DO CONDUCTIVE RESIDUES IN AIRCRAFT FUEL TANKS POSE A COMUSTION HAZARD?

Part I: Formation Mechanisms

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Copper and Silver Sulfide Conductive Deposits

- Found on Fuel Tank Components
  - Fuel Quantity Indication System (FQIS)
    - **Nuts, Connectors, Insulated Wires**
  - Terminal Block
    - **Nuts, Connectors, Wires, Polymeric Surfaces**
  - Bundled Wires At/Near Insulation Damage
  - Fuel Pump
    - **Stator Wires, Fuses**
- Caused Numerous FQIS Malfunctions
- Found on Components from TWA800 Accident Aircraft

NTSB Recommendation to FAA Due to TWA800 Inquiry Results

Require Research Into Copper-Sulfide Deposits on FQIS Parts in Fuel Tanks to Determine:

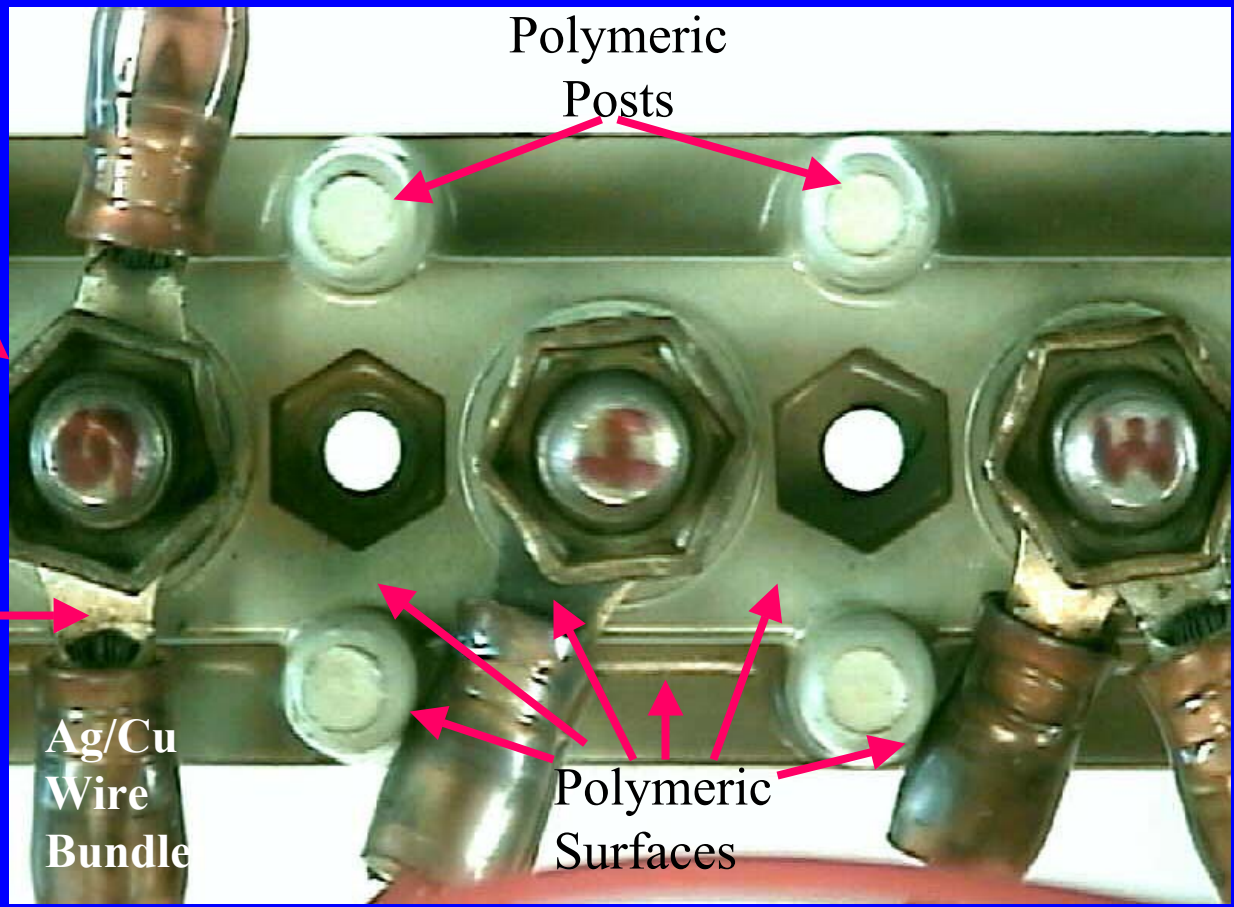
- Levels of Deposits That May Be Hazardous
- How to Inspect and Clean Deposits
- When to Replace the Components

