DESIREE-Fire

Direct Current Electrical Shorting In Response to Exposure Fire

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Presented at:
10th International Probabilistic Safety Assessment & Management Conference, Seattle, Washington, June 6-11, 2010

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Acknowledgements

- **DESIREE-Fire is a U.S. NRC Office of Research sponsored project**
  - **Gabe Taylor – RES program technical lead**
  - **Mark Salley – RES management lead**

- **Collaborative partners: EPRI and several of their utility members**
  - **Ken Canavan – EPRI lead**
  - **In-kind material support**
  - **Peer review**

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Project Background

- **NRC and industry continue efforts to address cable failure modes and effects**
  - **e.g., spurious actuation for control circuits**
- **Most prior efforts have focused on AC circuits**
  - **NEI/EPRI testing 2001-2002**
  - **NRC/CAROLFIRE (NUREG/CR-6931)**
- **Question is: Can the AC-based testing be extrapolated to DC-powered circuits?**

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Insights from Duke Energy Tests

- **Duke Energy conducted tests in 2006 that included both AC and DC circuits**
- **DC circuits seemed to behave differently from AC circuits**
  - **Protective fuses did not always clear faults**
  - **DC coils not rated for continuous energizing and overheated in some cases**
  - **Voltage shunts overheated and failed during testing**
- **Intent of DESIREE Fire was to follow-up on these preliminary findings**

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The Testing Approach

- **Utilize a realistic battery set to power multiple circuits**
  - **Duke had used car batteries, DESIREE-Fire used a more representative set**
- **Two Scales of testing were pursued (same as CAROLFIRE)**
  - **Small-scale radiant heating experiments**
  - **Intermediate-scale open burn tests**
- **Test a range of cables**
  - **From CAROLFIRE set: XLPE, EPR, PE/PVC, PVC/PVC, Tefzel**
  - **Cables from industry: armored cable, Kerite**
- **Test a range of DC-powered control circuits**
  - **Monitor circuit response on cable failure**

- **Specific details may be found in the test plan, ADAMS Accession No. ML082520518**

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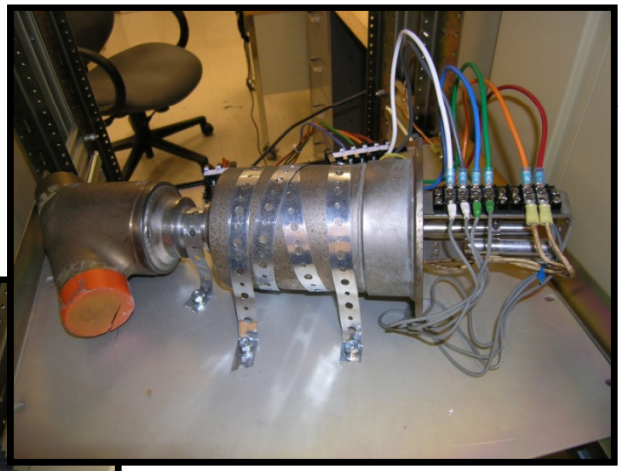
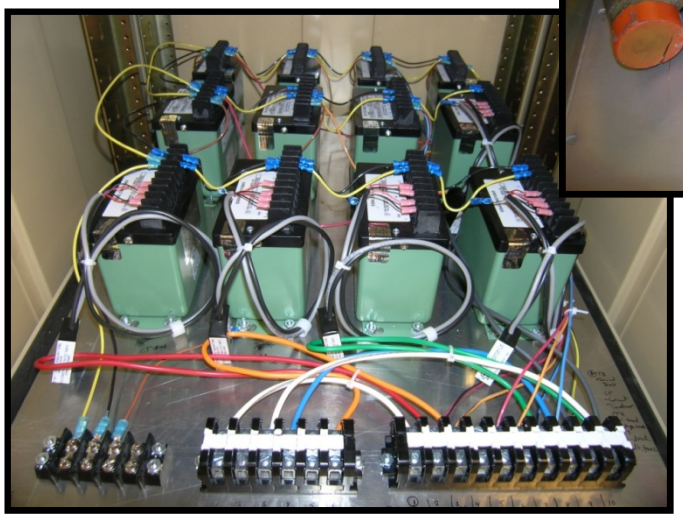
The Battery Bank

