ORBITER KAPTON WIRE

OPERATIONAL REQUIREMENTS AND EXPERIENCE

R.V. Peterson
Rockwell International

LEWIS RESEARCH CENTER
SPACE APPLICATION WIRING WORKSHOP
JULY 23, 1991

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213-922-3144
AGENDA

- ORBITER WIRE SELECTION REQUIREMENTS
- ORBITER WIRE USAGE
- FABRICATION & TEST REQUIREMENTS
- TYPICAL WIRING INSTALLATIONS
- KAPTON WIRE EXPERIENCE
- NASA KAPTON WIRE TESTING
- SUMMARY
- BACKUP DATA

ORBITER REQUIREMENTS FOR GENERAL PURPOSE WIRE (6/73)

- MINIMUM WEIGHT WITHOUT COMPROMISING CONDUCTOR INSULATION INTEGRITY
- TEMPERATURE (OPERATING) -100°F TO 260°F
- NON-FLAMMABLE/NO OUTGASSING/NON-TOXIC
- RESISTANCE TO DAMAGE DURING & AFTER INSTALLATION
- NO DEGRADATION DUE TO VACUUM EXPOSURE
- COMPLIANCE WITH ELECTRICAL REQUIREMENTS
- PRODUCIBILITY-UTILIZATION OF STANDARD TOOLS & TECHNIQUES TO FABRICATE HARNESSES & TERMINATE WIRES IN CRIMP OR SOLDER CONNECTIONS AND MARKABILITY
- MINIMUM COST
# Wire Properties Summary

<table>
<thead>
<tr>
<th>INSULATION</th>
<th>KAPTON</th>
<th>TEFLEX TE</th>
<th>POLY-Y</th>
<th>TEFZEL</th>
<th>HALAR</th>
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<tr>
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<tr>
<td>Specific Gravity</td>
<td>1.42</td>
<td>2.15</td>
<td>1.33</td>
<td>1.70</td>
<td>1.68</td>
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<tr>
<td>Tensile/Yield</td>
<td>19k/7.9k</td>
<td>3-5k</td>
<td>13.2k</td>
<td>6.5k/4.0k</td>
<td>5.26k</td>
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<tr>
<td>Flex Life; Insulated Wire</td>
<td>130 cycles</td>
<td>160 cycles</td>
<td>Not Tested</td>
<td>85 cycles</td>
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<tr>
<td>Cut-Through Resistance 150°C</td>
<td>pass</td>
<td>pass</td>
<td>pass</td>
<td>Fall</td>
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<tr>
<td>Notch Sensitivity</td>
<td>8.25kv at 4 mil cut in 6 mil Insul vs 49kv w/o cut</td>
<td>26kv at 4 mil cut in 10 mil Insul vs 34.2kv w/o cut</td>
<td>3kv 6 mil cut in 10 mil wall</td>
<td>Pass 60%</td>
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<td>Wear Abrasion Resistance</td>
<td></td>
<td></td>
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<tr>
<td>Scrape 25°C</td>
<td>4k cycles 10 mils</td>
<td>5k cycles 12 mils</td>
<td>30 cycles 10 mils</td>
<td>No Data</td>
<td>No Data</td>
</tr>
<tr>
<td>Tape 25°C</td>
<td>3 inches 1/4 lb load</td>
<td>30 inches 1/4 lb load</td>
<td>63 in 1 lb load</td>
<td>35 inches</td>
<td>28.5 inches</td>
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<tr>
<td>Tape 25°C</td>
<td>normal wt 6 inches</td>
<td>10 inches</td>
<td>10.5 inches</td>
<td>7 1/2 inches</td>
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<tr>
<td><strong>Thermal</strong></td>
<td><strong>Thermal</strong></td>
<td><strong>Thermal</strong></td>
<td><strong>Thermal</strong></td>
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<tr>
<td>Service Temp</td>
<td>200°C</td>
<td>250°C</td>
<td>200°C</td>
<td>150°C</td>
<td>165°C</td>
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<tr>
<td>Melting Point</td>
<td>None</td>
<td>327°C</td>
<td>365°C</td>
<td>271°C</td>
<td>245°C</td>
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<td>Flammability/Smoke</td>
<td>pass</td>
<td>pass</td>
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<td>Low Temp Embrittlement</td>
<td>-65°C</td>
<td>-100°C</td>
<td>-65°C</td>
<td>-100°C</td>
<td>180° Bend @ -5°C per MIL-W-22759/13</td>
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<td>pass -65°C</td>
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<td>pass - 65°C</td>
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<td>Heat Distortion</td>
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<td>Insul. Shrinkage</td>
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<td>no change</td>
<td>no change</td>
<td>no change</td>
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**Legend:** ▲ Indicates data source - see enclosure