NTSB Recommendation A-98-37

Research Was Performed To:

- Analyze Conductive Deposits to Determine Chemical Composition and Structure
- Study Fuels to Identify Possible Contaminants
- Produce Conductive Deposits in Laboratory
- Perform Fuel Ignition Tests (Next Paper)

Terminal Block



Analyzed Deposits Found On Nuts, Connectors, Surfaces Between Nuts, Lower Surfaces Between Posts and On Posts of Terminal Blocks

Conductive Deposit Analyses
(Ten Different Terminal Blocks Analyzed)

- Only Present With Silver (Ag) Nuts: 4 Blocks
  - 1 Block Also Had Drop of Fuel Gum on End
- Deposits on Ag Nuts: Ag_2S
- Deposits on Polymeric Surfaces and Posts
  - Thin, Shiny, Brown/Black
  - Conductive: Resistances at 2mm Below 10 KΩ
  - Mainly (>90 %) Organic : Fuel Gums
  - Layered : Gums/Ag/CuS_x (Layer Closest to Surface)
- Deposits on Metal Connectors (Tin Plated)
  - Same as Polymeric Surfaces and Posts Except CuS_x Layer Also Contains Tin and Oxygen

World–Wide Survey of Jet A Fuels

- 64 Fuels Supplied by FAA
  - Obtained From Center Fuel Tanks of US and European Aircraft after Landing
- 3 Fuels Supplied by Aerospace Company
  - Obtained From Fuel Line Components of Aircraft in Asia with Clogged Fuel Lines/Fuel Oil Coolers
- 2 Fuels Obtained from Wright Patterson AFB
  - Obtained From US Commercial Airport Fuel Reserves

Fuel Analyses

- Total Sulfur Analyses: 0.003 to 0.15%
- When Ag Wires Were Soaked in Fuels Overnight, 2 Fuels (FAA) Created Ag_2S Films
- When Heated (290°F) in Air for 4 Hours,

  7 "Low Sulfur" Fuels Oxidized at a High Rate to Produce Hydroperoxides, Acids and Gums

  (4 FAA, 1WPAFB and 2 Aerospace Fuels)

THEREFORE FUELS CAPABLE OF PRODUCING Ag_2S AND FUEL GUMS PRESENT IN FUEL SURVEY

INITIAL DEPOSIT FORMATION
(Cu/Ag Wires in Glass Vials)

- Heated Fuels at 350°F to Produce Fuel Vapors
- Majority of Fuels DID NOT Produce Deposits in Vapor Phase on Wires– Particles in Liquid
- "Low Sulfur" Fuels DID Produce Deposits in Vapor Phase on Wires - Gums in Liquid
- Analyses of Deposits/Gums Matched Deposits on Terminal Blocks [C, O, Cu, S] Except for No Ag
- Deposits/Gums Had High Resistance (>1MΩ), But Lower Resistance Than Fuel (>100 MΩ)

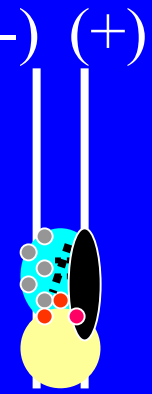
Literature Search

- Focused on Conductive Deposits – Ag or Cu
- Most Important Literature Identified:

