Activity | Max Coil Volt/Current Reading | Damage to Fuel/Ox Wires | Breach of All Protection Layers |
|--------------|-----------------|-------------------|--------------|--------------------|-----------------|----------------------------------|----------------------------|------------------------|-------------------------------|-------------------------|---------------------------------|
|              |                 |                   |              | 1st Layer (Bottom) | 2nd Layer (Top) |                                  |                            |                        |                               |                         |                                 |
| N264 1-5     | 1               | 1                 | Twist Quad   | NA                 | NA              | 15 A                             | 5/5                        | Yes                    | 24 V / 2.1 A                  | Yes                     | NA                              |
| N264 6-10    | 1               | 3                 | Twist Quad   | NA                 | NA              | 15 A                             | 4/5                        | Yes                    | 23 V / 2.0 A                  | Yes                     | NA                              |
| N264 136-140 | 1               | 1                 | Twist Quad   | NA                 | NA              | 10 A                             | 2/5                        | Yes                    | 24.8 V / 2.1 A                | Yes                     | NA                              |
| N264 141-145 | 1               | 3                 | Twist Quad   | NA                 | NA              | 10 A                             | 0/5                        | No                     | 3.5 V / 0.1 A                 | Yes                     | NA                              |
| N264 11-15   | 2               | 3                 | 2 Sh/Tw/Pair | NA                 | NA              | 15 A                             | 0/5                        | No                     | 2.2 V / 0.2 A                 | Yes                     | NA                              |
| N264 16-20   | 3               | 3                 | 2 Sh/Tw/Pair | PTFE Wrap          | None            | 15 A                             | 0/5                        | No                     | < 1 V                         | Slight                  | 4/5                             |
| N264 21-25   | 3               | 3                 | 2 Sh/Tw/Pair | Mystik             | None            | 15 A                             | 0/5                        | No                     | < 1 V                         | Slight*                 | 2/5*                            |
| N264 26-30   | 3               | 3                 | 2 Sh/Tw/Pair | Convolute          | None            | 15 A                             | 0/5                        | No                     | < 1 V                         | No                      | 2/5                             |
| N264 31-35   | 3               | 3                 | 2 Sh/Tw/Pair | PTFE Wrap          | PTFE Wrap       | 15 A                             | 0/5                        | No                     | < 1 V                         | No                      | 0/5                             |
| N264 36-40   | 3               | 3                 | 2 Sh/Tw/Pair | PTFE Wrap          | Mystik          | 15 A                             | 0/5                        | No                     | < 1 V                         | No                      | 0/5                             |
| N264 41-45   | 3               | 3                 | 2 Sh/Tw/Pair | PTFE Wrap          | Convolute       | 15 A                             | 0/5                        | No                     | < 1 V                         | No                      | 0/5                             |
| N264 46-50   | 3               | 3                 | 2 Sh/Tw/Pair | Mystik             | PTFE Wrap       | 15 A                             | 0/5                        | No                     | < 1 V                         | No                      | 1/5                             |
| N264 51-55   | 3               | 3                 | 2 Sh/Tw/Pair | Mystik             | Mystik          | 15 A                             | 0/5                        | No                     | < 1 V                         | No                      | 0/5                             |
| N264 56-60   | 3               | 3                 | 2 Sh/Tw/Pair | Mystik             | Convolute       | 15 A                             | 0/5                        | No                     | < 1 V                         | No                      | 0/5                             |
| N264 61-65   | 3               | 3                 | 2 Sh/Tw/Pair | Convolute          | PTFE Wrap       | 15 A                             | 0/5                        | No                     | < 1 V                         | No                      | 0/5                             |
| N264 66-70   | 3               | 3                 | 2 Sh/Tw/Pair | Convolute          | Mystik          | 15 A                             | 0/5                        | No                     | < 1 V                         | No                      | 0/5                             |
| N264 71-75   | 3               | 3                 | 2 Sh/Tw/Pair | Convolute          | Convolute       | 15 A                             | 0/5                        | No                     | < 1 V                         | No                      | 0/5                             |
| N264 76-80   | 4               | 3                 | 2 Tw/Pair    | PTFE Wrap          | None            | 15 A                             | 0/5                        | No                     | < 1 V                         | Yes                     | 4/5                             |
| N264 81-85   | 4               | 3                 | 2 Tw/Pair    | Mystik             | None            | 15 A                             | 0/5                        | No                     | < 1 V                         | Slight                  | 3/5                             |
| N264 86-90   | 4               | 3                 | 2 Tw/Pair    | Convolute          | None            | 15 A                             | 0/5                        | No                     | < 1 V                         | No                      | 1/5                             |
| N264 91-95   | 4               | 3                 | 2 Tw/Pair    | PTFE Wrap          | PTFE Wrap       | 15 A                             | 0/5                        | No                     | < 1 V                         | No                      | 0/5                             |
| N264 96-100  | 4               | 3                 | 2 Tw/Pair    | PTFE Wrap          | Mystik          | 15 A                             | 0/5                        | No                     | < 1 V                         | No                      | 1/5                             |
| N264 101-105 | 4               | 3                 | 2 Tw/Pair    | PTFE Wrap          | Convolute       | 15 A                             | 0/5                        | No                     | < 1 V                         | No                      | 0/5                             |
| N264 106-110 | 4               | 3                 | 2 Tw/Pair    | Mystik             | PTFE Wrap       | 15 A                             | 0/5**                      | No**                   | < 1 V**                       | No                      | 0/5                             |
| N264 111-115 | 4               | 3                 | 2 Tw/Pair    | Mystik             | Mystik          | 15 A                             | 0/5                        | No                     | < 1 V                         | No                      | 0/5                             |
| N264 116-120 | 4               | 3                 | 2 Tw/Pair    | Mystik             | Convolute       | 15 A                             | 0/5                        | No                     | < 1 V                         | No                      | 0/5                             |
| N264 121-125 | 4               | 3                 | 2 Tw/Pair    | Convolute          | PTFE Wrap       | 15 A                             | 0/5                        | No                     | < 1 V                         | No                      | 0/5                             |
| N264 126-130 | 4               | 3                 | 2 Tw/Pair    | Convolute          | Mystik          | 15 A                             | 0/5                        | No                     | < 1 V                         | No                      | 0/5                             |
| N264 131-135 | 4               | 3                 | 2 Tw/Pair    | Convolute          | Convolute       | 15 A                             | 0/5                        | No                     | < 1 V                         | No                      | 0/5                             |

