SAFT
DIVISION SPACE
ESPACE DEPARTMENT
ROMAINVILLE FRANCE

1992- NASA AEROSPACE BATTERY WORKSHOP

CYCLE LIFE STATUS OF SAFT VOS NICKEL-CADMIUM CELLS

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HUNTSVILLE - AL
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CONTENT

. LOW EARTH ORBIT CYCLING

ESA TEST - ELAN PROGRAM - 24 AH - 40 AH CELLS

- RESULTS OF DESTRUCTIVE PHYSICAL ANALYSIS

NASA TEST - 20 AH - 24 AH CELLS

AIR FORCE TEST - 24 AH - 40 AH CELLS

. GEOSYNCHRONOUS ORBIT CYCLING

ESA TEST : HIGH DOD 90% - 100 % - 18 AH BATTERIES

AIR FORCE TEST : DOD 80% 24 AH AND 40 AH CELLS

. LIFE TIME EXPECTANCY

1992 - NASA AEROSPACE BATTERY WORKSHOP

CYCLE LIFE STATUS OF SAFT NICKEL-CADMIUM CELLS

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The SAFT prismatic VOS Ni-Cd cells have been flown in geosynchronous orbit since 1977 and in low earth orbit since 1983. In parallel cycling tests are performed by several space agencies in order to determine the cycle life in a wide range of temperature and depth of discharge.

In Low Earth Orbit the ELAN Program is conducted on 24 Ah and 40 Ah cells by CNES and ESA at the European Battery Test Center at temperatures ranging from 0°C to 27°C and DOD from 10 to 40 %, data are presented up to 37000 cycles, one pack (X-80) at 10°C 23% DOD has acheived 49000 cycles.

Results of destructive physical analysis of cells cycled at 27°C and 8° C show that the first cause of failure is the tickness increase of the positive electrode leading to the drying up of the separator. At the negative electrode the overcharge protection is consumed, Hydrogen content in the cell is increased but the negative electrode is not the cause of failure.

In the frame of the qualification program conducted at NSWC-CRANE :

NASA Tests : 3 packs of 20 and 24 Ah have completed 18 400 cycles at 40% DOD

AIR FORCE Tests : 2 packs 24 and 40 Ah have completed 14000 cycles at 40% DOD.

In geosynchronous orbit simulation a high DOD test is conducted by ESA on 3 batteries at 10°C a 70%, 90% and 100% DOD, 31 eclipses seasons have been completed and no sign of degradation is noticed.
The AIR FORCE test at CRANE on 24 Ah and 40 Ah cells at 80% DOD 20°C has acheived 19 shadow periods.

Life time expectancy is discussed, the VOS cell technology could be used for :

in geosynchronous conditions

15 years at 10-15°C 80% DOD

in low earth orbit

10 years at 5-15°C 25-30 % DOD.

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LOW EARTH ORBIT CYCLING - ELAN PROGRAM							
VOS 24A							
TEST NUMBER	50	53	54	55	56	57	58	59
BATTERY NUMBER	X 80	01	02	03	04	05	06	07
DOD %	23	10	10	10	20	20	20	20
TEMPERATURE (°C)	10	+6	+16	+25	+7	+17	+26	-2
DISCHARGE (A) STEP 1 (25 MIN) STEP 2 (10 MIN)	9.15 (35 MN)	3.45 5.77	3.45 5.77	3.45 5.77	3.45 20.0	3.45 20.0	3.45 20.0	3.45 20.0
CHARGE (A)	9.8	8	8	8	8	8	8	8
VOLTAGE LIMIT (V)	1.466	1.456	1.425	1.40	1.49	1.45	1.46	1.523
RECHARGE RATIO	1.06	1.14	1.165	1.17	1.13	1.164	1.078	1.13
CYCLES	49000	37000	37000	37000	37000	37000	37000	36000
END OF DISCHARGE VOLTAGE (V)	1.08	1.25	1.24	1.22	1.07	1.13	1.09	1.13
RECONDITIONING	NO	R1	R1	R2 C 8400	R2 C 4130	R1	No	R1
R1 = RECONDITIONING ON A REGULAR BASIS (3000 CYCLES) R2 = TEST RECONFIGURATION								

SAFT SPACE DEPARTMENT			1992 NASA BATTERY WORKSHOP				
LOW EARTH ORBIT CYCLING - ELAN PROGRAM							
VOS 24A							
TEST NUMBER	60	61	62	63	64	65	66
BATTERY NUMBER	09	10	08	12	15	13	14
DOD %	20	24	30	30	30	40	40
TEMPERATURE (°C)	+17	+17	+8	-1	+17	+8	+27
DISCHARGE (A) STEP 1 (25 MIN) STEP 2 (10 MIN)	3.45 20.0	CONSTANT POWER	7.0 26.0	7.0 26.0	7.0 26.0	7.0 40.0	15.0 20.0
CHARGE (A)	8	MAX:11.4	12	12	12	16	16
VOLTAGE LIMIT (V)	1.475	1.46	1.52	1.52	1.495	1.51	1.464
RECHARGE RATIO	1.16	1.045	1.14	1.07	1.164	1.07	1.14
CYCLES	36000	21000	37000	36000	36000	37000	21000
END OF DISCHARGE VOLTAGE (V)	1.09		1.00	1.03	.97	.80	
RECONDITIONING	No	R2 C 12000	No	R2	No	R2 C 15080	No
						5 FAILED CELLS	DISCONTINUED

SAFT SPACE DEPARTMENT	1992 NASA BATTERY WORKSHOP				
LOW EARTH ORBIT CYCLING-ELAN PROGRAM					
	VOS 40A				VOS 20B
TEST NUMBER	67	68	69	70	71
BATTERY NUMBER	11	17	18	19	20
DOD %	30	30	10	20	30
TEMPERATURE (°C)	+27	+17	+5	+5	+15
DISCHARGE (A) STEP 1 (25 MIN) STEP 2 (10 MIN)	 20 25	 20 25	 6.80 6.80	 13.70 13.70	 5.80 21.55
CHARGE (A)	20	20	10	10	10
VOLTAGE LIMIT (V)	1.463	1.48	1.457	1.504	1.48
RECHARGE RATIO	1.13	1.16	1.14	1.08	1.16
CYCLES	31000	31000	28000	27000	27000
END OF DISCHARGE VOLTAGE (V)	0.91	1.03	1.27	1.21	1.01
RECONDITIONING	No	No	R1	R1	No
	3 FAILED CELLS				

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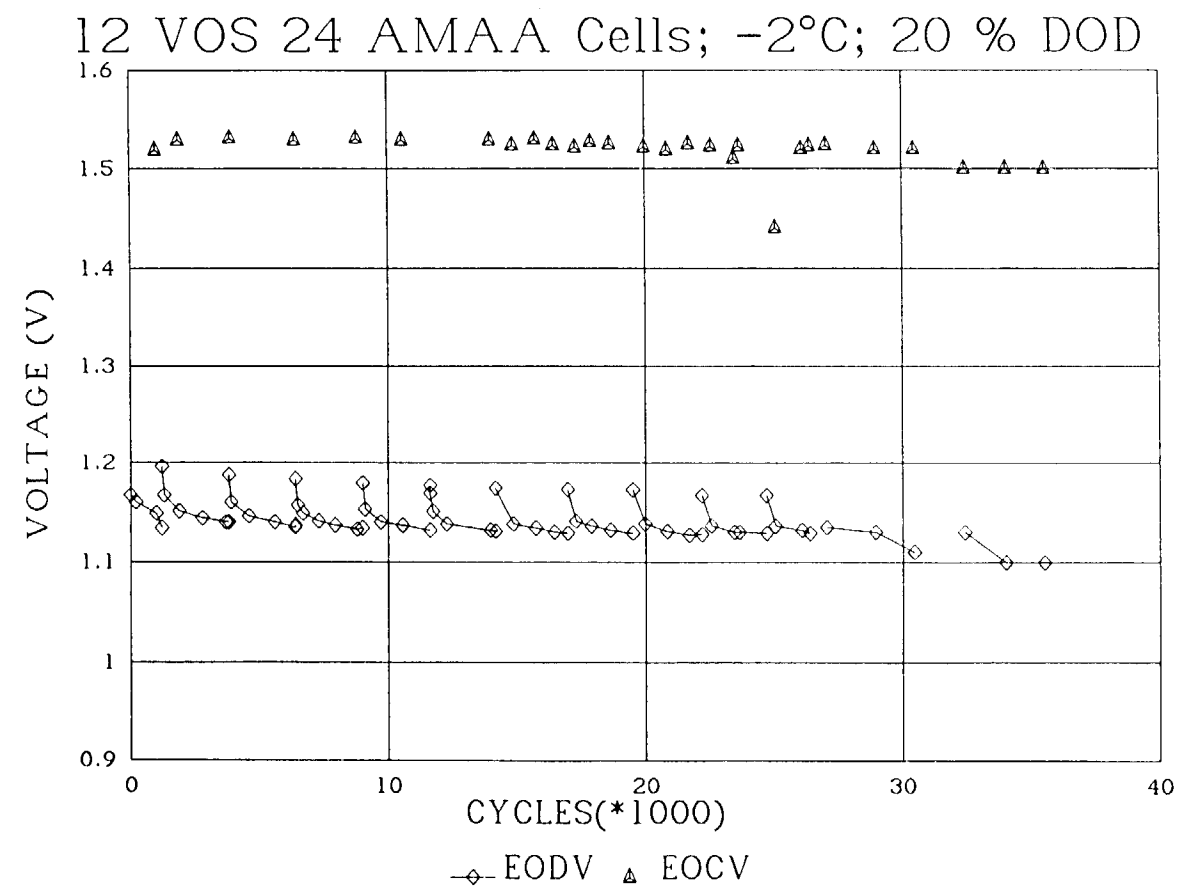
NiCd Cells | ELAN Program | Low Earth Orbit Cycling



TEST N°59

DISCHARGE:
25 MN AT 3.45A
10 MN AT 20A

CHARGE:
65 MN AT 8A

AS PER SEPTEMBER 1992

NO CELL REMOVED
CYCLING STILL RUNNING

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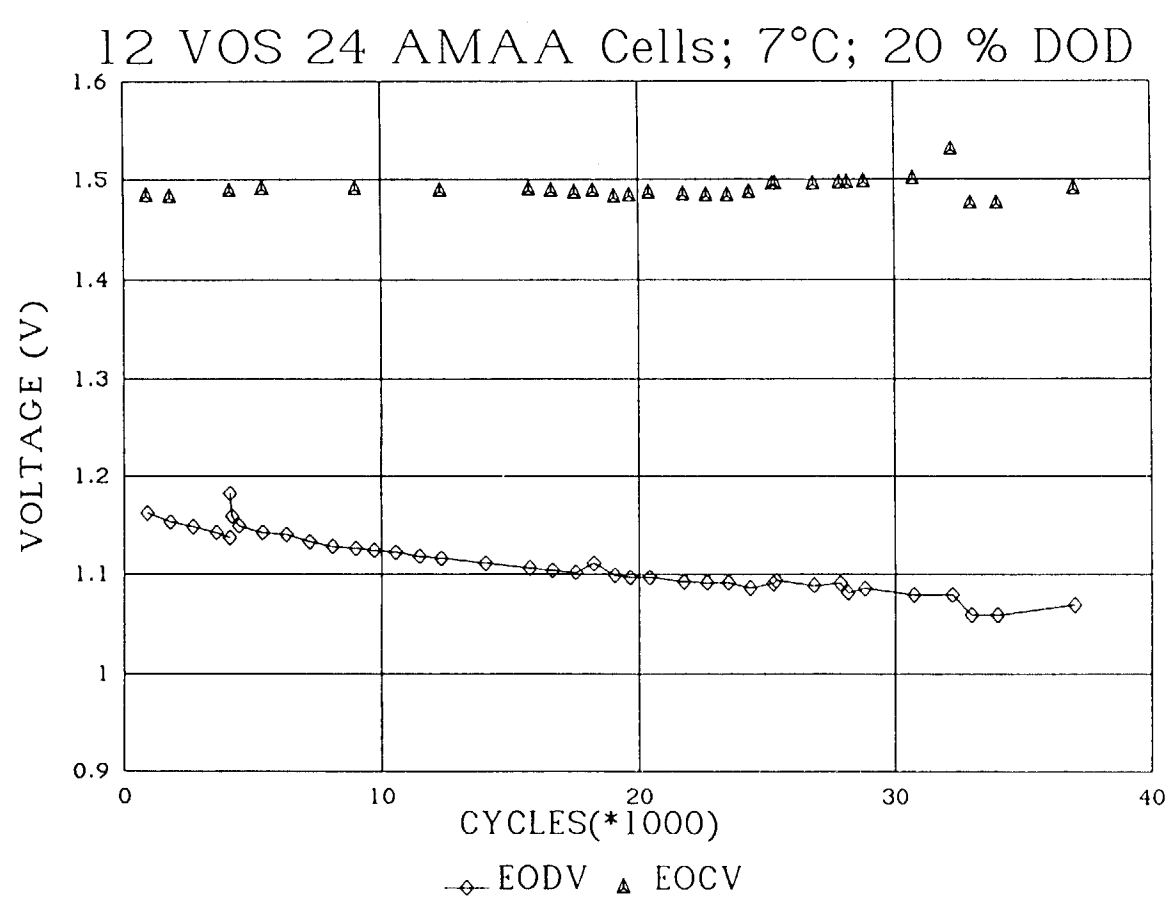
NiCd Cells	ELAN Program	Low Earth Orbit Cycling