  W.R. Downs, NASA Technical Note TN D-4327

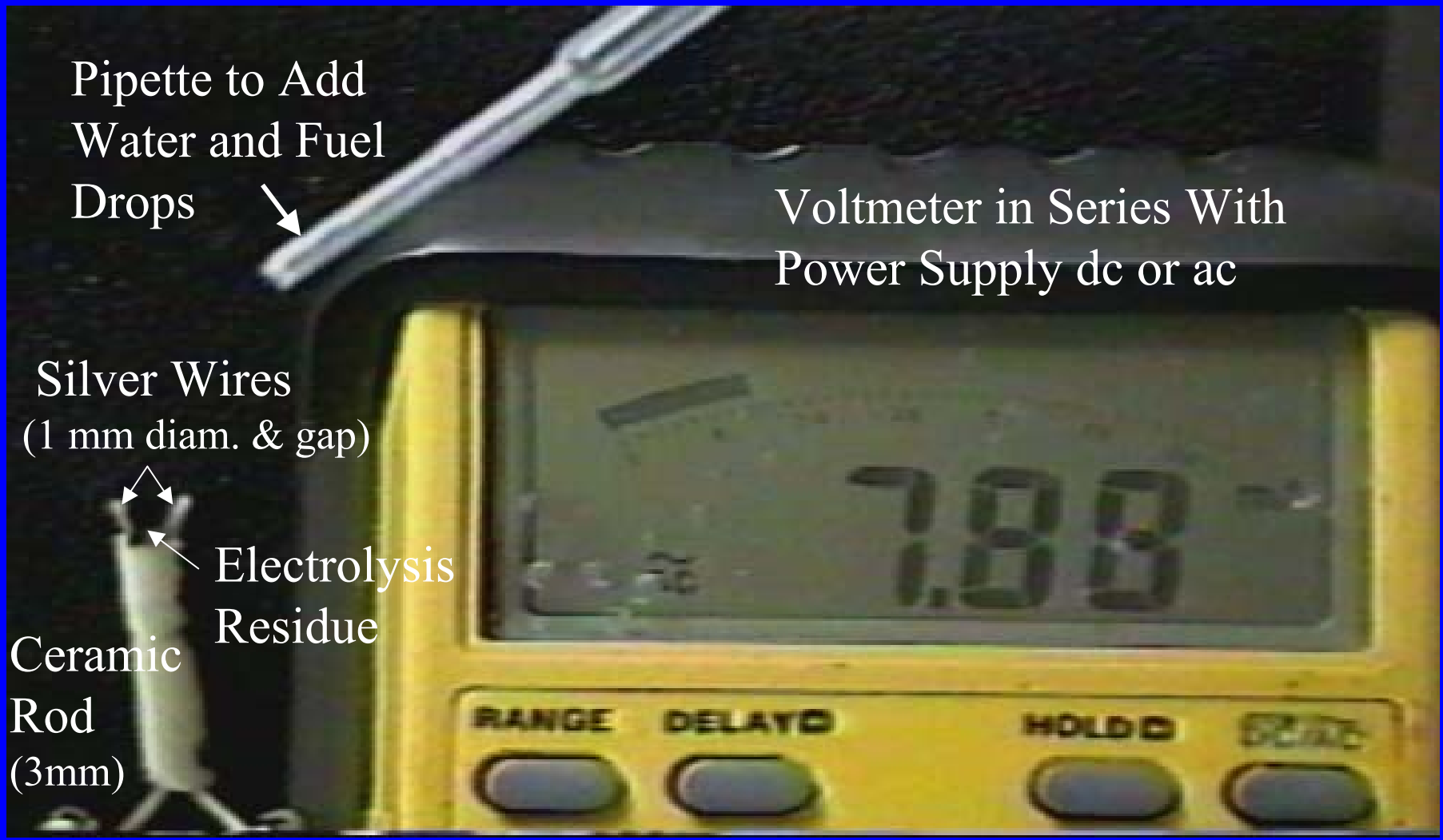
  "Chemically Induced Ignition in Aircraft and Spacecraft Electrical Circuitry by Glycol/Water Solutions" April '68 (NTIS N6822213)
- Apollo AS – 204 Incident in January 1967
- Ag Coated Cu Wire Carrying 28V dc in Air/Oxygen Produced Smoke/Fire (RF) with Coolant Solution Drop
- Resolved by Adding Chemical Inhibitor to Coolant and New Designs with Ni Coated Wires

Ag/Cu Wires on Glass Tests



- Two Parallel Wires (0.2mm dia.) on Glass
- Spaced 1mm Apart : 9V dc Battery (<100 mA)
- Drop of Water Produced Bubbling (H_2) at (-) Wire and Black Deposit (Ag and Cu Oxides) at (+) Wire
- Resistance Between Wires Decreased from 1MΩ Down to Below 10 KΩ As Deposit Grew Across
  + Fresh Fuel – Deposit BUT NO Flashes or Smoke
  + Oxidized Fuel with Gums - Deposit & Flashes
- Flashes and Smoke at Water/Fuel Interface

