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DISCRIMINATING PERFORMANCE PARAMETERS FOR 50 AMP-HOUR AND 60 AMP-HOUR NICKEL-CADMIUM PLATES AND BATTERY CELLS

PRESENTED: 1993 NASA AEROSPACE BATTERY WORKSHOP
16 - 18 NOVEMBER 1993

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OVERVIEW

THIS IS A FOLLOW-UP TO STUDIES OF THE NASA STANDARD 50 AMP-HOUR CELL PRESENTED AT THE NASA BATTERY WORKSHOP EACH OF THE LAST TWO YEARS:

1991 - RECOGNITION OF THE DATABASE

1992 - USE OF THE DATABASE TO DETECT ANOMALOUS TRENDS

1993 - DISTILLATION OF DISCRIMINATING PARAMETERS FROM THE DATABASE

THIS IS A DYNAMIC STUDY. DATA TRENDS CONTINUE TO BE DEVELOPED AND ANALYZED FOR THEIR UTILITY IN JUDGING NICD PERFORMANCE.

THE TRENDS AND PARAMETERS PRESENTED HERE MAY BEAR RELEVANCE TO MANY DESIGNS OF CONVENTIONAL NICD BATTERIES, NOT JUST THE 50 AH AND 60 AH SIZES.

McDONNELL DOUGLAS AEROSPACE IS USING THE INSIGHT GAINED FROM THESE TRENDS TO JUDGE THE QUALITY OF PRESENT AND FUTURE CELL LOTS PROCURED FROM GATES AEROSPACE BATTERIES.

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OVERVIEW (cont'd)

THE TYPES OF TRENDS AND PARAMETRIC RELATIONSHIPS PRESENTED HERE MAY BE QUITE SUITABLE FOR APPLICATION IN NICKEL-HYDROGEN TECHNOLOGY.

A CONSIDERABLE PERFORMANCE (LIFE-CYCLE) DATABASE FOR NICKEL HYDROGEN IS BEING BUILT.

A DATABASE CHARACTERIZING NICKEL HYDROGEN IS SOMEWHAT LACKING.

THE TYPES OF TRENDS AND PARAMETRIC RELATIONSHIPS PRESENTED HERE MAY BE IDEALLY SUITABLE FOR A FLEDGLING TECHNOLOGY LIKE NICKEL METAL-HYDRIDE.

NICKEL METAL-HYDRIDE MANUFACTURERS SEEK TO CHARACTERIZE THEIR PRODUCT AS WELL AS PROVE ITS PERFORMANCE.

THE TECHNIQUES PRESENTED HERE MAY ALLOW THE END USER TO SUPPLEMENT THOSE MEASURES OF PERFORMANCE THAT ARE LESS READILY ATTAINABLE, SUCH AS COMPLETE LIFE-CYCLE TESTING; OR LESS RELIABLE, SUCH AS CONFIDENCE IN A SUPPLIER OR CONFORMANCE OF THE DELIVERED PRODUCT TO SPECIFICATION.

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SCOPE

THIS STUDY BUILDS ON TWO PREVIOUS STUDIES.

THOSE TWO STUDIES HAVE NOW BEEN EXPANDED TO INCLUDE 15 YEARS OF HISTORY ON A 60 AH DESIGN THAT McDONNELL DOUGLAS AEROSPACE HAS BEEN PROCURING OVER THE LAST TEN YEARS.

THROUGHOUT THIS PRESENTATION, THIS "NEW" PRODUCT WILL BE REFERRED TO AS THE "60 AH DESIGN" WHILE NASA CELL LOTS WILL BE REFERRED TO AS THE "NASA STANDARD 50 AH DESIGN".

THE 60 AH DESIGN IS ALMOST IDENTICAL TO THE NASA STANDARD 50 AH DESIGN EXCEPT THAT THE CELL CASE IS TALLER, AND BOTH THE POSITIVE AND NEGATIVE PLATES ARE MORE HEAVILY LOADED.

THE 60 AH DESIGN, LIKE THE NASA STANDARD 50 AH DESIGN, HAS YIELDED SEVERAL CELL LOTS IN THE LAST FIVE YEARS THAT BEGAN TO SHOW PERFORMANCE ANOMALIES EARLY IN CYCLE-LIFE.

ALSO LIKE THE NASA CELLS, THESE 60 AH CELLS CONFORMED TO ALL SPECIFICATIONS (WITH <u>RARE</u> EXCEPTION) DURING ASSEMBLY AND TEST AT THE CELL SUPPLIER.

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THE DATABASE

OVER THE LAST 18+ MONTHS, McDONNELL DOUGLAS AEROSPACE HAS BEEN COMPILING A DATABASE OF ALMOST 80 PARAMETERS OR PARAMETRIC RELATIONSHIPS AT THE PLATE, CELL, AND BATTERY LEVEL IN AN EFFORT TO FIND THE ROOT CAUSE OF THE ANOMALOUS PERFORMANCE OF BATTERIES.

OF THESE 80 PARAMETERS, A GROUP OF 16 HAVE BEEN IDENTIFIED, WHICH IF

- TAKEN INDIVIDUALLY, MAY OR MAY NOT IDENTIFY A CAUSE FOR CONCERN ABOUT A PARTICULAR CELL LOT.
- TAKEN TOGETHER, PROVIDE COMPELLING DISCRIMINATION BETWEEN GOOD LOTS AND SUSPICIOUS LOTS.

AT THE SAME TIME, 25 CELL LOTS OF BOTH THE 60 AH AND STANDARD 50 AH DESIGNS WERE IDENTIFIED FROM A DATABASE OF 30 CELL LOTS SPANNING 16 YEARS.

THESE 25 LOTS COULD BE LABELLED "GOOD" OR "SUSPECT" BASED ON THE WEIGHT OF THE EVIDENCE FROM CELL LIFE-CYCLE TESTING, BATTERY LONG-TERM MISSION USAGE, AND/OR LONG-TERM TEST-BATTERY USAGE.

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THE DISCRIMINATORS

PLATE LEVEL:

1. MEASURED N/P RATIO
2. RATIO OF POSITIVE LOADING WEIGHT TO TOTAL POSITIVE WEIGHT
3. RATIO OF NEGATIVE LOADING WEIGHT TO TOTAL NEGATIVE WEIGHT
4. NEGATIVE UTILIZATION
5. NEGATIVE ANTI-POLAR MASS
6. NEGATIVE TEFLON LOADING

CELL LEVEL:

7. FORMATION CYCLES: OXYGEN RECOMBINATION CHARACTERISTICS
8. MAXIMUM CAPACITY DURING FORMATION CYCLING

CELL LEVEL:(CONTINUED)

9. OXYGEN RECOMBINED IN PRECHARGE DPA CELLS vs OXYGEN PRECHARGE GOAL
10. OVERCHARGE PROTECTION AS A PERCENT OF TOTAL NEGATIVE CAPACITY
11. MAXIMUM RECORDED VOLTAGE IN THE 0°C CAPACITY TEST
12. 0°C CAPACITY
13. FINAL ELECTROLYTE AMOUNT
14. POSITIVE CAPACITY TO 0.0 VOLTS IN DPA CELLS
15. TRANSFER OF CADMIUM TO THE POSITIVE PLATE UNDER LIMITED CYCLING

BATTERY LEVEL:

16. RATIO OF CELL-LEVEL 0°C CAPACITY TO BATTERY-LEVEL 0°C CAPACITY

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THE GOOD LOTS

LOT	JUSTIFICATION
50AB20 LOT 1	QUALIFICATION LOT/BATTERY; LONG LIFE AS TEST BATTERY
50AB20 LOT 2	LONG LIFE AS TEST BATTERIES; CELLS ON LIFE TEST TO 25000 CYCLES AT NSWC-CRANE WITHOUT INCIDENT; CELLS ON STRESS TEST TO 19000+ CYCLES AT NSWC-CRANE
50AB20 LOT 3	LANDSAT 4
50AB20 LOT 4	LANDSAT 5
50AB20 LOT 5	LANDSAT 4
50AB20 LOT 7	LANDSAT 5
50AB20 LOT 12	EARTH RADIATION BUDGET SATELLITE
50AB20 LOT 14	LONG LIFE AS TEST BATTERIES; CELLS ON STRESS TEST TO 15000+ CYCLES AT NSWC-CRANE; CONTAINED DEGRADED NYLON 2505 SEPARATOR
50AB20 LOT 17	COMPTON GAMMA RAY OBSERVATORY (GRO) MPS-2
50AB19 LOT 2	60 AH DESIGN DEVELOPMENT PROGRAM
50AB19 LOT 3	60 AH DESIGN DEVELOPMENT PROGRAM
50AB19 LOT 4	60 AH DESIGN DEVELOPMENT PROGRAM
50AB19 LOT 5	60 AH DESIGN DEVELOPMENT PROGRAM
50AB22 LOT 3	LONG LIFE AS TEST BATTERIES; CELLS ON LIFE TEST TO 15000+ CYCLES
50AB22 LOT 6	CELLS ON LIFE TEST TO 15000+ CYCLES
50AB22 LOT 7	60 AH DESIGN'S MPS-1

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THE SUSPECT LOTS

LOT	JUSTIFICATION
50AB22 LOT 2	FIRST ANOMALOUS BATTERIES FOR 60 AH DESIGN; CONTAINED DEGRADED NYLON 2505 SEPARATOR
50AB22 LOT 11	CELLS UNDELIVERABLE: LOW ELECTROLYTE, HIGH VOLTAGE, HIGH PRESSURE
50AB22 LOT 13	60 AH DESIGN'S MPS-2 ANOMALOUS BATTERIES AND ANOMALOUS LIFE-TEST CELLS
50AB36 LOT 2	EARLY ANOMALIES IN LIFE-TEST OF PRE-ACCEPT CELLS
50AB20 LOT 13 / 50AB25 LOT 1	EARLY ANOMALIES IN LIFE-TEST AT NSWC-CRANE; SAME PLATE LOT WITH TWO KINDS OF NYLON SEPARATOR (2505 AND 2536); 50AB20 LOT 13 CELLS CONTAINED DEGRADED NYLON 2505
50AB20 LOT 15 / 50AB25 LOT 2	EARLY ANOMALIES IN LIFE-TEST AT NSWC-CRANE OF PRE-ACCEPT CELLS CONTAINING DEGRADED NYLON 2505 SEPARATOR (50AB20 LOT 15); BULK OF CELL LOT REWORKED TO INSTALL NYLON 2536 SEPARATOR (50AB25 LOT 2)
50AB20 LOT 16	ANOMALOUS* BATTERIES IN EXTREME ULTRAVIOLET EXPLORER (EUVE); EARLY ANOMALIES** IN LIFE-TEST OF PRE-ACCEPT CELLS AT NSWC-CRANE
50AB35 LOT 1	ANOMALOUS BATTERIES IN COMPTON GAMMA RAY OBSERVATORY (GRO) MPS-1; ANOMALIES IN STRESS-TEST OF CELLS AT NSWC-CRANE
50AB35 LOT 2	ANOMALOUS BATTERIES IN UPPER ATMOSPHERE RESEARCH SATELLITE (UARS); EARLY ANOMALIES IN LIFE-TEST OF CELLS AT NSWC-CRANE; EARLY ANOMALIES IN STRESS-TEST OF CELLS AT NSWC-CRANE

* WHILE THE SIGNATURE OF THE EUVE FLIGHT BATTERY ANOMALY IS SIMILAR TO THAT OF THE GRO MPS-1 AND UARS BATTERIES, THE LEVEL OF ITS SEVERITY HAS BEEN MUCH LOWER. THIS DIFFERENCE IN SEVERITY IS DENOTED IN THE ENSUING DATA PLOTS BY THE USE OF A SLIGHTLY DIFFERENT AND SLIGHTLY SMALLER "SUSPECT" SYMBOL FOR THE EUVE PLATE/CELL LOT.

** THESE PRE-ACCEPT CELLS CONTAINED 3 MILLILITERS LESS ELECTROLYTE THAN THE SUBSEQUENTLY-ACTIVATED FLIGHT CELLS. THEIR PERFORMANCE MAY ALSO HAVE BEEN COMPROMISED FROM DAMAGE RECEIVED DURING SHIPMENT TO NSWC-CRANE.

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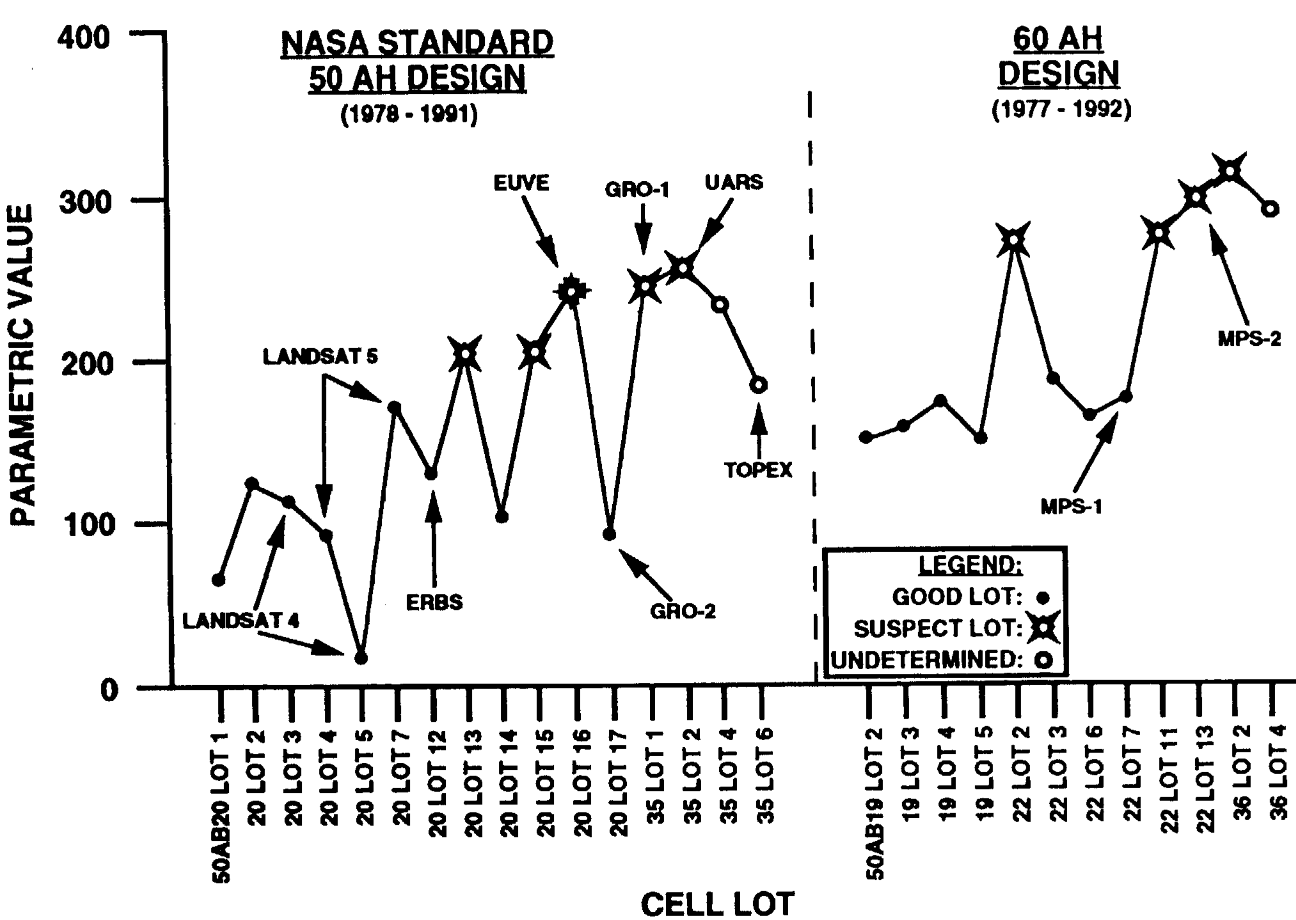
THE FORMAT

CHRONOLOGICALLY FROM LEFT TO RIGHT



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BREAKDOWN OF CELL LOTS:

DISCRIMINATOR	GOOD	SUSPECT
> X.YYY VOLTS	1	7
< X.YYY VOLTS	15	2

NOT ALL CELL LOTS COULD BE EVALUATED vs ALL 16 DISCRIMINATORS DUE TO SLIGHT PROCESSING DIFFERENCES.

