Accelerated Test Program for the battery used in the M234 Self Destruct Fuze

ERIC R. BIXON

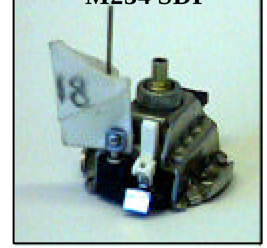
FRANK A. GAGLIARDI

AMSTA-AR-QAT-P

FEBRUARY 12, 2003

M234/XM235 Description

- ***M234/XM235 Self Destruct Fuze (SDF) is a state of the art electro-mechanical fuze for DPICM bomblets with an independent self destruct feature***
  - ***M234 for use on 105mm artillery & mortar projectiles***
  - ***XM235 for use on MLRS rockets***
  - ***XM236 for use on 155mm artillery***



M234 SDF

- ***Addresses Humanitarian Issues (UXO)***

M80 Grenade with M234 SDF

- ***Improves Maneuver Forces Mobility***
- ***Dramatically Reduces the Hazardous Dud Rate***
  - ***99.5% Reliability Demonstrated in ER-MLRS***
  - ***99.8% Reliability Demonstrated in M915 105mm Projectile***

- ***THE BATTERY IS A LITHIUM RESERVE BATTERY***

- ***THE BATTERY HOUSING CONTAINS A GLASS/STEEL AMPULE FILLED WITH A SULFURYL CHLORIDE-BASED ELECTROLYTE***

- ***WHEN THE AMPULE BREAKS, THE SULFURYL CHLORIDE CONTACTS THE LITHIUM AND THE BATTERY IS ACTIVATED***

CHEMISTRY OF THE BATTERY

Lithium Battery

- Lithium Anode
- Electrolyte 1.5 M $AlCl_3 + SO_2Cl_2$
  - ***Aluminum Chloride (Anhydrous) – 11.83 Weight percent***
  - ***Sulfuryl Chloride – 88.16 Weight Percent***

Overall Chemical Reaction for Lithium reacting with Sulfuryl Chloride

$$2Li + SO_2Cl_2 \rightarrow SO_2\uparrow + 2LiCl$$

Lithium is oxidized

$$2Li \rightarrow 2Li^+ + 2e^-$$

And Sulfur is reduced

$$SO_2Cl_2 + 2e^- \rightarrow 2Cl^- + SO_2 \uparrow$$

Other Chemical Reactions Occurring in the System

$$2AlCl_3 + Cl_2 + 2e^- \Leftrightarrow 2AlCl_4^-$$

Other Chemical Reactions Occurring in the System

complex ion

$$SO_2Cl^+ + AlCl_4^- \Leftrightarrow SO_2Cl^+(AlCl_4^-)$$

$$SO_2Cl_2 \Leftrightarrow SO_2(g)\uparrow + Cl_2(g)\uparrow$$

$$2SO_2Cl_2 \Leftrightarrow 2SO_2Cl^+ + Cl_2 + 2e^-$$

BACKGROUND

- An Accelerated Test Program has been started on the M234 battery to investigate potential failure mechanisms which may have an impact on the shelf life
- The objective of the program is to verify the 20 year shelf life requirement for the battery

BACKGROUND (cont)

- The tested samples were batteries designed and produced by ATK Power Sources Center in Horsham, PA
- L3-KDI in Cincinnati, OH, is currently under contract to develop a high-rate automated assembly line to produce an improved version of the ATK battery design

Summary of Experiments

- Determine ampule breaking point via Progressive Stress Experiment
- Determine battery failure modes via Isothermal Experiments

Summary of Experiments (cont)

- Determine ampule breaking point via Progressive Stress Experiment
  - Run 1: Progressive Stress Experiment from 70 F to 340 F to determine temperature range at which ampule fractures and battery activates

Summary of Experiments (cont)

2. Determine battery failure modes via Isothermal Experiments
   - Isothermal experiments
     - Run 2: 275 F for 216.8 hours
     - Run 3: 295 F for 47 hours
     - Run 4: 300 F for 87.6 hours
     - Run 5: 250 F for 21 days
     - Run 6: 184 F (84.7 C) for 29 days and 7 hours
     - Ambient Controls

Summary of Experiments (cont)

2. Determine battery failure modes via Isothermal Experiments (cont)
   - Investigate Potential Failure Mechanisms
     - Ampule Leakage – generation of “ghost voltages in storage”
     - Electrolyte Degradation/Decomposition
     - Corrosion due to reaction of sulfuryl chloride with the metal

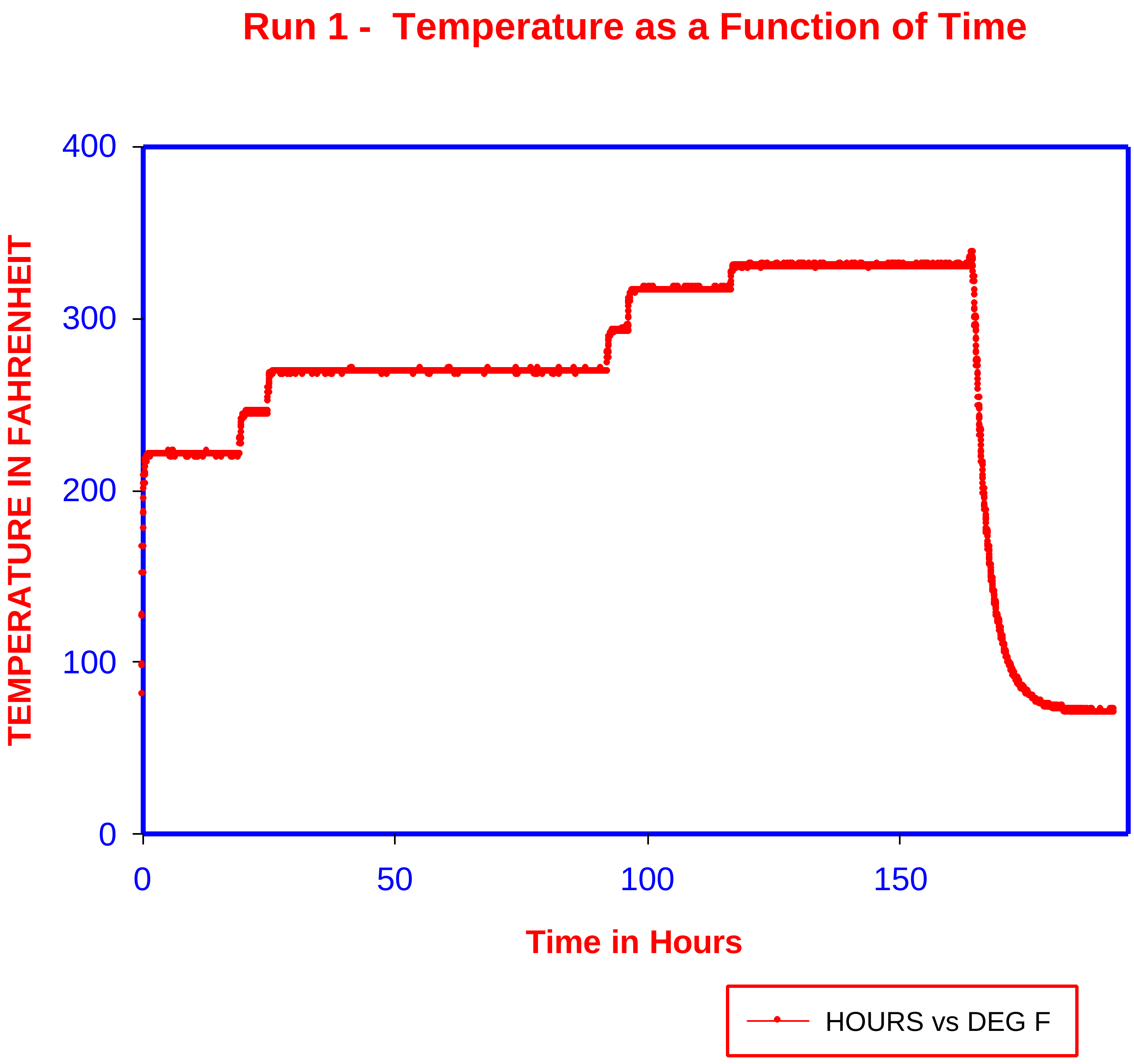
Part 1: Progressive Stress Experiment

Part 1: Progressive Stress Experiment (cont)