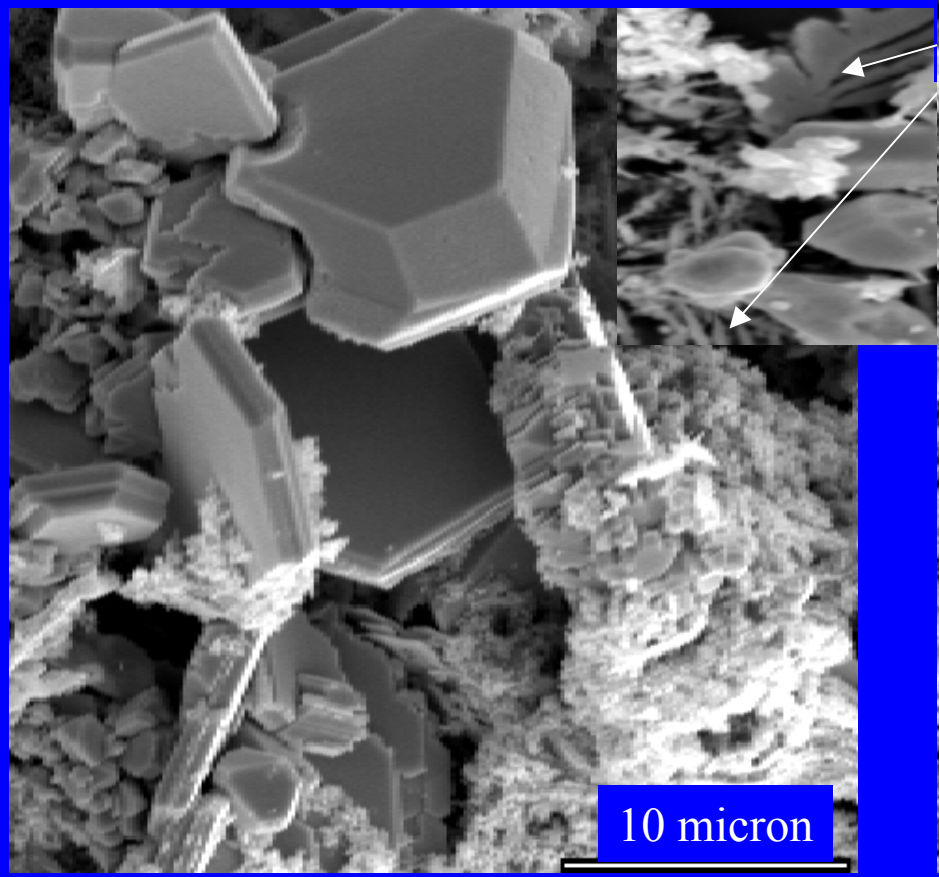
Ag Wires/Ceramic Rod Tests



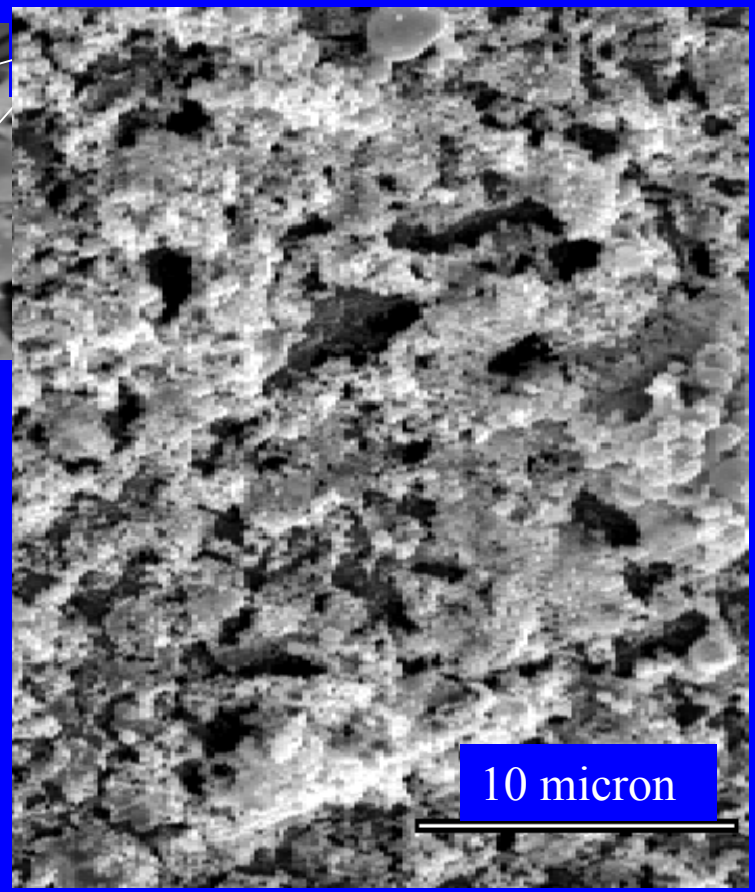
Ag Wires/Ceramic Rod Tests (Electrolysis)

- Add a Drop of Water Between Ag Wires
- Apply ac or dc Power – Black Deposit Forms Between Ag Wires on Ceramic Rod Surface in Minutes
- RF Produced - Detected with AM Radio
- Dry Residue Resistance in 5 - 5000Ω Range
- Analysis of Residue
  - Crystals/Dendrites with ac Power (400 or 7400 Hz)
  - Spheres/Dendrites with dc Power (Battery or Supply)
  - Majority of Residue Ag, Some Ag_xO

Microphotographs of Ag Electrolysis Residues



ac (7400 Hz)