- **Battery set being taken out of service was provided via the EPRI collaboration**
  - **Thank you North Anna…**
- **60 Exide ES-13 cells**
  - **Each cell weighs about 60 pounds (27 kg)**
  - **Wet-acid**
  - **Lead-calcium alloy plates**
  - **Bank of 60 provides nominal 125VDC**
  - **Overall bank has potential 13,000-ampere fault current**

Cable performance monitoring systems

- **Surrogate Circuit Diagnostic Unit (SCDU) from CAROLFIRE**
  - **Simulates an AC-powered MOV circuit**
- **Direct Current Simulation Panels (DCSim Panels)**
  - **Two small solenoid operated valves (SOV)**
  - **Two reversing MOVs**
  - **One-inch SOV**
  - **Large SOV coil**
  - **15kV switchgear**
  - **Inter-cable circuit**





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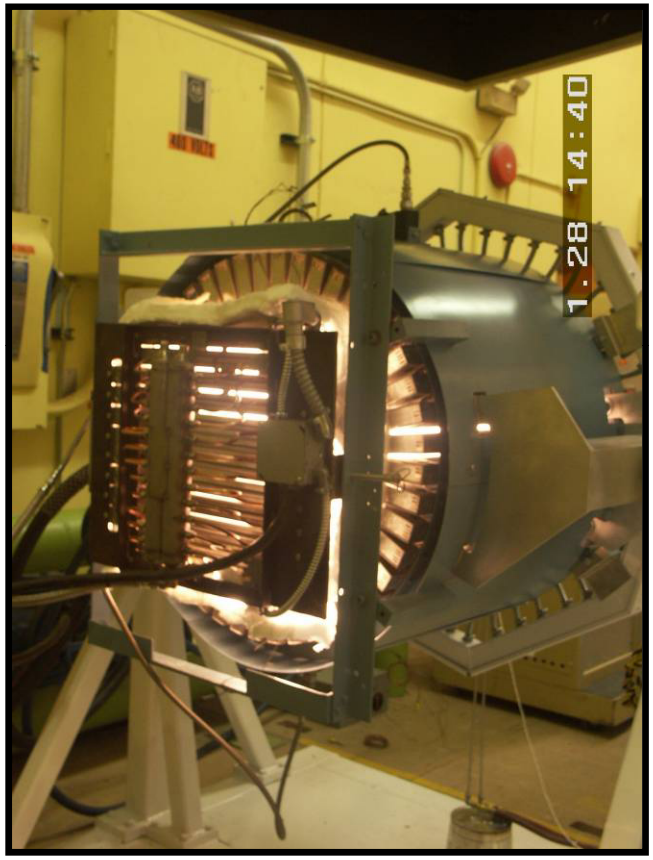
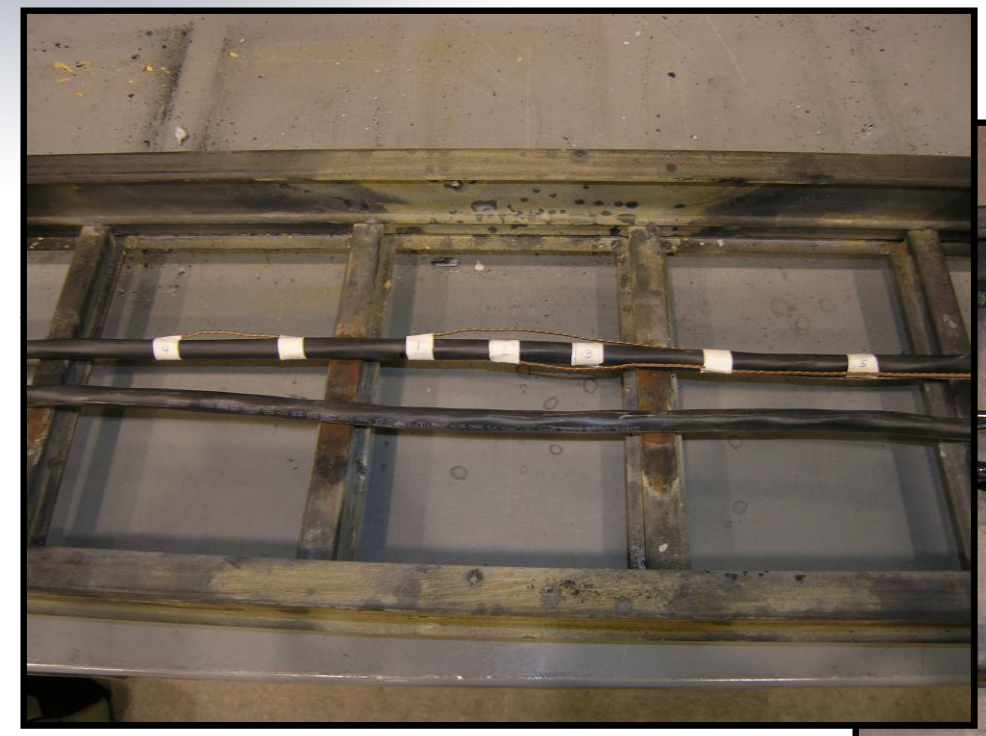
Small Scale Tests