**JUNE, 73**
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<tr>
<th>PROPERTY</th>
<th>KAPTON</th>
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<th>POLY-Y</th>
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<th>HALAR</th>
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<td>Dielectric Constant</td>
<td>3.46</td>
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<td>Dielectric Strength v/ml</td>
<td>2500</td>
<td>1160</td>
<td>1000</td>
<td>1480</td>
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<td>Insulation Resistance 25°C</td>
<td>3000</td>
<td>2250</td>
<td>5000</td>
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<tr>
<td>Megohm/1000 ft</td>
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<tr>
<td>175°C</td>
<td>12</td>
<td>12</td>
<td>50</td>
<td>31</td>
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<td><strong>Chemical</strong></td>
<td></td>
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<tr>
<td>Water Absorption</td>
<td>1%-3%</td>
<td>0.1%</td>
<td>0.3%</td>
<td>0.02%</td>
<td>0.01%</td>
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<tr>
<td>Chemical Resistance</td>
<td>unaffected</td>
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<td>to the following chemicals:</td>
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<td>1. Nitrogen Tetroxide</td>
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<tr>
<td>2. MMH Hydrazine</td>
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<td>3. Skydrol 500A</td>
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<td>4. Aerosafe 2300</td>
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<td>5. Jet Fuel JP4</td>
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<tr>
<td>6. Ethylene Elycol</td>
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<td>7. Freon</td>
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<tr>
<td>8. Lube Oil</td>
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<tr>
<td><strong>Wire Weight</strong></td>
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<tr>
<td></td>
<td>107%</td>
<td>124%</td>
<td>100%</td>
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<td><strong>Cost</strong></td>
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<tr>
<td></td>
<td>100%</td>
<td>145%</td>
<td>142%</td>
<td>Not Quoted</td>
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</tbody>
</table>

Note 1: Water absorption applies to Kapton mat'. When fabricated into wire, an impervious top coat is added and provides a barrier to moisture.
1. **Cut-Through Resist.**: Ref. P.24; Test - 10 mil radius blade forced .05 inch/min into insulation, record pounds req'd.

2. **Notch Sensitivity**: Ref. P. 23; Test - 4 or 65 mil razor cut then wrap over 1/4" diameter rod cut faces out, record dielectric breakdown volts - indicates decrease in effective insulation.

3. **Wear Abrasion**: Ref. P. 29; Test - 1kgm wt on 10 mil radius back-and-forth, record cycles to fail. (scrape abrasion)

4. **DUPONT TEFZEL SPEC. SHT. APD #4 July 20, 1971**
   1. **Wear Abrasion**: Ref. P.3; Test - 1.0 lb vert wt on wire, 400 grit tape abrades wire. Record tape length upon contact with conductor.

5. **RAYCHEM SPEC. SHT. "COMPARATIVE TEST DATA - RAYCHEM TYPE 88 AIRFRAME WIRE"**
   1. **Tape Abrasion**: Test - 1.0 lb vert wt on wire 400 grit tape abrades wire. Record tape length upon contact with conductor.
   2. **Scrape Abrasion**: Test - 2.25 lb load on 5 mil flat edge on 90° wedge moved back-and-forth, record cycles to fail.
   3. **Cut-Through**: Test - 5 mil flat on 90° wedge forced 0.2 in./min into insul., record pounds to fail.

