PHYSICS OF DC CARBON TRACKING OF PLASTIC MATERIALS

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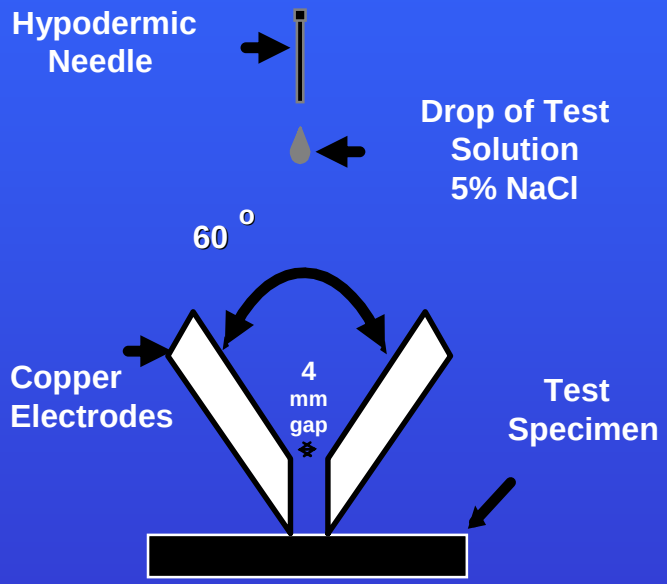
MVFRI BACKGROUND

- MVFRI IS A NON-PROFIT ORGANIZATION SPONSORING RESEARCH ON CRASH INDUCED AUTOMOBILE FIRES
- $ 4.1 M FUNDING FROM A GM SETTLEMENT
- ENTERING OUR 4TH YEAR
- PROJECTS AND RESULTS CAN BE FOUND AT: www.mvfri.org

CARBON TRACKING BACKGROUND

- AUTO INDUSTRY IS CONSIDERING 42-VOLT ELECTRICAL SYSTEMS
- CARBON TRACKING AND HIGH INTENSITY ARCING ARE A BIGGER CONCERN AT 42-V
- UL HAS A LONG HISTORY OF AC CARBON TRACKING TESTS – BUT NOT DC
- USCAR HAS A 42-V WORKING GROUP
- USCAR AND MVFRI JOINTLY FUNDED UL TO DEVELOP A DC TEST AND TO TEST 24 CANDIDATE INSULATING MATERIALS
- TWO FINAL REPORTS AVAILABLE AT MVFRI WEBSITE

DC CTI TEST SETUP



TEST CHANGES FROM AC TO DC

- ELECTROLYTE CHANGED FROM AMMONIUM CHLORIDE TO SODIUM CHLORIDE (ROAD SALT)
- RESISTIVITY CHANGED FROM 385 OHM-CM TO 15 OHM-CM (FACTOR OF 26) (5% NaCl TYPICAL OF ROAD SALT CONCENTRATIONS)
- ELECTRODES CHANGED FROM PLATINUM TO COPPER (REPRESENTS REAL APPLICATION)

TEST PROCEDURE

- SERIES RESISTOR IS USED TO LIMIT CURRENT TO 20 AMPS
- VOLTAGE APPLIED FROM DC POWER SUPPLY
- HYPERDERMIC NEEDLE WITH POSITIVE DISPLACEMENT PUMP SUPPLIES NaCl ELECTROLYTE TO SIMULATE ROAD SALT AND TO ACCELERATE THE TEST