- *Penlight* **heats target cables via grey-body radiation from a heated shroud**
- *Penlight* **was originally developed to support RES testing in the 1980's and has been used in a number of prior test programs**
- **Well controlled, well instrumented tests**
- **Allows for many experiments in a short time**
- **Thermal response and failure for single cables and small cable bundles (up to six cables)**
- **Cable trays, conduits**

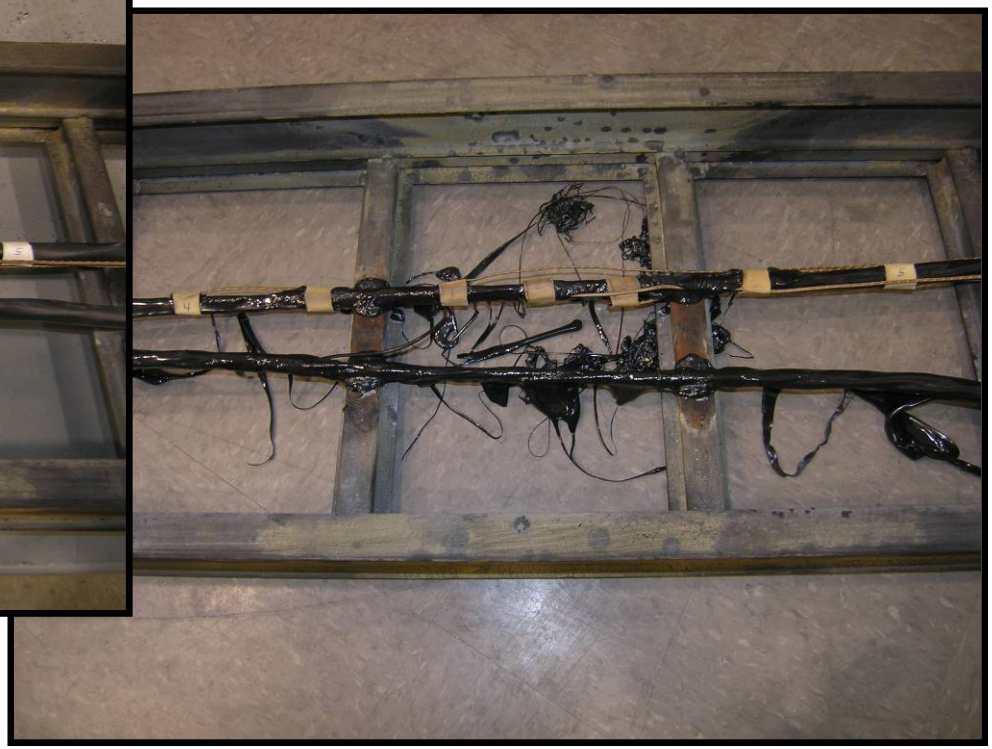