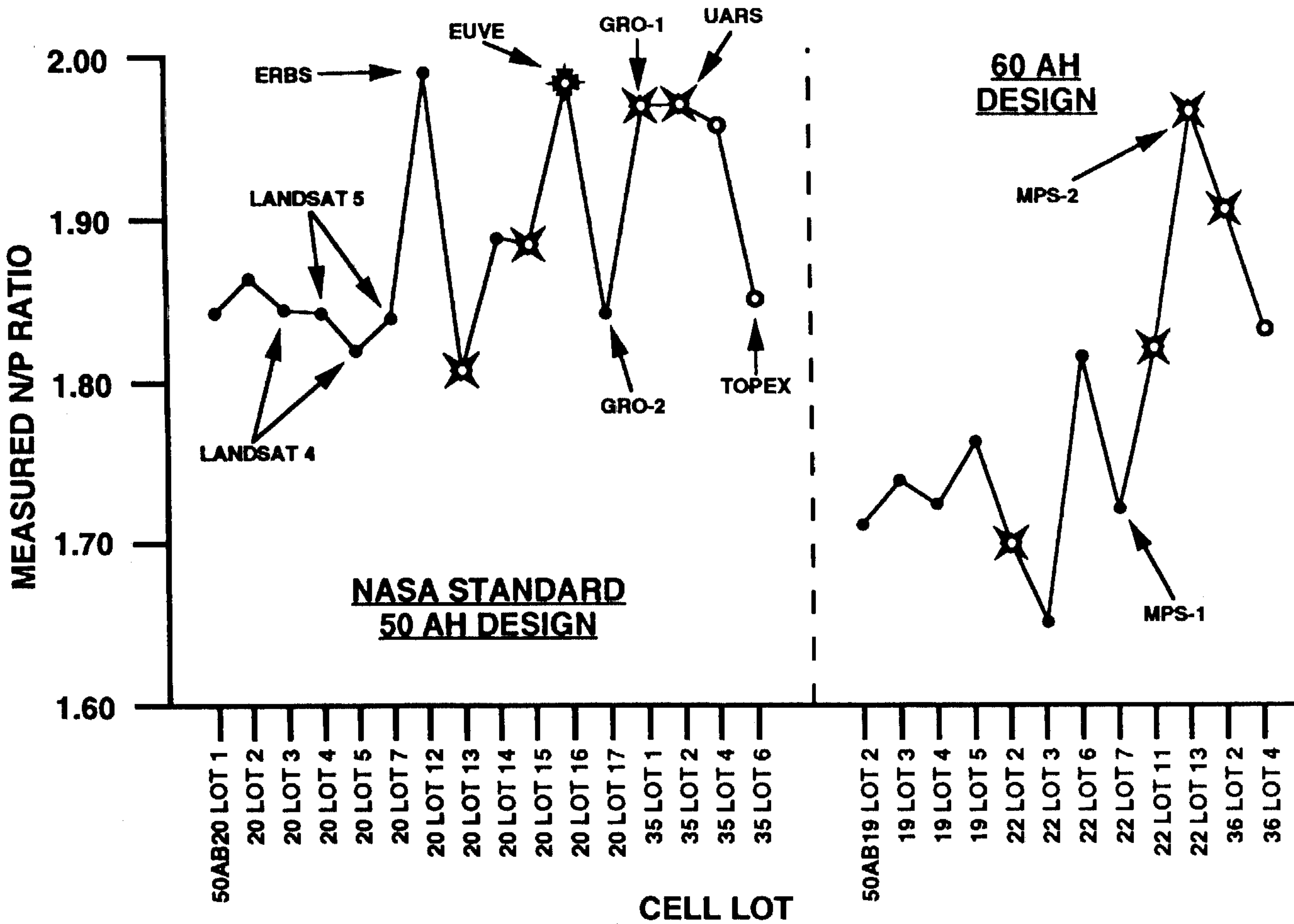
SOME CELL LOTS WERE HANDICAPPED WITH DEGRADED SEPARATOR. FOUR SUCH LOTS WERE IDENTIFIED; THREE FAILED PREMATURELY.

THE ERBS CELL LOT HAS BEEN RE-EVALUATED SINCE LAST YEAR'S STUDY. IT IS NOW CONSIDERED A "GOOD" CELL LOT BECAUSE ITS TWO BATTERIES GREATLY EXCEEDED MISSION LIFE REQUIREMENTS. THE BATTERIES DID, HOWEVER, DEVELOP SIGNIFICANT DIFFERENTIAL VOLTAGES AFTER LAUNCH. 4 OF 44 CELLS WERE LOST TO INTERNAL SHORTS BETWEEN 8 AND 9 YEARS AFTER LAUNCH.

ALL LOTS CONTAIN NYLON 2505 EXCEPT 50AB36 LOT 2 WHICH CONTAINS NYLON 2536 SEPARATOR, AND 50AB36 LOT 4 WHICH CONTAINS NYLON 2536.

50AB36 LOT 4 HAS ONE LESS POSITIVE AND ONE LESS NEGATIVE PLATE THAN ALL OTHER LOTS.

1. MEASURED NEGATIVE-TO-POSITIVE RATIO



DISCRIMINATOR	GOOD	SUSPECT
> 1.9	1	5
< 1.9	15	4

DATA IS FROM 100% (TEMPORARY) FLOODED-CELL TESTING AND IS THE RATIO OF THE NEGATIVE PLATE CAPACITY (DISCHARGED TO -0.5 VOLTS) TO THE POSITIVE PLATE CAPACITY (DISCHARGED TO 0.7 VOLTS).

TEMPORARY FLOODED CELLS CONTAIN THE SAME NUMBER OF PLATES AS THE SEALED CELL.

SPEC MINIMUM IS 1.5

NO SPEC MAXIMUM.

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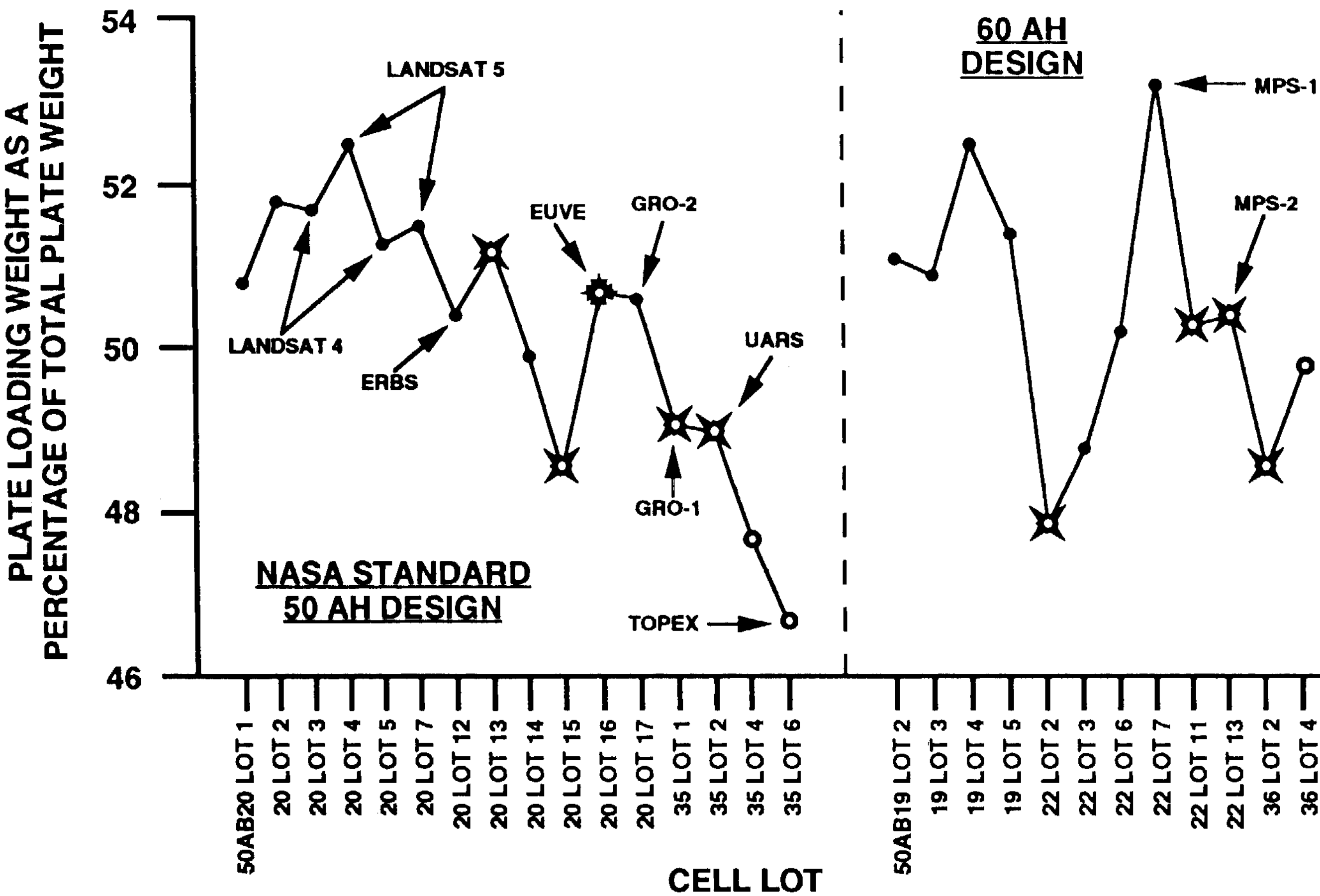
2. RATIO OF POSITIVE LOADING WEIGHT TO TOTAL POSITIVE WEIGHT



DISCRIMINATOR	GOOD	SUSPECT
< 50.6%	4	7
> 50.6%	12	2

NO SPEC MINIMUM OR MAXIMUM.

RATIO HAS DECREASING IN THE NASA DESIGN.

RATIO IN LATER LOTS IS LOWER THAN EARLY LOTS IN THE 60 AH DESIGN.

CAUSED BY A DECREASE IN CORROSION OF THE NICKEL SINTER (LESS NICKEL ATTACK) COMBINED WITH NO DECREASE IN PLATE LOADING.

NOTE: THIS DISCRIMINATOR IS THE LEAST UNDERSTOOD. IT IS LIKELY CONTRIBUTING TO LOWER ELECTROLYTE LEVELS (MORE PLATE MASS -> LESS CELL FREE VOLUME).

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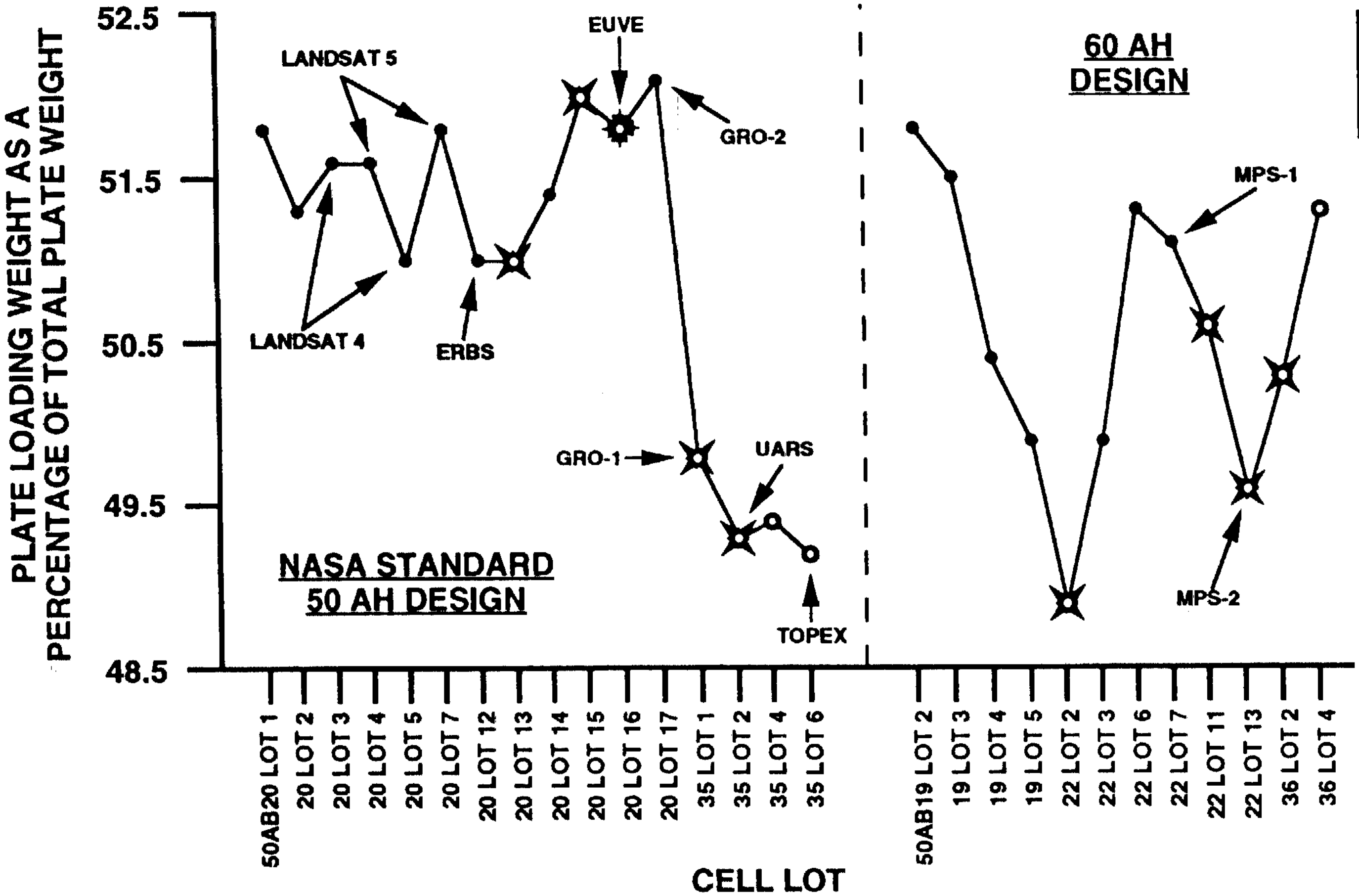
3. RATIO OF NEGATIVE LOADING WEIGHT TO TOTAL NEGATIVE WEIGHT



DISCRIMINATOR	GOOD	SUSPECT
≤ 50.6%	3	6
> 50.6%	13	3

NO SPEC MINIMUM OR MAXIMUM.