TEST N°56

DISCHARGE:
25 MN AT 3.45A
10 MN AT 20A

CHARGE:
65 MN AT 8A MAX
CURRENT TAPERING

AS PER SEPTEMBER
1992

NO CELL REMOVED
CYCLING STILL RUNNING

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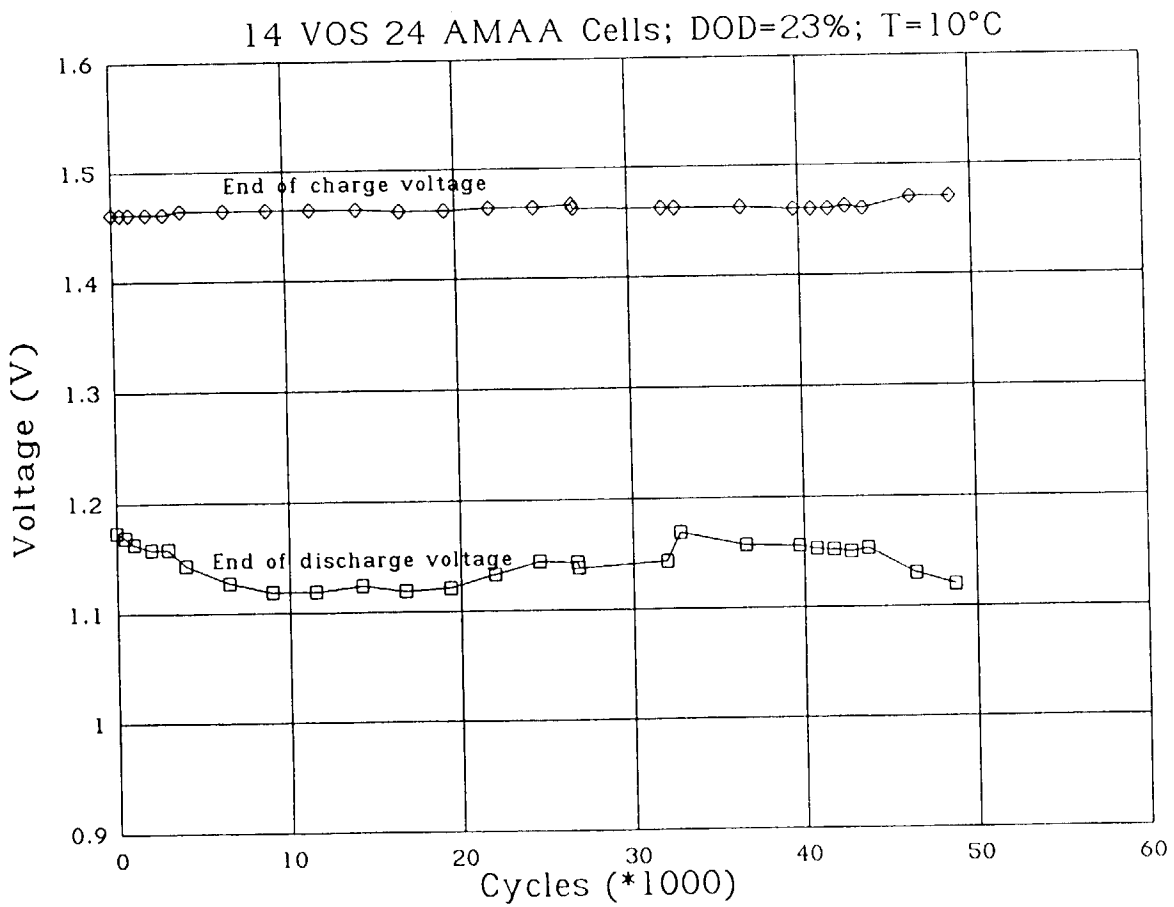
NiCd Cells | X80 cycling | Low Earth Orbit Cycling



TEST N°50

DISCHARGE:
35MN AT ~~5.5A~~ 9.15A

CHARGE:
CURRENT TAPERING

AS PER SEPTEMBER 1992

NO CELL REMOVED
CYCLING STILL
RUNINNG

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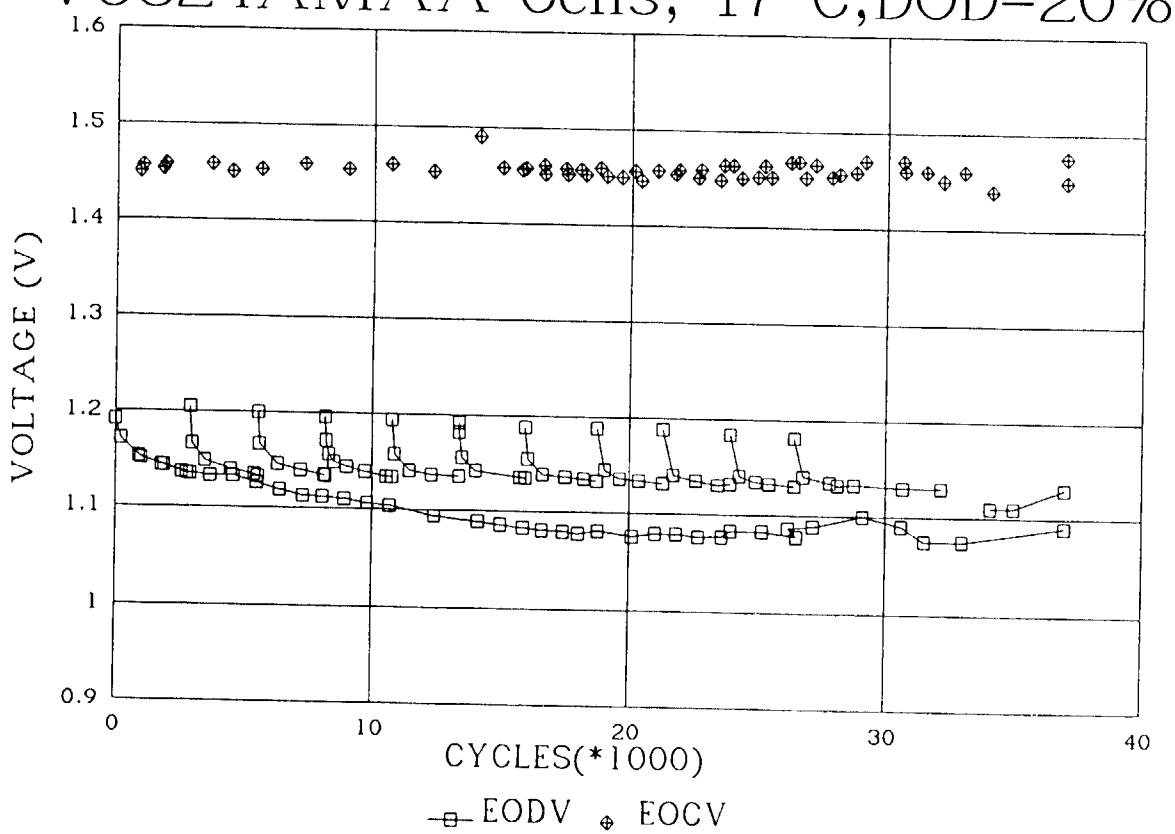
NiCd Cells | ELAN Program | Low Earth Orbit Cycling



TESTS N°57 AND 60

DISCHARGE:
25 MN AT 3.5A
10 MN AT 20A

CHARGE:
65 MN AT 8A MAX
CURRENT TAPERING

WITH AND WITHOUT RECONDITIONING

AS PER SEPTEMBER 1992

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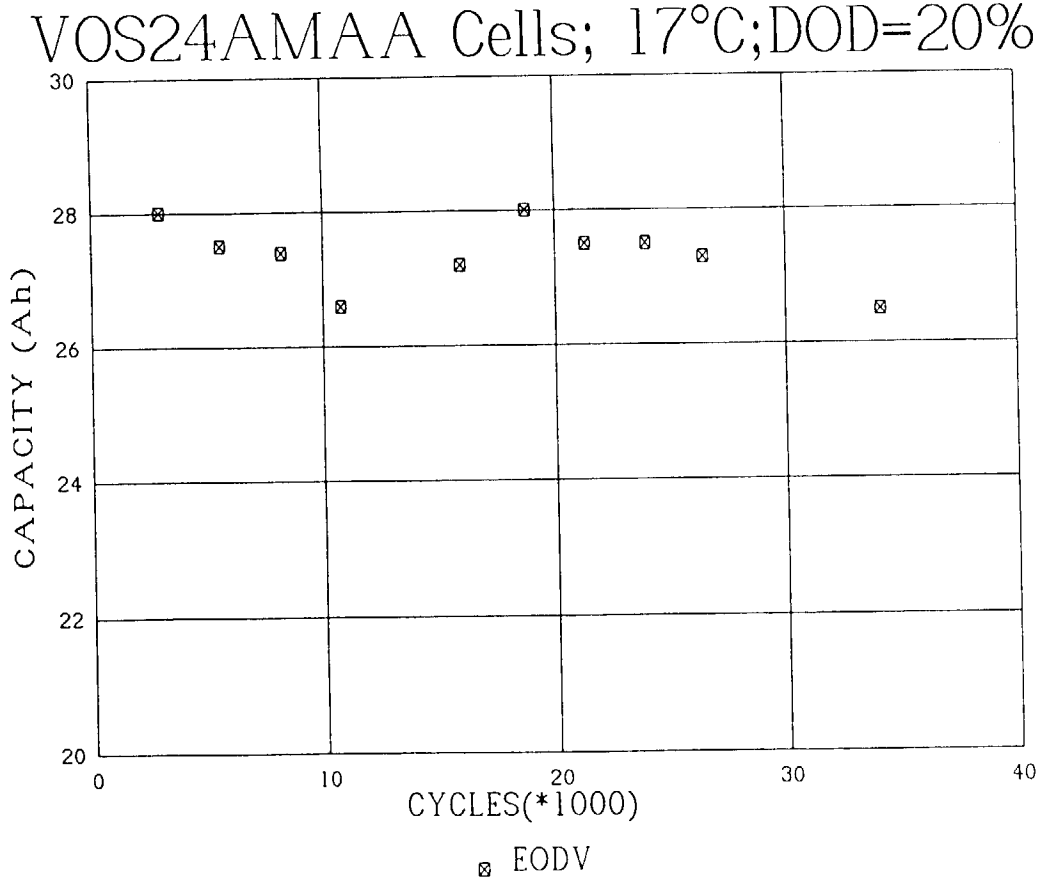
NiCd Cells | ELAN Program | Low Earth Orbit Cycling