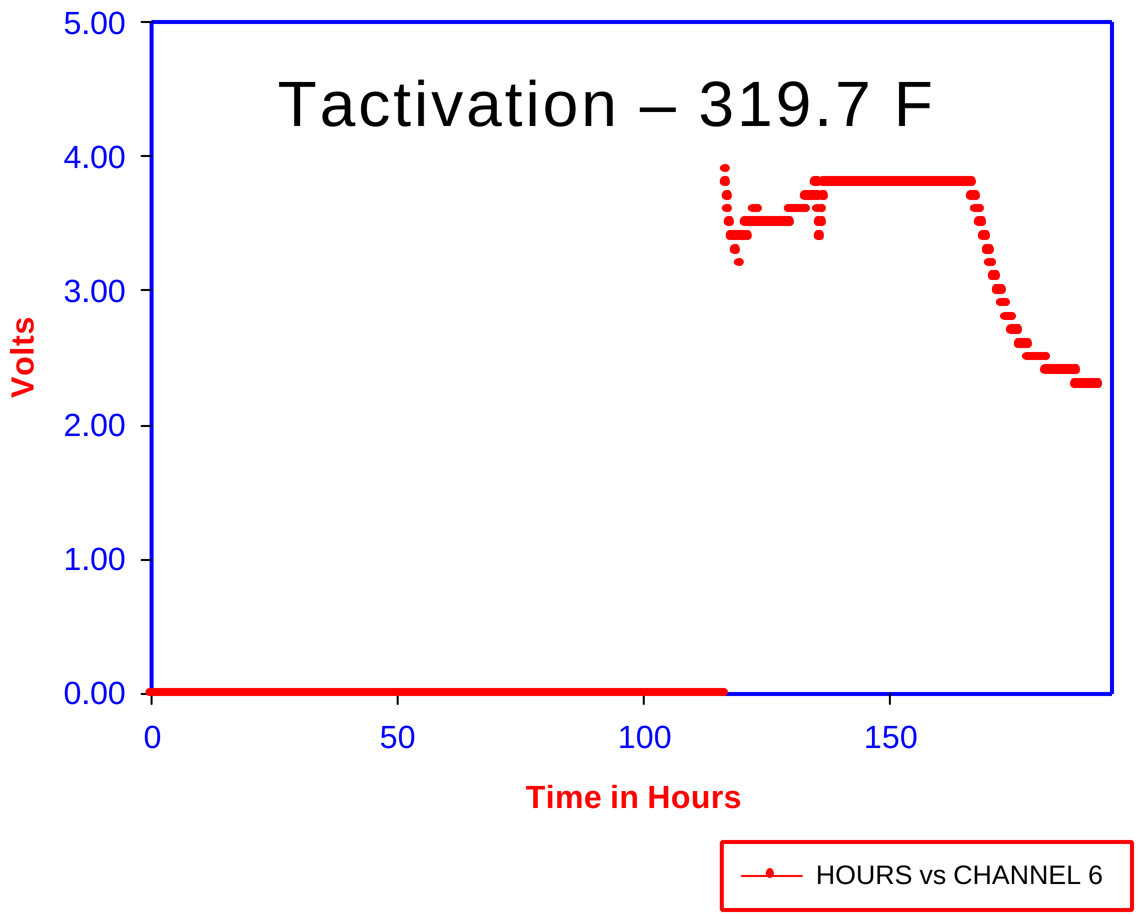
BLUF: Run 1 Results

Two batteries activated during accelerated aging due to expansion of the electrolyte in the ampules and fracture of the ampule at temperatures over +310 F

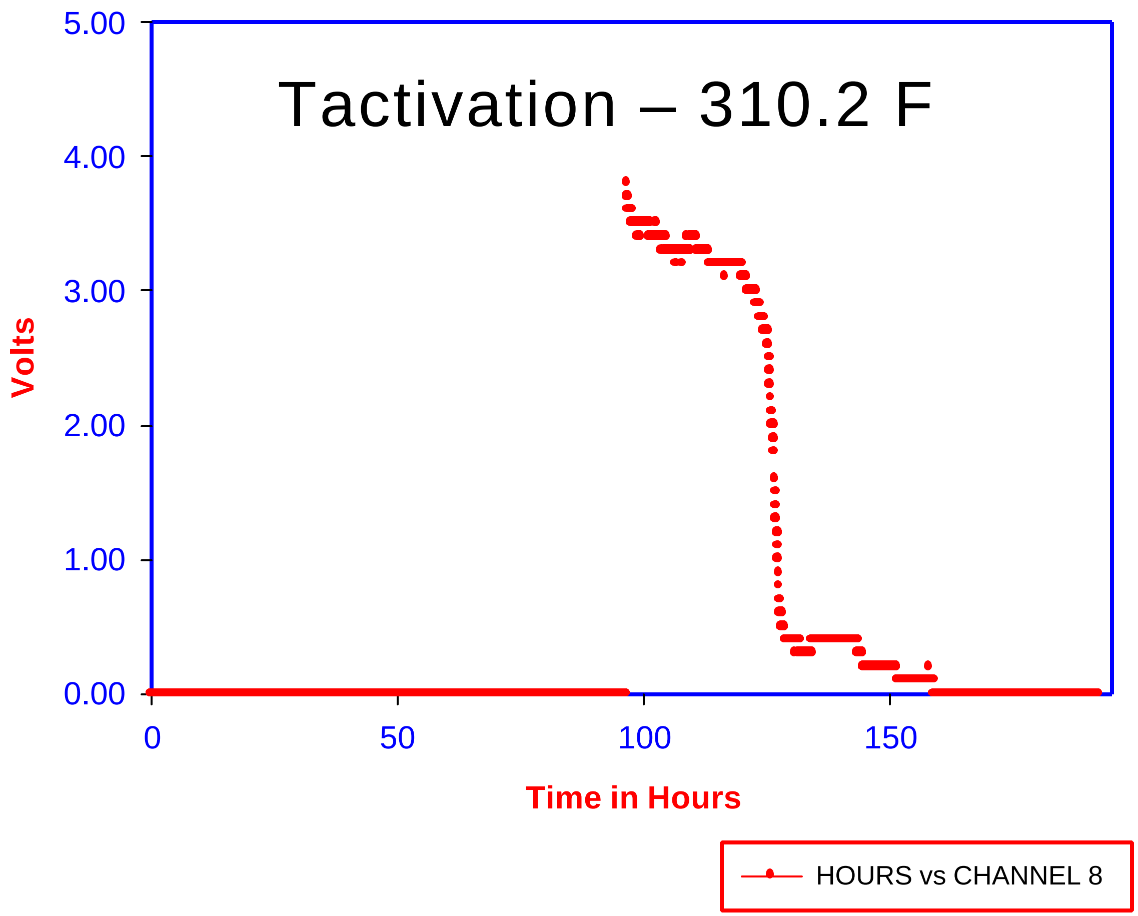
(Required battery temperature functioning range: -50F to +145F)


Run 1 - Temperature as a Function of Time
400
300
200
100
0
0
50
100
150
TEMPERATURE IN FAHRENHEIT
Time in Hours
HOURS vs DEG F

Run 1 - Channel 6 - Accelerated Aging



Run 1 - Channel 8 - Accelerated Aging



Part 2: Determine battery failure modes via Isothermal Experiments

Part 2: Determine battery failure modes via Isothermal Experiments (cont)

Battery Performance Requirements of Interest

- Battery must reach 3.6V within 60 seconds after activation at hot temperatures

- Battery must maintain 3.6V minimum for 10 minutes after activation at all temperatures

Part 2: Determine battery failure modes via Isothermal Experiments (cont)

Battery Activation Data

- **DATA OBTAINED DURING ACCELERATED AGING CYCLE**
  - **Sampling Rate = one reading every 189 seconds**

- **PERFORMANCE DATA AFTER AGING WHEN BATTERY IS ACTIVATED AND PERFORMANCE IS MEASURED**
  - **Sampling Rate = one reading per second**

- **BOTH TYPES ARE VOLTAGE vs TIME**

Part 2: Determine battery failure modes via Isothermal Experiments (cont)

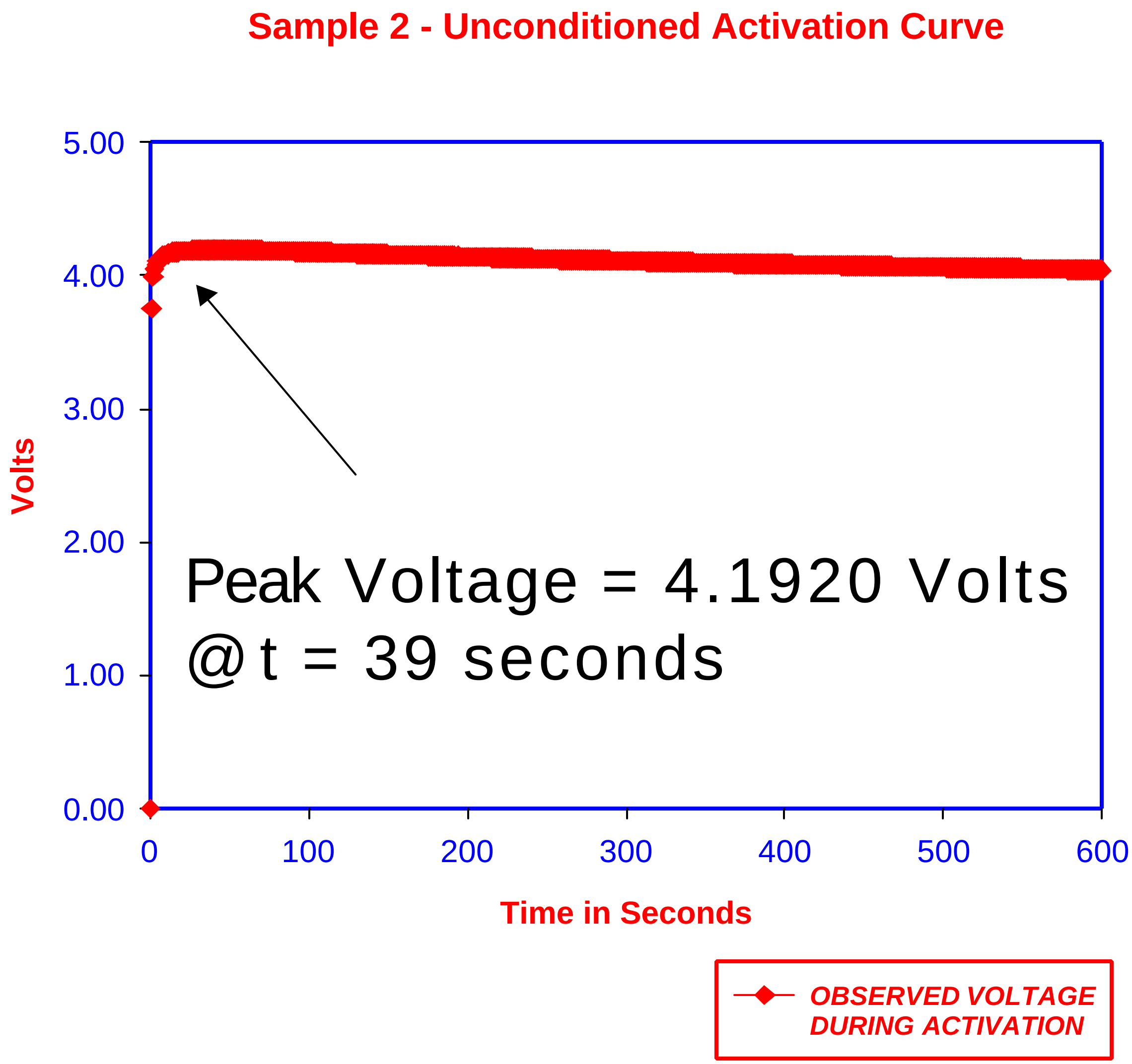
Battery Activation Data (cont)