NASA DESIGN UNDERWENT A DRAMATIC CHANGE AFTER 1985. THE RATIO HAD BEEN DECLINING PARTLY AS A RESULT OF DECREASED (BY SPECIFICATION) LOADING (YET PLATE WEIGHT HAD REMAINED CONSTANT).

THE 60 AH DESIGN HAS VARIED CONSIDERABLY OVER THE LIFE OF ITS DESIGN.

NO KNOWN CHANGES TO THE STEEL SUBSTRATE.

PROBABLE FACTORS IN A DECREASED RATIO:
- HEAVIER SINTER (HEAVIER COATED WEIGHT).
- MORE CONVERSION OF THE SINTER TO NICKEL HYDROXIDE (A.K.A. NEGATIVE ANTI-POLAR MASS -> HEAVIER THAN NICKEL).

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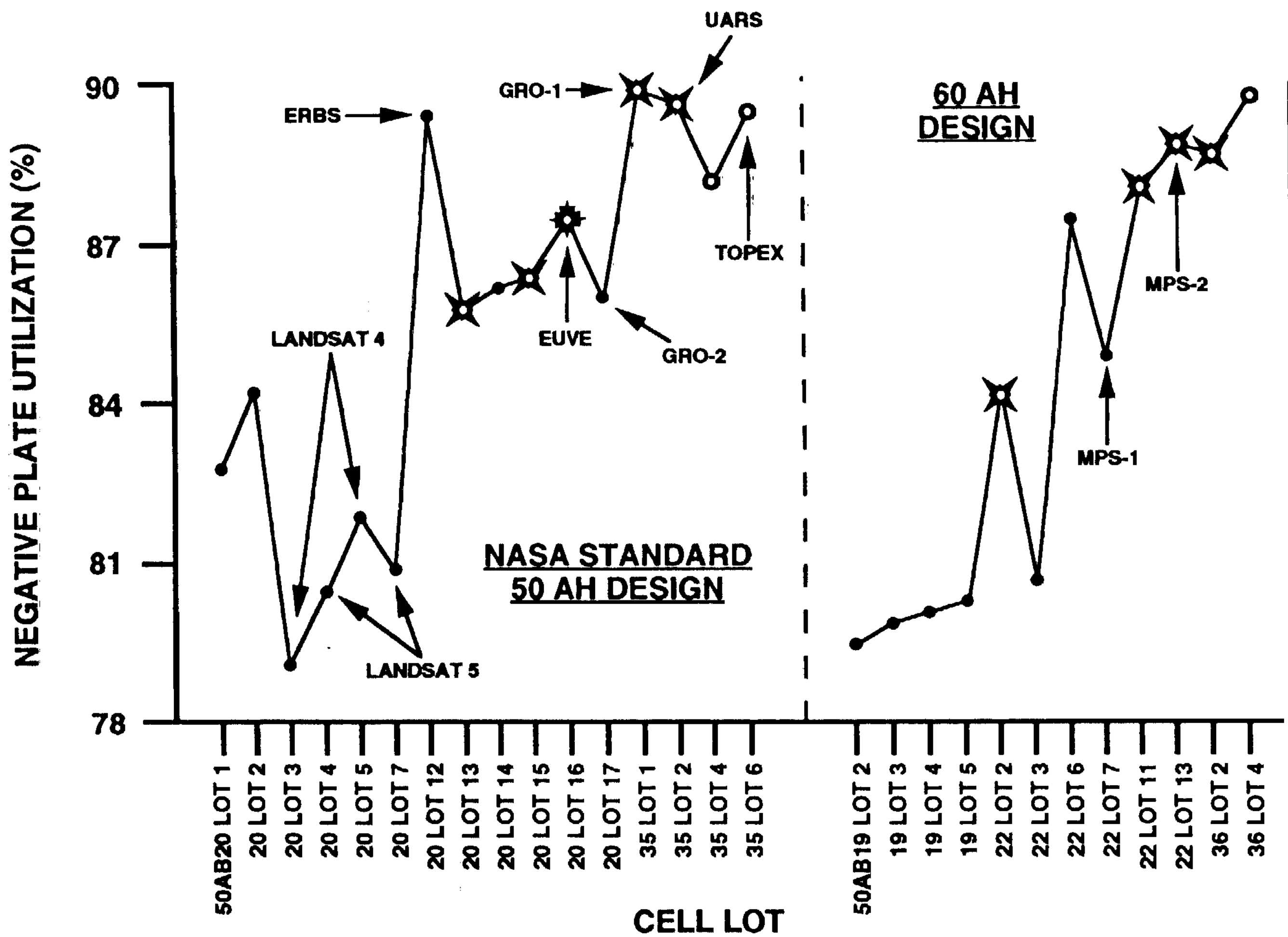
4. NEGATIVE UTILIZATION



DISCRIMINATOR	GOOD	SUSPECT
> 88%	1	5
< 88%	15	4

OBTAINED BY DIVIDING THE FLOODED-CELL NEGATIVE PLATE CAPACITY BY THE MAXIMUM THEORETICAL NEGATIVE PLATE CAPACITY.

UTILIZATION HAS INCREASED DRAMATICALLY IN BOTH DESIGNS.

NO SPEC MINIMUM OR MAXIMUM.

HIGH UTILIZATION CORRESPONDS VERY WELL WITH HIGH N/P RATIO.

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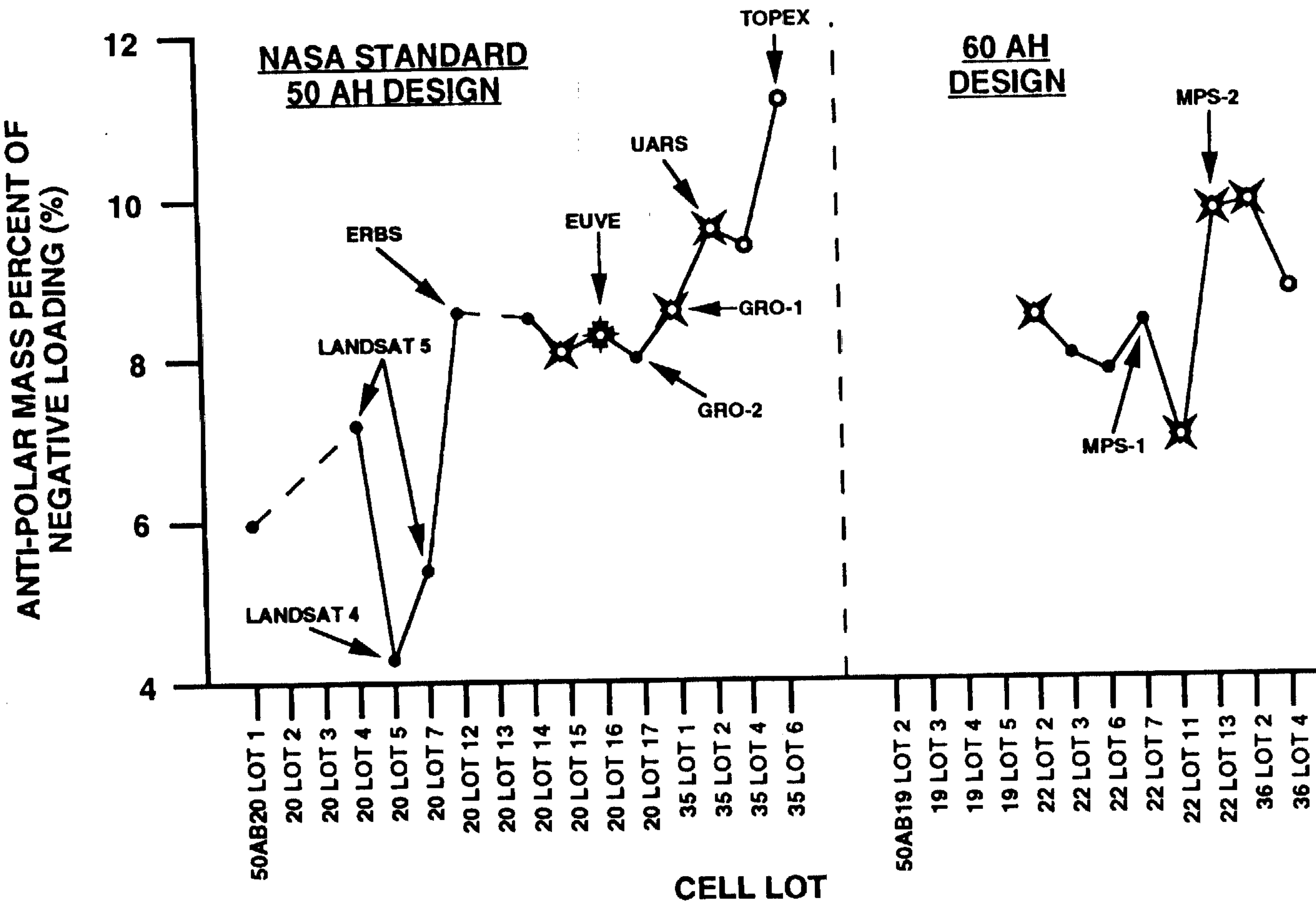
5. NEGATIVE ANTI-POLAR MASS (APM)



DISCRIMINATOR	GOOD	SUSPECT
> 8.5%	2	5
< 8.5%	8	3

APM IS THE NICKEL HYDROXIDE CREATED BY CORROSION OF THE SINTER IN THE IMPREGNATION PROCESS.

APM IS MUCH HIGHER IN RECENT LOTS OF BOTH DESIGNS.

NO SPEC MINIMUM OR MAXIMUM.

HIGH AMOUNTS OF APM CORRESPOND RATHER WELL WITH HIGH NEGATIVE UTILIZATION.

NO DATA FOR EITHER 50AB19 LOTS 2 THROUGH 5, OR 50AB20 LOTS 2, 3, AND 13.

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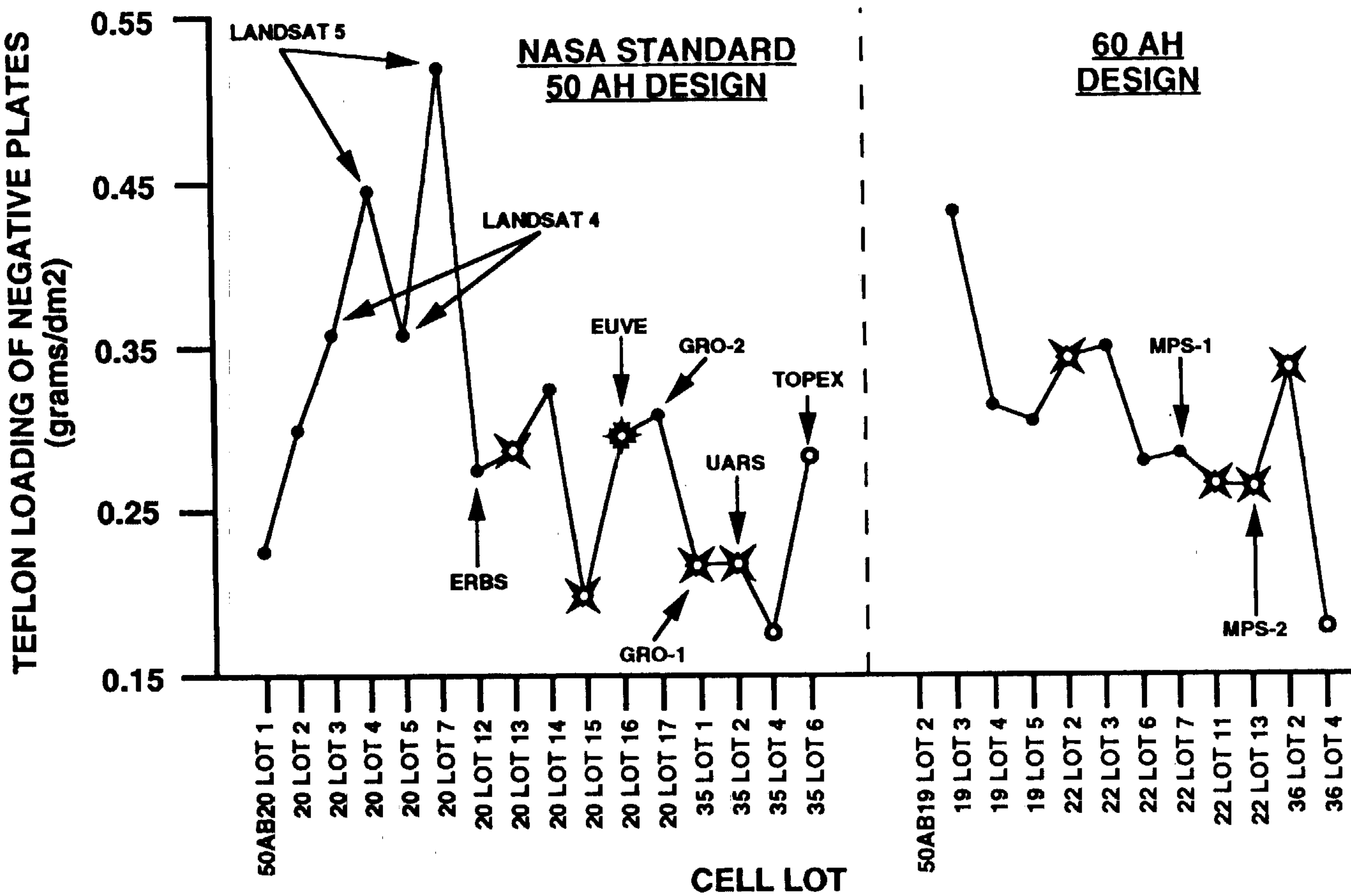
6. NEGATIVE PLATE TEFLON LOADING



DISCRIMINATOR	GOOD	SUSPECT
< 0.28 gm/dm2	3	5
≥ 0.28 gm/dm2	12	4

NO SPEC MINIMUM OR MAXIMUM.