TEST N°57

DISCHARGE AT 3.45 A DOWN TO 1V AFTER CYCLING DISCHARGE

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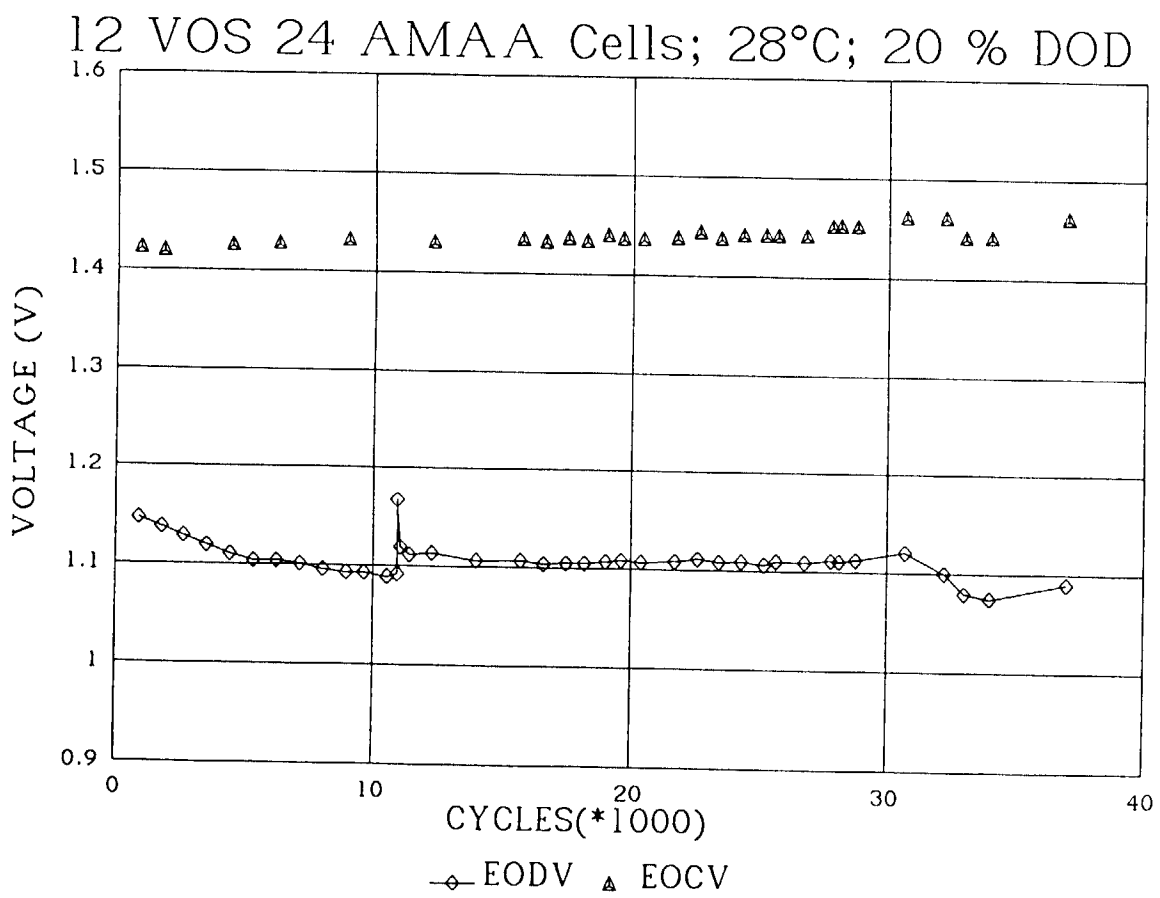
NiCd Cells | ELAN Program | Low Earth Orbit Cycling



TEST N°58

DISCHARGE:
25 MN AT 3.5A
10 MN AT 20A

CHARGE:
65 MN AT 8A MAX
CURRENT TAPERING

AS PER SEPTEMBER 1992

NO CELL REMOVED
CYCLING STILL RUNNING

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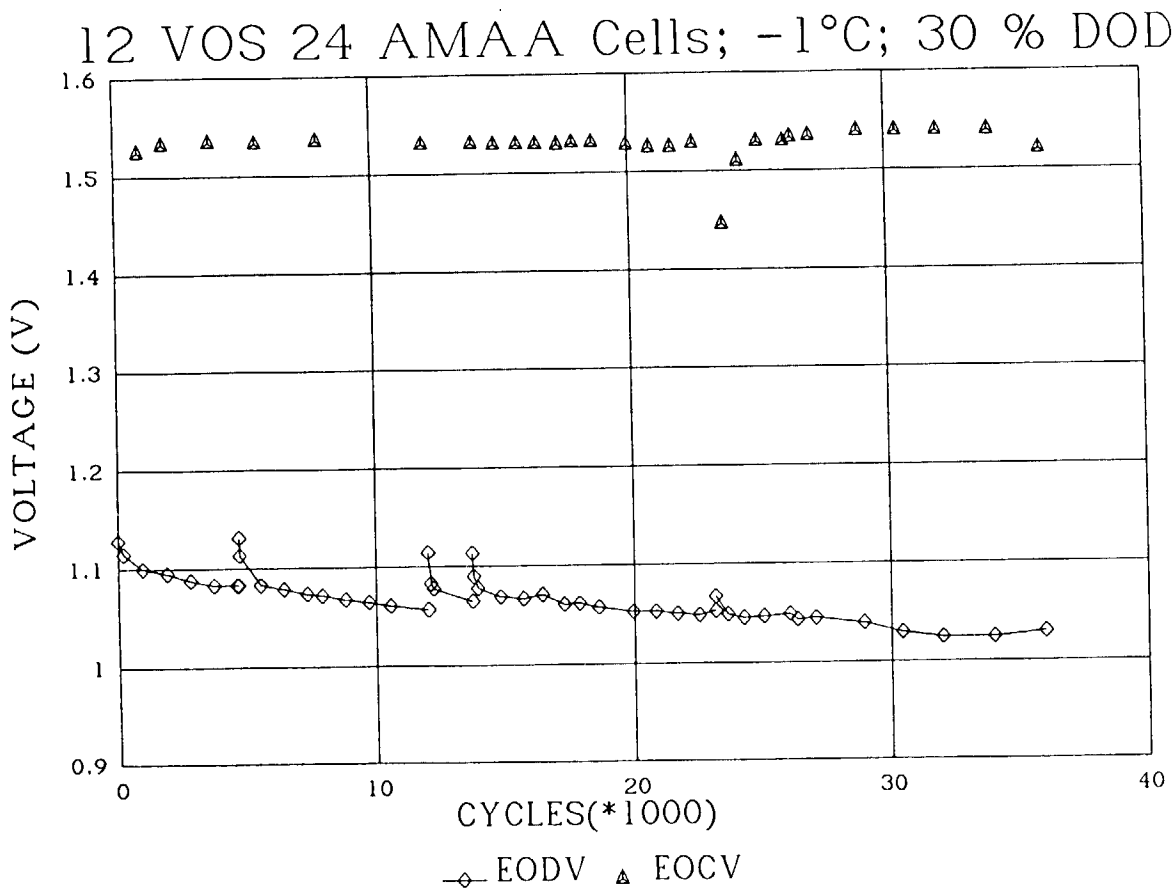
NiCd Cells | ELAN Program | Low Earth Orbit Cycling



TEST N°63

DISCHARGE:
25 MN AT 7A
10 MN AT 26A

CHARGE:
65 MN AT 12A MAX
CURRENT TAPERING

AS PER SEPTEMBER 1992

NO CELL REMOVED
CYCLING STILL RUNNING

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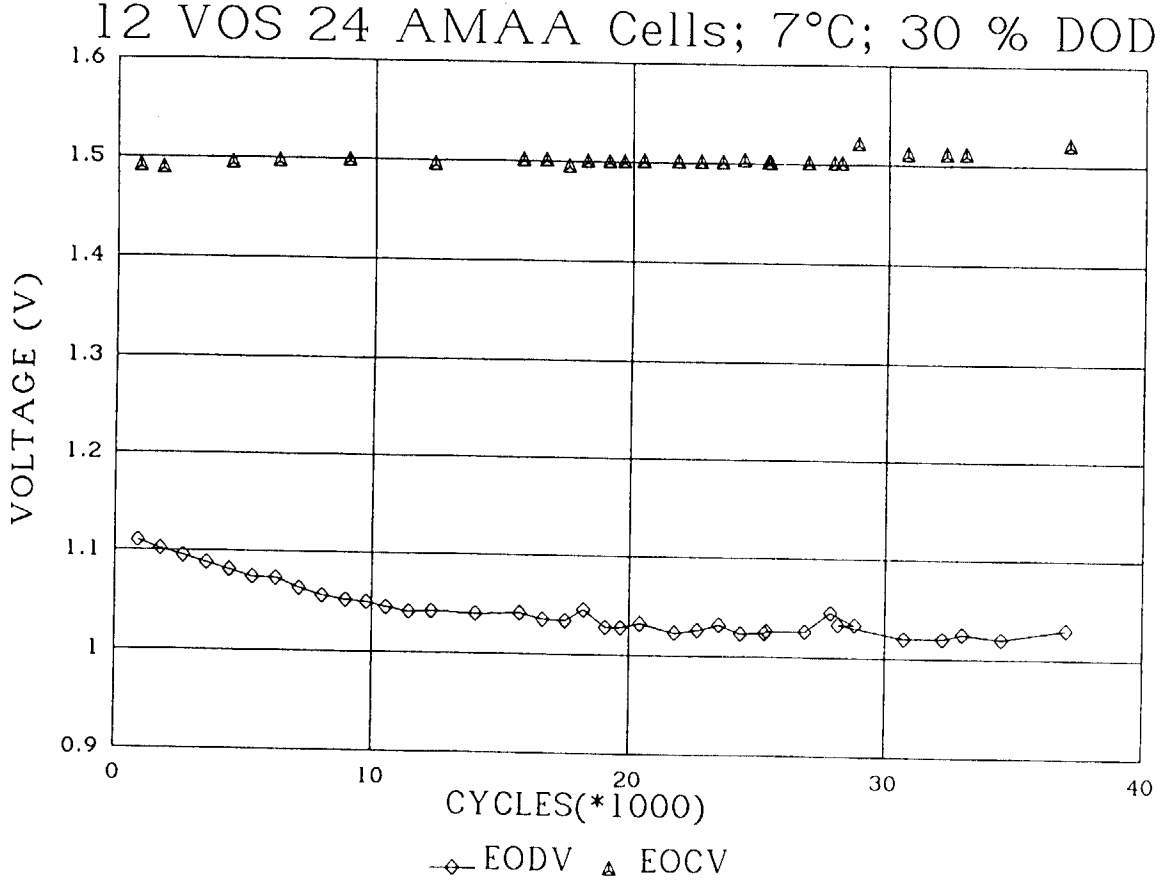
NiCd Cells | ELAN Program | Low Earth Orbit Cycling