6. **ALLIED CHEMICAL CORP. "HALAR FLUOROPOLYMER RESIN" May 1, 1972**
   1. **Chemical Resistance**: See Page C-1 thru C-17
   2. **Flame/Smoke**: Test - See Pages F-1 thru F-6


8. **DUPONT TEFZEL SPEC. SHT. APD #1 February 1, 1971**

9. **McDAC RPT. MDC A0515 June 16, 1972**
   1. **Cut-Through Resistance**: Ref. P.9; Test - 90° edge .010 radius blade applied 205 grams/sec.

10. **ALLIED CHEMICAL CORP. DATA SHEET "HALAR - NEW GENERATION FLUOROPOLYMER"**

11. **ALLIED CHEMICAL CORP. PAPER BY A. ROBERTSON & W. MILLER "HALAR FLUOROPOLYMER - A VERSATILE INSULATION FOR WIRE"**

12. **RAYCHEM DATA - LETTER - C. HAWKINS TO J. D. DOYLE "POLYARLENE TYPE 88B WIRE & CABLE" - 5-9---**

13. **JSC/Houston: TEST DATA AVAILABLE AT A LATER DATE**


15. **ROCKWELL L&T REPORT NO. LR9931-901 DATED MAY 1973**

16. **ROCKWELL IL 044-110-73-4-11, EVALUATION OF SPACE SHUTTLE WIRE TYPES**

17. **ROCKWELL IL M3-053-JEB-1881, SHUTTLE WIRE EVALUATION**
### ORBITER WIRE USAGE

- **KAPTON IS PRIMARY WIRE USED ON ORBITER PROGRAM**
  - MIL SPEC 81381, RI SPEC MB0150-048
  - KAPTON PRIMARY INSULATION & OUTER JACKET
  - 26 TO "0" AWG SIZES USED
  - CURRENT CARRYING CHARACTERISTICS ESTABLISHED BY TEST, NASA-JSC, REPORT LEC-1756 & JSC-09155
- **TEFLON USED IN D&C PANELS & POWER & CONTROL ASSEMBLIES**
  - MIL SPEC 22759/12, RI SPEC MB0150-061
  - TFE TEFLOL PRIMARY INSULATION
  - KAPTON OUTER JACKET
- **CONTROLLED IMPEDANCE USED FOR DATA BUS WIRE**
  - MIL SPEC 22759/23, RI MB0150-051
  - TFE TEFLOL PRIMARY INSULATION
  - KAPTON OUTER JACKET
- **PFA USED FOR LARGE GAGE IN POWER & CONTROL ASSEMBLIES & EQUIPMENT BAYS**
  - MIL SPEC 22759, RI MB0150-062
  - PFA TEFLOL PRIMARY INSULATION
- **MPS ENGINE CONTROLLER DATA BUS WIRE**
  - 40 M 50578B22-2SR

### ORBITER WIRE USAGE PER VEHICLE

**ORBITER WIRE USAGE BY TYPE & LENGTH**

- **KAPTON**
  - UNSHIELDED: 577,900 FT.
  - SHIELDED: 176,000 FT
  - TOTAL: 753,900 FT

- **TEFLON**
  - UNSHIELDED: 64,500 FT
  - SHIELDED: 700 FT
  - PFA (LARGE GAGE): 1100 FT

- **DATA BUS (2 CONDUCTOR SHIELDED)**
  - TOTAL: 32,600 FT

**GRAND TOTAL**: 852,800 FT

**VEHICLE WIRE SEGMENTS**: 83,000 SEGMENTS

**D&C PANELS & PWR & CONT. ASSY. WIRE SEGMENTS**: 32,000 SEGMENTS

**TOTAL SEGMENTS**: 115,000 SEGMENTS

**TOTAL VEHICLE WIRE WEIGHT (WITH CONNECTORS)**

- DOES NOT INCLUDE D&C PANELS & PWR & CONT. ASSY’S.
  - 5,369 LBS
FABRICATION & TEST REQUIREMENTS

• HARNESS FABRICATION
  • ORBITER MOCKUP BUILT FOR WIRING & PLUMBING
  • FLIGHT DECK & EQUIPMENT BAY HARNESSSES BUILT ON 3D TOOL
  • ALL OTHER HARNESSSES BUILT ON FLAT BOARDS
  • MECHANICAL STRIPPERS USED FOR KAPTON INSULATION
  • SLEEVES USED TO MARK WIRES