EARLY LOTS OF BOTH DESIGNS HAD 1.5 - 2.5 TIMES THE LOADING OF RECENT LOTS.

DECREASE MAY BE DUE TO CHANGES IN THE TREATMENT PROCESS AND/OR DUE TO THE CHARACTERISTICS OF THE PLATE UNDERGOING TREATMENT.

DECREASE IS A LIKELY CONTRIBUTOR TO REDUCED ELECTROLYTE AMOUNTS.

LOWER LEVELS OF TEFLON LOADING MAY BE LESS UNIFORM, RENDERING IT INEFFECTIVE AND/OR CREATING NON-UNIFORM DISTRIBUTION OF THE ELECTROLYTE.

NO DATA FOR 50AB19 LOT 2.

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FORMATION CYCLE PRESSURE TRENDS

THESE FOUR CYCLES ARE THE FIRST FOUR CHARGES AND DISCHARGES PERFORMED ON ALL NEW CELLS OF THESE TWO DESIGNS.

AT THIS POINT IN THEIR LIFE, CELLS OF THESE TWO DESIGNS SHOULD BE POSITIVE-LIMITED IN A DISCHARGE.

IDEALLY, ANY EXCESS OXYGEN GENERATED ON CHARGE WILL BE RECOMBINED ON THE SUBSEQUENT DISCHARGE. IF NOT, THERE MAY BE A PROBLEM WITH THE NEGATIVE ELECTRODE.

THE PRESENCE OF RESIDUAL UNRECOMBINED OXYGEN IS INDICATED BY A NET INCREASE IN THE BEGINNING OF CHARGE PRESSURE FROM THE <u>2ND</u> TO THE <u>4TH</u> FORMATION CYCLE.

THE PRESENCE OF RESIDUAL UNRECOMBINED OXYGEN CAN BE CONFIRMED BY OBSERVING THE FIRST FOUR HOURS OF CHARGING IN THE <u>4TH</u> FORMATION CYCLE. IF CELL PRESSURE DECREASES IN THIS TIME FRAME, OXYGEN IS BEING CONSUMED BY THE NEWLY-CHARGED CADMIUM IN THE NEGATIVE PLATE.

ACCUMULATION OF LARGE AMOUNTS OF OXYGEN ON CHARGE, IN CONJUNCTION WITH SIGNIFICANT AMOUNTS OF OXYGEN NOT RECOMBINING ON DISCHARGE, HAS SHOWN A STRONG CORRELATION TO SUSPECT LOTS.

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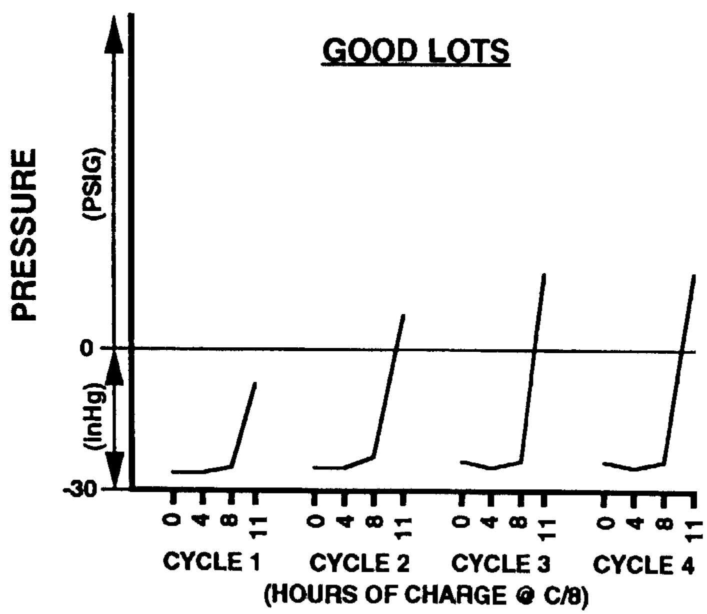
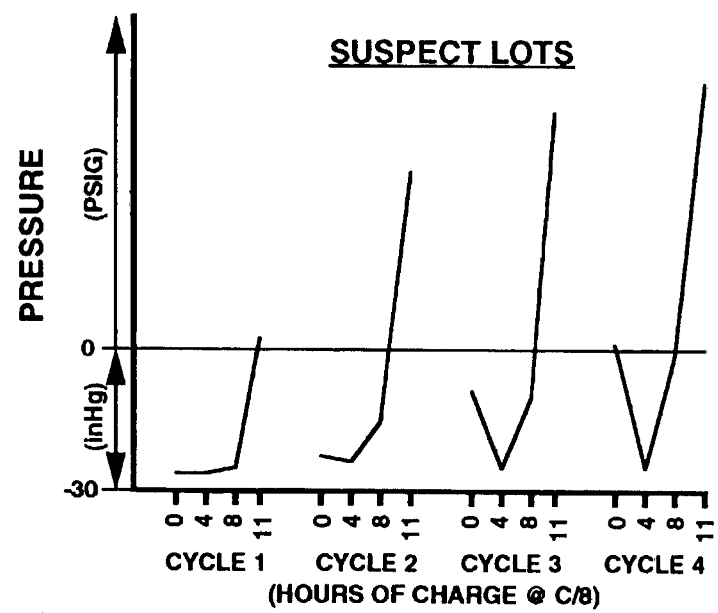
FORMATION CYCLE PRESSURE TRENDS (cont'd)

TWO NOTES OF CAUTION HOWEVER:

1.) HIGH PRESSURES AND POOR RECOMBINATION MAY BE MASKED BY "UNDERFILLING" THE CELLS WITH ELECTROLYTE.

2.) CONVERSELY, HIGH PRESSURES AND POOR RECOMBINATION CAN BE ARTIFICIALLY INDUCED BY "OVERFILLING" THE CELLS WITH ELECTROLYTE.





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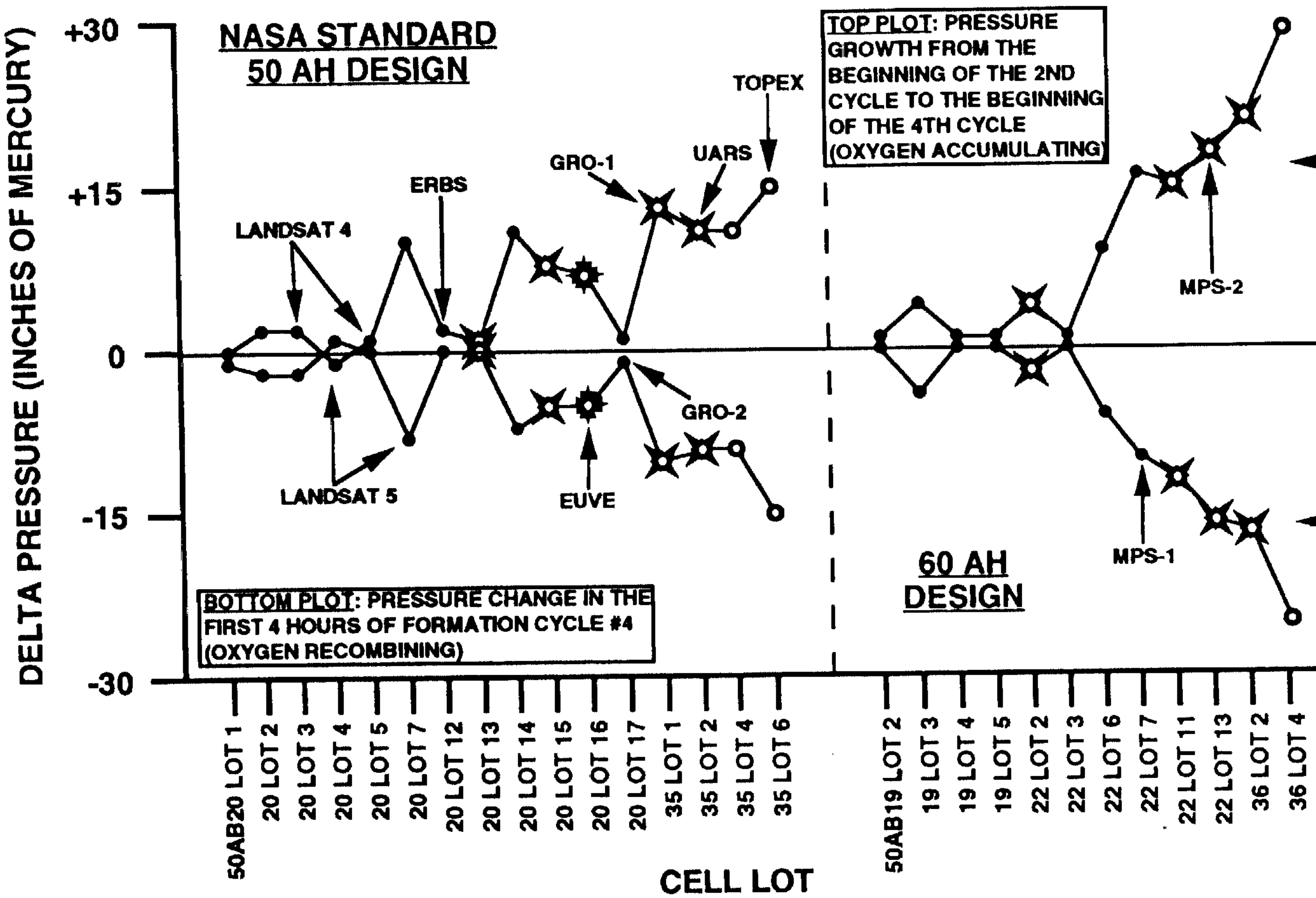
7. FORMATION CYCLES: OXYGEN RECOMBINATION CHARACTERISTICS



DISCRIMINATOR	GOOD	SUSPECT
> 6 InHg growth in pressure	4	7
< 6 InHg growth in pressure	12	2

NOTE THE DIVERGENCE OF BOTH DESIGNS FROM AN IDEAL ZERO, ESPECIALLY THE 60 AH DESIGN.

50AB20 LOT 12 (ERBS) AND 50AB20 LOT 13 ARE EXAMPLES OF ELECTROLYTE UNDERFILLING.

50AB20 LOT 7 AND 50AB22 LOT 7 ARE EXAMPLES OF ELECTROLYTE OVERFILLING.

DISCRIMINATOR	GOOD	SUSPECT
> 6 InHg drop in pressure	3	5
< 6 InHg drop in pressure	13	4

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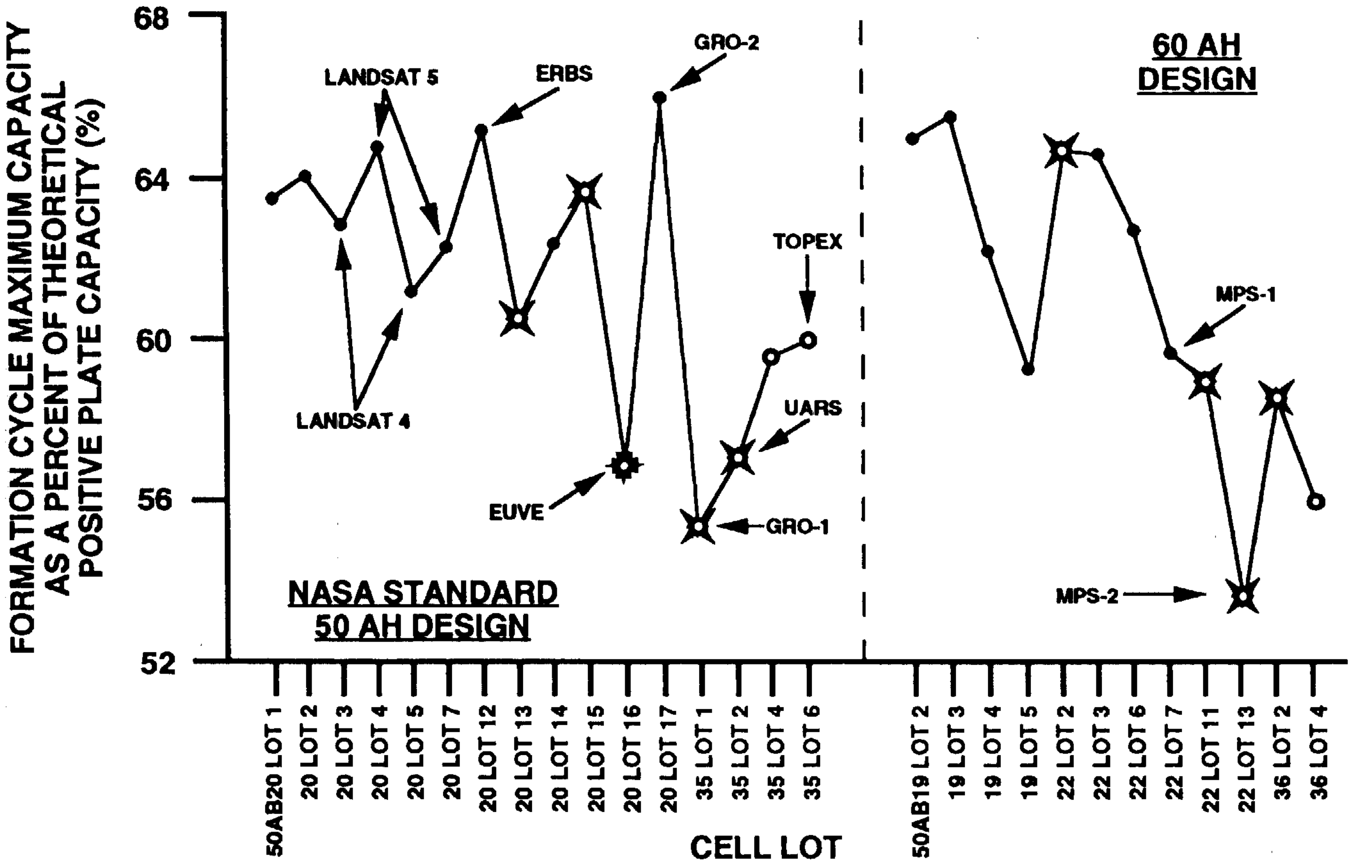
8. MAXIMUM CAPACITY DURING FORMATION CYCLING



DISCRIMINATOR	GOOD	SUSPECT
≤ 59% OF THEORETICAL	0	6
> 59% OF THEORETICAL	16	3

A MINIMUM OF FOUR CYCLES ARE PERFORMED.