TEST N°62

DISCHARGE:
25 MN AT 7A
10 MN AT 26A

CHARGE:
65 MN AT 12A MAX
CURRENT TAPERING

AS PER SEPTEMBER 1992

NO CELL REMOVED
CYCLING STILL RUNNING

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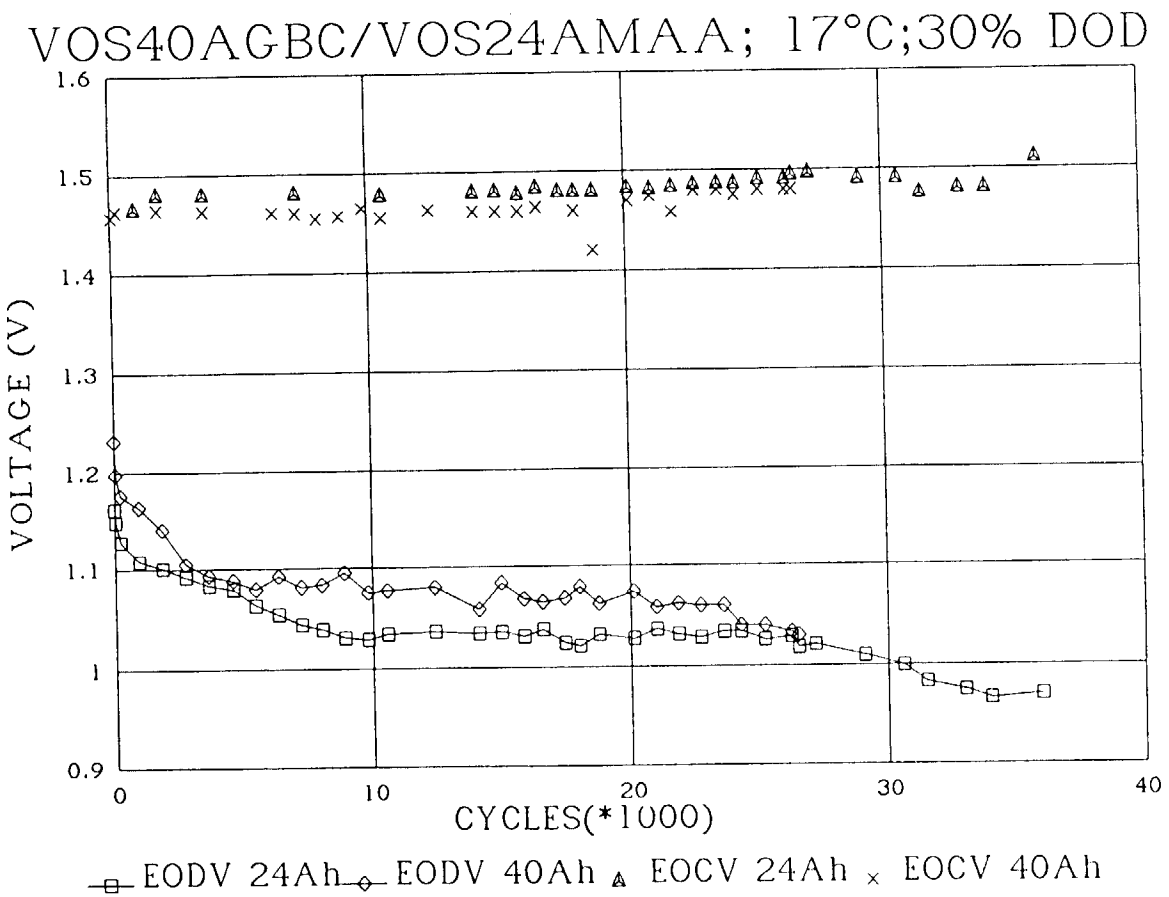
NiCd Cells | ELAN Program | Low Earth Orbit Cycling



Comparison

VOS40AGBC/VOS24AMAA

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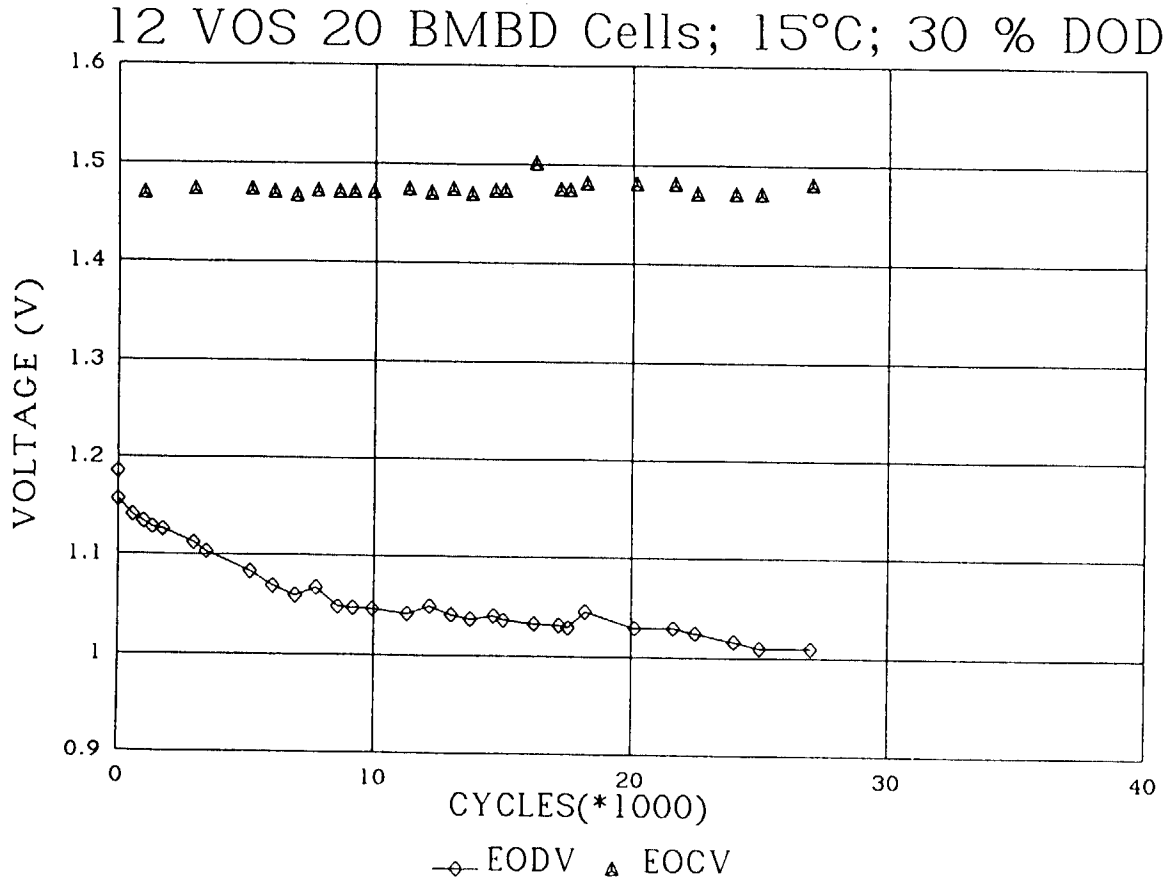
NiCd Cells | ELAN Program | Low Earth Orbit Cycling



TEST N°71

DISCHARGE:
25 MN AT 5.8A
10 MN AT 22A

CHARGE:
65 MN AT 10A MAX
CURRENT TAPERING

AS PER SEPTEMBER
1992

NO CELL REMOVED
CYCLING STILL RUNNING

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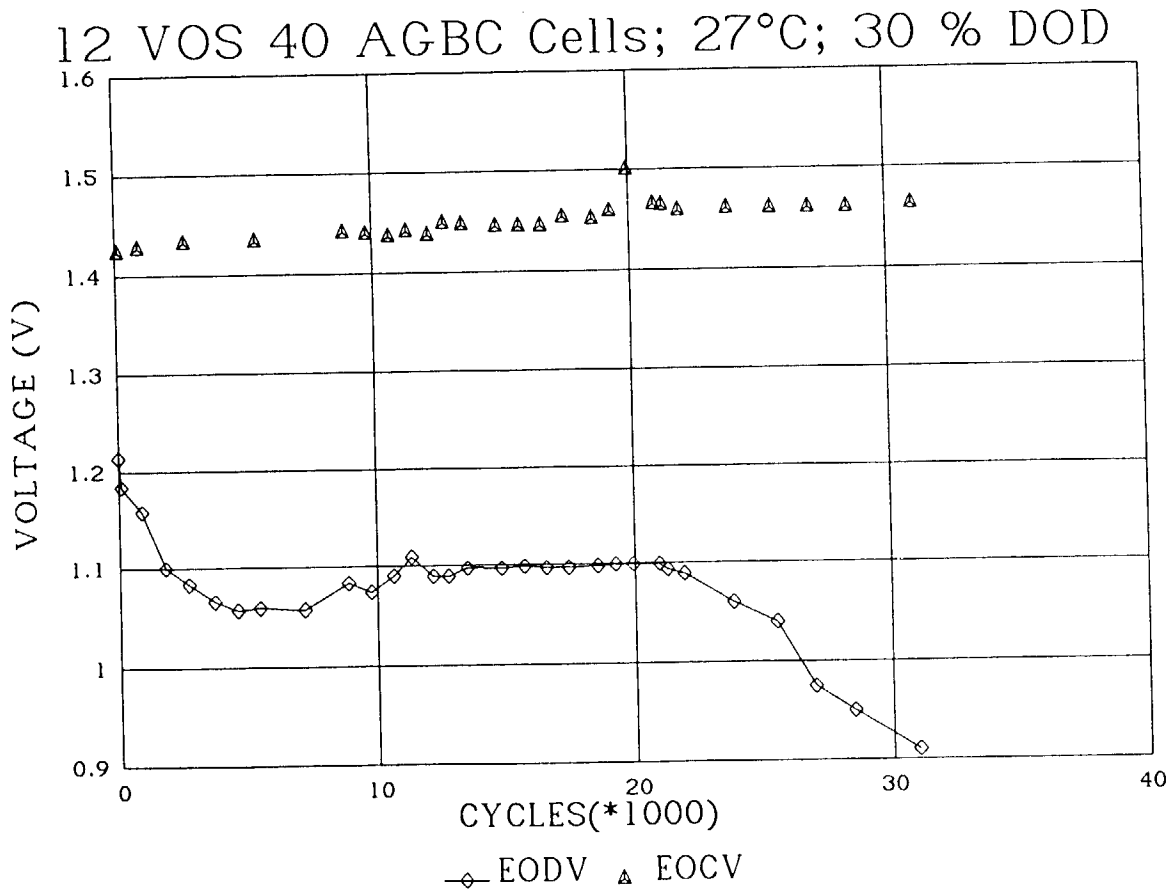
NiCd Cells | ELAN Program | Low Earth Orbit Cycling



TEST N°67

DISCHARGE:
25 MN AT 20A
10 MN AT 25A

CHARGE:
65 MN AT 20A MAX
CURRENT TAPERING

AS PER SEPTEMBER 1992

3 CELLS REMOVED (CYCLE N°30391, 30394, 30662)

CYCLING STILL RUNNING

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NiCd Cells

ELAN Program

Low Earth Orbit Cycling

TEST N°65

Discharge:
25 mn at 7A
10 mn at 40A

Charge:
65 mn at 16A max
current tapering

As per September 1992

5 cells removed
(cycle n° 27039, 29194
31984, 33104, 37098)