- **Summary of Activation Procedures**
  - **-Most Activations were at ambient**
  - **-In Some Cases the batteries were conditioned at -55 F for 24 hours**
  - **-Then they were withdrawn and activated within 60 seconds, but generally, the time to activate was about 30 seconds**

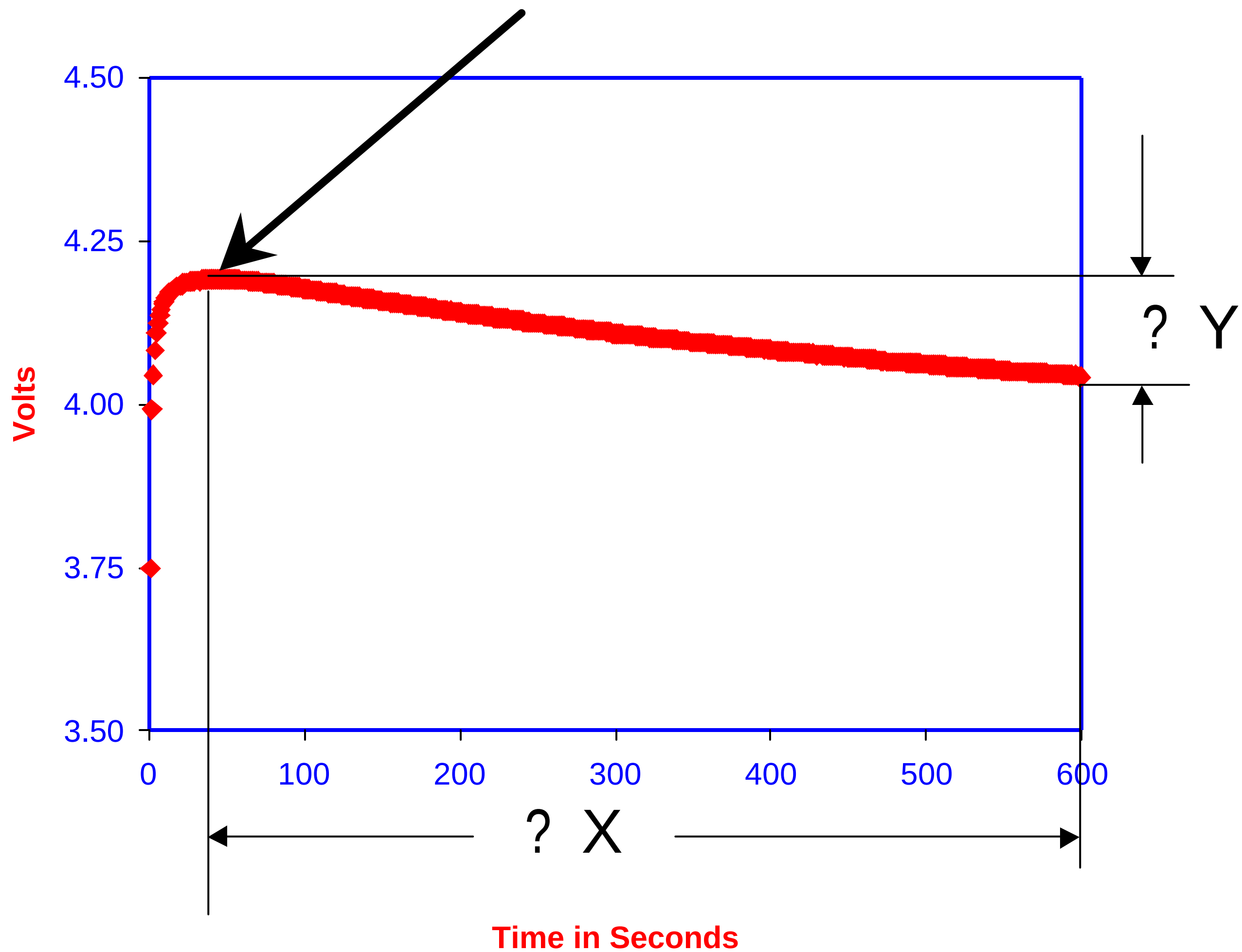
Part 2: Determine battery failure modes via Isothermal Experiments (cont)

Baseline Performance Data Obtained On Unconditioned Batteries

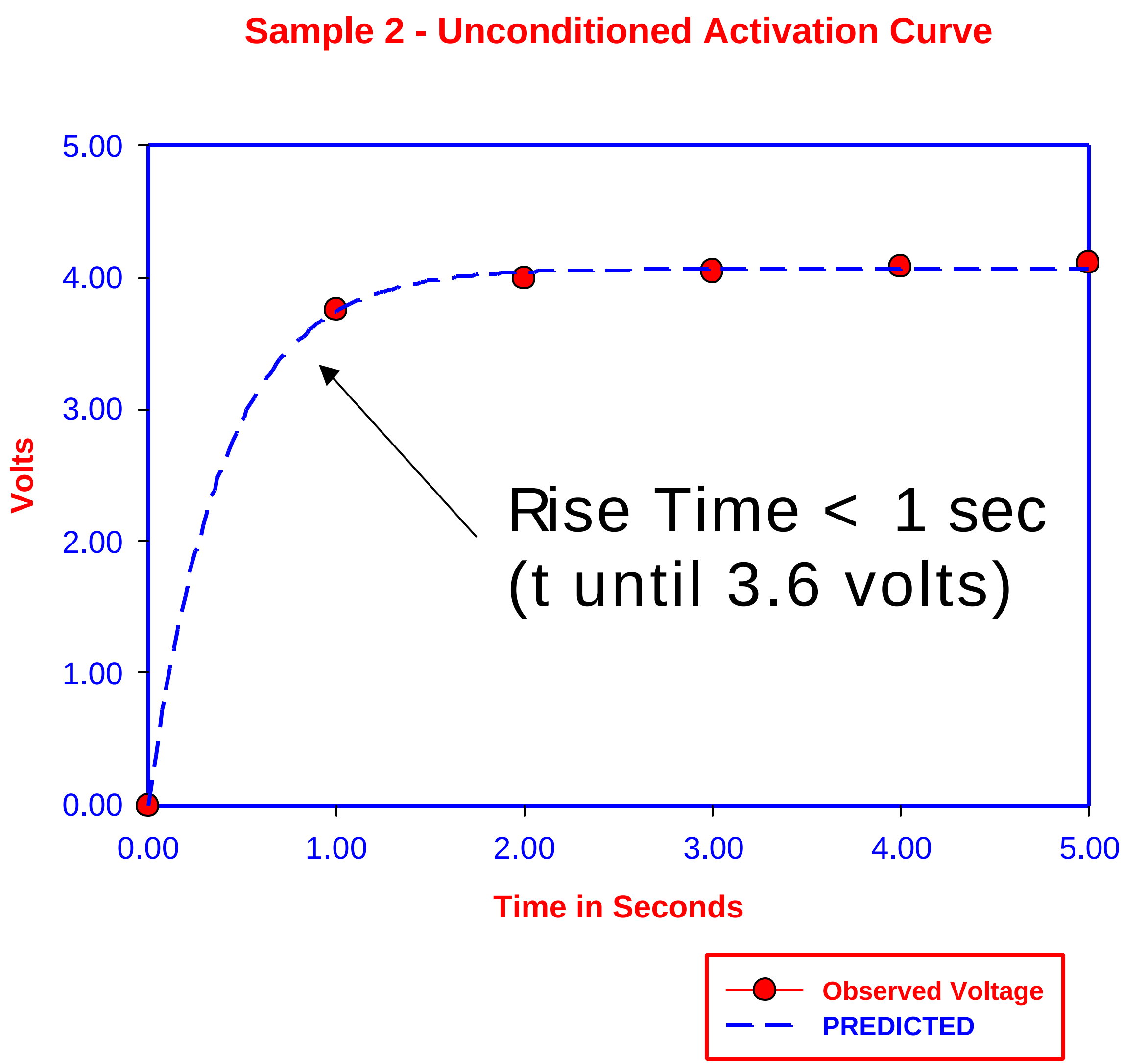
- Peak Voltage Estimate
- Voltage Degradation Rate Over a ten minute interval
- Rise Time = time to reach 3.6 volts