DISCHARGES TO 1.0 VOLT SHOULD BE LIMITED BY THE POSITIVE ELECTRODE.

PRIOR TO 1983, FORMATION CYCLE CHARGE TIME WAS 12 HOURS AND MAXIMUM CAPACITY WAS OBTAINED ON THE FIRST CYCLE.

AFTER 1983, CHARGE TIME WAS REDUCED TO 11 HOURS AND MAXIMUM CAPACITY WAS OBTAINED IN THE SECOND CYCLE.

DATA OBTAINED FROM DIVIDING MAXIMUM FORMATION CYCLE CAPACITY BY MAXIMUM THEORETICAL POSITIVE PLATE CAPACITY.

CAN ALSO BE PLOTTED AS A PERCENT OF THE FLOODED-CELL POSITIVE PLATE CAPACITY:

DISCRIMINATOR	GOOD	SUSPECT
< 77% of flooded cell capacity	1	7
> 77% of flooded cell capacity	15	2

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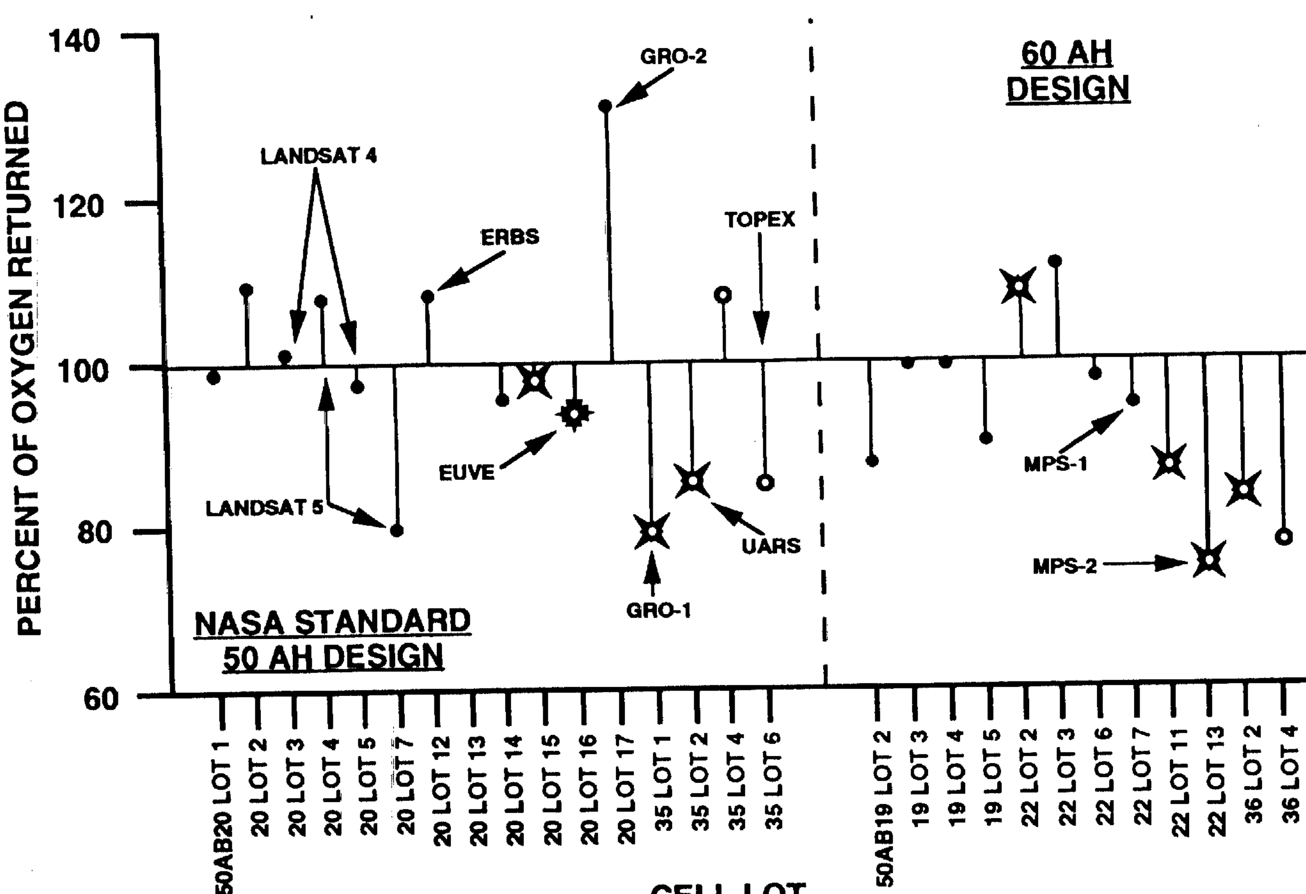
9. OXYGEN RECOMBINED IN PRECHARGE DPA CELLS VS OXYGEN PRECHARGE GOAL



DISCRIMINATOR	GOOD	SUSPECT
< 90%	2	5
> 90%	14	3

ONE CELL FROM EACH LOT UNDERGOES DESTRUCT PHYSICAL ANALYSIS (DPA) TO VERIFY NEGATIVE PRECHARGE.

DPA IS INITIATED BY BACK-FILLING A DISCHARGED CELL WITH OXYGEN UNTIL NO MORE OXYGEN RECOMBINES.

THE OXYGEN ADDED BACK SHOULD BE NEARLY EQUAL TO THE AMOUNT VENTED IN PRECHARGE.

SIGNIFICANT INABILITY TO REACH 100% OXYGEN RETURN MAY SIGNAL A PROBLEM WITH THE NEGATIVE ELECTRODE. [IN SUCH LOTS, CHEMICAL ANALYSIS CONFIRMS THAT THE TOTAL PRECHARGE (RESIDUAL + OXYGEN) WAS CORRECT, BUT THAT THE RESIDUAL IS HIGHER THAN NORMAL.]

SUGGESTS THAT THE MORPHOLOGY OF THE NEGATIVE IS UNDERGOING DRAMATIC CHANGE EVEN AS PRECHARGE IS BEING SET.

NO PRECHARGE DPA CELL FOR 50AB20 LOT 13.

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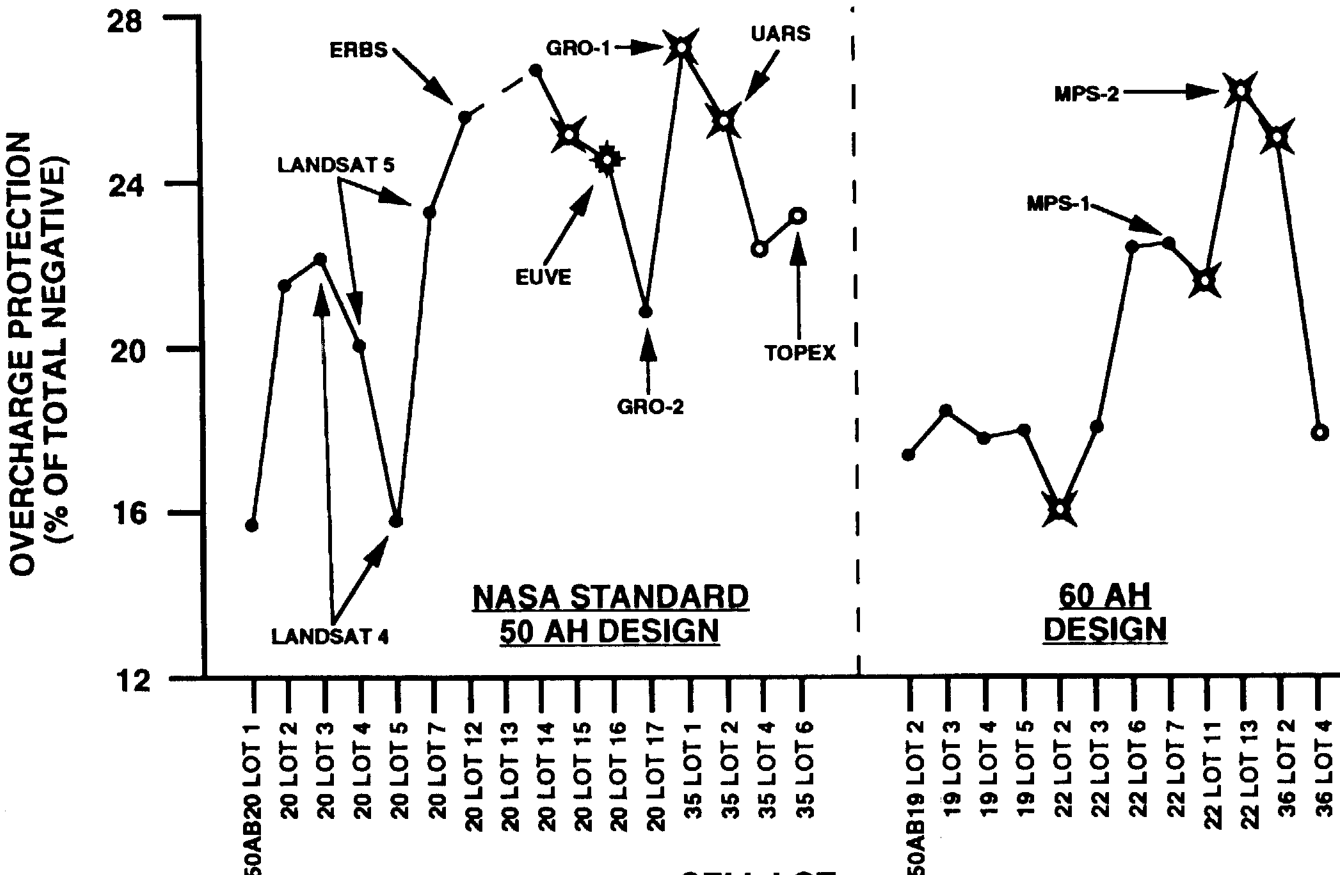
10. OVERCHARGE PROTECTION AS A PERCENT OF TOTAL NEGATIVE CAPACITY



DISCRIMINATOR	GOOD	SUSPECT
> 24% of total negative	2	6
< 24% of total negative	14	2

DATA FROM PRECHARGE DPA SAMPLES ONLY.

OVERCHARGE PROTECTION IS THE AVAILABLE EXCESS UNCHARGED NEGATIVE MATERIAL IN A FULLY CHARGED CELL (AT ROOM TEMPERATURE).

THE AMOUNT OF OVERCHARGE PROTECTION IS DIRECTLY AFFECTED BY THE SETTING OF THE PRECHARGE.

50AB35 LOT 1 AND 50AB22 LOT 7 SUBSEQUENTLY UNDERWENT ADDITIONAL PRECHARGING.

NO PRECHARGE DPA SAMPLE FOR 50AB20 LOT 13.

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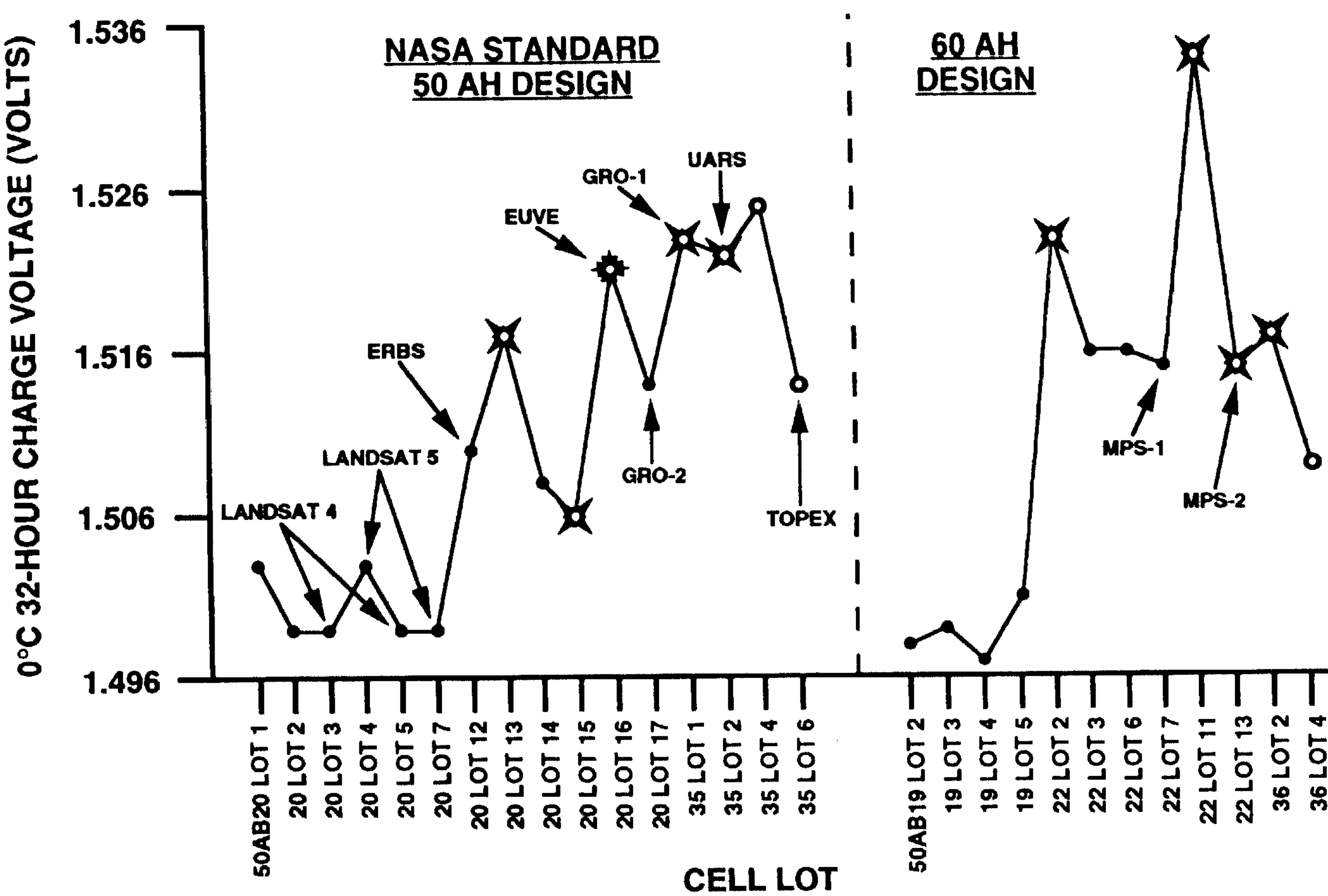
11. MAXIMUM RECORDED VOLTAGE IN THE 0°C CAPACITY TEST



DISCRIMINATOR	GOOD	SUSPECT
> 1.517 VOLTS	0	7
< 1.517 VOLTS	16	2

MAXIMUM RECORDED VOLTAGE OCCURS AT 32 HOURS INTO CHARGE.