Typical before/after for a Penlight test - thermoplastic cables

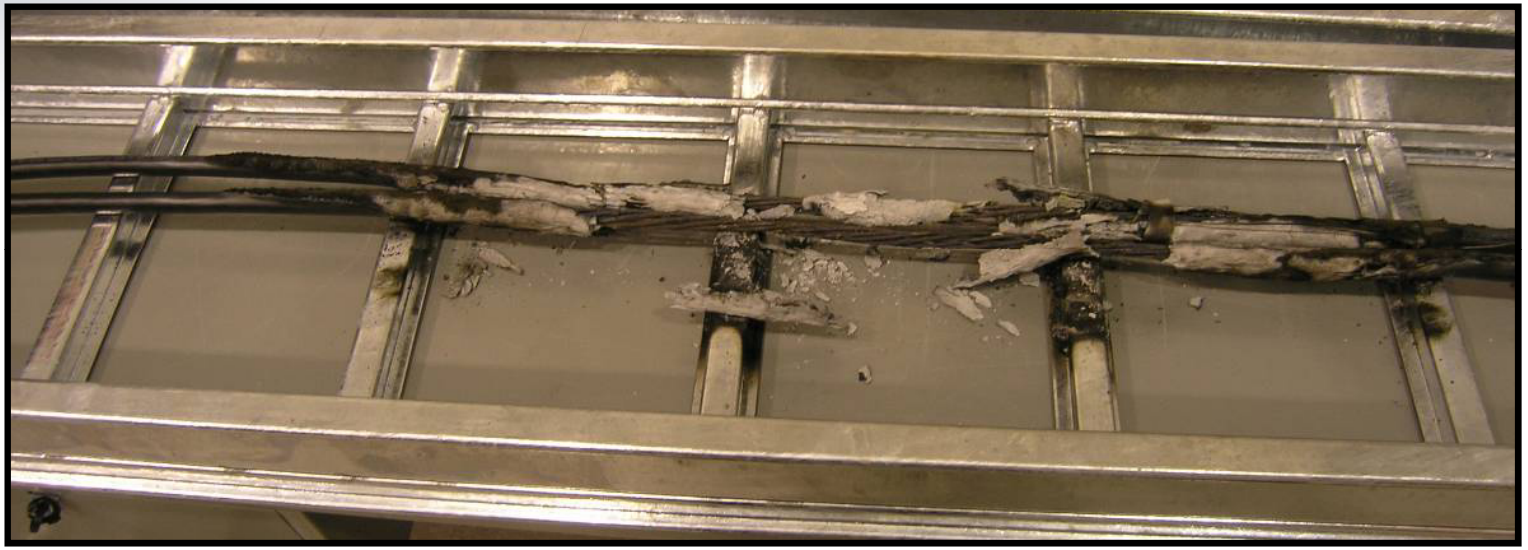


Top cable measures temperature response, bottom cable electrical performance

Note the obvious melting behavior typical of thermoplastics



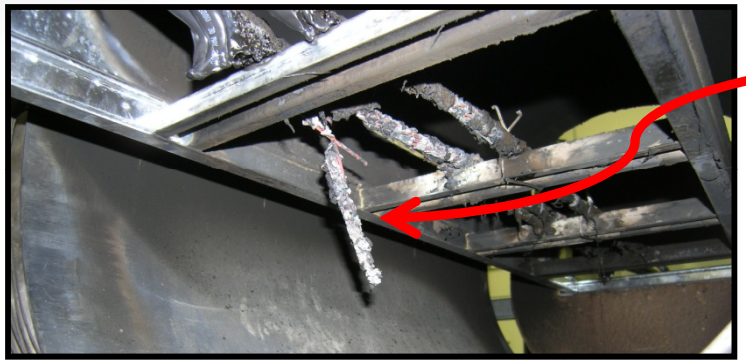
Typical Post-Test Conditions – Thermoset Cables



Note the remnants of charred insulation and jacket, but no melted materials. These cables did burn during the test.