\* Specimen N264 – 021 had only 1 wrap of Mystic Tape instead of 3 called for in ML 0303-0014. This shield for this specimen failed the DW where the shield for the other 4 specimen in this configuration did not.

\*\* Specimen N264 – 106: movement of sample during arc caused Fuel/Ox valve clip lead to touch the heater terminal block and the valve opened. However this was not due to arcing damage or power transferred by the arc. Note: The protection layers were not fully breached.

# Effectiveness of Different Segregation Materials

Number of times that the top layer was breached

| Material on Top   | Number of Breaches | Percent Breached |
|-------------------|--------------------|------------------|
| PTFE Tape         | 31/40              | 78%              |
| Mystik® Tape      | 23/40              | 58%              |
| PTFE Convolutated | 12/40              | 30%              |



# Comparison of Present Tests (RJD) with Similar Tests Involving Higher Power Levels

| Protection Scheme       | Breached All Layers |            | Wet DVW Failure |                     |
|-------------------------|---------------------|------------|-----------------|---------------------|
|                         | Previous Tests      | RJD Tests  | Previous Tests  | RJD Tests           |
| None                    | NA                  | NA         | 100% (6/6)      | 100% (10/10)        |
| PTFE                    | 78% (7/9)           | 80% (8/10) | 44% (4/9)       | 0% (0/10)           |
| Mystic                  | 67% (2/3)           | 50% (5/10) | 33% (1/3)       | 10% (1/10) (shield) |
| Teflon Convolute        | 100% (12/12)        | 30% (3/10) | 42% (5/12)      | 0% (0/10)           |
| PTFE/PTFE               | 50% (1/2)           | 0% (0/10)  | 0% (0/2)        | 0% (0/10)           |
| Mystic/PTFE             | 0% (0/2)            | 10% (2/20) | 0% (0/2)        | 0% (0/20)           |
| Teflon Conv/Teflon Conv | 14% (1/7)           | 0% (0/10)  | 0% (0/7)        | 0% (0/10)           |

- Present Test (RJD): Arcing currents were typically 50-60 amps
- Previous Tests: Arcing currents were typically ~230 amps

# Conclusions

- ✍ Non-segregated/Non-shielded: Arcing can open the fuel/ox valve.
- ✍ Non-segregated/Shielded wire: Arcing did not open valve, but significant damage observed.
- ✍ Single Layer: Effective method of segregation for arcing in the 50-60 amp range.
  - ✍ Order of effectiveness of material
    - ✍ Convolute (PTFE)
    - ✍ Mystik® Tape
    - ✍ PTFE Tape
- ✍ Two Layers: More effective for higher current levels (~230).

# Questions?

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