Cycling still running

C-6

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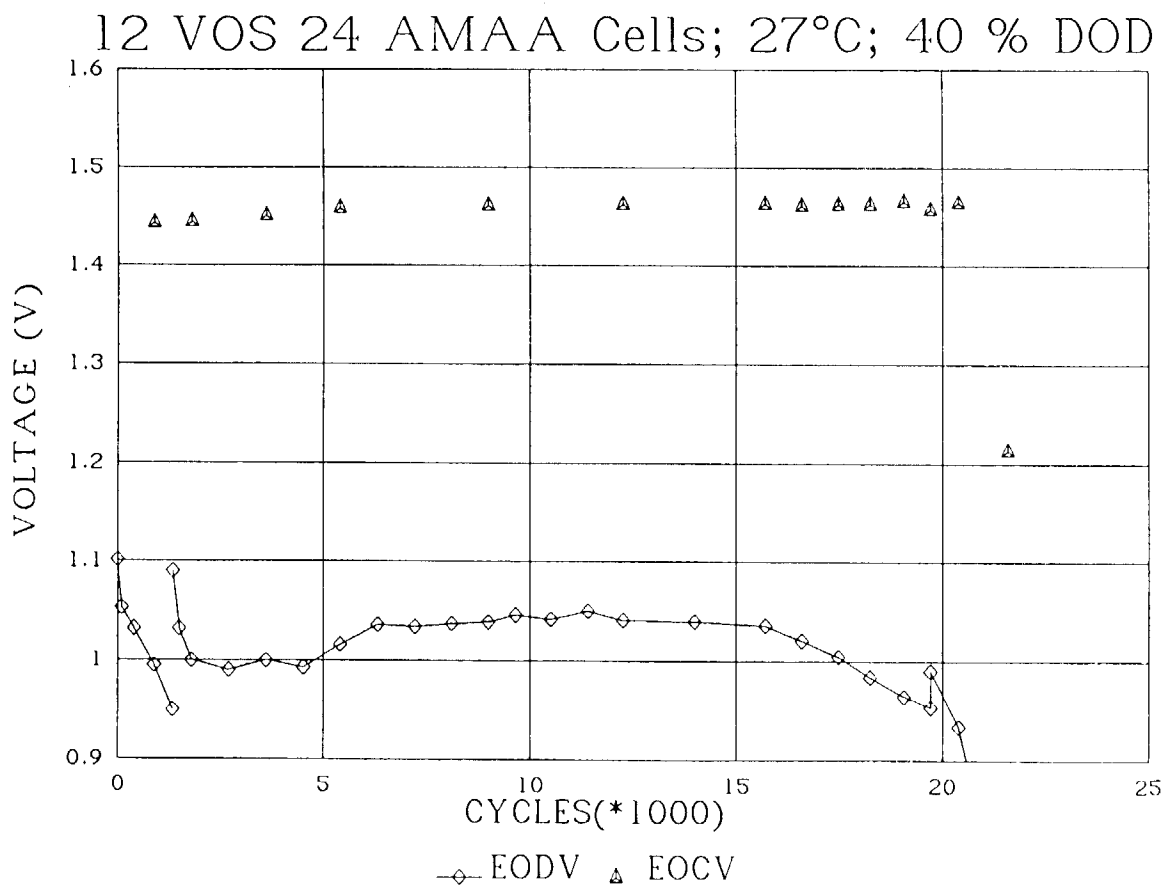
NiCd Cells | ELAN Program | Low Earth Orbit Cycling



TEST N°66

DISCHARGE:
25 MN AT 15A
10 MN AT 20A

CHARGE:
65 MN AT 16A MAX
CURRENT TAPERING

AS PER SEPTEMBER 1992

8 CELLS REMOVED
CYCLING STOPPED

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CHARACTERISTICS OF CELLS COMPONENTS AFTER CYCLING :

ELAN PROGRAM : LOW EARTH ORBIT CYCLING

		VOS 24 AMAA					
		BOL	DOD 40%				
Temperature		–	8 °C		27 °C		
Identification		–	110.179	108.031	109.119	109.123	108.060
Cycles number		0	29194	27039	20169	21604	21424
Capacity Ah		30.5	22.7	27.36	16.32	17.12	10
Internal resistance mohms		3.5	5.2	6.2	5.5	4.2	8.9
H2 %		0			85.6		93.2
Separator aspect		–		dry	dry	dry	dry
Thickness 10^{-2} mm	electr.+	76		88.5(16.4%)	99(30%)	103.5(36%)	100(31.6%)
(swelling %)	electr.–	89		87.5(0%)	103(16%)	104.5(18.5%)	107.5(20.7%)
DIE mm		.26		.21	.0	.0	.0
KOH g/dm2		1		.4	.12	.09	.07

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MAIN DRIVING PARAMETERS OF CELL DEGRADATION :

(FAILURE CRITERIA EOD VOLTAGE < .8 V)

- Positive electrodes swelling -> 35%
- Inter electrode spacing reduced to zero.
- Separator drying -> High internal resistance -> Low voltage.
- Cd° quantity increasing -> overcharge protection reduction.
  -> H_2 production.

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NI-CD CELLS	NSWC PROGRAM		LOW EARTH ORBIT CYCLING	
	NASA/GSFC		AIR FORCE	
	VOS 20 B	VOS 24 A	VOS 24 A	VOS 24	VOS 40
TEST NUMBER	93	94	95	107	108
BATTERY NUMBER	6120S	6024S	6124S	6324S	6340S
DOD (%)	39	39	39	40	40
TEMPERATURE (°C)	20	0	20	20	20
DISCHARGE (A)	16	19.2	19.2	17.2	28.6
CHARGE (A)	16	19.2	19.2	12	20
VOLTAGE LIMIT (V)	1.463	4.489	1.452	1.484	1.494
RECHARGE RATIO	1.056	1.019	1.030	1.07	1.06
CYCLES	18400	18400	18300	14821	12416
END OF DISCHARGE VOLTAGE (V)	1.036	1.12	1.049	1.08	1.115
				DISCONTINUED	DISCONTINUED

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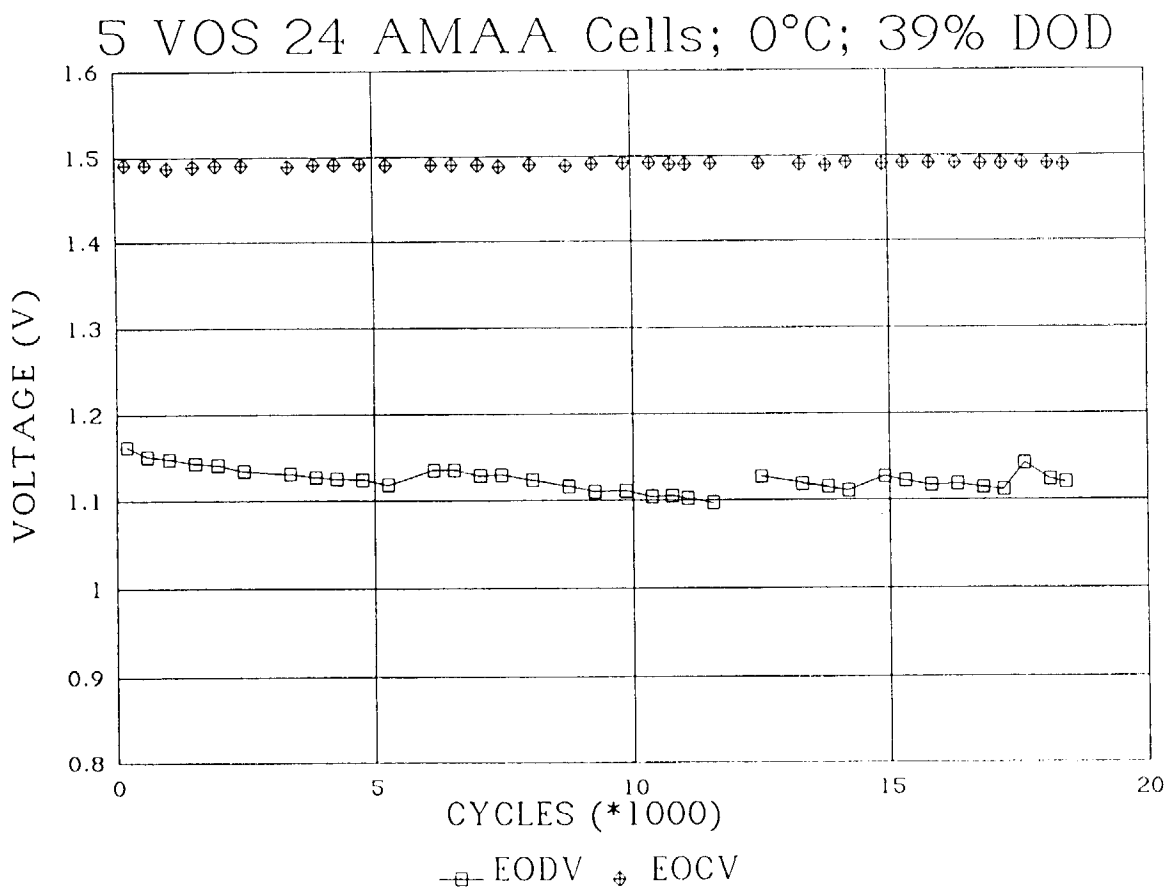
NiCd Cells	NASA/GSFC Pack 6024S	Low Earth Orbit Cycling



TEST N°94

DISCHARGE:
29MN AT 19A

CHARGE:
60 MN AT 19A MAX
CURRENT TAPERING

AS PER SEPTEMBER
1992

NO CELL REMOVED
CYCLING STILL
RUNNING

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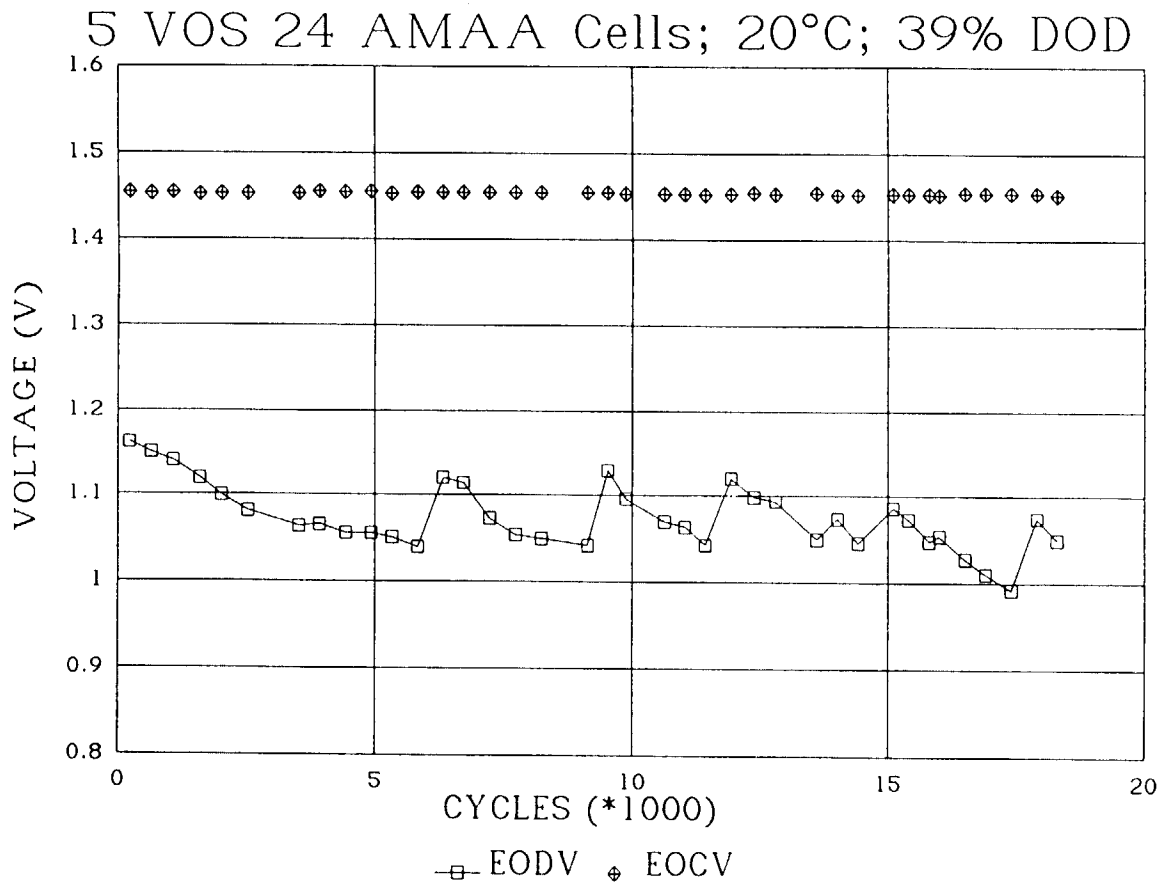
NiCd Cells	NASA/GSFC Pack 6124S	Low Earth Orbit Cycling