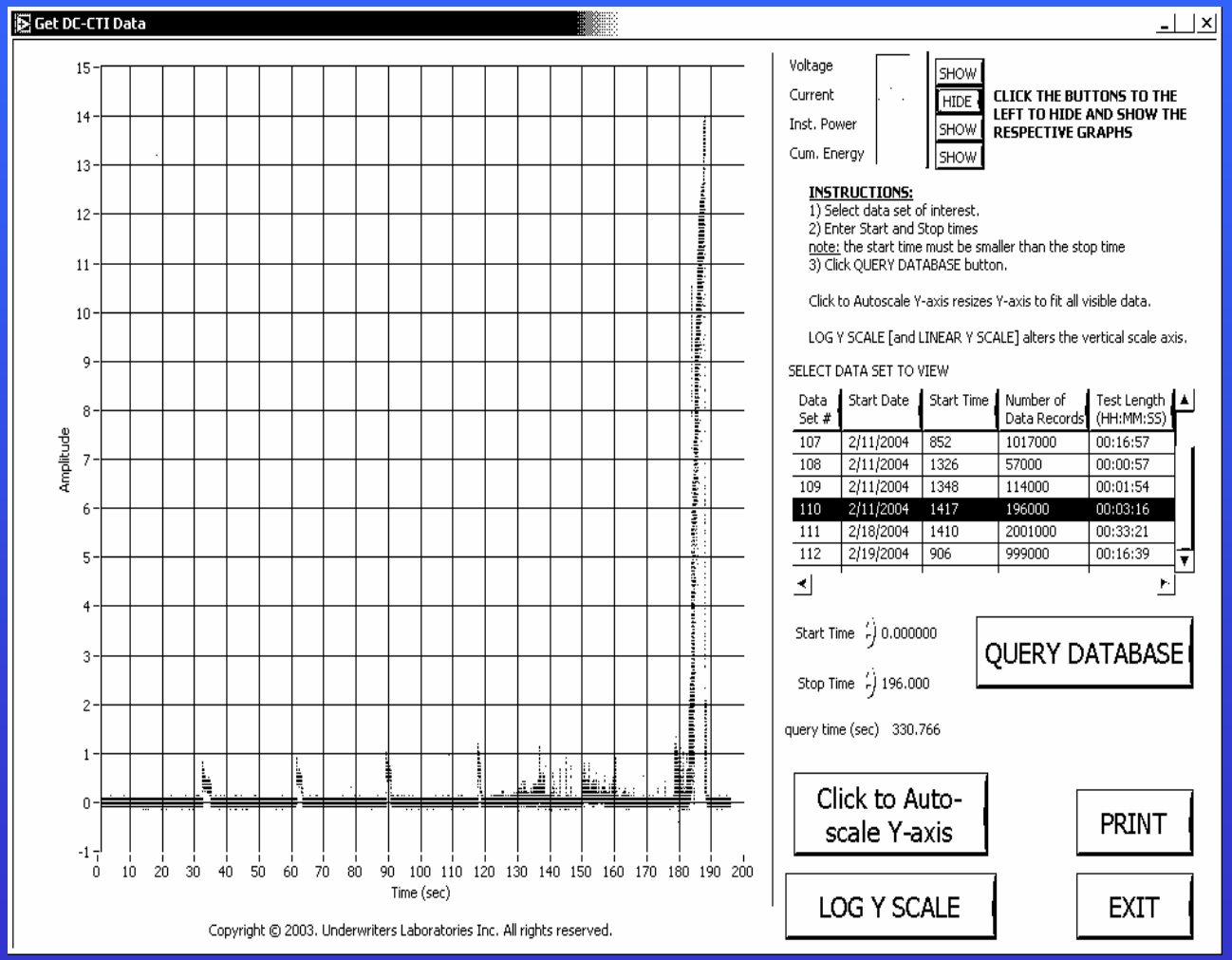
MATERIAL RATING

- HIGHEST VOLTAGE FOR WHICH THE MATERIAL CAN SURVIVE 50 DROPS OF ELECTROLYTE
- VOLTAGES TESTED: 150, 100, 60, 50, 42, 12
- WIDE RANGE OF RESULTS