Some unique aspects to the DC tests

- **Electrical failure was more energetic than AC circuits**
- **Often saw conductor breakage, arcing**



Live cable hanging after heat exposure

Copper slag from conductors

Conductor welded to tray

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Intermediate-Scale Tests

- **Less controlled, but a more realistic testing scale**
- **Hood is roughly the size of a typical ASTM E603 type room fire test facility (more open to allow for ready access)**
- **Propene (Propylene) burner fire source (200-300 kW typical)**
- **Cables in trays, conduits and air drop**

Intermediate-Scale Test Structure and Gas Burner

Cable Orientation During Intermediate Tests

- **Cables were either in trays or conduit**
- **Thermocouples were strategically placed, but not to the extent of CAROLFIRE**
- **Five possible tray locations were utilized**

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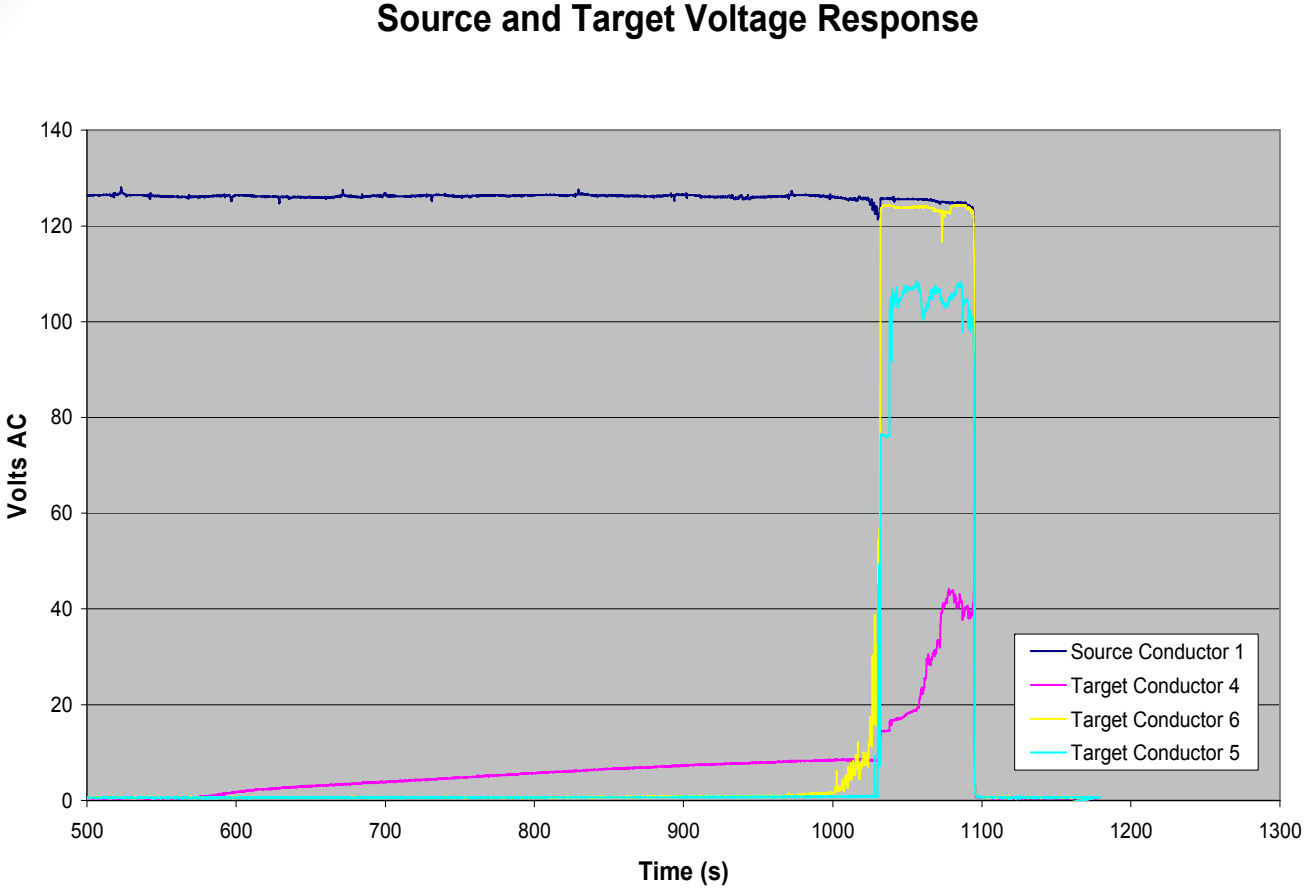
AC Circuit Analysis