TEST N°95

DISCHARGE:
29MN AT 19A

CHARGE:
60 MN AT 19A MAX
CURRENT TAPERING

AS PER SEPTEMBER
1992

NO CELL REMOVED
CYCLING STILL
RUNNING

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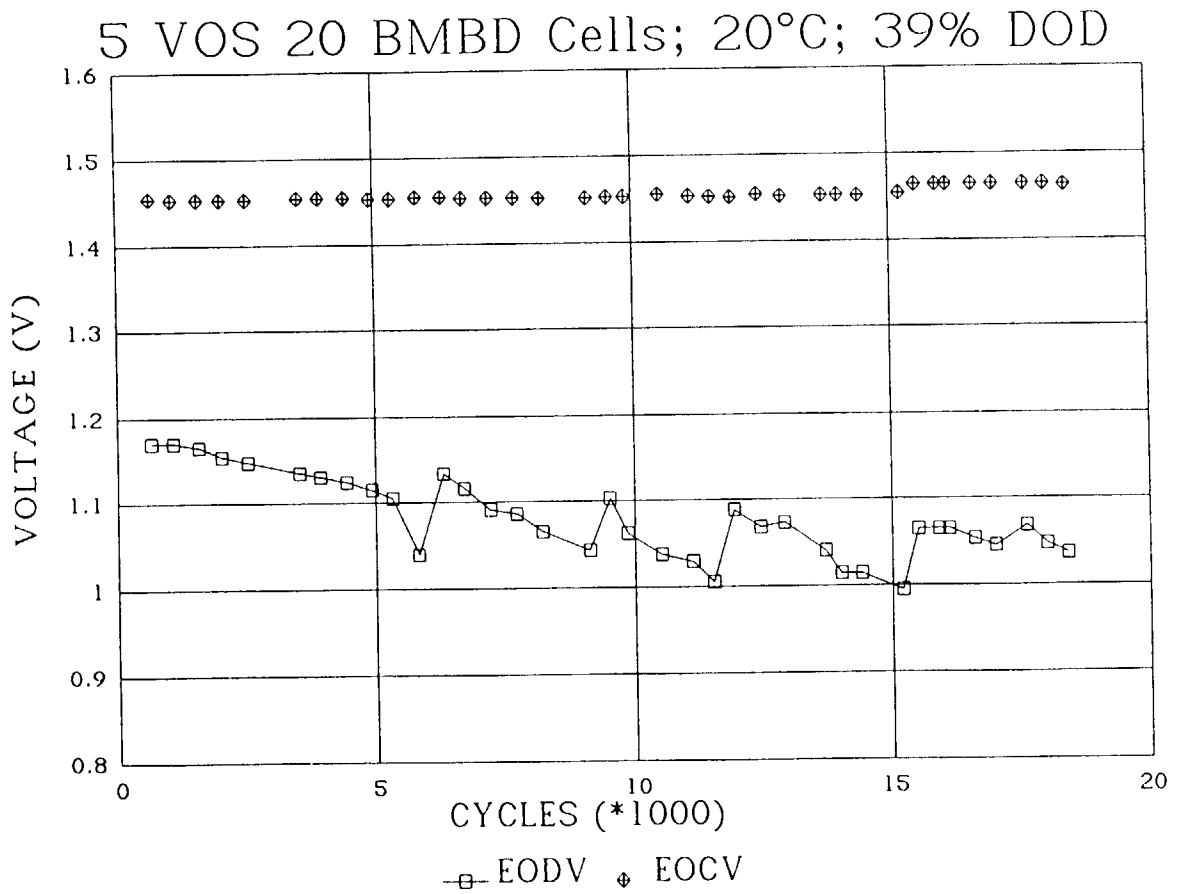
NiCd Cells	NASA/GSFC Pack 6120S	Low Earth Orbit Cycling



TEST N°93

DISCHARGE:
29MN AT 16A

CHARGE:
60 MN AT 16A MAX
CURRENT TAPERING

AS PER SEPTEMBER
1992

NO CELL REMOVED
CYCLING STILL
RUNNING

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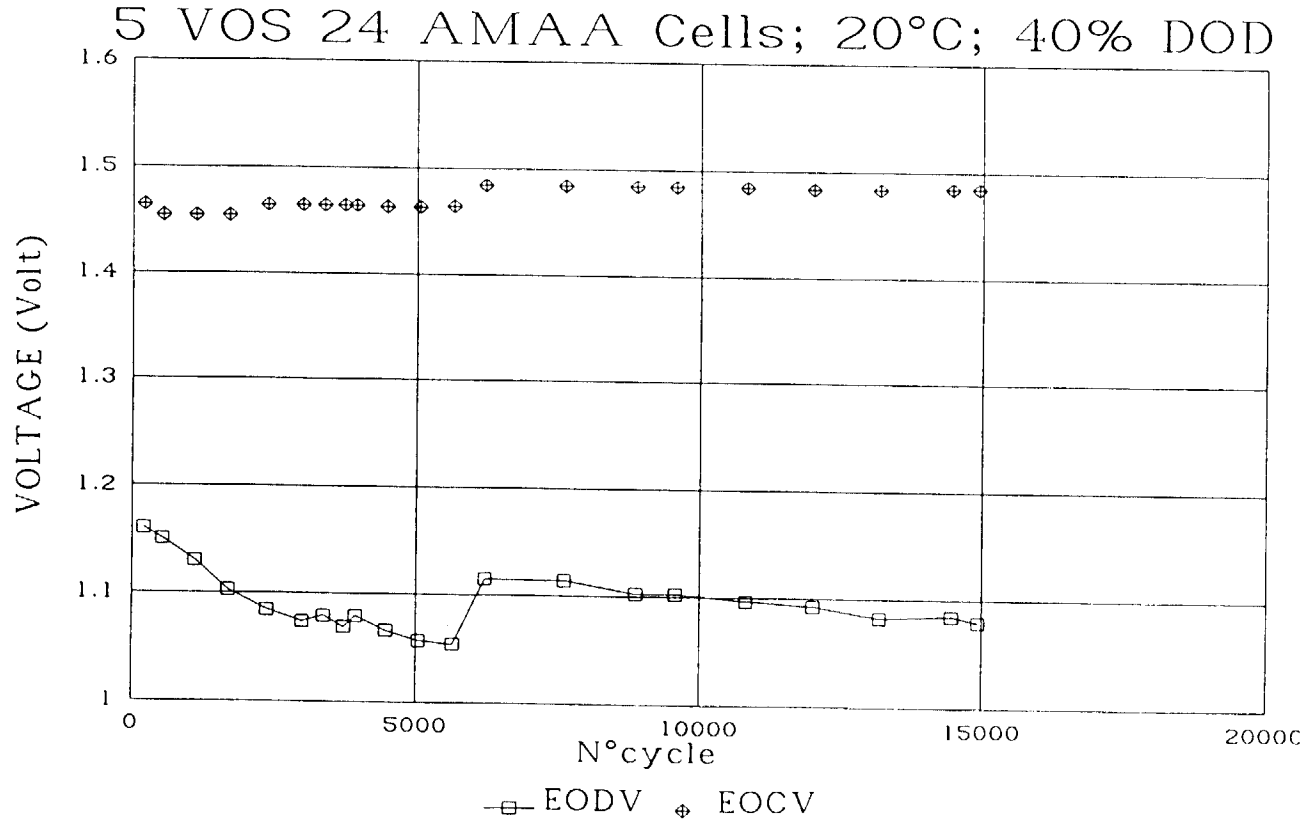
NiCd Cells

AIR FORCE
Pack 6324S

Low Earth orbit
Cycling



TEST N°107

DISCHARGE:
34 MN AT 17.2 A

CHARGE:
66 MN AT 12 A MAX
CURRENT TAPERING

TEST DISCONTINUED

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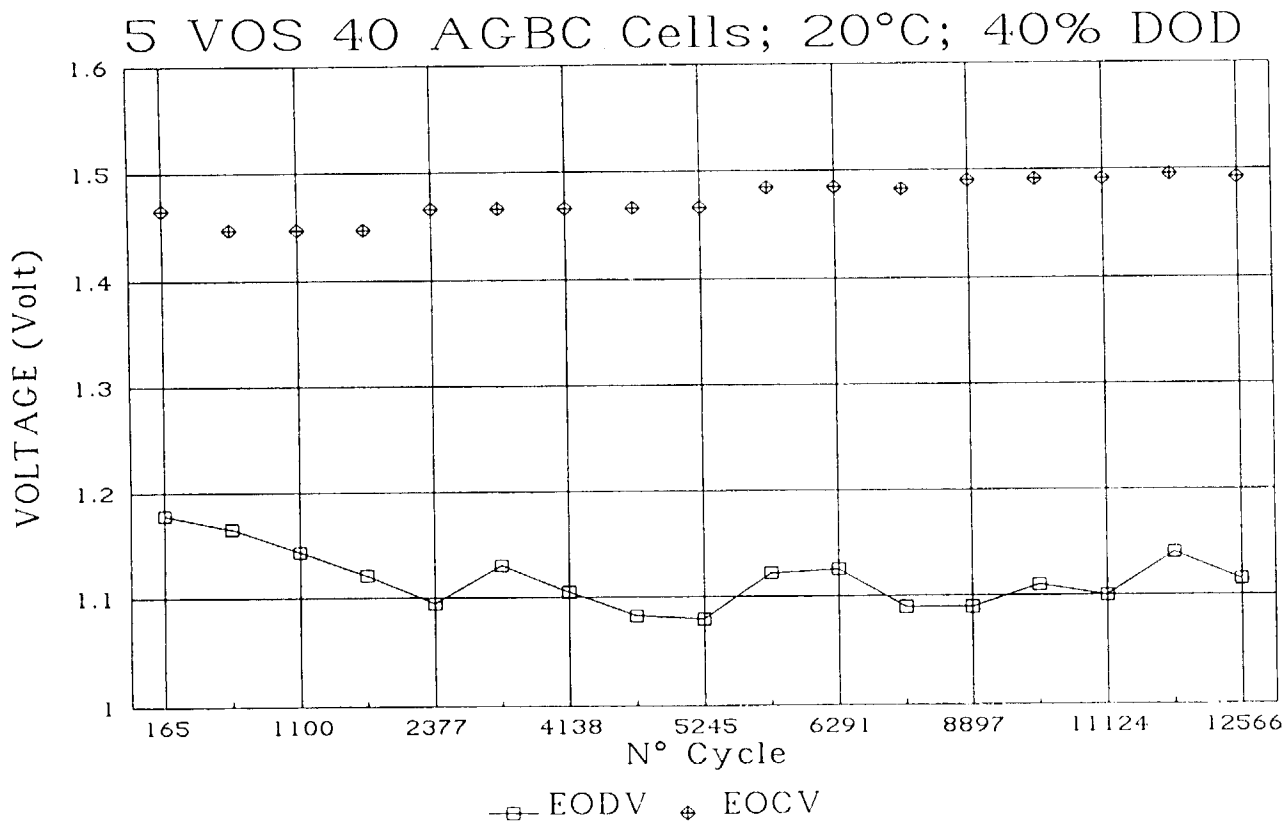
NICD	AIR FORCE PACK 6340	LOW EARTH ORBIT CYCLING