• HARNESS TEST REQUIREMENTS
  • CONTRACT REQUIRES CONTINUITY & 1500 VDC HIGH POTENTIAL TEST AFTER INSTALLATION
    • MANUFACTURING PERFORMS SAME TEST ON EACH HARNESS PRIOR TO INSTALLATION
  • AFTER POWER ON TESTING CONTINUITY REQUIRED ON ALL REWORK
    • HIGH POTENTIAL TEST ON DATA BUS & PYRO FIRING CIRCUITS

ORBITER WIRE INSTALLATIONS
CREW MODULE WIRING INSTALLATION

- Flight deck wire congested due to quantity of wiring required for display & control panels
  - Large wire bundles behind secondary structure, D&C panels & close out panels
- Mid deck equipment bays have large quantity of wires
  - Routed in wire trays in front of LRU's
  - Covers installed over bays
- Environmental control bay congested with wire routing from equipment bays thru pressure bulkheads
MID FUSELAGE WIRE INSTALLATIONS

- WIRE TRAYS WITH COVERS ON EACH SIDE OF MID FUSELAGE
- WIRING TO EQUIPMENT PROTECTED FROM TRAFFIC
  - LINER CLOSES OUT LOWER PORTION OF BAY
  - WIRING FOR PAYLOADS ABOVE LINER
    - TEFILON BRAID ON ALL HARNESSES FOR ADDED PROTECTION
AFT FUSELAGE WIRE INSTALLATION

- EQUIPMENT BAYS HAVE LARGE QUANTITY OF WIRES
  - WIRE TRAYS IN FRONT OF LRU'S
  - COVERS INSTALLED OVER BAYS
- AFT FUSELAGE WIRING ROUTED ON SIDE WALLS
  - PERMANENT COVERS & CONVOLUTED TUBING ADDED IN HIGH TRAFFIC AREAS
  - WIRE TRAYS ORIGINALLY PLANNED BUT DELETED DUE TO WEIGHT
  - WORK STANDS ADDED/REMOVED EACH FLOW FOR ACCESS TO EXTERNAL TANK INTERFACES
KAPTON WIRE EXPERIENCE

- MANY ELECTRICAL SHORT CIRCUITS DUE TO INSULATION DAMAGE HAVE OCCURRED
  - PROTECTION DEVICES OPERATED AND INTERRUPTED FAULT CURRENT
  - ORBITER HAS EXPERIENCED TWO INSTANCES OF ARC TRACKING
    - OV-099 STS-6 HUMIDITY SEPARATOR WIRING
      - SIX CONDUCTORS MELTED THRU
      - ARCING INTERRUPTED BY FOUR CIRCUIT BREAKERS OPENING
      - CORRECTIVE ACTION PERFORMED TO VERIFY CLEARANCE OF ALL STORAGE CONTAINERS AND ADDITIONAL WIRE INSULATION PROTECTION INSTALLED
    - OV-102 STS-28 TELEPRINTER CABLE SHORT
      - ARC TRACKING OCCURRED FOR APPROXIMATELY 1.6 SECONDS UNTIL ARC EXTINGUISHED ITSELF AT BACK OF CONNECTOR
      - CIRCUIT BREAKER DID NOT OPEN
      - CORRECTIVE ACTION CHANGED HARNESS WIRES TO TEFLOX INSULATION FOR GREATER FLEXIBILITY & USED 90° CONNECTOR AT PANEL INTERFACE
KAPTON WIRE EXPERIENCE