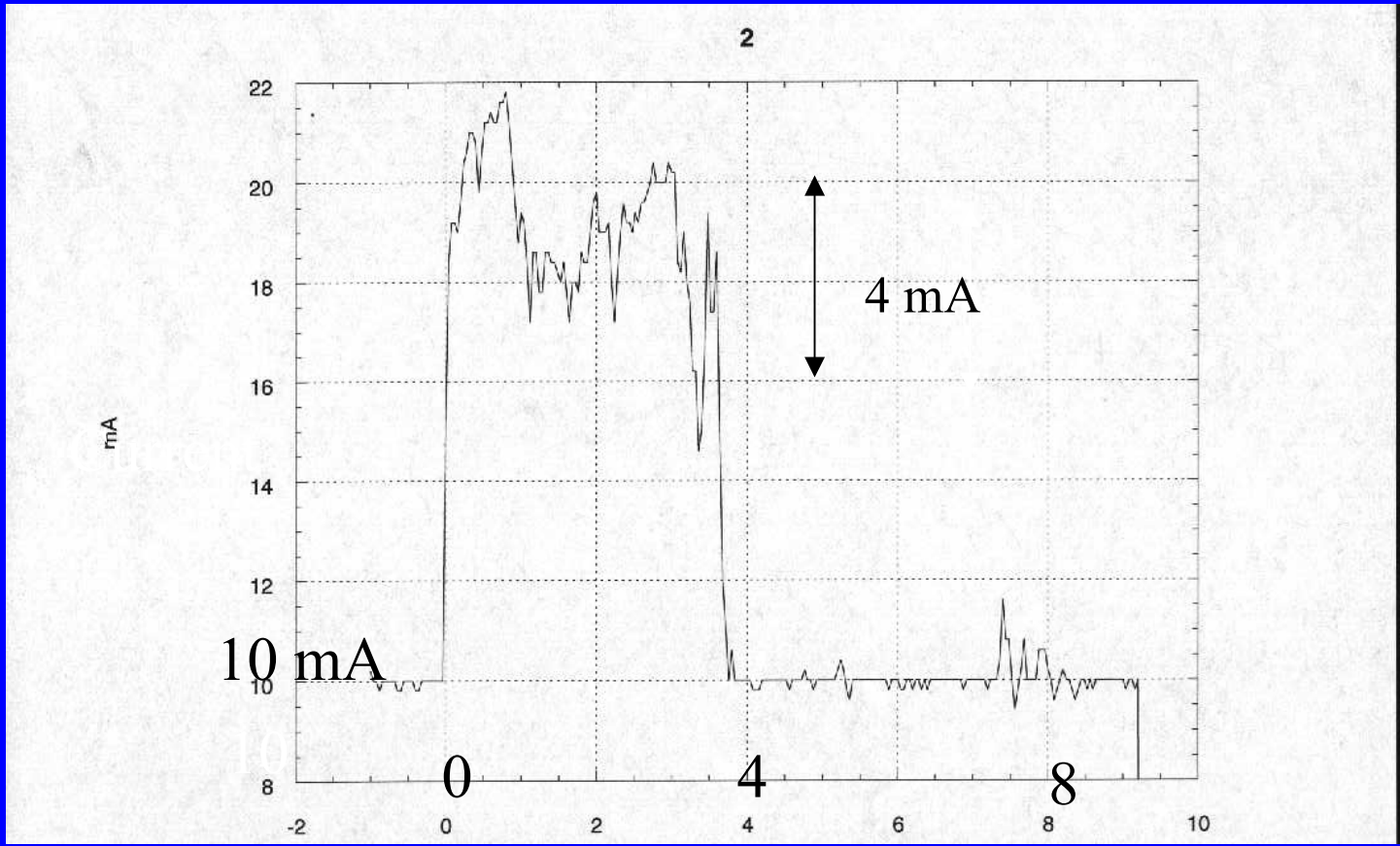


dc (Battery)

Ag Wires/Ceramic Rod Tests
(Initial Fuel Drops – ac or dc Power)

- For Ag Residues with Resistances > 5000Ω
  - Addition of Most Fuels (Sulfur > 0.02%)
    - Resistance Increases > 50 KΩ
  - Addition of "Low Sulfur" Fuels
    - Resistance Decreases to Below 2 KΩ
    - Flashes/Smoke
- For Ag Residues with Resistances 50 - 2000Ω
  - Addition of All Fuels Cause Flashes/Smoke
- For Ag Residues with Resistances < 10Ω
  - Addition of All Fuels Cause No Flashes/Smoke

Current Spike During Flash
(Recording Oscilloscope)



Ag Wires/Ceramic Rod Tests

(Further Additions of Fuel Drops)

50Vac Power Supply or 27 - 45Vdc (Linked Batteries)

Current Limited to 300mA

1. Flashes/Smoke Become Stronger
2. Flashes Replaced by Constant Glow

(Glow Continues Even If Rod Submerged in Fuel)