- **AC circuit fault tests are relatively easy to analyze**
- **In this example, MOV motor starter coil actuation is clearly distinguishable**

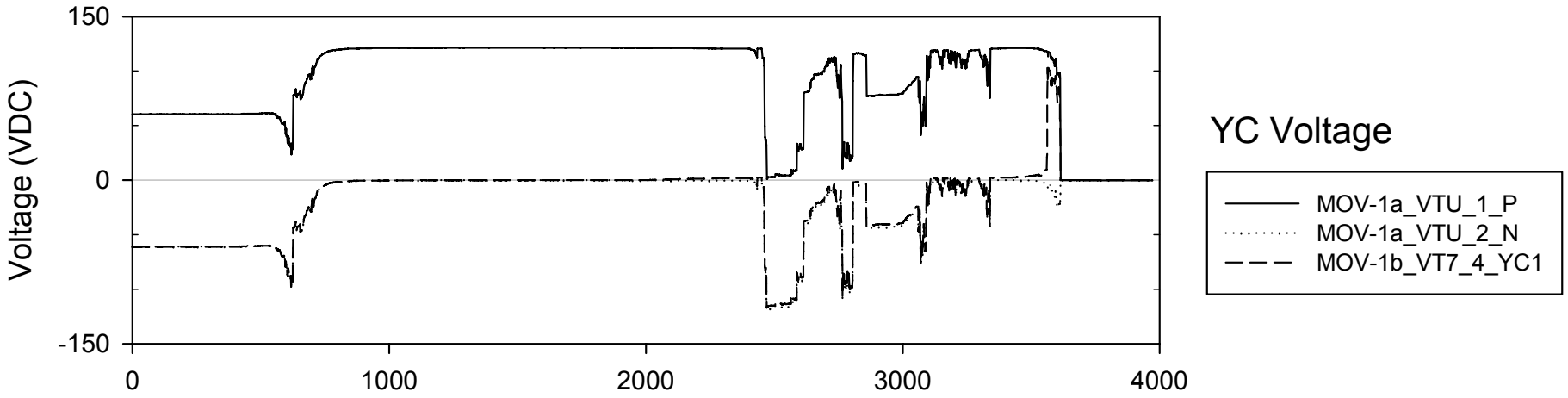


DC circuit analysis is more complex

- **Battery bank is ungrounded, but there is a common earth-ground reference for all circuits**
- **Battery bank may become grounded with cable failures**
- **Target actuation is <u>very difficult</u> just looking at raw data**

Example showing Batt-pos (…P), Batt-neg (…N), and MOV Coil (…YC1)

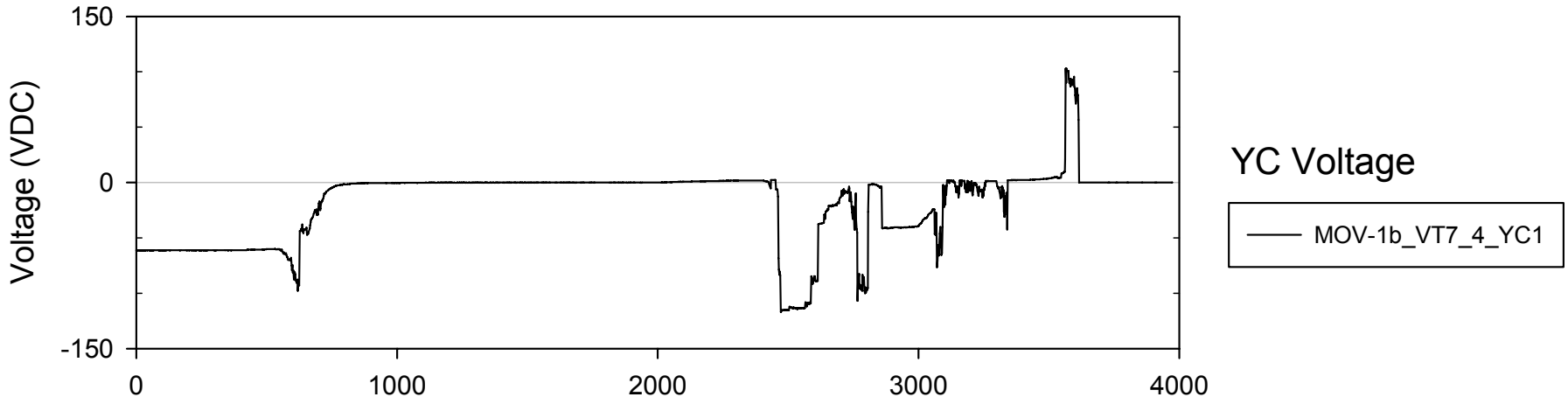
So what happened and when?