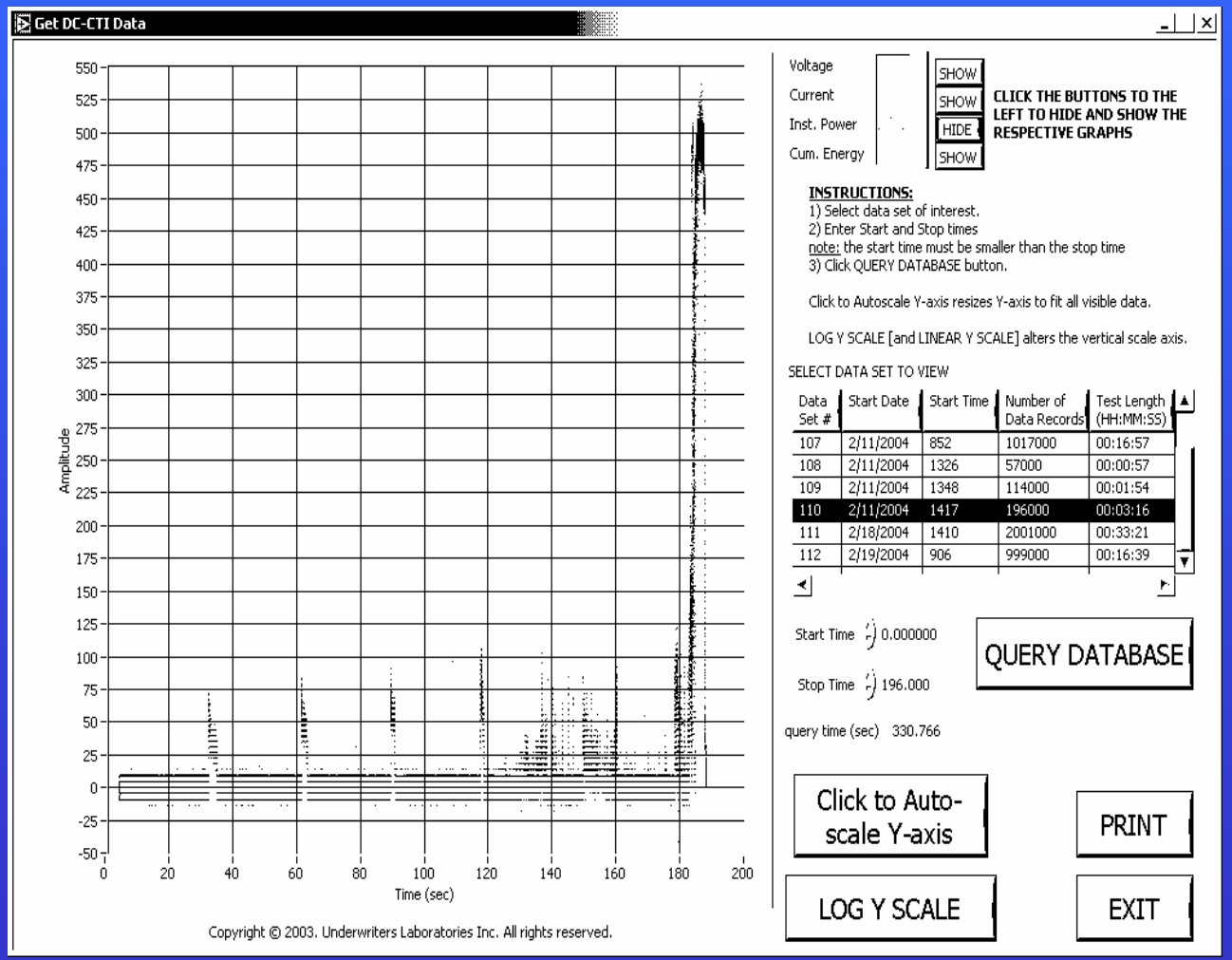
INSTRUMENTATION

- MEASURED VOLTAGE AND CURRENT AT 1000 HERTZ
- CALCULATED INSTANTANEOUS POWER AND INTEGRATED TO GET CUMULATIVE ENERGY
- PLOTS SHOW TEST NUMBER 4: MATERIAL 16, 5% NaCl ELECTROLYTE, 100 V
- FAILS AFTER 6 DROPS – FLAME AND HIGH CURRENT ARC