3. Ignitions

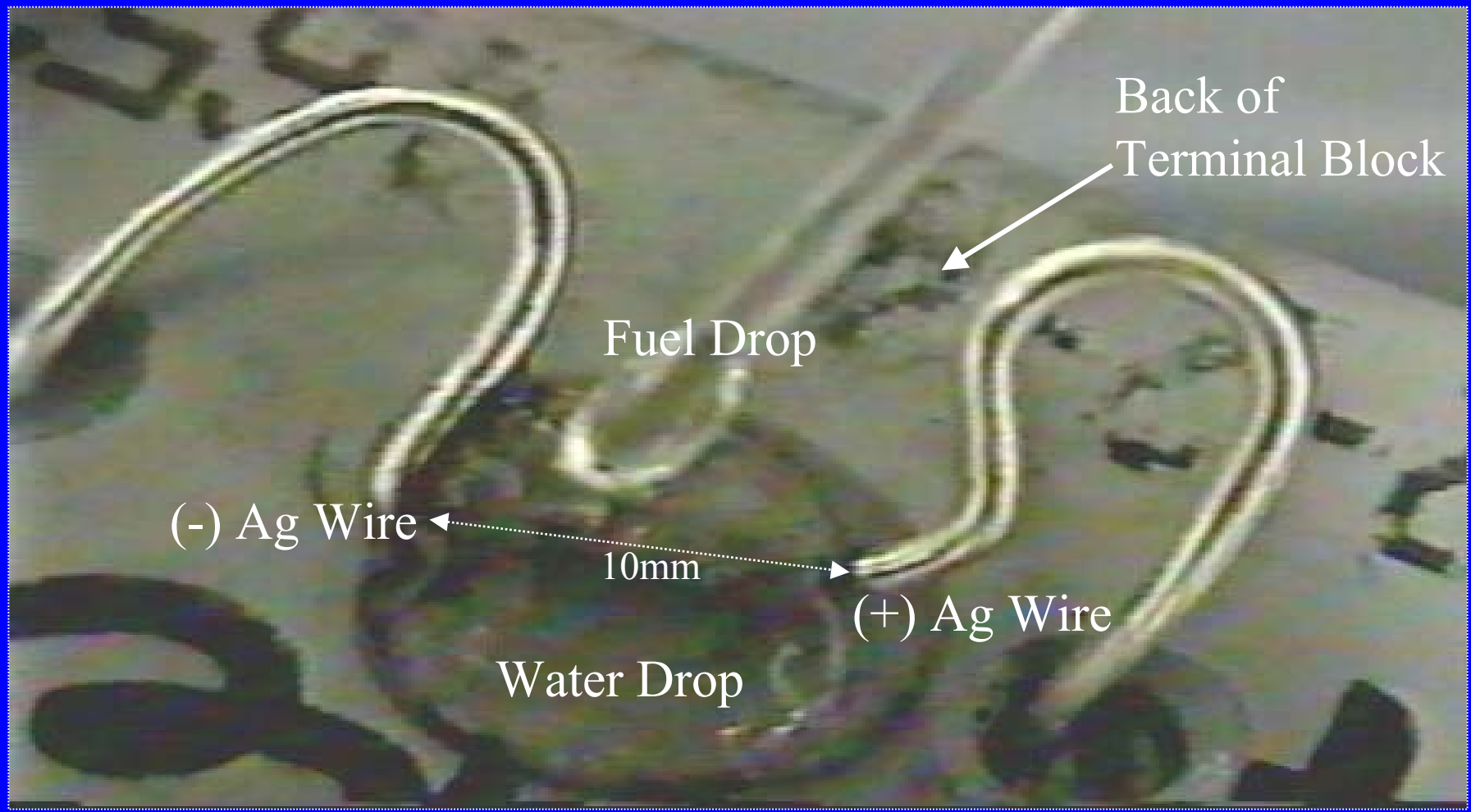
Metal Wires/Ceramic Rod Tests (9V dc Battery)

- Electrolysis With Other Wires
  - Produced RF : Ag, Cd and Cu
  - Produced Residues
    - Large Amount: Ag, Al, Cd, Cu and Ni
    - Small Amount: Au, Sn, 316 Steel and Ti
  - Produced Conductive (< 20 KΩ) Residues
    - Wet (Water): Ag, Cd and Cu
    - Dry: Ag and Cu
    - Fuel: Ag
- Fuel Reactions With Electrolysis Residue
  - Produced Flashes/Smoke
    - Ag Wires
    - Ag/Metal Combination Only If Ag (+) Wire

Ag Wires/Terminal Block Tests

(Water and Fuel Added Together)