THE 32-HOUR CHARGE VOLTAGE IS THE CLOSEST AVAILABLE DATA FOR MAXIMUM (ROLLOVER) VOLTAGE.

BOTH THE MAXIMUM AND END-OF-CHARGE VOLTAGES (NOT SHOWN) HAVE INCREASED SIGNIFICANTLY (20 - 30 MILLIVOLTS) OVER TIME IN BOTH DESIGNS.

THE TREND RAISES THE CONCERN THAT RECENTLY-MADE CELLS MAY NOT BE AS COMPATIBLE WITH THE NASA STANDARD V/T LEVELS.

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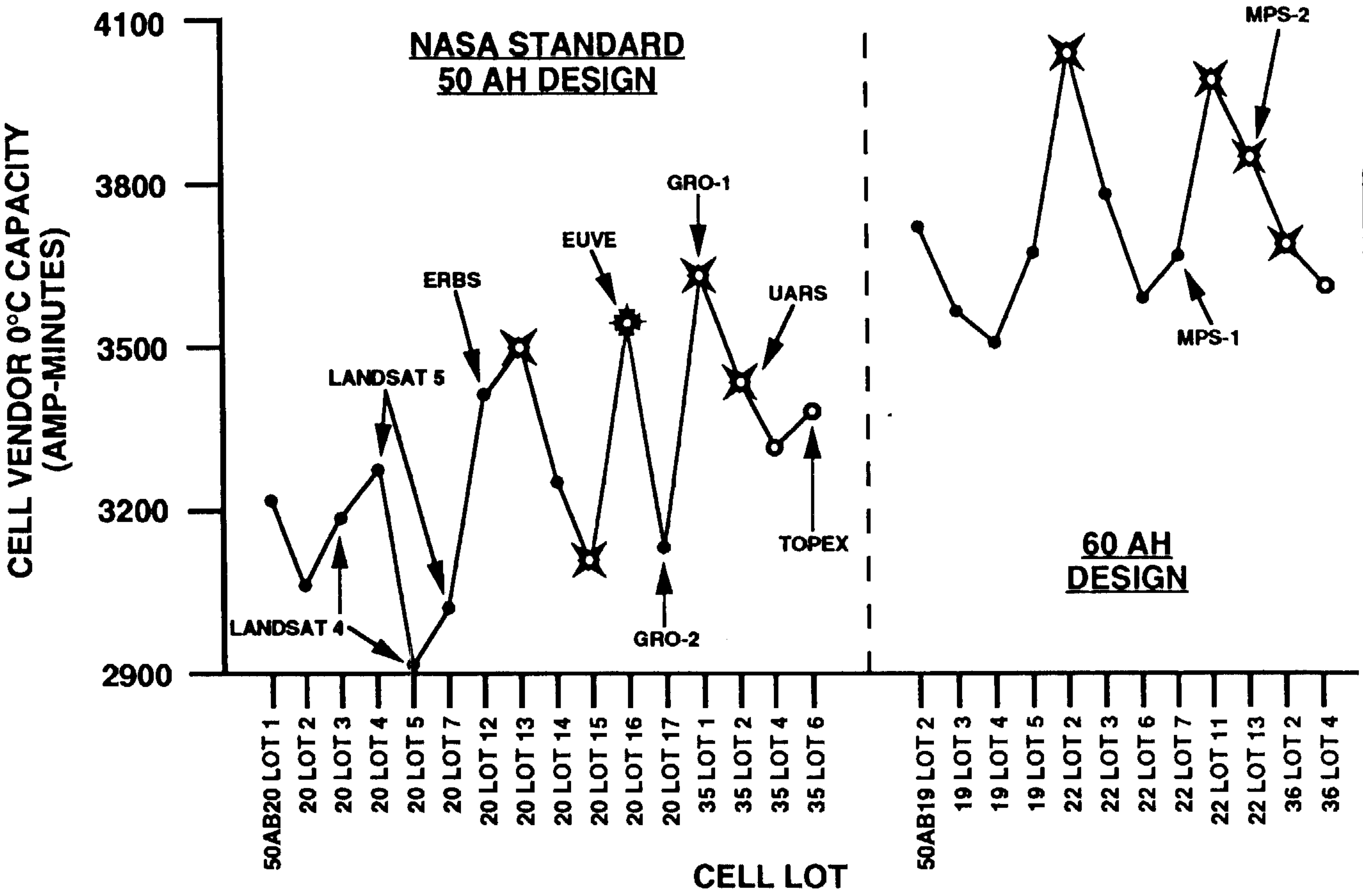
12. 0°C CAPACITY



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SINCE POSITIVE PLATE LOADING IS A FACTOR, THE TWO DESIGNS SHOULD BE CONSIDERED SEPARATELY:

NASA:

DISCRIMINATOR	GOOD	SUSPECT
> 3400 amp-minutes	1	4
< 3400 amp-minutes	8	1

60 AH DESIGN:

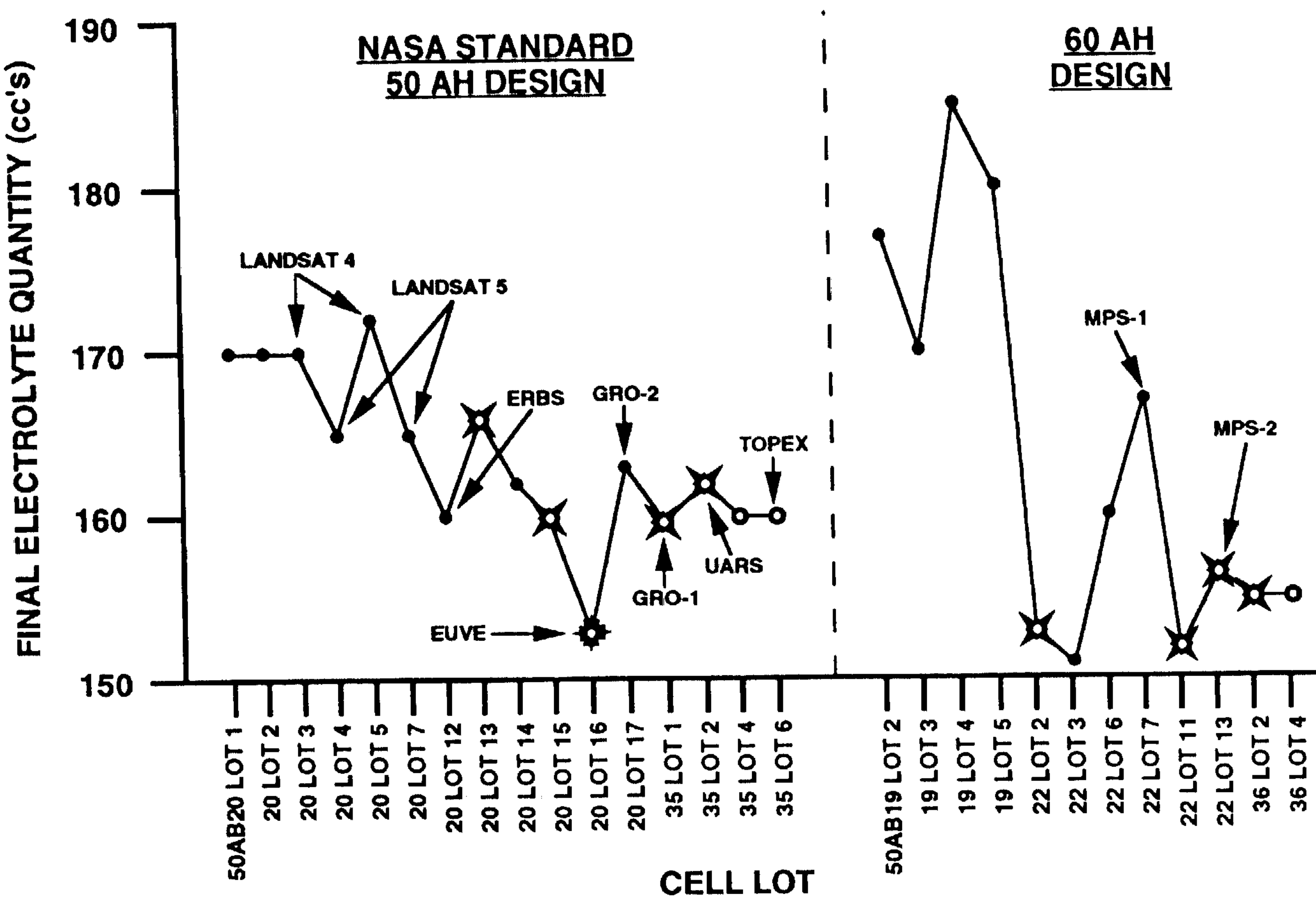
DISCRIMINATOR	GOOD	SUSPECT
> 3800 amp-minutes	0	3
< 3800 amp-minutes	7	1

NO SPEC MAXIMUM.

CAPACITIES IN THE NASA DESIGN HAVE VARIED GREATLY AND HAVE SHOWN A GENERAL INCREASE WITH TIME.

CAPACITIES IN THE 60 AH DESIGN ARE HIGHER THAN NASA, BUT WITHIN THE RANKS OF THE 60 AH DESIGN, CERTAIN LOTS ARE HIGHER THAN OTHERS.

13. FINAL ELECTROLYTE AMOUNT



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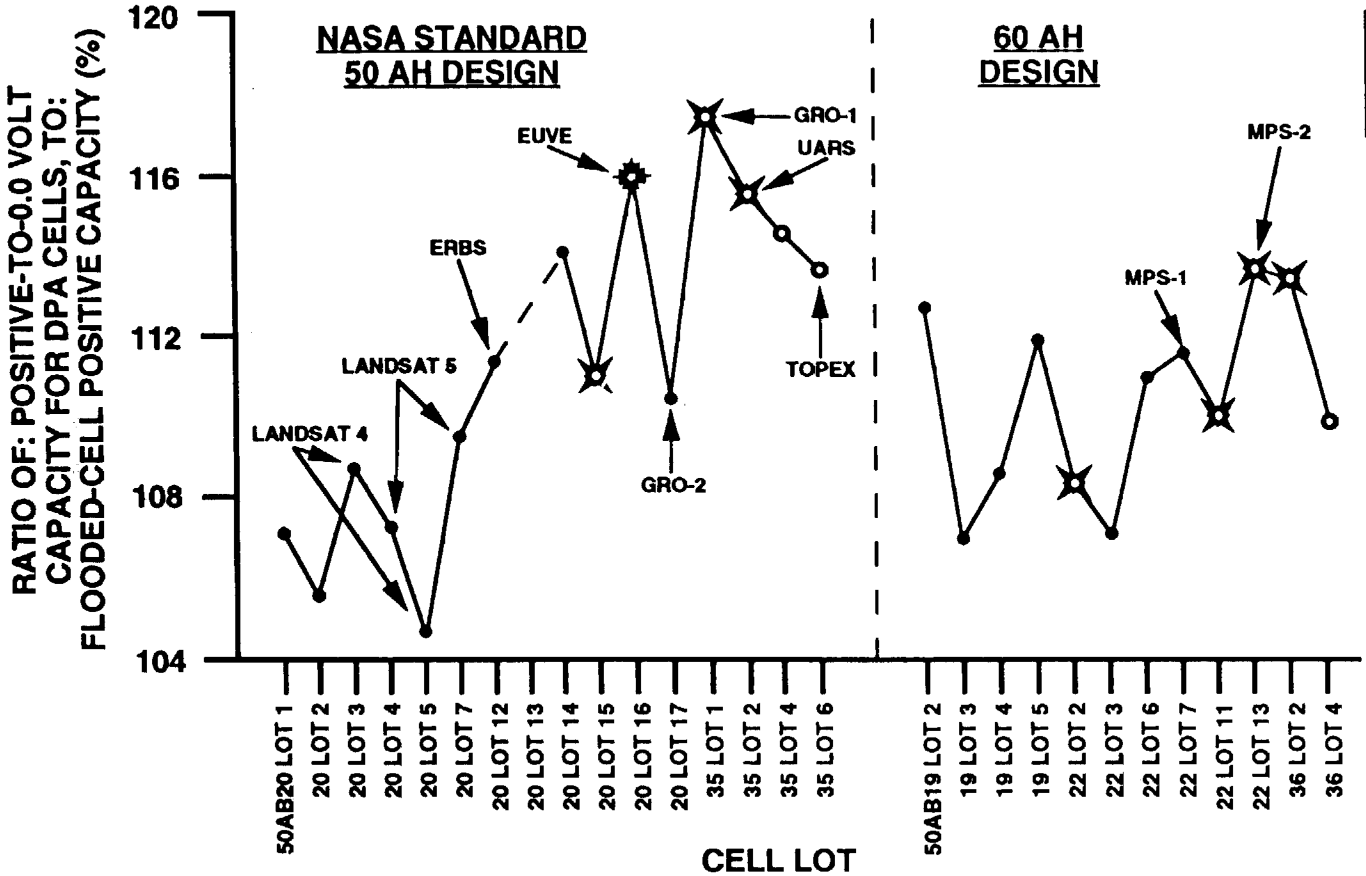
DISCRIMINATOR	GOOD	SUSPECT
< 162 cc's	3	8
≥ 162 cc's	13	1

NO SPEC MINIMUM OR MAXIMUM.

THERE HAS BEEN A DECREASE FROM THE HIGHER AMOUNTS OBSERVED IN THE EARLY YEARS OF BOTH DESIGNS (~6% LESS FOR NASA AND OVER 12% LESS FOR THE 60 AH DESIGN).

BOTH DESIGNS SEEM TO HAVE REACHED A "PLATEAU" FOR ELECTROLYTE AMOUNT.

14. POSITIVE CAPACITY TO 0.0 VOLTS IN DPA CELLS



DISCRIMINATOR	GOOD	SUSPECT
> 112%	2	5
< 112%	14	3

BASED ON ALL AVAILABLE STANDARD DPA CELLS:
- PRECHARGE
- POST-ATP
- POST 500-CYCLE

CAPACITY TO 0.0 VOLTS OBTAINED BY A COMBINATION OF A C/2 DISCHARGE FOLLOWED BY RESISTIVE LETDOWN.

AVERAGE CAPACITY TO 0.0 VOLTS OF ALL DPA SAMPLES IS THEN DIVIDED BY THE LOT AVERAGE FLOODED-CELL POSITIVE CAPACITY.

NO SPEC MINIMUM OR MAXIMUM.

COMBINED WITH OTHER ANALYSIS (NOT SHOWN) SUGGESTS THAT A GREAT DEAL OF CAPACITY IS CONTAINED BELOW ONE VOLT IN THE CELLS OF SUSPECT LOTS.