Sample 2 - Unconditioned Activation Curve
5.00
4.00
3.00
2.00
1.00
0.00
Volts
0
100
200
300
400
500
600
Time in Seconds
Peak Voltage = 4.1920 Volts
@ t = 39 seconds
OBSERVED VOLTAGE DURING ACTIVATION

Peak Voltage = 4.1920 Volts
@ t = 39 seconds



Voltage Degradation Rate = ? Y/ ? X


Sample 2 - Unconditioned Activation Curve
5.00
4.00
3.00
2.00
1.00
0.00
Volts
0.00
1.00
2.00
3.00
4.00
5.00
Time in Seconds
Rise Time < 1 sec
(t until 3.6 volts)
Observed Voltage
PREDICTED

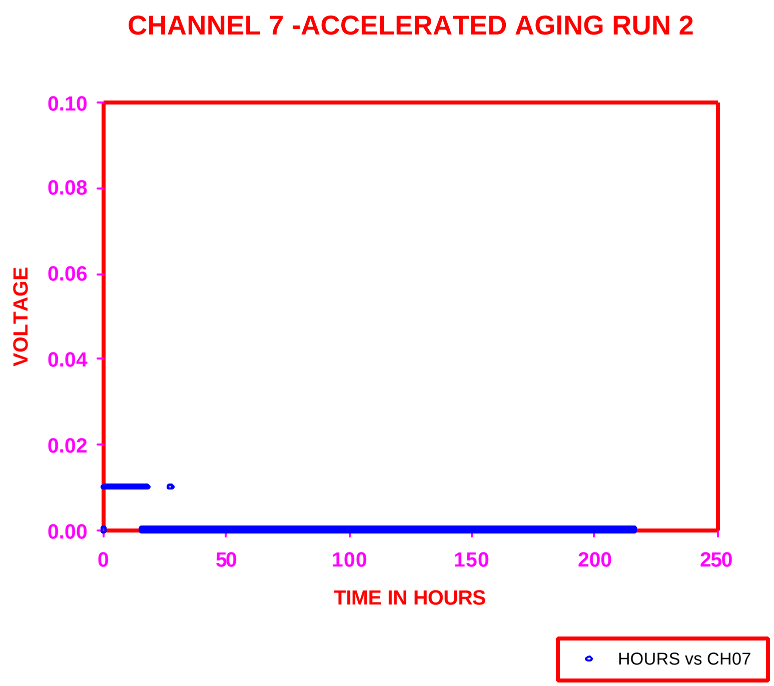
Part 2: Determine battery failure modes via Isothermal Experiments (cont)

CHARACTERIZATION OF AMPULE LEAKS

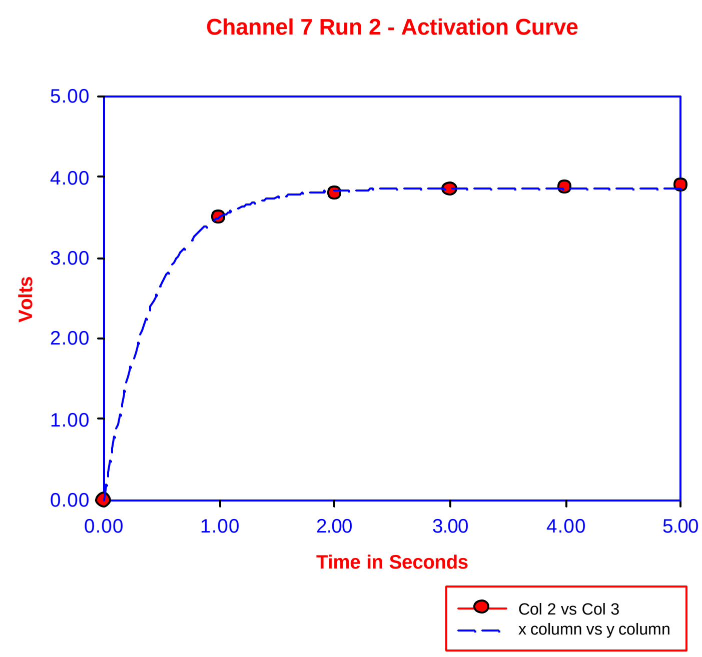
Part 2: Determine battery failure modes via Isothermal Experiments (cont)

SMALL LEAKS

Accelerated Aging



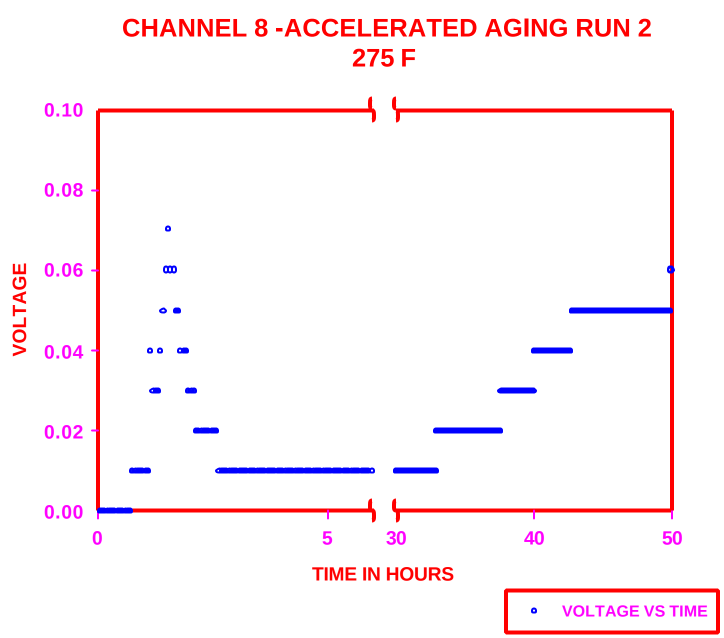
5 Second Performance



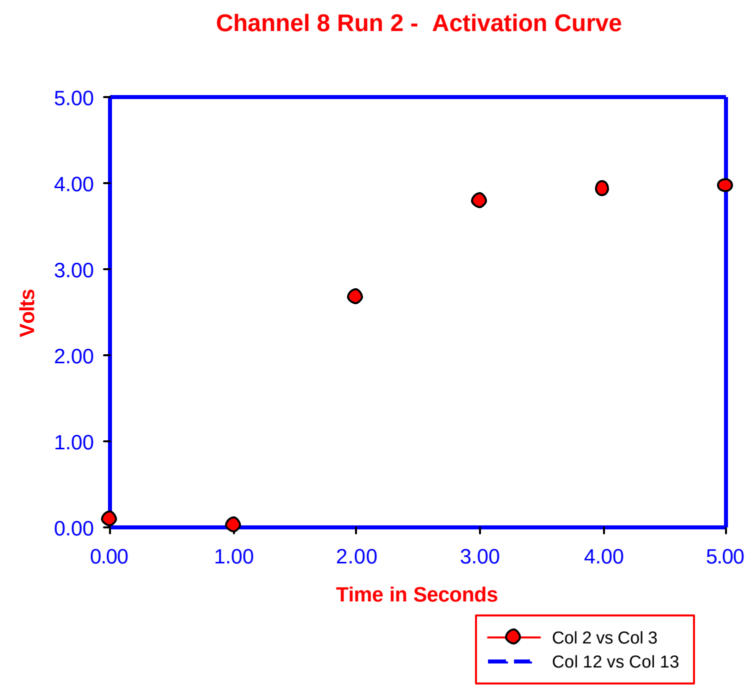
Part 2: Determine battery failure modes via Isothermal Experiments (cont)