DC Circuit Analysis

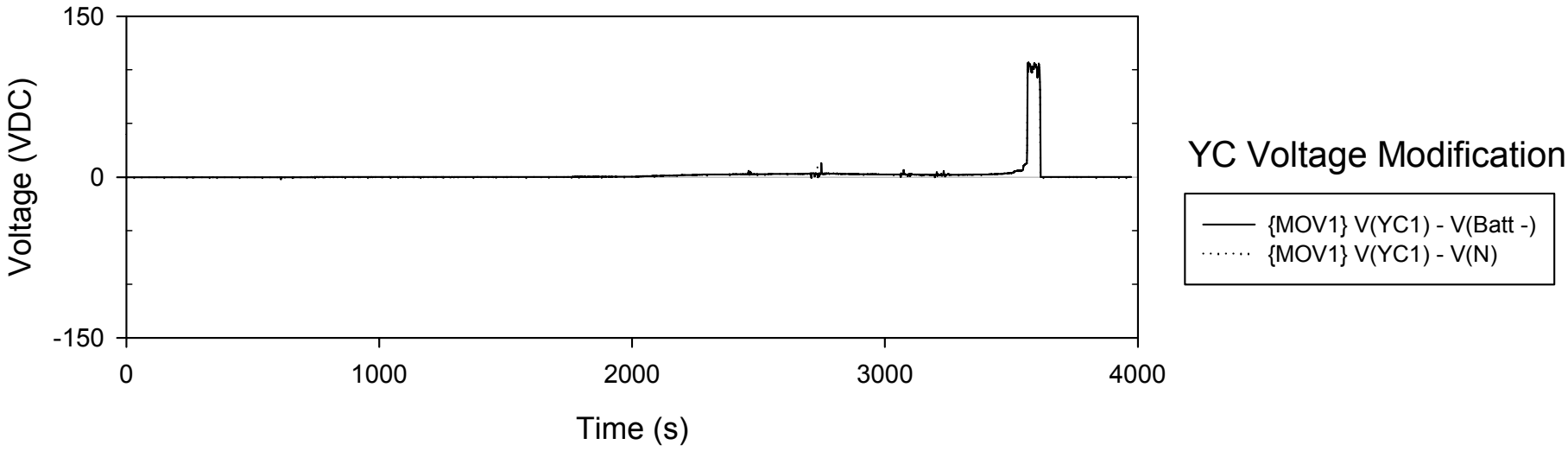
What if we just plot the coil voltage?

This is not much better!



DC Circuit Analysis

But when we filter out the ground fault behavior, the picture becomes somewhat clear …



This is just one circuit – typical test had nine separate DC circuits

…Ground faults on the DC battery can make life rather complicated!

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Summary

- **60 Penlight Tests and 17 Intermediate Scale Experiments have been completed**
- **Data analysis remains underway – preliminary insights:**
  - **We confirmed that dc-circuit failures tends to be more energetic than their ac counterparts (energetic arcing)**
  - **Smaller fuses did tend to clear faults, but larger fuses did not (e.g., 30A fuses rarely cleared)**
- **Spurious operations did occur and some were relatively long-lasting compared to AC tests**
- **Final report should be in for publication by the end of August**

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