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SAFT
ADVANCED BATTERIES

SAFT NICKEL HYDROGEN CELL CYCLING STATUS

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SAFT ADVANCED BATTERIES
POITIERS FRANCE

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SAFT
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1– SAFT NIH2 CELL DEVELOPMENT

1972–1984

Development of NiH2 at SAFT (mass advantage over NiCd) : HRN cell design.

1985–1988

Common CNES–ESA–SAFT–AEROSPATIALE development of VHS BL cell.
Study on reproducibility of electrochemical impregnation and mechanical design.

1989

Qualification of the VHS50BL
Common CNES–ESA–SAFT–AEROSPATIALE development of VHS CM cell : GEO applications.
Focus on pressure vessel fracture mechanical analysis.

1990

Beginning of the battery 27 VHS CM development

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1– SAFT NIH2 CELL DEVELOPMENT (Cont'd)

1992

VHS CM range 35–107 Ah : ESA qualified for GEO applications
VHS BL cells reach 33 simulated GEO eclipse seasons
Battery 23 VHS 60 CM selected for ARTEMIS program
Commmon ESA–CNES–SAFT development of VHS DM (LEO applications) for COLOMBUS/MTFF program

1993

Qualification of the VHS CM battery
Battery 27 VHS 50 CM selected for ARABSAT II program
HRN 42 cells reach 6.5 years simulated LEO operation

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SAFT NICKEL HYDROGEN CELL CYCLING STATUS

2– CELLS DESIGN

The NiH2 SAFT system is an electrochemical (single or dual) stack (IPV). The stack is mounted in an hydroformed inconel 718 vessel operating at high pressure (up to 75 bars, 1090 psi with a safety factor of 2.5), equipped with "rabit ears" ceramic brazed electrical feedthroughs.

Two container diameters used :

- 81 mm (3.2") for HRN and VHS BL designs
- 89 mm (3.5") for VHS CM and VHS DM designs

ENERGY DENSITY (Wh/Kg):

- BETWEEN 50 TO 60 Wh/Kg FOR THE VHS CM CELL (GEO DESIGN)
- BETWEEN 45 TO 55 Wh/Kg FOR THE VHS DM CELL (LEO DESIGN)

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SAFT NICKEL HYDROGEN CELL CYCLING STATUS

2– CELLS DESIGN (Cont'd)

2–1 POSITIVE ELECTRODE

– *Sintered material on steel perforated grid*
– *Active material deposited by electrochemical process*

	HRN	VHS BL/DM	VHS CM
Sinter manufacturing	Wet slurry	Wet slurry	Wet slurry
Sintered material thickness (mm)	0.82	0.82	0.87
Perforated grid thickness (mm)	0.10	0.10	0.08
Total sinter material thickness (mm)	0.92	0.92	0.95
Porosity (%)	86	86	86
Impregnation	ECI	ECI	ECI
Loading (g/cm3 of void)	1.65	1.7	1.7
Average electrode thickness (mm)	0.98	1.00	1.06
Capacity Ah/electrode	1.00	1.22/1.52	1.79

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2– CELLS DESIGN (Cont'd)

2–2 NEGATIVE ELECTRODE

– *Active charcoal with platinum on expanded nickel collector*
– *Goretex hydrophobic layer with polypropylen grid*

	HRN	VHS BL/DM	VHS CM
Active material thickness (mm)	0.35	0.35/0.30	0.22
Electrode thickness (mm)	0.39	0.39/0.35	0.27
Pt concentration (%)	5	5	5
Binding material	PTFE	PTFE	PTFE
Expanded grid (collector)	1.45 /12/10	1.45 /12/10	2.5/12/10
Hydrophobic layer material	Teflon SAFT	Teflon SAFT/GORE	Teflon GORE
Support	None	None/Polypropylen grid	Polypropylen grid
Polarization (mV) at 70 mA/cm2	100	100/70	60

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SAFT NICKEL HYDROGEN CELL CYCLING STATUS

2– CELLS DESIGN (Cont'd)

2–3 STACK CONFIGURATION

- *Back to back configuration*
- *Positive expansion accomodation*
- *Central tie rod*
- *Optimised oxygen recirculating*