LEAKS THAT STOP AND START

Accelerated Aging



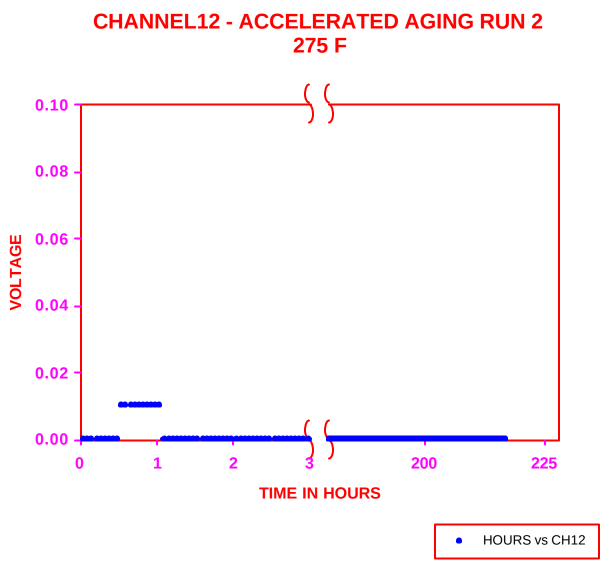
5 Second Performance



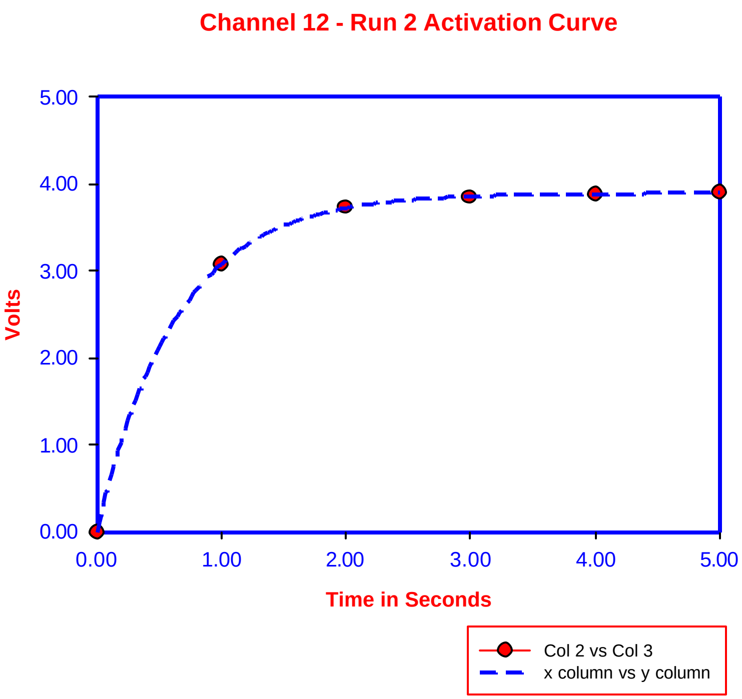
Part 2: Determine battery failure modes via Isothermal Experiments (cont)

LEAKS THAT STOP

Accelerated Aging

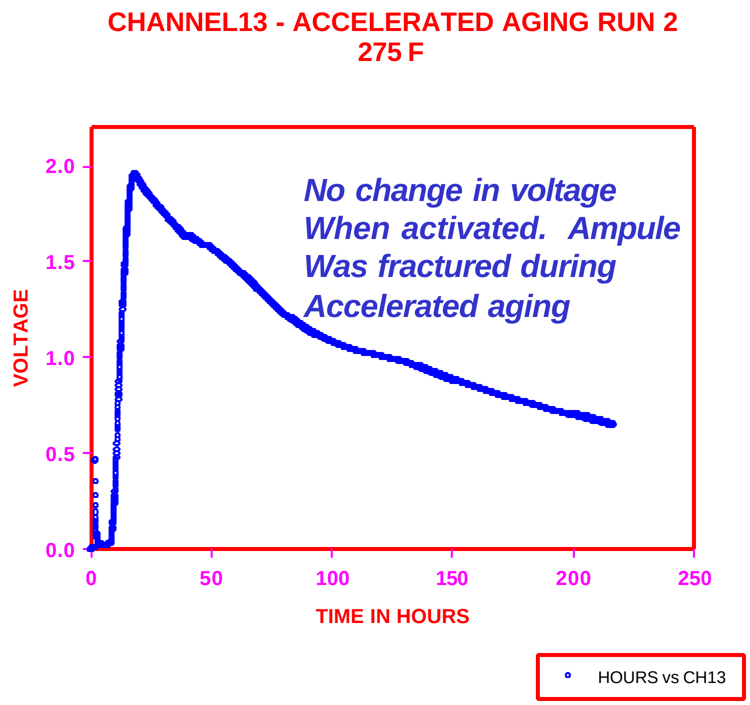


5 Second Performance



Part 2: Determine battery failure modes via Isothermal Experiments (cont)

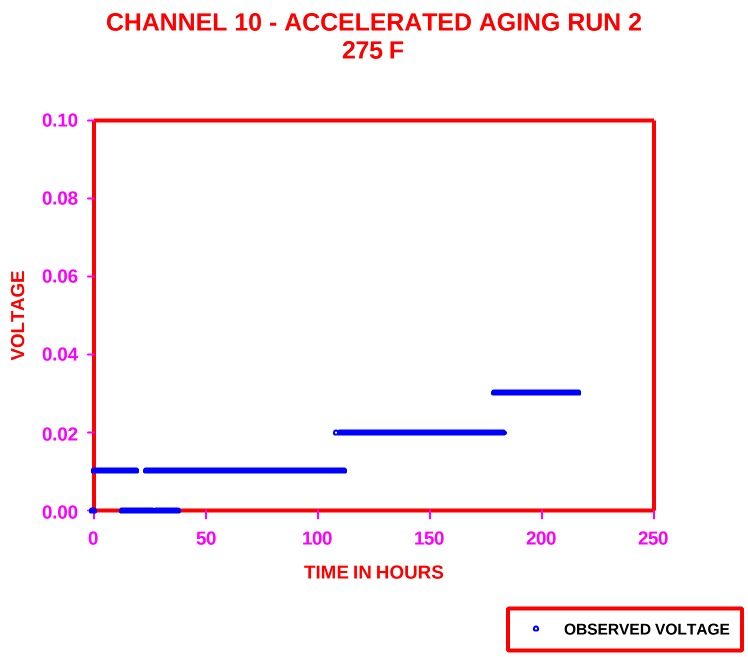
AMPULES THAT FRACTURE OR ELSE ALL ELECTROLYTE LEAKED OUT



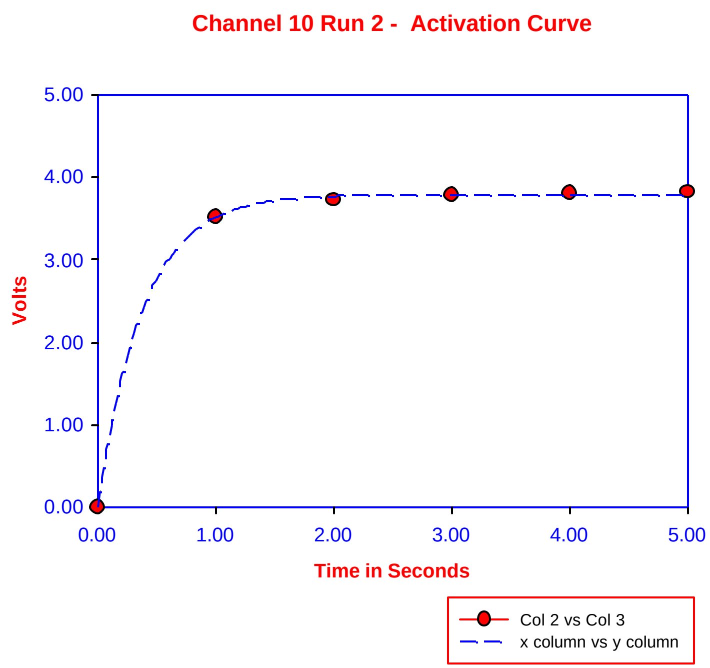
Part 2: Determine battery failure modes via Isothermal Experiments (cont)

SMALL LEAKS THAT INCREASE

Accelerated Aging



5 Second Performance

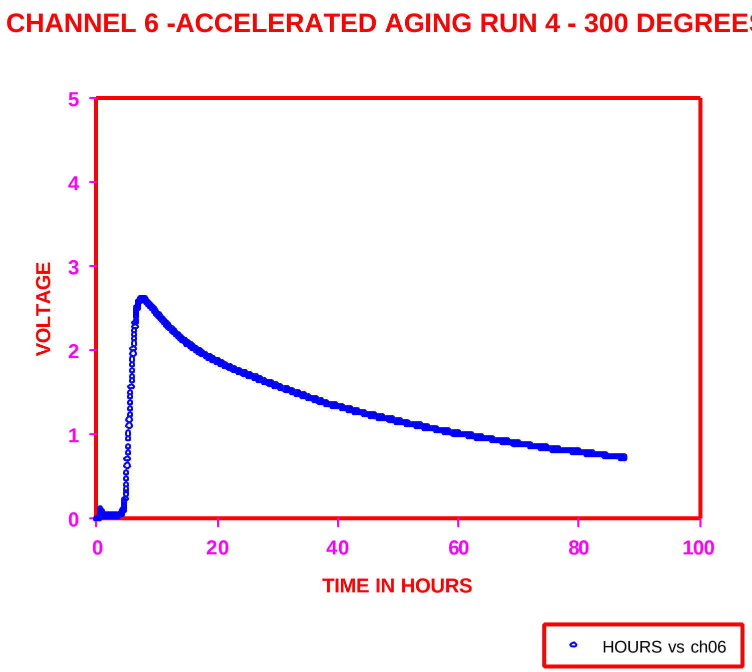


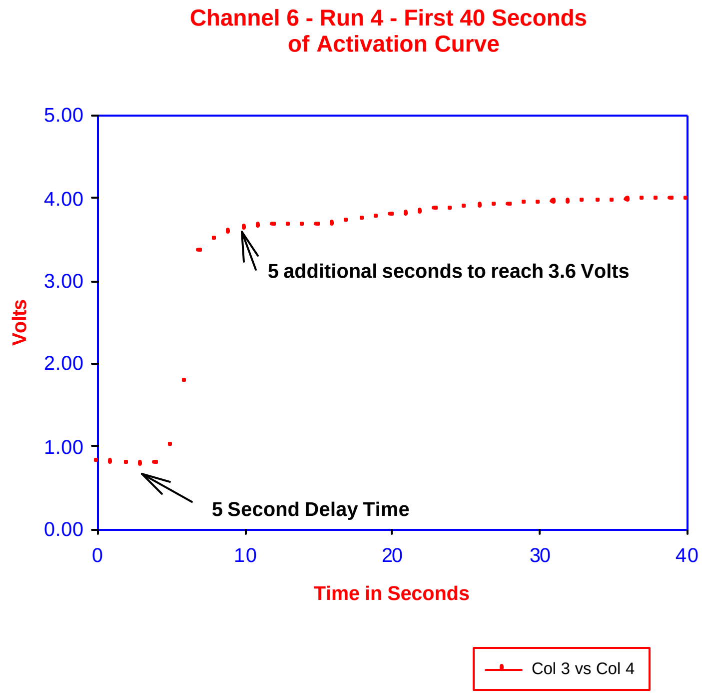
Part 2: Determine battery failure modes via Isothermal Experiments (cont)