NO STANDARD DPA CELLS FOR 50AB20 LOT 13.

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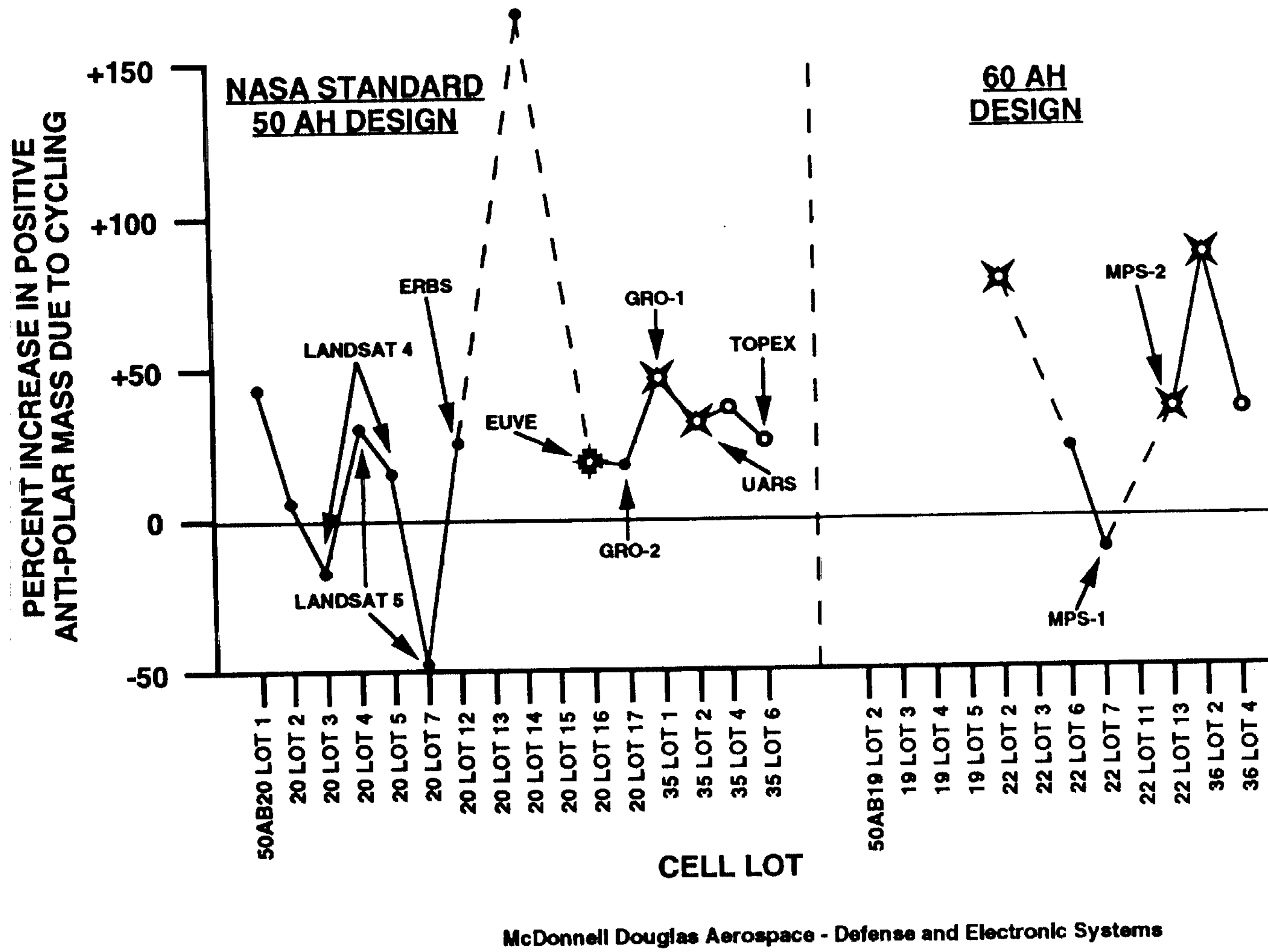
15. TRANSFER OF CADMIUM TO THE POSITIVE PLATE UNDER LIMITED CYCLING



DISCRIMINATOR	GOOD	SUSPECT
> 31%	2	5
< 31%	9	1

NO SPEC MINIMUM OR MAXIMUM.

BOTH DESIGNS HAVE CADMIUM TREATED POSITIVE PLATES (A.K.A. POSITIVE APM), EXCEPT FOR 50AB20 LOT 14 WHICH WAS INADVERTENTLY NOT TREATED.

DATA DERIVED BY CALCULATING THE DELTA IN POSITIVE APM BETWEEN EARLY PLATE SAMPLES (BLANKING, FLOODED-CELL PACKS, DECARB PACKS, PRECHARGE DPA CELLS) AND LATER PLATE SAMPLES (POST 500-CYCLE OR POST-ATP DPA CELLS).

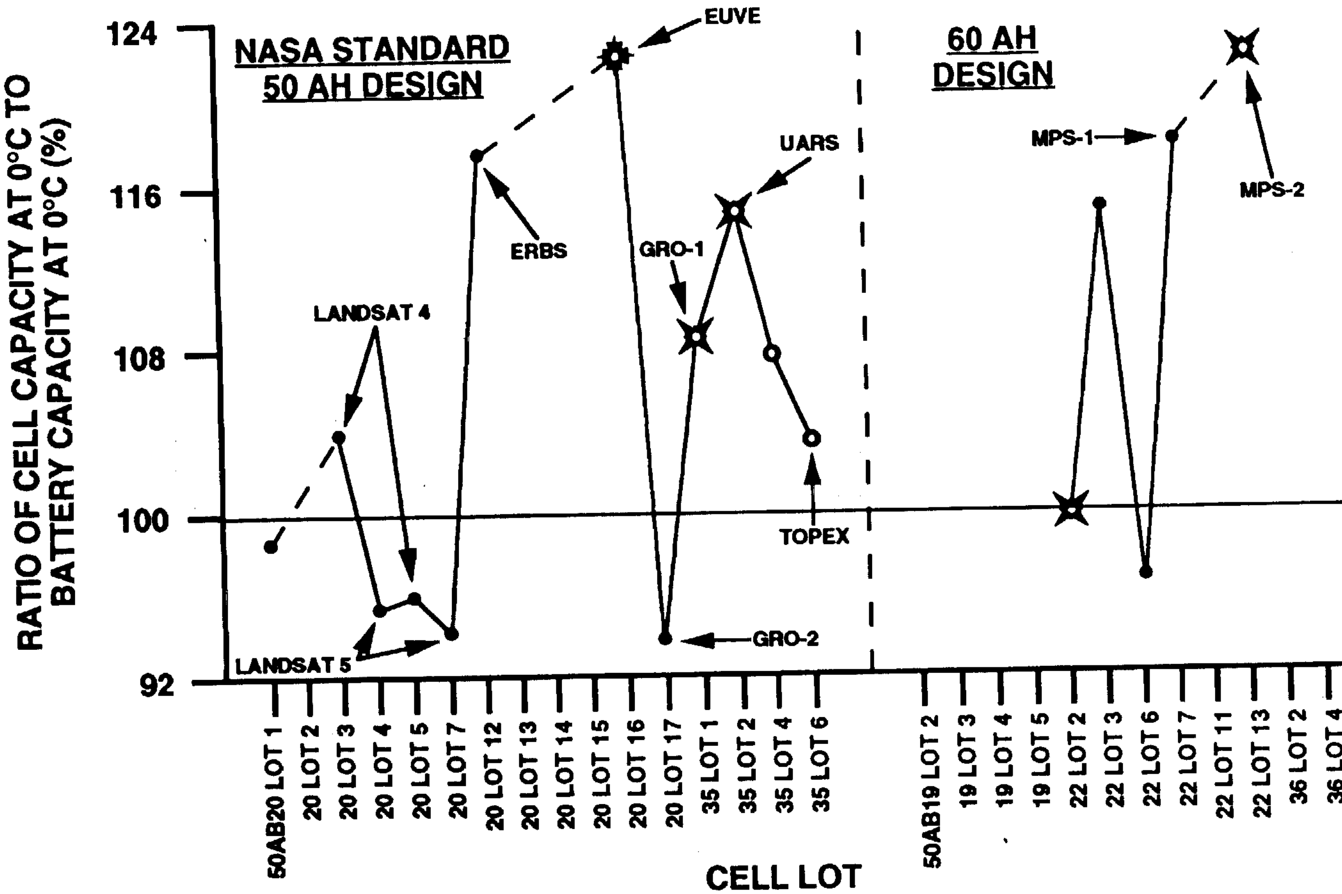
MAY INDICATE THE NEGATIVE PLATE'S PROPENSITY TO LOSE ACTIVE MATERIAL AND/OR THE SEPARATOR'S PROPENSITY TO LET IT PASS.

A TENUOUS DISCRIMINATOR AS IT USUALLY RELIES ON A SINGLE "LATER" SAMPLE.

HAS ALSO BEEN PLOTTED AS DELTA CADMIUM HYDROXIDE:

DISCRIMINATOR	GOOD	SUSPECT
> 0.2 gm/dm2	2	4
< 0.2 gm/dm2	9	2

16. RATIO OF CELL-LEVEL 0°C CAPACITY TO BATTERY-LEVEL 0°C CAPACITY



DISCRIMINATOR	GOOD	SUSPECT
> 108%	3	4
< 108%	7	1

NO DIRECT SPEC MINIMUM OR MAXIMUM.

DATA FOR THIS TREND MORE LIMITED AS IT ENCOMPASSES ONLY THOSE LOTS BUILT INTO BATTERIES AND PROCESSED THROUGH A FULL BATTERY ATP.

RATIO INDICATES HOW MUCH MORE CAPACITY A GIVEN LOT HAD AT 0°C AT THE CELL LEVEL VERSUS THE BATTERY LEVEL.

RATIOS GREATER THAN 100% INDICATE CAPACITY LOST BETWEEN CELL VENDOR TESTS AND BATTERY MANUFACTURER TESTS. (INCORRECTLY REPORTED AS CAPACITY GAIN IN LAST YEAR'S STUDY).

THE EFFECT SUGGESTS CONTINUING CHANGES TO THE MORPHOLOGY OF THE NEGATIVE PLATE.

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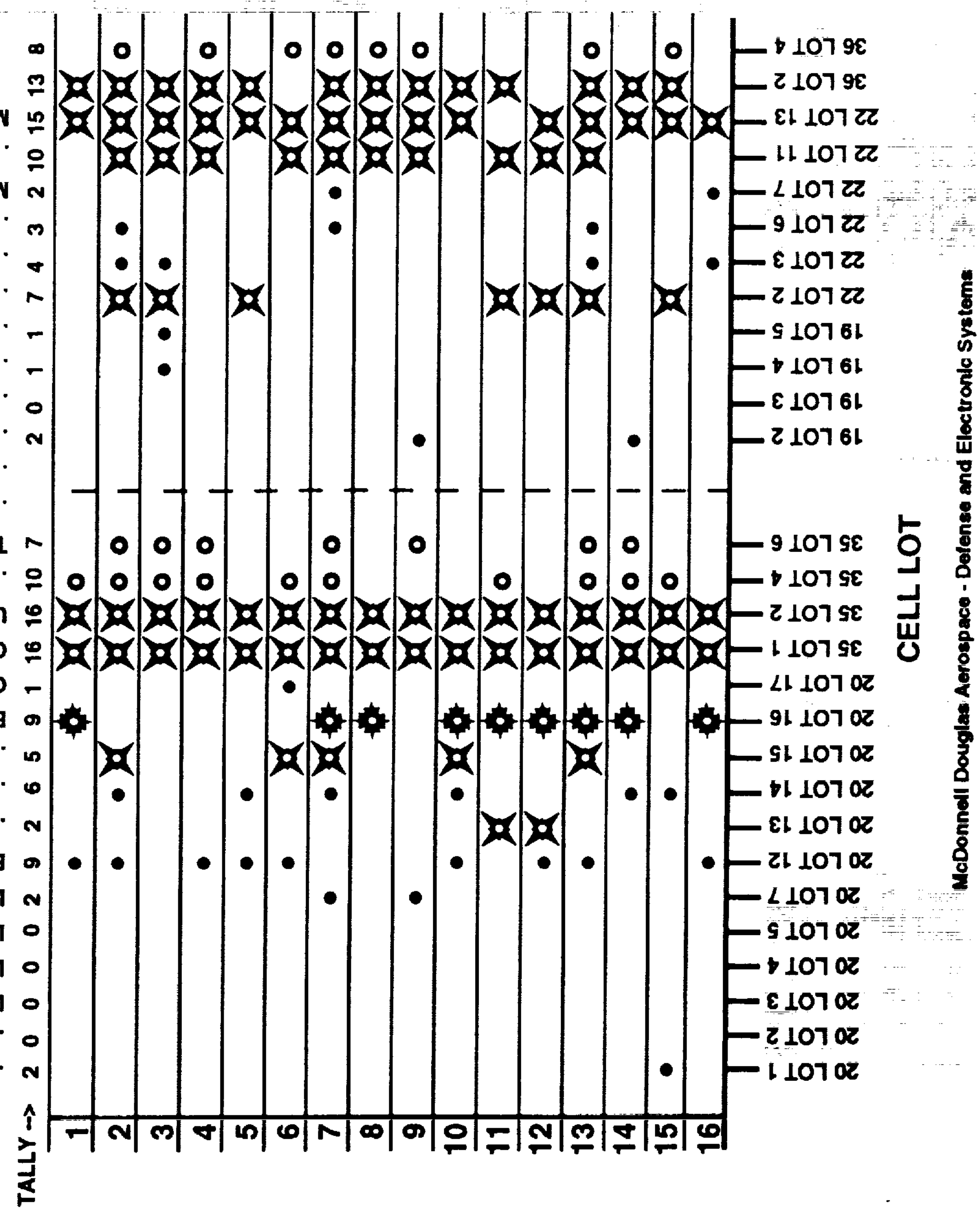
THE SCORECARD



SUMMARY

1. OVER THE LAST 5 YEARS, McDONNELL DOUGLAS AEROSPACE HAS PROCURED SEVERAL LOTS OF NICD CELLS OF TWO DESIGNS THAT SUBSEQUENTLY DISPLAYED ANOMALOUS PERFORMANCE.

2. RETROSPECTIVE ANALYSIS OF THE CHARACTERISTICS OF THE PLATES AND CELLS FROM THESE SUSPICIOUS LOTS HAS FOUND SEVERAL DISTINGUISHING FEATURES. THEY WERE SO DISTINCTIVE IN FACT, THAT VALUES WERE ESTABLISHED IN 16 DIFFERENT MEASURES OF PERFORMANCE TO DISCRIMINATE BETWEEN GOOD CELL LOTS AND SUSPECT CELL LOTS.