	HRN	VHS BL/DM	VHS CM
Number of electrodes	24 to 42	24 to 42/20 to 60	20 to 60
Stack assembly	Single/Single or dual	Single/Single or dual	Single or dual
Separator	Non Woven polyamid felt	Non Woven polyamid felt	Non Woven polyamid felt
Gaz screen	Woven nylon	Woven nylon	Woven nylon
Electrolyte	KOH 31%	KOH 31% or 26 %	KOH 31%
Stack expansion system	None	Belleville/Spring	Spring
Interelectrode spacing (mm)	0.26	0.26	0.26

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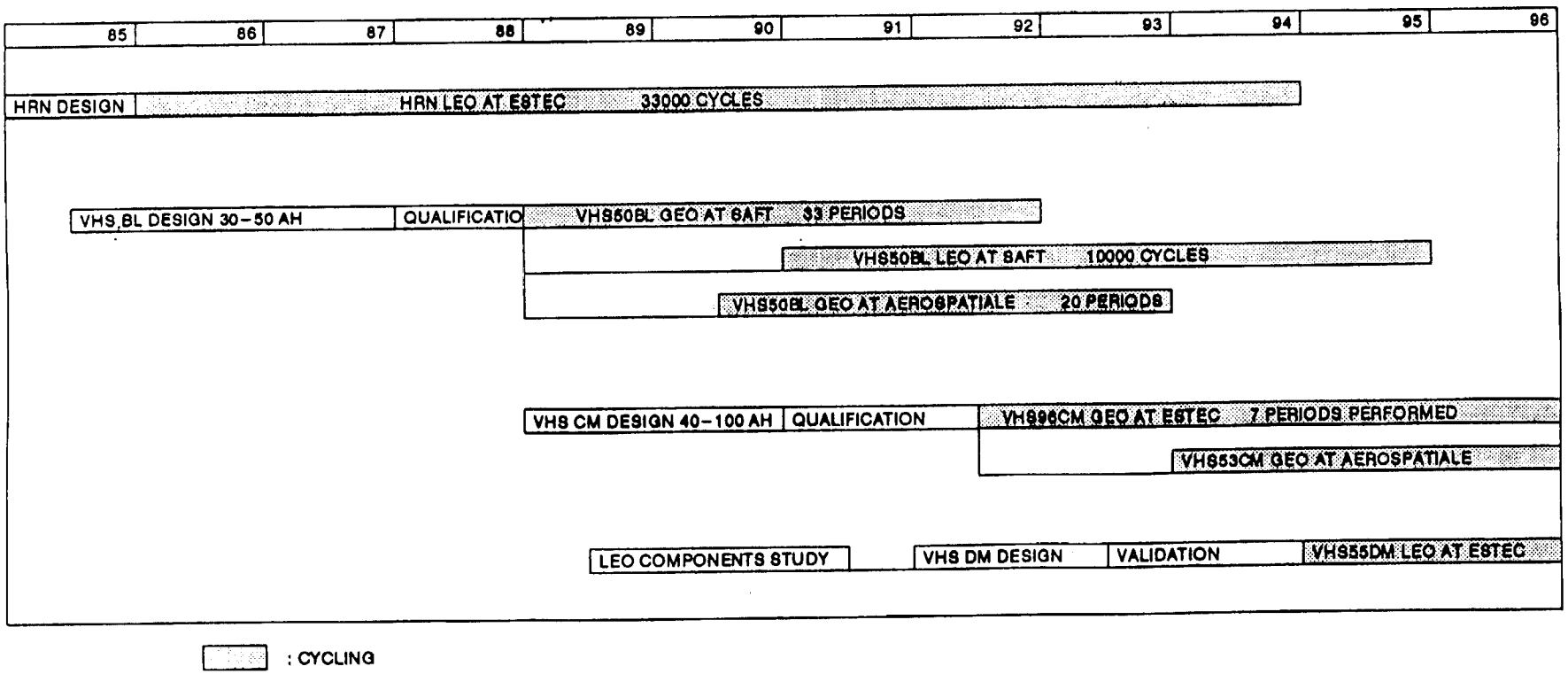
3– CYCLING STATUS



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SAFT NICKEL HYDROGEN CELL CYCLING STATUS

3–1 LEO CYCLING

3 LOW EARTH ORBIT CYCLING RUNNING :

– HRN42 CYCLING BEGUN IN 1985 : 33,000 CYCLES PERFORMED (T=10°C, DOD=40 %)
Test the suitability of HRN design (electrochemistry) for LEO missions
Compare taper versus cut–off charge management
Test in horizontal position