LARGE LEAKS WITHOUT AMPULE FRACTURE THAT AFFECT RISE TIME

Accelerated Aging

40 Second Performance

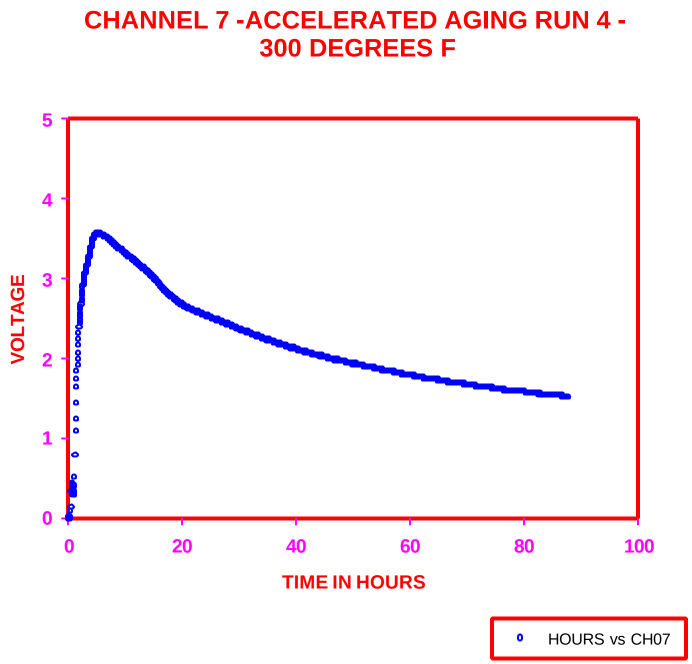




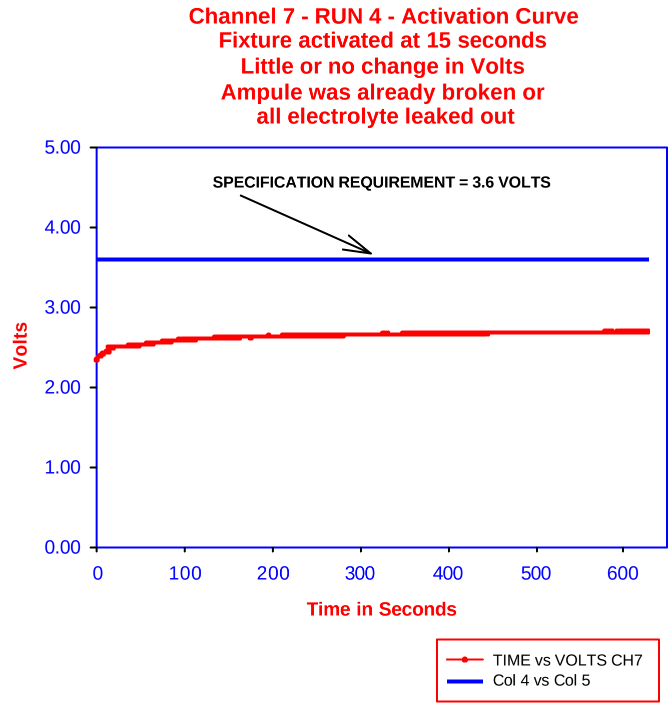
Part 2: Determine battery failure modes via Isothermal Experiments (cont)

LARGE LEAKS (OR AMPULE FRACTURE) CAUSING BATTERY FAILURE – UNABLE TO REACH PEAK VOLTAGE

Accelerated Aging



5 Second Performance



Part 2: Determine battery failure modes via Isothermal Experiments (cont)

Summary of Types of Leaks

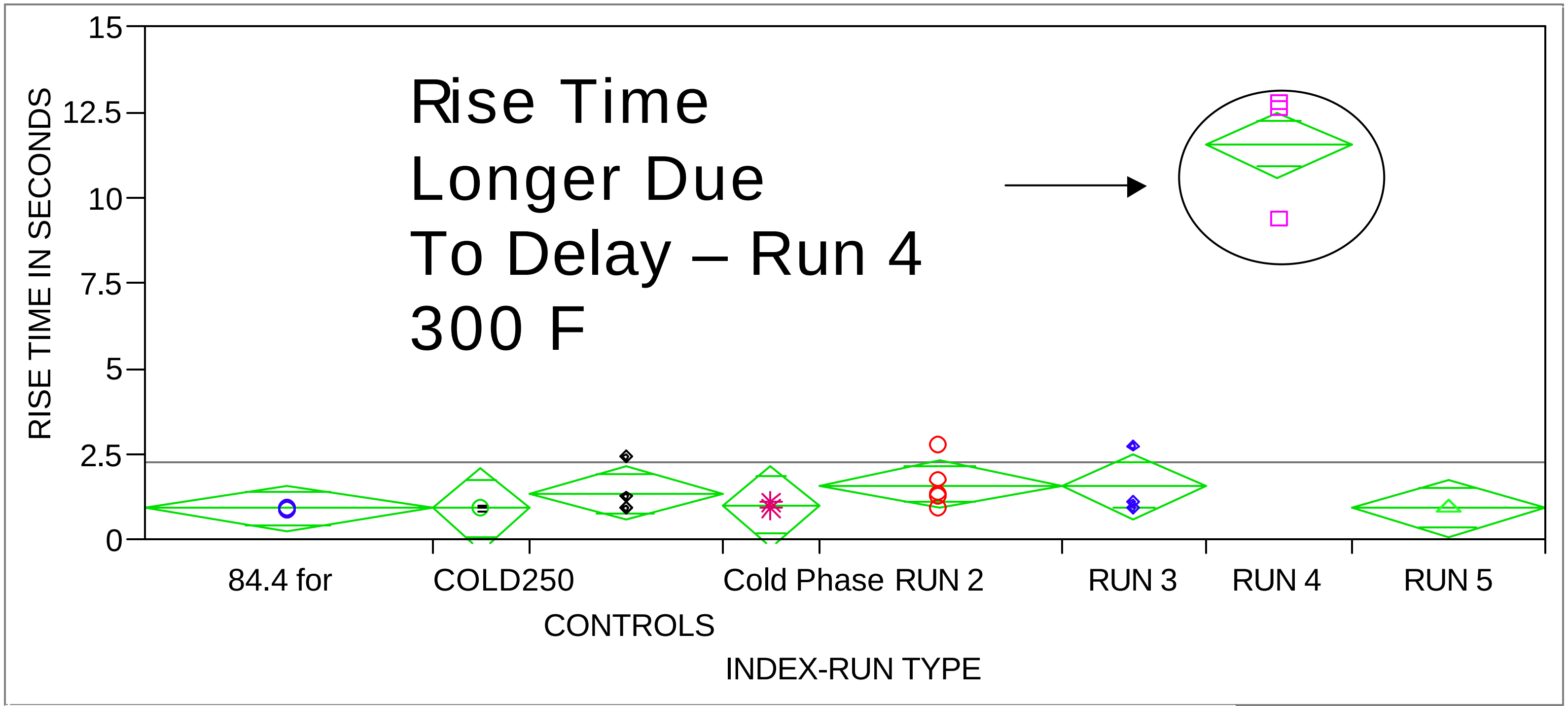
- Small Leaks
- Large Leaks
- Leaks that start and seal up
- Leaks that get worse

Part 2: Determine battery failure modes via Isothermal Experiments (cont)