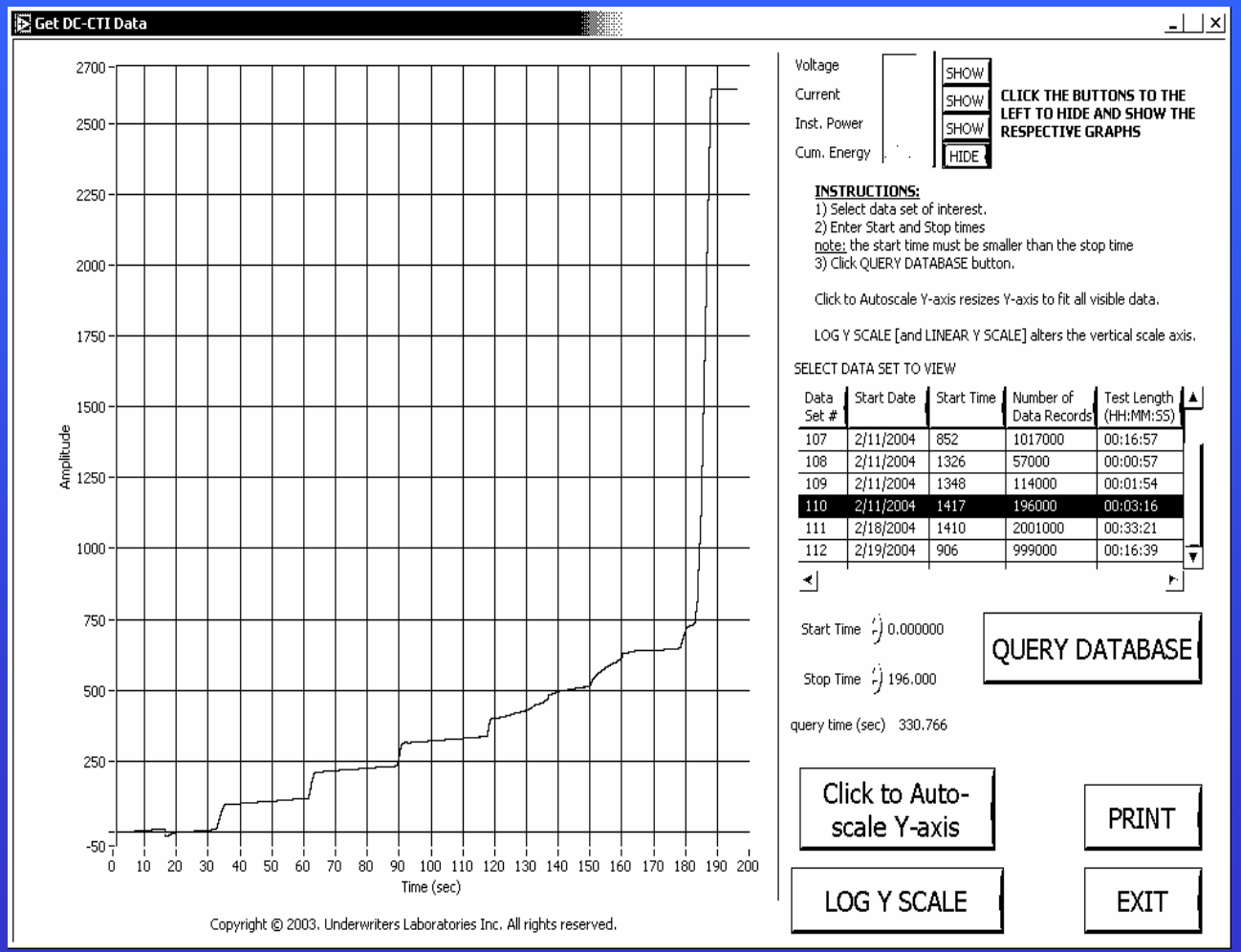
TEST 4 CURRENT (AMPS)



TEST 4 POWER (WATTS)



TEST 4 ENERGY (JOULES)



VIDEO – TEST 4 – DROP 1


Underwriters Laboratories Inc.®
COMPARATIVE
TRACKING INDEX (CTI)
DC VOLTAGE

VIDEO – TEST 4 – DROP 3

VIDEO – TEST 4
DROPS 5 & 6 TO FAILURE

OBSERVATIONS

- EVENT IS VERY ENERGETIC
- DROP RAPIDLY EVAPORATES
- SCINTILLATIONS AND SMALL FLAMES OCCUR BETWEEN DROPS

SIMPLE MODEL OF CARBON TRACKING

EQUATION 1: $P = V^2 / R$

EQUATION 2: $R = \rho L / A$

FOR OUR GEOMETRY $R = 8 \rho$ (120 OHMS FOR 5% NaCl)

FOR 100 VOLT TEST, P = 80 WATTS

FOR 100 VOLT TEST, ENERGY TO HEAT AND EVAPORATE DROP = 50 JOULES

TABLE 2 - RESULTS

Test #	Hypothesis	Material ID #	Reagent / Concentration	Voltage (VDC)	Addendum Tests No. of Drops to Failure				December 15, 2003 Report Results No. of Drops to Failure											Energy (Joules)
					Trial				Trial											
					1	2	3	4	1	2	3	4	5	6	7	8	9	10	11	
1	1 - Material	22	NaCl / 5%	150	33	33	**7**		15	9	11									850
2	"	6	NaCl / 5%	60	**16**				26	17	10									1450
3	2 - Resistivity	16	NaCl / 1%	100	**38**	33			21	20	11									4375
4	"	16	NaCl / 5%	100	**6**				6	5	4	5	3	6	7	3	6	3		740
5	"	16	NaCl / 15%	100	**3**				3	3	3									300
6	3 - Electrolyte	5	NaCl / 5%	42	**33**	32	78		54	48	37	52	55+	33	51	55+	55+	26	77	3700
7	"	5	NH_4Cl / 35%	42	**48**	15	>65	19	32											5700
8	4 - Voltage	5	NaCl / 5%	150	**1**				2	1	1									200
9	"	5	NaCl / 5%	100	**3**				7	4	4									375
10	"	5	NaCl / 5%	60	11	**16**			17	25	20									1510
11	5 - Glass Substrate	glass	NaCl / 5%	150	**54**				61	61										7500
12	vs. Carbon Material	25	NaCl / 5%	60	**66**				70	55+	55+	55+								7620