TEST N°108

DISCHARGE:
34 MN AT 28.6 A

CHARGE:
66 MN AT 20 A MAX
CURRENT TAPERING

TEST DISCONTINUED

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NiCd CELLS	GEOSTATIONARY ORBIT CYCLING				
	ESA			AIR FORCE	
	VOS 18	VOS 18	VOS 18	VOS 24	VOS 40
TEST NUMBER	43	45	44	109	110
BATTERY NUMBER	ECS-70	ECS-90	ECS-100	6224S	6240S
DOD MAX (%)	70	90	100	80	80
TEMPERATURE (°C)	10°	10°	10°	20°	20°
DISCHARGE (A)				16	26.7
CHARGE (A)				2.4 MAX	4 MAX
VOLTAGE LIMIT (V)	1.52	1.492	1.494	1.41	1.41
RECHARGE RATIO	1.05	1.05	1.05	1.6	1.55
SHADOW NUMBERS	31	31	31	19	19
END OF DISCHARGE VOLTAGE (V)	1.162	1.11	1.084	1.11	1.02

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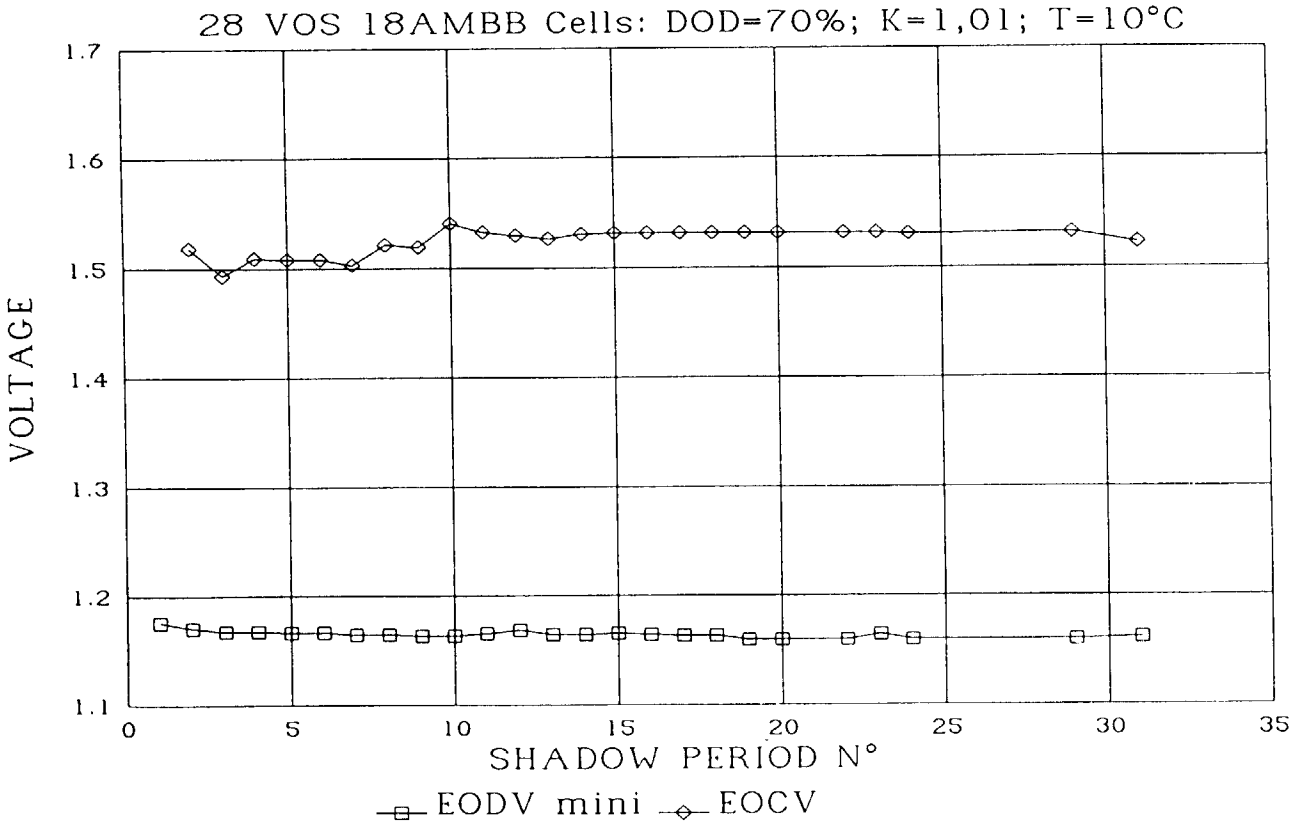
NiCd Cells | ECS SIMULATION | Geostationary Orbit Cycling



TEST N°43

21 DAYS SHORTEN SOLSTICES WITH TRICKLE CHARGE

APPROXIMATED DOD PROFILE

AS PER SEPTEMBER 1992

NO CELL REMOVED CYCLING STILL RUNNING

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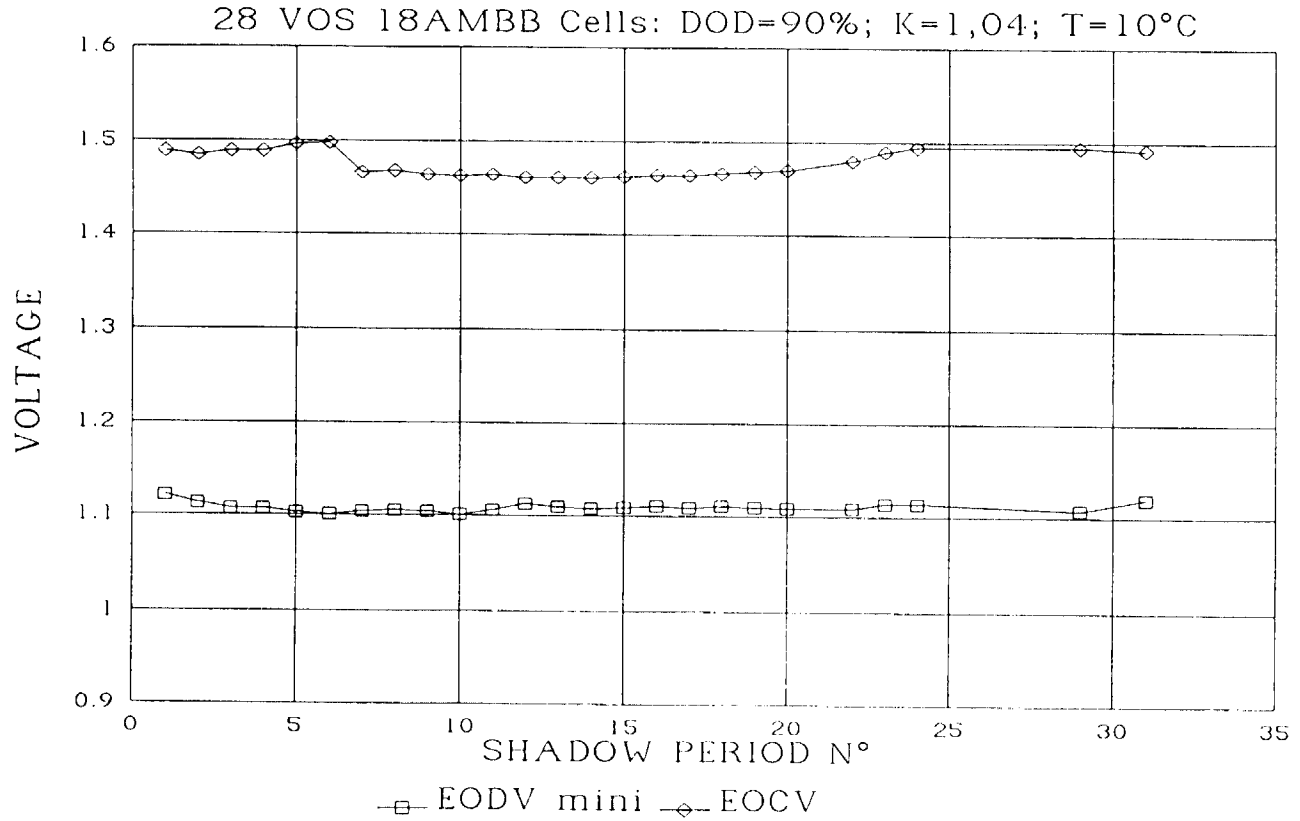
NiCd Cells | ECS SIMULATION | Geostationary Orbit Cycling



TEST N°45

21 DAYS SHORTEN SOLSTICES WITH TRICKLE CHARGE

APPROXIMATED DOD PROFILE

AS PER SEPTEMBER 1992

NO CELL REMOVED CYCLING STILL RUNNING

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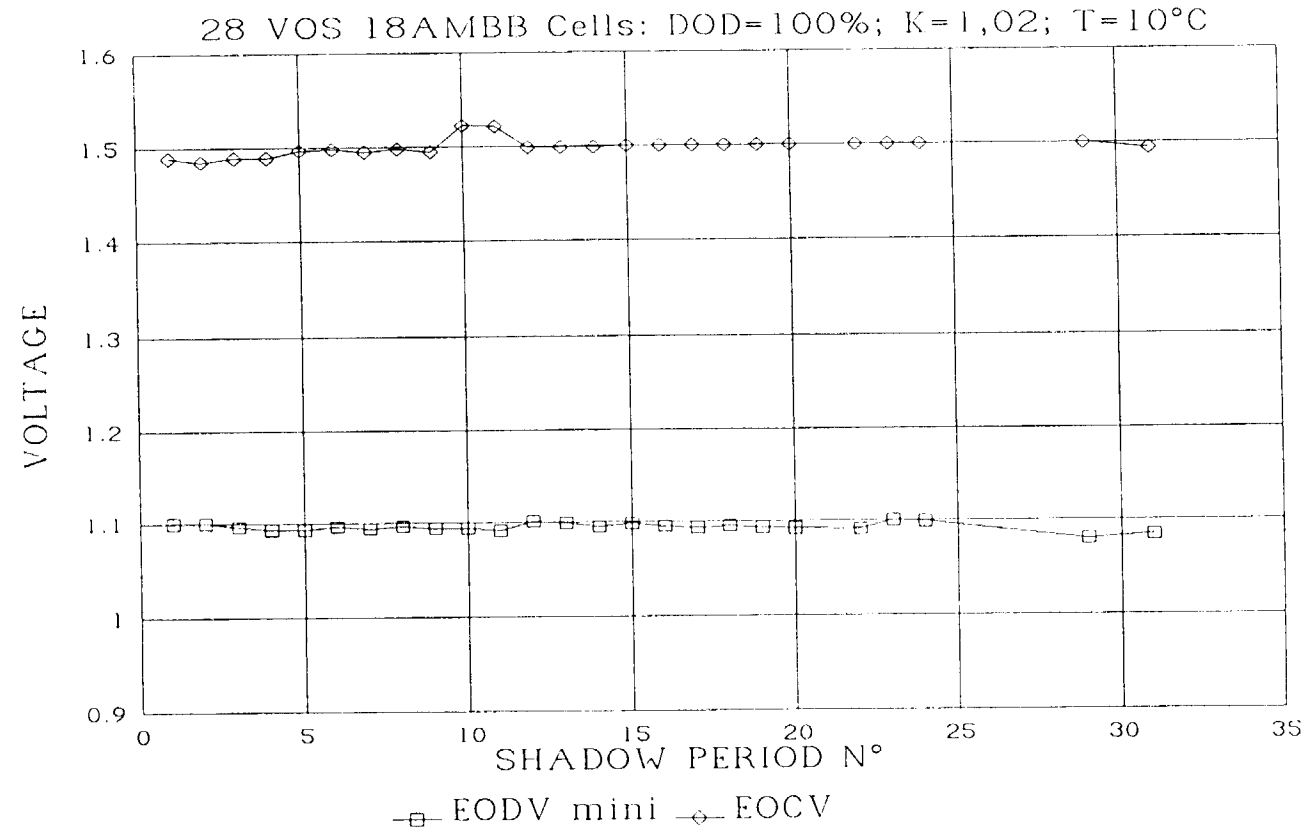
NiCd Cells | ECS SIMULATION | Geostationary Orbit Cycling