– VHS50BL CYCLING : 10,000 CYCLES PERFORMED (T=10°C, DOD= 40 %)
Compare cycle life of different cells (DBAG and SAFT) under Colombus/MTFF conditions
Compare 26 % versus 31 % KOH
Investigate reduction of charge power at EOC
Test in horizontal position

– VHS50BL CYCLING : 10,000 CYCLES PERFORMED (T=10°C, DOD= 40 %)
Verify the cycle life VHS BL versus HRN
Test in vertical position, in sleeves

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SAFT NICKEL HYDROGEN CELL CYCLING STATUS

3–1 LEO CYCLING (Cont'd)

	ESA					CNES
CELL TYPE	HRN 42 S2	HRN 42 S2	VHS 50 BL	VHS 50 BL	VHS 50 BL	VHS 50 BL
SAFT TEST REFERENCE	504	503	511	512	513	509
BATTERY REFERENCE	35	33	1	2	5	
DOD (%)	40*	40*	31	40	40	40
TEMPERATURE (°C)	10	10	10	10	10	10
DISCHARGE (A)	26.88	26.88	cst power	34.29	34.29	34.29
CHARGE (A)	17.35	21	cst power	22.69	22.69	30
VOLTAGE LIMIT (V)	1.67	1.54	1.54	1.585	1.59	1.56
RECHARGE RATIO	1.04	1.04	1.04	1.04	1.04	1.04
CYCLES	33954	35264	11800	11800	11800	10000
END OF DISCHARGE VOLTAGE (V)	1.04	1.19	1.167	1.2	1.16	1.05
* BASED ON 42 Ah	1 CELL REMOVED FOR DPA After 15694 Cycles	1 FAILED CELL After 31629 Cycles		26% KOH 1 CELL REMOVED at beginning of life after 5500 cycles		2 FAILED CELLS at beginning of life

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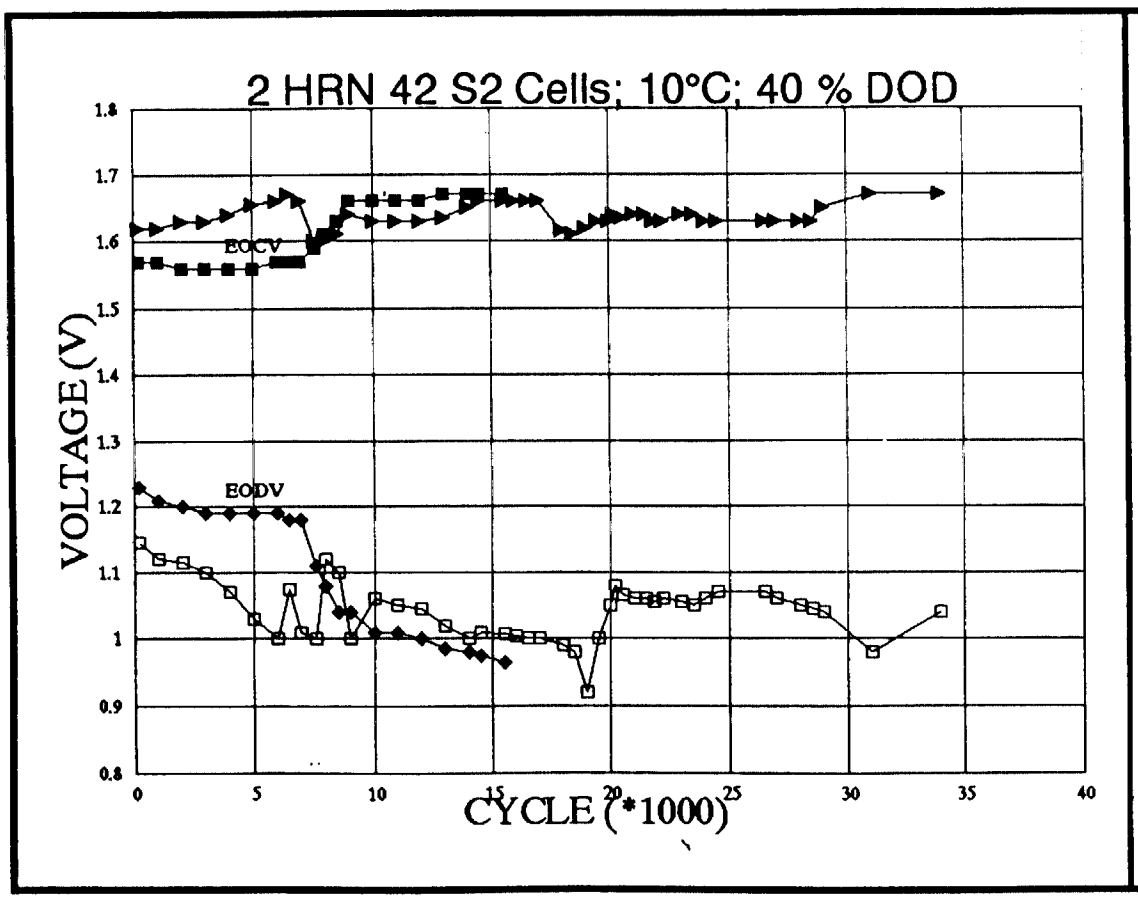
SAFT NICKEL HYDROGEN CELL CYCLING STATUS