FIVE HYPOTHESES

1. MATERIAL
2. RESISTIVITY
3. ELECTROLYTE COMPOSITION
4. VOLTAGE
5. GLASS VESUS PLASTIC

HYPOTHESIS 1 - MATERIAL

- LOW PERFORMING MATERIAL SHOULD FAIL WITH LESS CUMULATIVE ENERGY THAN A HIGH PERFORMING MATERIAL
- SEE TESTS 1 AND 2 IN TABLE 2
- HYPOTHESIS NOT CORRECT

HYPOTHESIS 2 - RESISITIVITY

- TOTAL ENERGY SHOULD BE ABOUT THE SAME FOR SAME MATERIAL, ELECTROLYTE COMPOSITION, AND VOLTAGE
- SEE TESTS 3, 4, AND 5 IN TABLE 2
- HYPOTHESIS NOT CORRECT
- NUMBER OF DROPS TO FAILURE ABOUT = 0.5 ρ

HYPOTHESIS 3 – ELECTROLYTE COMPOSITION

- COMPOSITION SHOULD BE SECOND ORDER EFFECT AFTER RESISTIVITY AND VOLTAGE
- SEE TESTS 6 AND 7 IN TABLE 2
- TOTAL ENERGY AND NUMBER OF DROPS TO FAILURE ARE WITHIN 20% OF AVERAGE
- HYPOTHESIS APPEARS TO BE CORRECT

HYPOTHESIS 4 - VOLTAGE

- NUMBER OF DROPS TO FAILURE AND TOTAL ENERGY SHOULD GO AS $1 / V^2$
- SEE TESTS 8, 9, AND 10 IN TABLE 2
- UL ADDENDUM REPORT PLOTS ENERGY VERSUS V^2 AND SUPPORTS HYPOTHESIS
- DROPS TO FAILURE ABOUT = $37,000 / V^2$
- SEEMS OK

HYPOTHESIS 5 – GLASS VS PLASTIC

- GLASS SHOULD NOT TRACK
- SEE TESTS 11 AND 12 IN TABLE 2
- CLEARLY WRONG – GLASS TRACKS AT 54 TO 61 DROPS
- UL REPORT ALSO TESTED CERAMIC AND IT TRACKED ALSO

OBSERVATIONS AND CONCLUSIONS

- DC TEST DEVELOPED – BECOMING ASTM STANDARD
- REPEATABILITY IS PRETTY GOOD – 20 TO 30% ON NUMBER OF DROPS TO FAILURE
- THERMALLY INTENSE EVENT – NOT A 15-YEAR LIFE TEST

OBSERVATIONS (CONTINUED)
WHAT CAUSES FAILURE?

- WHAT COMES FIRST – THE FLAME OR THE ARC?
  - ARC ENERGY RELEASE IS EMORMOUS
  - ANY PLASTIC WILL QUICKLY FLAME
- THREE MECHANISMS
  - JOULE HEATING – THERMAL DEGRADATION
  - BUILD UP OF DEPOSITS (SALT, COPPER, AIR)
  - BUILD UP OF CARBON
- HYDROGEN FROM ELECTROLYSIS?
  - SMALL FLAMES WELL BEFORE FAILURE

THE BIG QUESTION

- CAN “CARBON TRACKING” OCCUR WITHOUT CARBON?

RECOMMENDATIONS

- DROP “PASS” CRITERION TO 35 DROPS
- DO EXTENSIVE CHEMICAL ANALYSIS OF THE DEPOSITS LEFT ON THE SAMPLES
  - WHAT IS THE DIFFERENCE BETWEEN GLASS AND PLASTIC?
- IMPROVE REPEATABILITY (BETTER DROP SIZE CONTROL, REMOVE BALLAST RESISTOR, AUTOMATION)
- DEVELOP 15-YEAR LIFE TEST