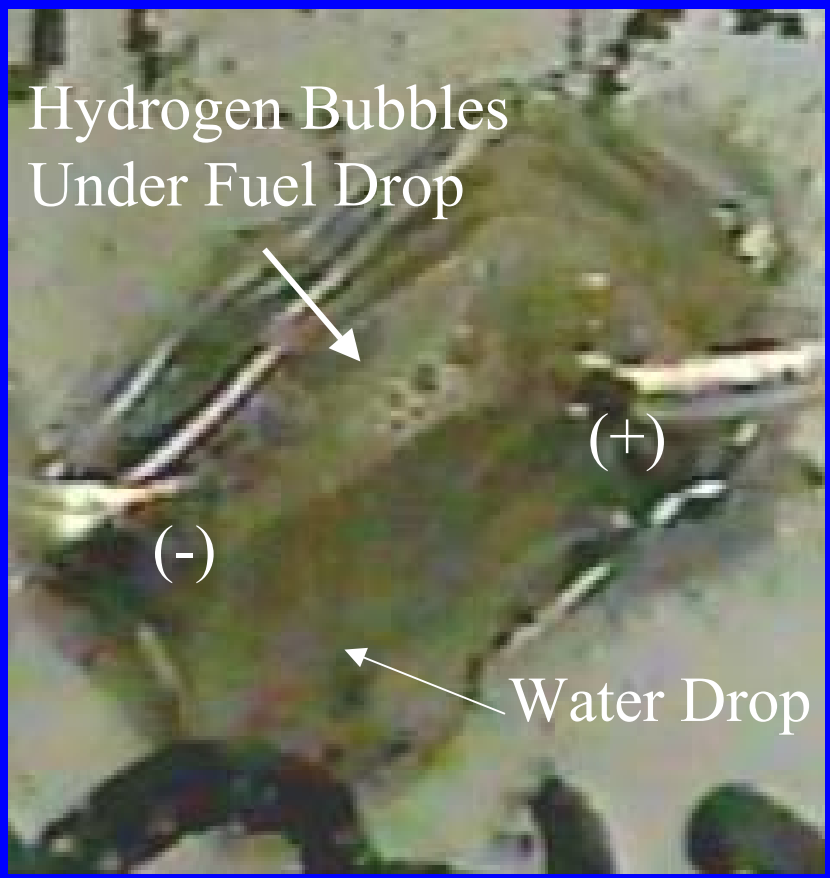
(40Vdc Power Supply- 0.7 Watt Maximum)



Ag Wires/Terminal Block Tests

40V dc Power Supply – 0.7 Watt Maximum
(Electrolysis of Fuel/Water Drops)