STATISTICAL RESULTS

RISE TIME IN SECONDS BY GROUP

Oneway Analysis of RISE TIME IN SECONDS By INDEX-RUN TYPE



Oneway Anova

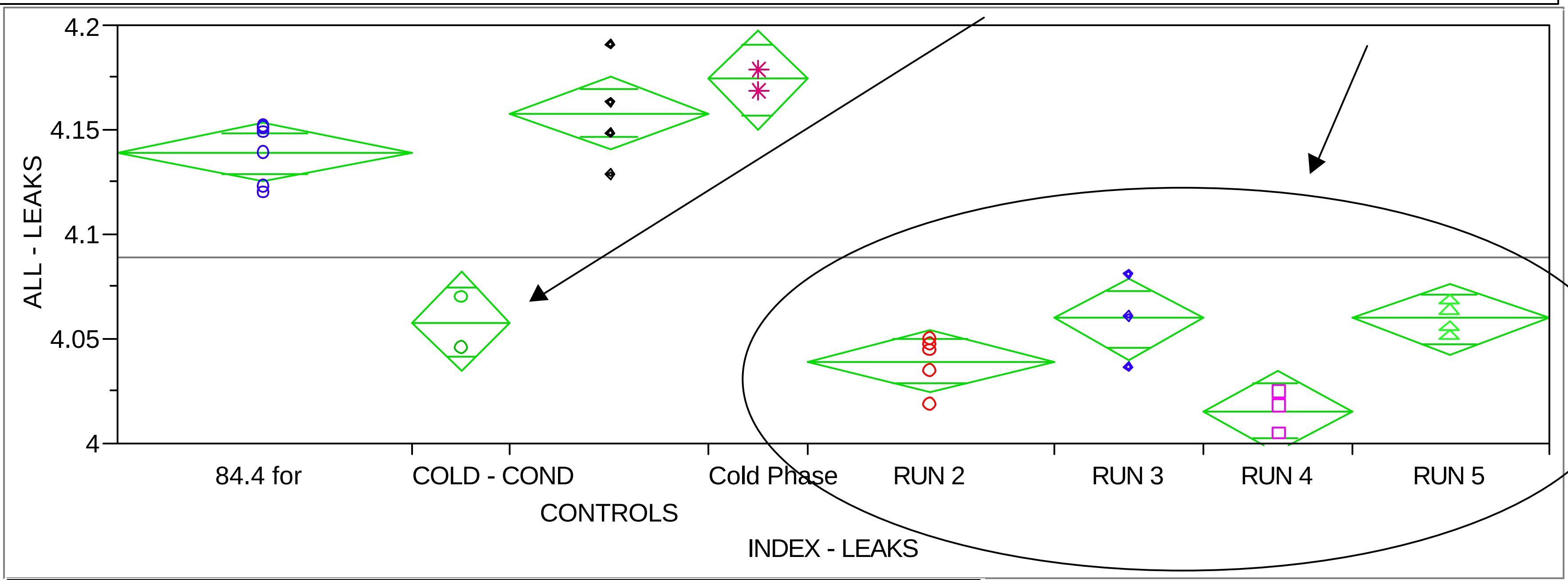
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
INDEX-RUN TYPE	7	291.77722	41.6825	65.6380	<.0001
Error	21	13.33575	0.6350		
C. Total	28	305.11297			

PEAK VOLTAGES BY GROUP

All Runs Over 250 F Resulted in Slight Decrease in Peak Voltage

Oneway Analysis of ALL - LEAKS By INDEX - LEAKS



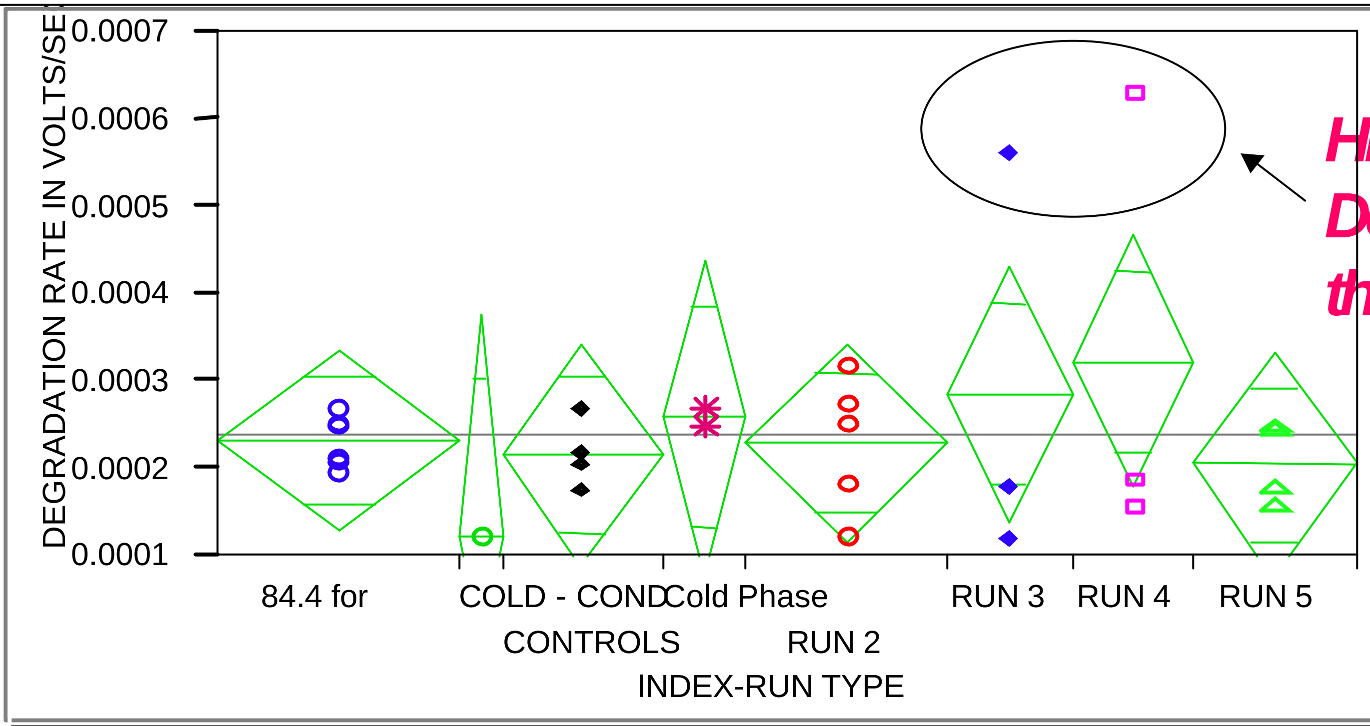
Oneway Anova

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
INDEX - LEAKS	7	0.08534050	0.012191	46.5752	<.0001
Error	21	0.00549695	0.000262		
C. Total	28	0.09083745			

DEGRADATION RATE IN VOLTS/SEC BY GROUP

Oneway Analysis of DEGRADATION RATE IN VOLTS/SEC By INDEX-RUN TYPE



High Degradation rates for these two

Oneway Anova

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
INDEX-RUN TYPE	7	5.0084e-8	7.1549e-9	0.4844	0.8346
Error	20	2.95398e-7	1.477e-8		
C. Total	27	3.45482e-7			

Part 2: Determine battery failure modes via Isothermal Experiments (cont)

SUMMARY OF RESULTS

PRIMARY FAILURE MODE: Peak Voltage failure due to leaking or ampule fracture

Only way to force the batteries to go out of SPECIFICATION was to induce leaking of electrolyte in sufficient quantities so that batteries could not meet peak voltage

CONCLUSIONS

- ***Accelerated Aging produced a negligible effect on battery performance, including peak voltages, rise times and voltage degradation rates***

CONCLUSIONS

- ***Leaking out of the electrolyte was the only technique that could induce failure of the battery to meet the peak voltage specification requirement.***

CONCLUSIONS

- ***BATTERIES ARE EXTREMELY ROBUST***
- ***ELECTROLYTE IS VERY GOOD***
- ***BATTERY VOLTAGE DEGRADES VERY LITTLE DURING THE 10 MINUTE REQUIRED OPERATION TIME***