TEST N°44

21 DAYS SHORTEN SOLSTICES WITH TRICKLE CHARGE

APPROXIMATED DOD PROFILE

AS PER SEPTEMBER 1992

NO CELL REMOVED CYCLING STILL RUNNING

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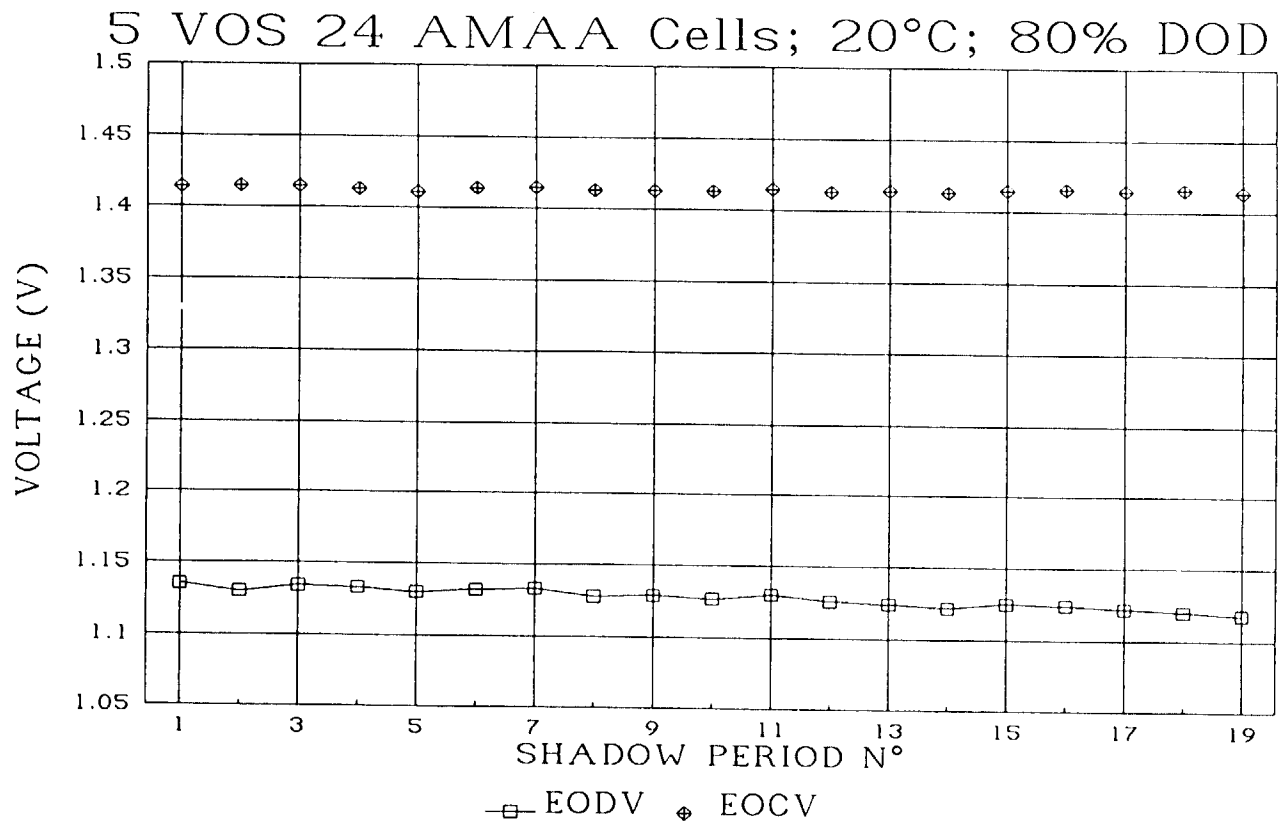
NiCd Cells	AIR FORCE Pack 6224S	Geostationary Orbit Cycling



TEST N°109

Real DOD profile

2 weeks shorten solstices with trickle charge

Discharge: 16 A

Charge:
2.4 A max
current tappering

As per September 1992

No cell removed
Cycling still running

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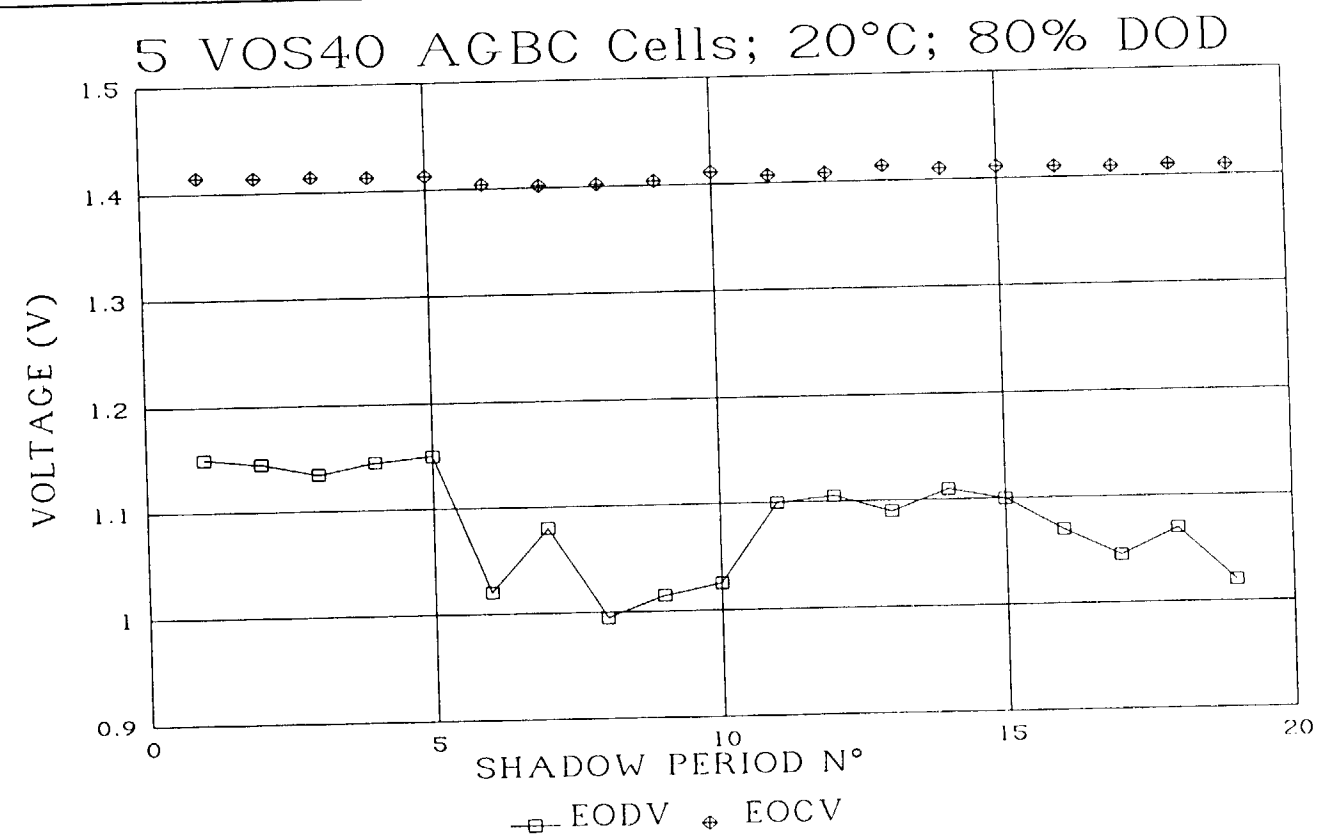
NiCd Cells

AIR FORCE PACK 6240S

Geostationary Orbit Cycling



TEST N°110

Real DOD profile

2 weeks shorten solsticies with trickle charge

Discharge: 27 A

Charge: 4 A max current tapering

As per September 1992

No cell removed Cycling still running

NICD CELL LIFE TIME
OCTOBER 1992
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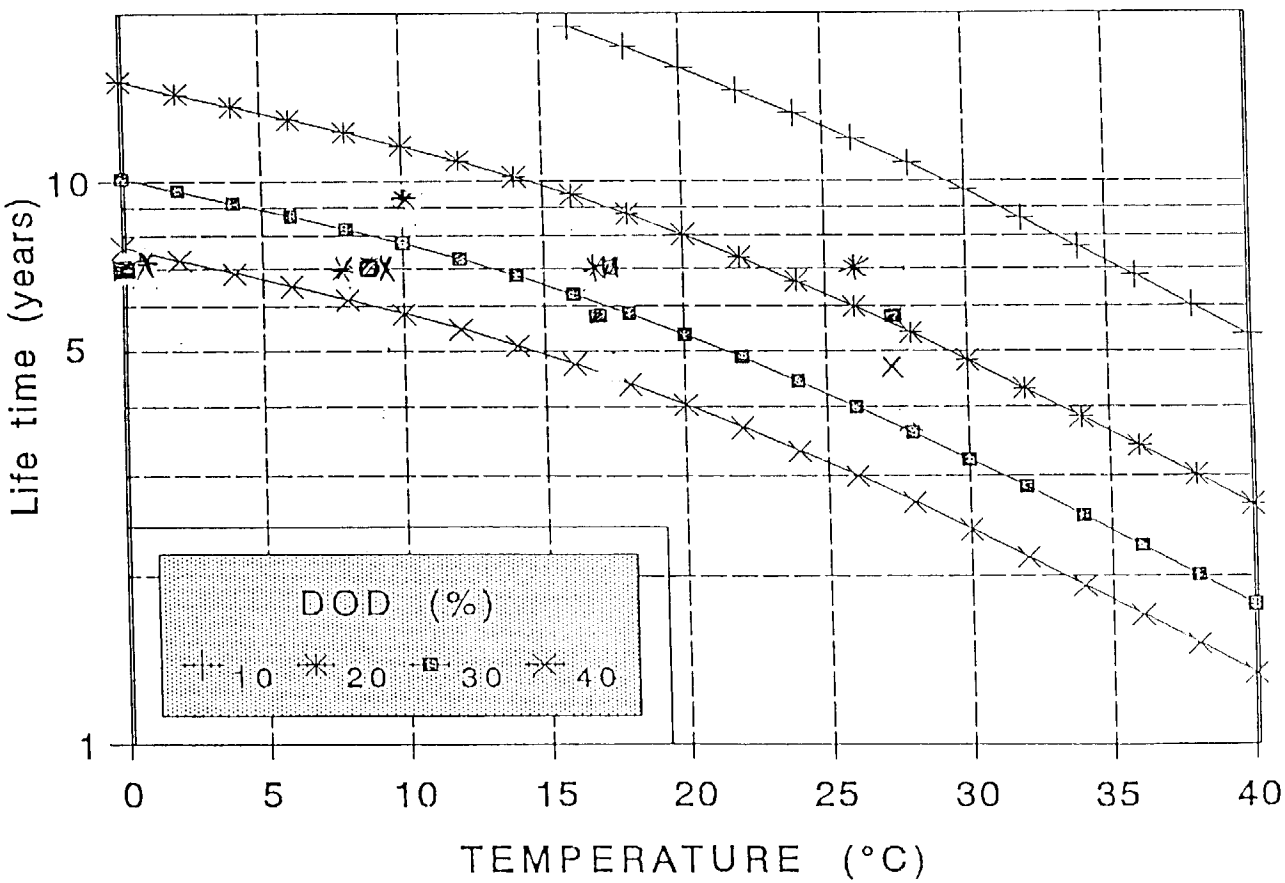
CALCULATED LIFE TIME FOR GEO APPLICATIONS :
Life time (year)
Temperature (C)
DOD
90%
70%
50%
30%
0
5
10
15
20
25
30
35
40

SAFT

NICD CELL LIFE TIME

OCTOBER 1992

CALCULATED LIFE TIME FOR LEO APPLICATIONS :



SAFT SPACE DEPARTMENT

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Nickel-Hydrogen Technologies Session