- VEHICLE INSPECTIONS CONDUCTED TO REVIEW CONDITION OF KAPTON WIRE
  - 11/6/89 NASA HEADQUARTERS, NASA JSC, NASA KSC, ROCKWELL & LOCKHEED PERSONNEL REVIEWED THREE VEHICLES AT KSC BECAUSE OF ARC TRACKING CONCERNS
    - INSPECTION INDICATED ORBITER WIRING WAS GENERALLY IN GOOD SHAPE
    - OVERALL CONDITION OF WIRING WAS VERY GOOD
    - SOME TWO CONDUCTOR SHIELDED CABLES IN HIGH TRAFFIC AREAS HAD TOP COAT CRACKS/FRAYING
    - SAW WHERE DAMAGED WIRES HAD BEEN REPAIRED IN HIGH TRAFFIC AREAS
    - FLUID SPILLS
      - FIRST TEST VEHICLE HAD A HYDRAZINE SPILL WHICH CAUSED KAPTON INSULATION TO DETERORATE
      - HYDRAULIC FLUID HAS NOT AFFECTED INSULATION
    - PROTECT AGAINST DAMAGE
      - INSPECTIONS DURING BUILD PHASE TO IDENTIFY AND PROTECT AREAS OF POTENTIAL DAMAGE
      - TECHNICIAN TRAINING HAS BEEN EXPANDED TO STRESS IMPORTANCE OF PREVENTING DAMAGE
      - WIRING IS INSPECTED FOR DAMAGE AS PART OF CLOSEOUT OF AREAS REQUIRING WORK DURING TURNAROUND
      - ORBITER DESIGN REQUIREMENT ROUTE CRITICAL FUNCTIONS IN SEPARATE HARNESSSES
        - PRECLUDES SINGLE HARNESS FAILURE FROM CREATING A SAFETY OF FLIGHT CONDITION
      - WIRE COVERS BEING ADDED IN HEAVY TRAFFIC AREAS OF AFT FUSELAGE
      - CONVOLUTED TUBING ADDED IN AREAS WHERE DAMAGE OR POTENTIAL FOR DAMAGE HAS BEEN IDENTIFIED
NASA KAPTON WIRE TESTING

- ARC TRACKING TESTS PERFORMED AT JSC IN THE ELECTRICAL POWER SYSTEMS LABORATORY

- TEST OBJECTIVES WERE:
  - OBTAIN DATA FROM TESTS PERFORMED ON KAPTON WIRE IN SIMULATED ORBITER CONFIGURATIONS
  - USE DATA TO ASSESS SAFETY OF ORBITER WIRE SYSTEM

- ARC TRACKING TESTS EVALUATED EFFECTS OF
  - WIRE SIZE/CONFIGURATION
  - ORBITER CIRCUIT PROTECTION DEVICES
  - AC/DC VOLTAGES
  - ARCING TO STRUCTURE
  - ELECTRICAL LOADING
  - INSTALLATION HARDWARE BUNDLING & ARC PROPAGATION

RESULTS OF ARC TRACKING TEST

- SUMMARY OF TESTS
  - CIRCUIT PROTECTION DEVICES, AS A RULE, DO NOT PROTECT AGAINST ARC TRACKING
  - RE-CLOSING OF TRIPPED CIRCUIT PROTECTION DEVICES REINITIATES ARC TRACKING
  - ARC TRACKING OF WIRE IN A BUNDLE CAUSES DAMAGE TO ADJACENT WIRING
  - THE HIGHER THE VOLTAGE, THE EASIER IT IS TO START ARC TRACKING
    - DISTANCE OF ARC TRAVEL APPEARS TO BE LESS BEFORE CIRCUIT PROTECTION OPENS
  - WIRE SIZE 4 AWG WOULD NOT TRACK
TEST SET-UP FOR TWISTED PAIR TESTING