3. THE DATA USED TO GENERATE THESE DISCRIMINATORS IS EITHER OBTAINED DIRECTLY FROM THE CELL SUPPLIER OR IS EASILY DERIVED FROM THE CELL SUPPLIER'S DELIVERABLE DATA. THE RAW DATA IS NEITHER OBSCURE NOR ESOTERIC. THE DERIVED DATA DOES NOT REQUIRE EXTENDED OR CONVOLUTED FORMULAS.

4. MOST OF THE DISCRIMINATORS CONCERN EITHER THE NEGATIVE ELECTRODE ITSELF, OR PERFORMANCE EFFECTS STRONGLY AFFECTED BY THE NEGATIVE ELECTRODE.

5. EVERY SUSPICIOUS CELL LOT NOT ALREADY ASSOCIATED WITH DEGRADED SEPARATOR HAS FAILED A MAJORITY OF THESE 16 DISCRIMINATORS. (TWO NASA LOTS, UARS AND GRO MPS-1, FAILED ALL 16.)

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CONCLUSIONS

1. POST-DELIVERY PERFORMANCE OF NICD CELLS AND BATTERIES CAN BE AND SHOULD BE RELATED BACK TO THE PERFORMANCE OBSERVED IN THE PLATES AND CELLS AT THE CELL SUPPLIER.

2. CELL PERFORMANCE AT THE CELL SUPPLIER CAN BE AND SHOULD BE RELATED BACK TO PLATE PERFORMANCE. IN A LIKE MANNER, CELL PERFORMANCE ANOMALIES CAN OFTEN BE TRACED BACK TO THE PLATE COMPONENT LEVEL.

3. PAST PERFORMANCE OF PLATES AND CELLS SHOULD BE USED TO CREATE NEW PERFORMANCE SPECIFICATIONS AS WELL AS UPDATE EXISTING ONES. SOME CELL-LEVEL PERFORMANCE SPECIFICATIONS SHOULD BE DEPENDENT ON PLATE-LEVEL PERFORMANCE.

4. THE PRESENT STRUCTURE OF MOST PERFORMANCE SPECIFICATIONS DOES NOT ADEQUATELY ASSESS THE QUALITY OF THE END-PRODUCT. THE FORMAT IS SUCH THAT INDIVIDUAL SPECIFICATIONS CAN EITHER BE TOO OBJECTIVE OR (MORE LIKELY) NOT OBJECTIVE ENOUGH.

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CONCLUSIONS (cont'd)

5. THE EFFORTS TO MAKE A THICKER, MORE POROUS NEGATIVE PLAQUE HAD A PROFOUND EFFECT ON SUBSEQUENT PLATE PROCESSING, AND WAS EVIDENCED BY MARKED CHANGES IN PLATE PHYSICAL CHARACTERISTICS AND NEGATIVE PLATE PERFORMANCE. INCREASED NEGATIVE UTILIZATION, AT LEAST BY THESE MEANS, WAS NOT A PERFORMANCE ENHANCEMENT.

6. THE MOST COST-EFFECTIVE AND SCHEDULE-EFFECTIVE PERFORMANCE DISCRIMINATORS, FOR BOTH CUSTOMER AND SUPPLIER, WOULD BE AT THE PLATE LEVEL. SEVERAL HAVE BEEN IDENTIFIED HERE, BUT IT IS LIKELY THAT A SUFFICIENTLY GREATER NUMBER CAN BE DEVELOPED TO MAKE PLATE "BUY-OFF" A MORE EFFECTIVE SCREENING PROCESS.

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ACKNOWLEDGEMENTS

SINCERE THANKS TO THESE PROFESSIONAL MEN AND WOMEN, FOR THEIR CONTRIBUTIONS OF TIME, EFFORT, INSIGHT AND EXPERIENCE:

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DAN DELL
JUDY ULMER
GUY RAMPEL
ADELL AKRIDGE
WAYNE WILLIAMS
KEN WEBB
GLENN KLEIN

MDC

DON WEBB
TERRY GANLEY
JOANN WANKO
MAURICE ZOLLNER
DON BROWN

NASA - GSFC

MARLON ENCISO
KEN SCHWER
DR. GOPAL RAO
SMITH D. TILLER

NWSC - Crane

STEVE HALL

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Charge Control Session

Session Organizer: *Joe Stockel*
Office of Research & Development

INTELSAT BATTERY CHARGE PHILOSOPHY

Andrew Dunnet
INTELSAT
Washington, D.C., U.S.A.

*INTELSAT has 10 rather aged NiCd Batteries and 30 NiH2 batteries of various designs presently in orbit.

*With all of them we try to minimise the overcharge they are exposed to as well as maintaining temperatures in the moderate -5 to +20 deg.C. Preferably keeping the temperature under +10 deg.C.

*INTELSAT uses a current integration on discharge and returns between 105% and 115% depending on the battery and load.

The I-5 NiCd batteries are recharged to 105% or a cell voltage of 1.58V, which ever comes first.

The I-5 NiH2 batteries are recharged to 110% to 115% depending on current load.

The I-K NiH2 batteries are recharged to 112%.

The I-6 NiH2 batteries are recharged to 105%.

The I-7 NiH2 batteries will be recharged to 110%.

*INTELSAT always reconditions their batteries prior to an eclipse season. With the NiH2 the benefit to the batteries is not clear but the twice yearly health check is well worth the effort. Reconditioning is to the first cell to:

1V for the I-5 NiCd batteries.

0.9V for the I-6 NiH2 batteries.

0.5V for all other NiH2 batteries.

*INTELSAT minimises the temperature during solstice by reducing the recharge to just compensate for self discharge.

*In the past INTELSAT has always controlled the recharge by computer generated commands on the ground. Starting with I-7 this function will be controlled by the spacecraft in orbit. All the parameters; recharge ratio, thermal limits and recharge rates, are up-linked from the ground.

PRESSURE-BASED CHARGE CONTROL ON $Ni-H_2$ CELLS

Dean Maurer, AT&T / Bell Labs

SOME PRESSURE CONTROL CONCERNS

A. ABSOLUTE VALUE

- THERMAL EFFECTS OF OVERCHARGE
- CAPACITY/ TEMPERATURE EFFECTS
- TEMPERATURE/ PRESSURE EFFECTS

B. RATE

- THERMAL EFFECTS

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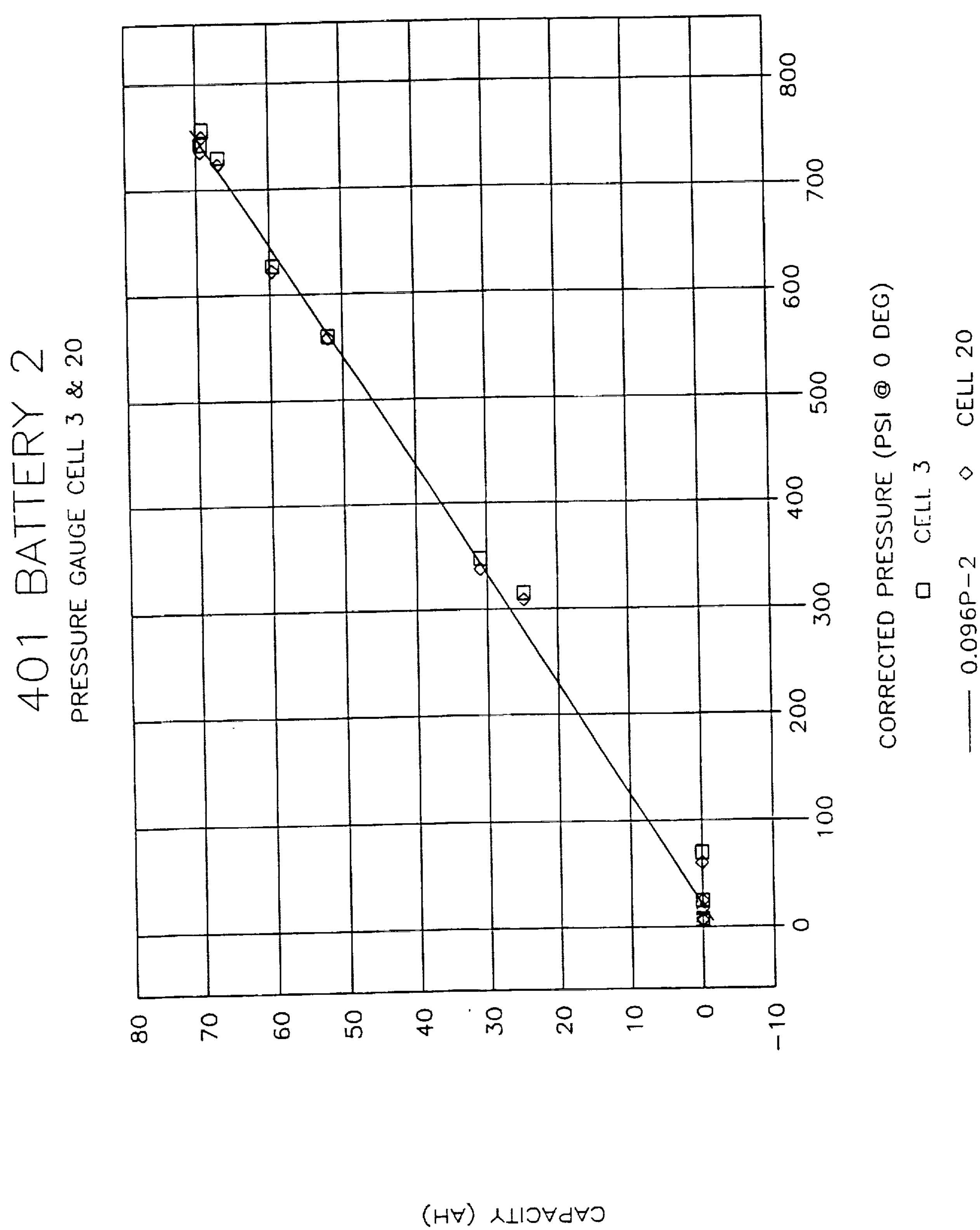
401 BATTERY 2
PRESSURE GAUGE CELL 3 & 20
CAPACITY (AH)
CORRECTED PRESSURE (PSI @ 0 DEG)
□ CELL 3
◇ CELL 20
—— 0.096P-2
80
70
60
50
40
30
20
10
0
-10
0
100
200
300
400
500
600
700
800

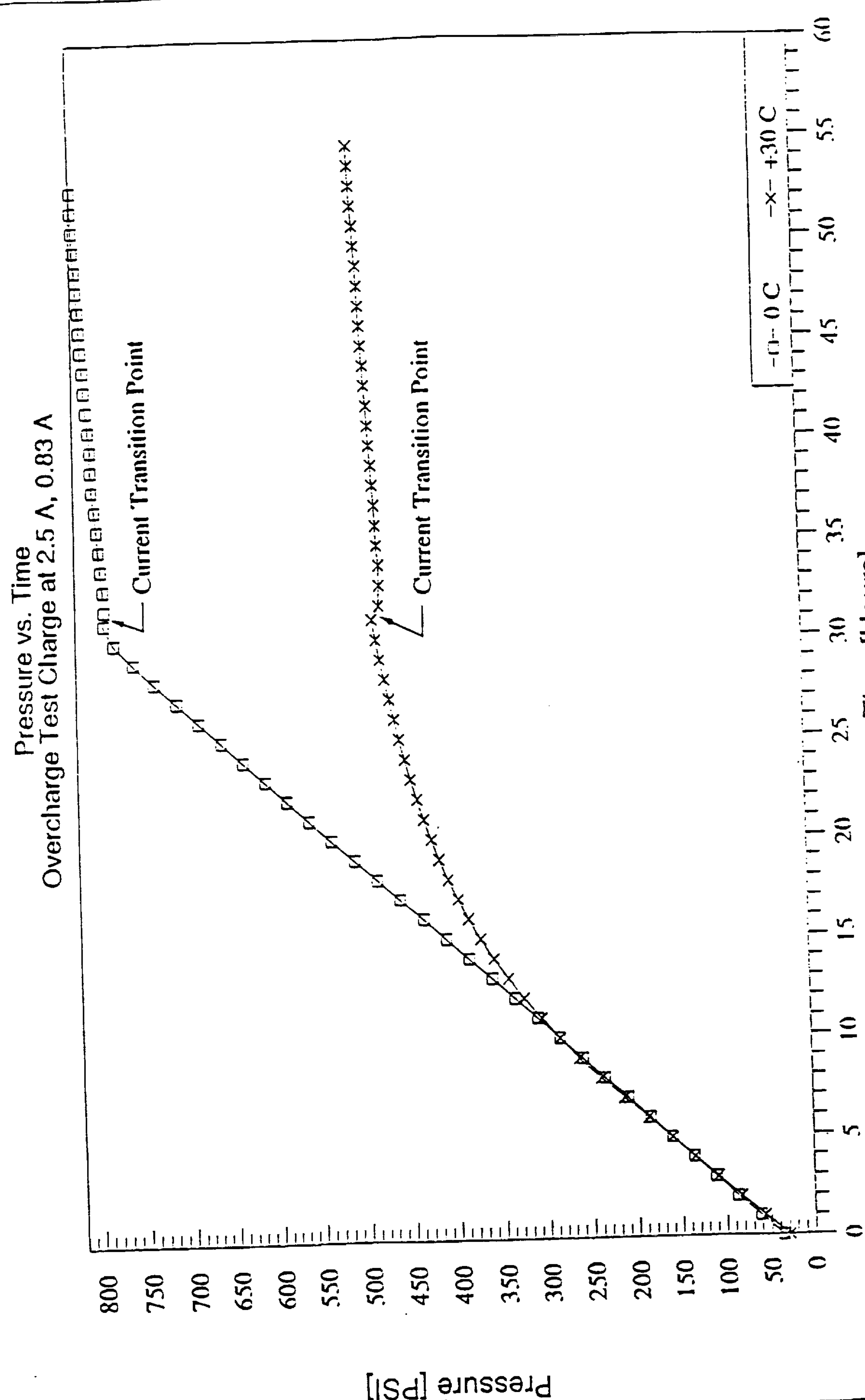
Pressure vs. Time
Overcharge Test Charge at 2.5 A, 0.83 A
Current Transition Point
Current Transition Point
Pressure [PSI]
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
Time [Hours]
0
5
10
15
20
25
30
35
40
45
50
55
60
0 C
+30 C

Figure 3

SOME PRESSURE CONTROL METHODS

A. ABSOLUTE VALUE

- CHARGE TO A $P_f = f(T,R)$, THEN TRICKLE
- CHARGE TO X%P_f THEN ADD (CAP -X) + Y% THEN TRICKLE

B. RATE

- CHARGE TO A $dP/dt = f(R)$ THEN TRICKLE