Initial Reactions with Power



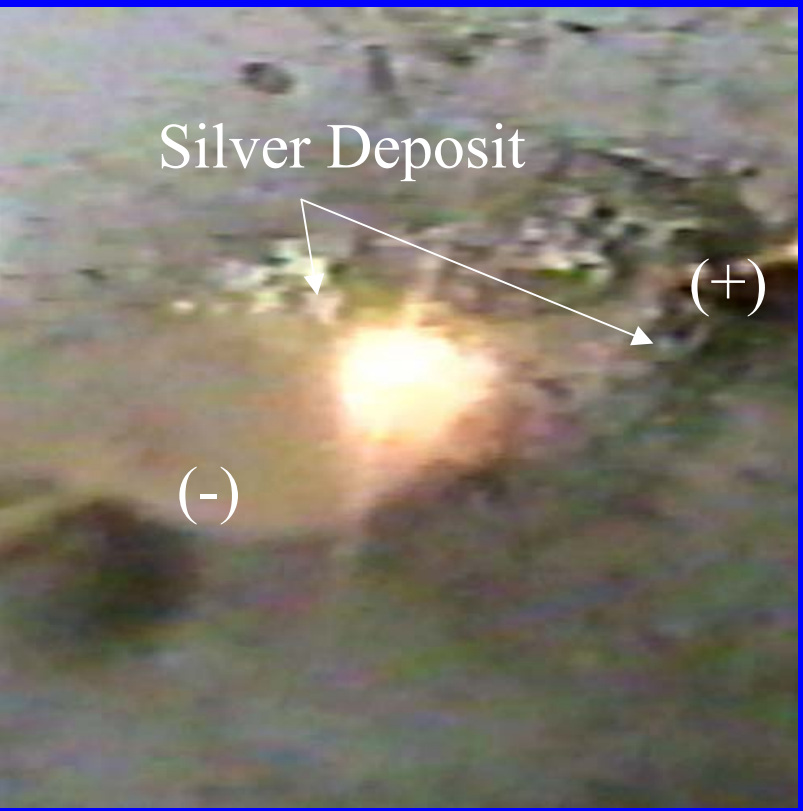
After Several Minutes

Ag Wires/Terminal Block Tests

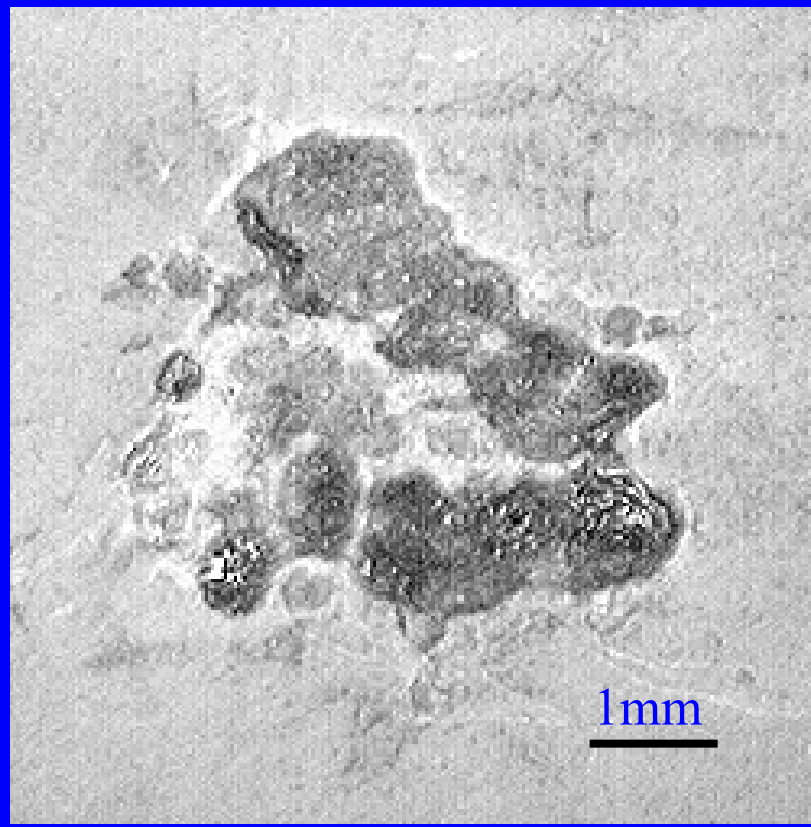
40V dc Power Supply – 0.7 Watt Maximum

(Deposit Fuel Reactions)

Hot Spot (Immediate) with
First Fuel Drop on Dried Deposit



Block Surface Damage
After Several Fuel Drops



CONCLUSIONS

Conductive Deposit Formation

- Conductive "Ag/Cu Sulfide" Deposits Are Actually Fuel Gums With Distinct Layers of Ag (Ag_2O) and CuS_x
- Electrolysis of Water Between Ag Nuts Produces Conductive Silver Layer on Terminal Block Surfaces
  - Occurs Under Normal Operating Conditions (28Vac, 1mA)
  - Other Metals Tested Did Not Produce Conductive Residues
- Gums Produced by "Low Sulfur" Fuels Support Conductive Deposit Formation by
  - Enhancing Current Flow During Electrolysis
  - Adhering Ag Electrolysis Particles to Surface

CONCLUSIONS
Conductive Deposit Fuel Reactions

- Low Current (<10mA): Smoke/Flashes
  - ac or dc Power with Voltage > 30V
  - Only with "Low Sulfur Fuels" and Ag
  - Flashes Last for Microseconds

- High Current (>200mA):Smoke/Flashes/Ignition
  - ac or dc Power with Voltage > 30V
  - All Fuels/Only With Ag
  - Multiple Fuel Drops to Produce Hot Spots
  - Ignitions Occur at Hot Spots: Last Several Seconds

CONCLUSIONS

- Lowest Power Hot Spot/Ignition
  - On Terminal Block with Silver Residue
  - dc Power Below 0.7 Watts (~25V, 25 mA)
- Appears That Conductive Ag Residues on Wires and Terminal Blocks **Do Pose** a Combustion Hazard
- Research Needed to Assess Probability of Ag Residues Causing Fuel Ignitions (Next Paper)

RECOMMENDATIONS
To Improve FQIS Reliability

- Short Term - Replace Ag Nuts to Eliminate Conductive Residues on Terminal Blocks
  - Fuel, Water and Low ac Electrical Power Normally Present
  - Electrolysis/Gums Not Inhibited by Inerting
- Long Term – Redesign Block Surface to Eliminate Bridging Water Layers
- Long term - Inhibitor (NASA) to Deactivate Exposed Ag Surfaces (Nuts, Fuses, Damaged Wires)

RECOMMENDATIONS
To Minimize Ignition Hazard

- Short Term – Incorporate Power Limitation Device to Minimize Power Into Fuel Tank To Eliminate Hot Spots

- Do Not Bundle 28Vac Wires (FQIS) and 28Vdc Wires (Automatic Fuel Shutoff Valve)

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