INITIATION POINT -- GRAPHITE COPPER MIX CONTROL BOX

TEST SET-UP FOR TWISTED PAIR ELECTRICAL LOADING TESTING

VARIABLE LOAD 12 INCHES INITIATION POINT GRAPHITE COPPER MIX CONTROL BOX
SUMMARY OF 20VDC ARC TRACK TESTS WITH PROPER Sized CIRCUIT PROTECTION

20 A CB  7" (#12,#10,#8) 7" (#12,#10,#8)
20 A FUSE  3' (#12) 3' (#12)
20 A RPC  3' (#12) 3' (#12)
15 A FUSE  3' (#16) 3' (#16)
10 A CB  6' (#20) 6' (#20)
10 A FUSE  3' (#20) 3' (#20)
10 A RPC  3' (#20) 3' (#20)
7 A CB  6' (#22) 6' (#22)
7.5 A RPC  6' (#22) 6' (#22)
5 A CB  10' (#22,#24) 10' (#22,#24)
5 A FUSE  7' (#22,#24) 7' (#22,#24)
5 A RPC  6' (#22,#24) 6' (#22,#24)
3 A CB  3' (#26) 3' (#26)
3 A FUSE  6' (#24,#26) 6' (#24,#26)
3 A RPC  6' (#24,#26) 6' (#24,#26)

SUMMARY OF 117VAC ARC TRACK TESTS WITH PROPER Sized CIRCUIT PROTECTION

3 A CB  14'
3 A FUSE  6'
2.5 A FUSE  3'

FIGURE 1

FIGURE 2
SUMMARY

- Inspection of fleet shows Kapton wire in good condition
  - First set of harness built 1977
  - Wire exposed to a relative benign environment
- Two instances of arc tracking have occurred on the orbiter
  - Insulation must be damaged to expose bare conductors
  - Protective devices limit duration & extent of arc tracking
- Exposed wiring in high traffic areas has resulted in numerous insulation damage
  - On an average one short circuit per turnaround has been occurring
  - Emphasis is placed on preventing/locating wire insulation damage
    - Physical protection
    - Technician training
    - Inspection

BACK UP

1500 VDC High Potential Test Requirements 10/4/89
Contractor Furnished Harneses

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* Numbers refer to test requirements explanation
1500 VDC HIGH POTENTIAL TEST REQUIREMENTS 10/4/89

1. SPECIFICATION STATES BENCH LEVEL TEST IS OPTIONAL EXCEPT FOR OPERATIONAL SPARE WIRES WHICH IS MANDATORY PRIOR TO INSTALLATION. MANUFACTURING HAS CHOOSEN TO TEST ALL HARNESSES AT THE BENCH LEVEL.

2. SPECIFICATION STATES TEST MANDATORY AFTER INSTALLATION. AFTER POWER ON TEST IT IS MANDATORY THAT TEST BE RUN ON ALL REWORKED DATA BUS, CONTROLLED IMPEDANCE, AND PYRO FIRING WIRES. SOME MISSION EQUIPMENT HARNESSES ARE INSTALLED DURING ORBITER ASSEMBLY AND NEVER REMOVED.

3. TEFLON WIRE USED FOR HARNESSES AND MID FUSELAGE HARNESSES HAVE AN OVERBRAID WHICH REQUIRE HIGH POTENTIAL TEST PRIOR TO AND AFTER BRAIDING.

4. TEST REQUIRED ON REWORKED AND/OR REPAIRED WIRES IS LIMITED TO DATA BUS CABLES, CONTROLLED IMPEDANCE CABLES AND PYRO FIRING WIRES OR CABLES.

5. TEST REQUIRED ON ALL PAYLOAD RELATED KITS. LOCKHEED (SPC) HAS REOCCURRING DOCUMENT OM1 V1199 THAT REQUIRES TEST TO BE RUN AT KITTING FACILITY PRIOR TO EACH INSTALLATION.

COMPARISON OF TEFZEL, TEFLON AND KAPTON

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TYPICAL COSMETIC WIRE DAMAGE FOUND DURING 4/91 REVIEW OF OV-102
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