3–1 LEO CYCLING (Cont'd)



SAFT TEST N°504

DISCHARGE:
37.5 mn
at 26.88 Amps

CHARGE:
60 mn at 17.35A
Non tapering

No reconditioning

As per june 93

1 cell removed
for DPA
(CYCLE 15694)
Cycling still
running

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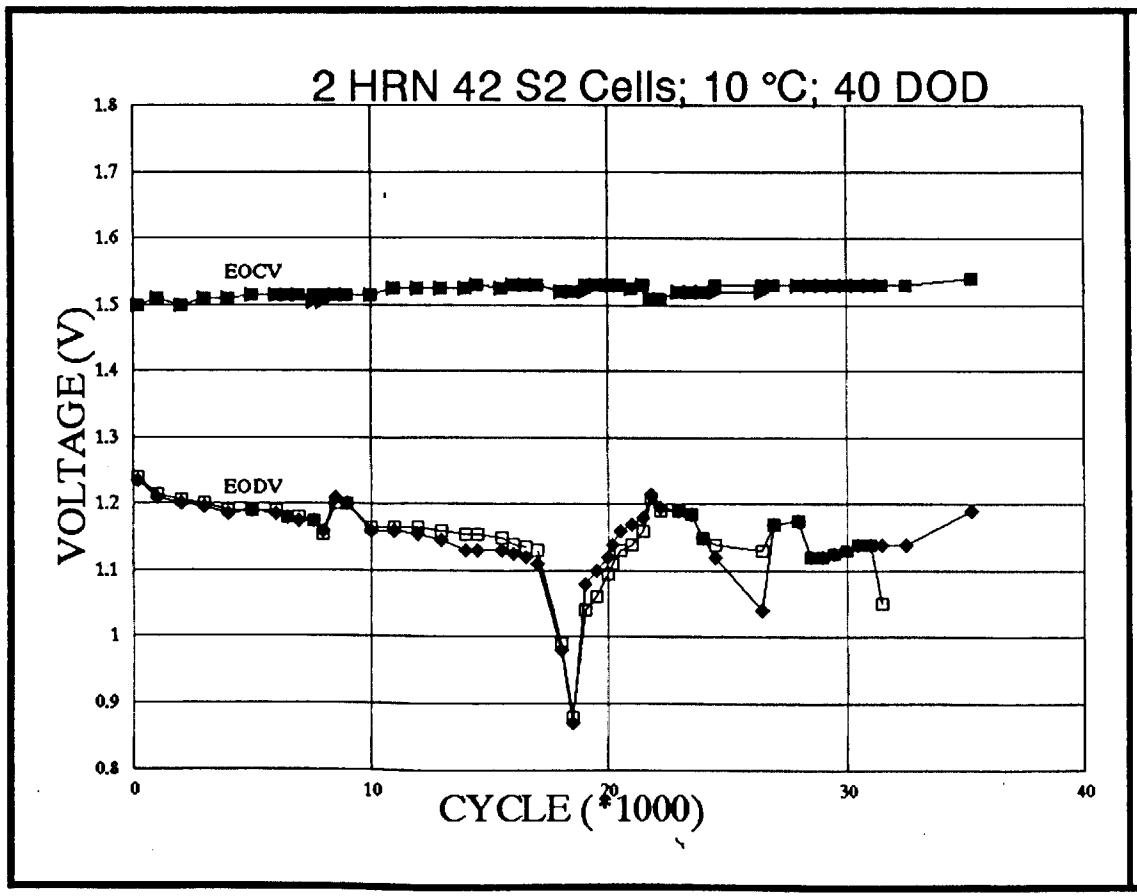
SAFT NICKEL HYDROGEN CELL CYCLING STATUS