FUTURE WORK

- ***DEVELOP MODEL WHICH PREDICTS LEAKAGE PROFILES AS A FUNCTION OF TEMPERATURE AND TIME***

- ***CHARACTERIZE AMPULE FRACTURE DISTRIBUTION AS A FUNCTION OF ACCELERATING TEMPERATURE***

FUTURE WORK

- ***PROVIDE SERVICE LIFE ESTIMATE***

- ***EVALUATE NEW, IMPROVED DESIGN FOR AMPULE***

- ***INVESTIGATE PEAK VOLTAGE DEGRADATION FOR BATTERIES THAT DID NOT LEAK***

FUTURE WORK

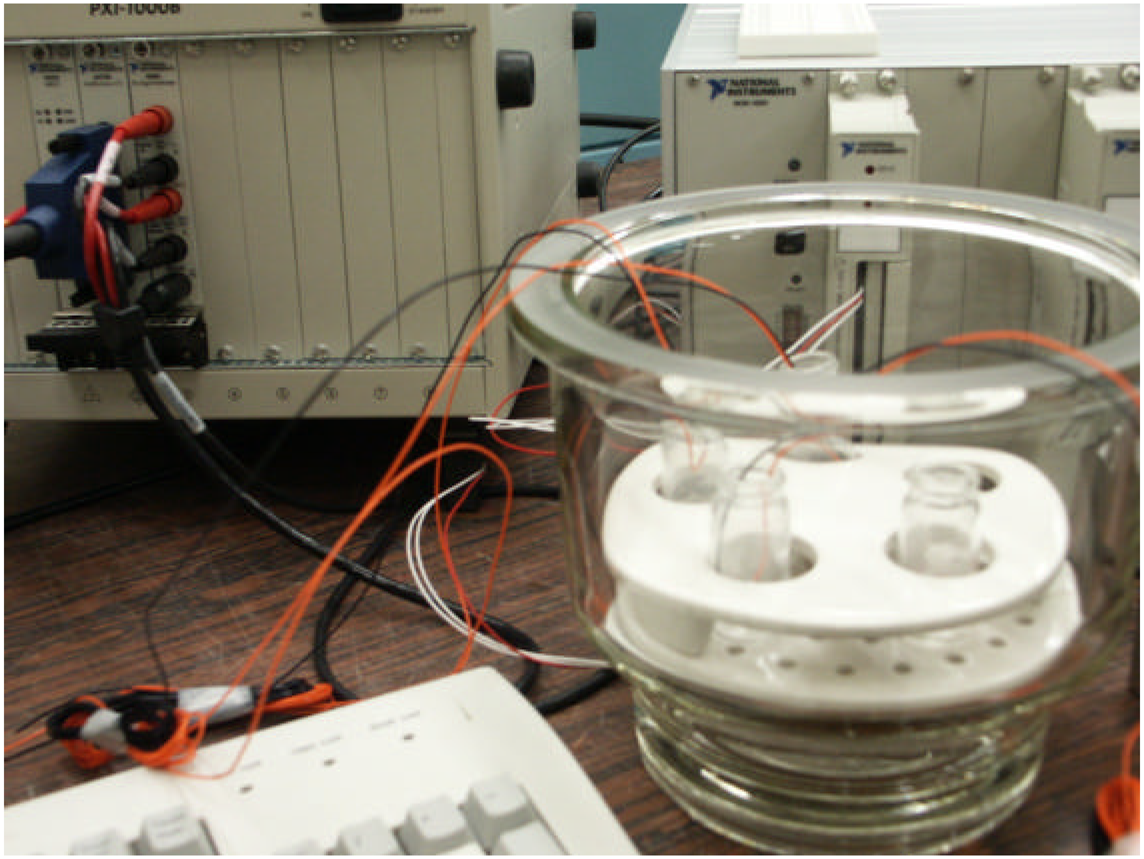
- ***ALL FUTURE ACTIVATIONS SHALL BE DONE AT – 50 F***

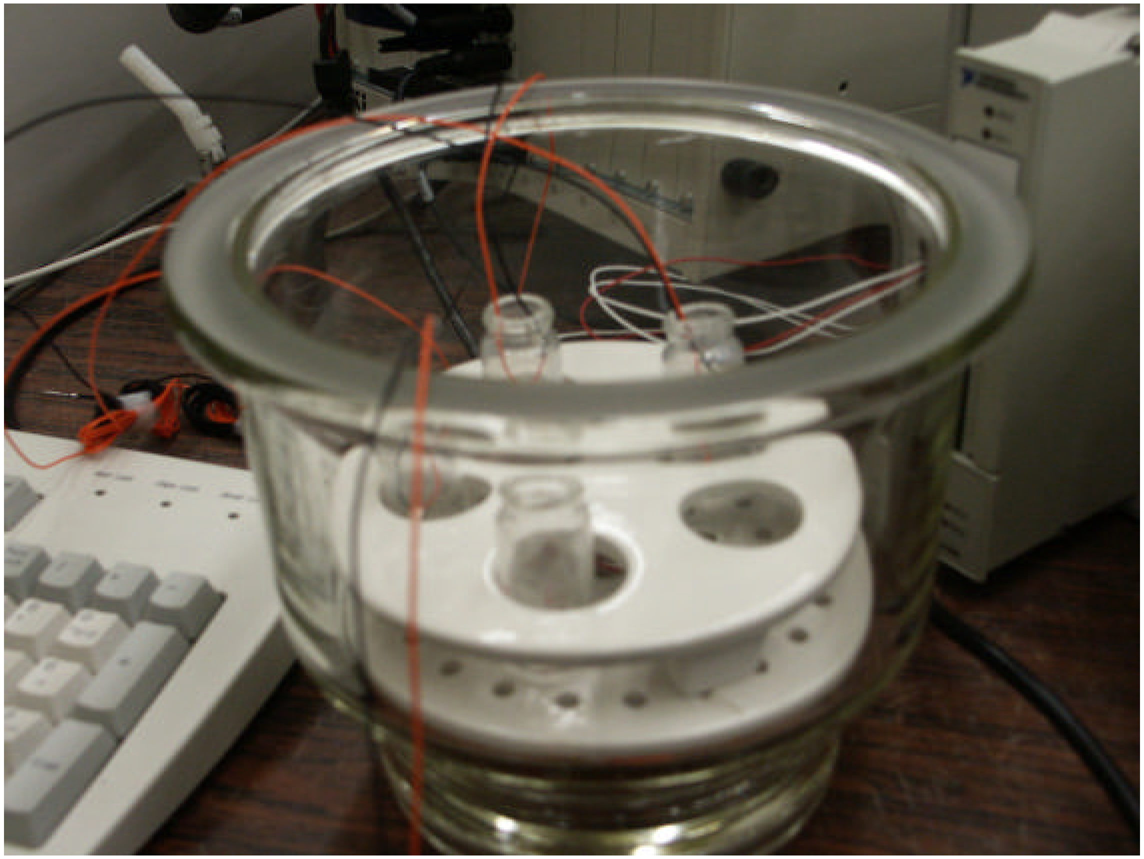
- ***ANY DEGRADATION EFFECT ON THE RISE TIME WILL BE MORE DISCERNIBLE AT –50 F***

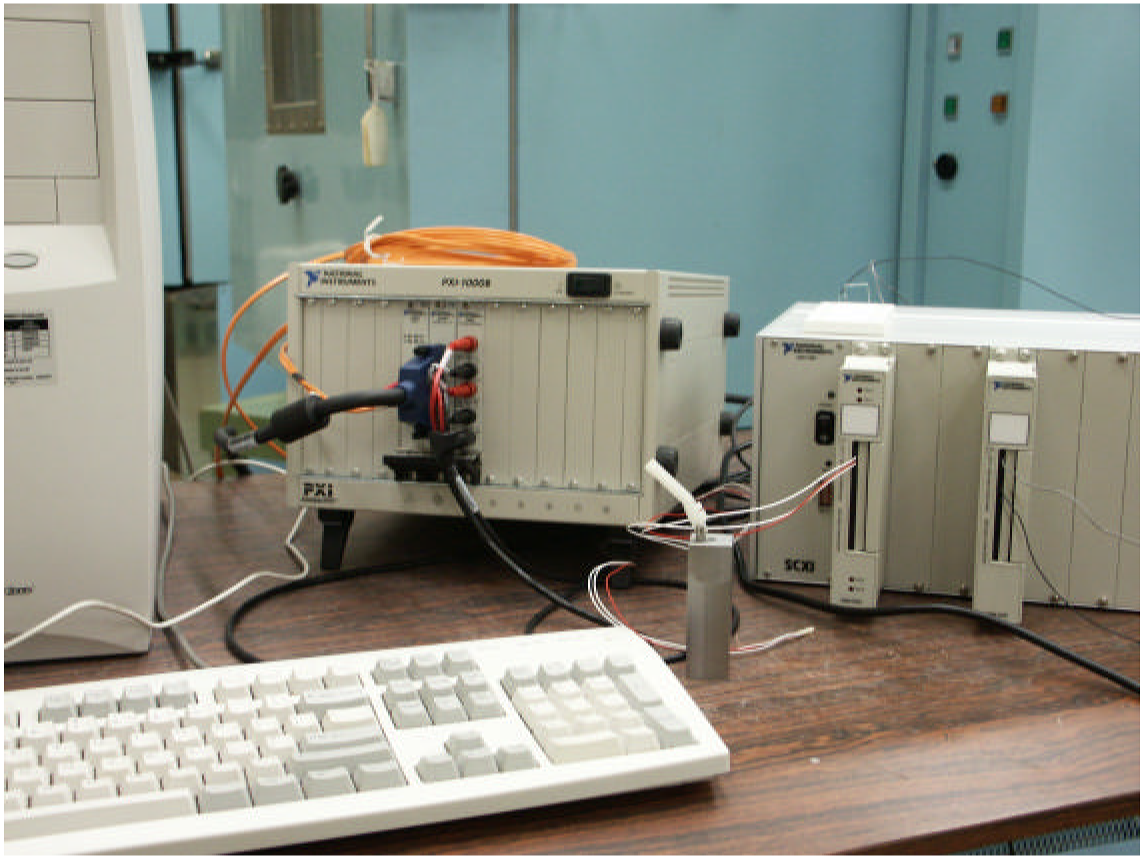
FUTURE WORK

- ***DEVELOP NEW ACTIVATION FIXTURE WHICH CAN BE ACTIVATED INSIDE CHAMBER KEPT AT –50 F***

EXPERIMENTAL SETUP


PXI-1000B
NATIONAL INSTRUMENTS




PXI
SCXI

Acknowledgements

The authors wish to thank the following colleagues without whose support this work could not have been accomplished.

- *The M234 SDF USG IPT at Picatinny Arsenal, NJ, including (but not limited to) the following:*
  - *Bill Vogt*
  - *Jim Murnane*
  - *Joseph Donini*
  - *Lawrence Raniere*
  - *Sing Eng*
  - *Leon Springer*

- *The M234 SDF Program Staff at L3-KDI, Cincinnati, OH, including (but not limited to) the following:*
  - *Bob Rankin*
  - *Mike Steele*