3–1 LEO CYCLING (Cont'd)



SAFT TEST N°503

DISCHARGE:
37.5 mn
at 26.88 Amps

CHARGE:
21 A max
Voltage tapering

No reconditioning

As per june 93

1 failed cell removed (cycle 31629) Cycling still running

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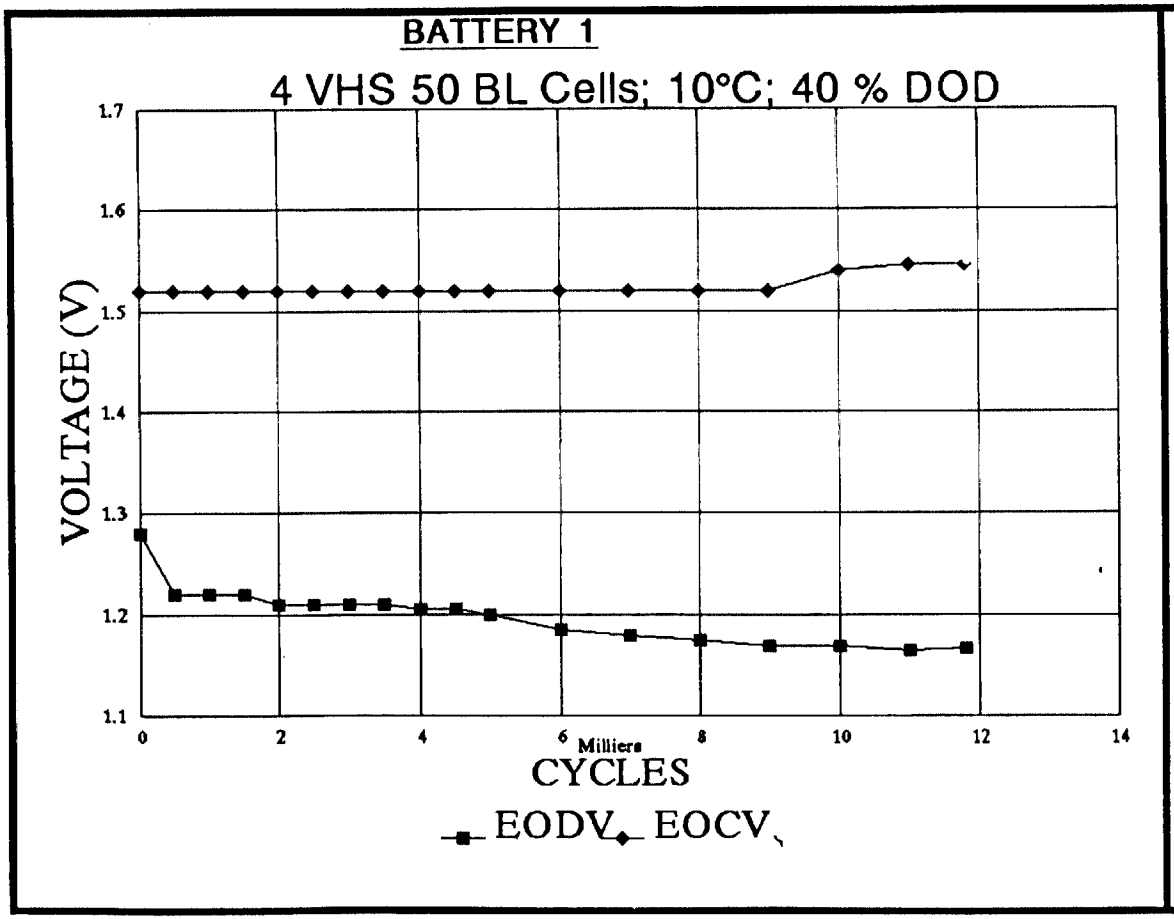
SAFT NICKEL HYDROGEN CELL CYCLING STATUS

3–1 LEO CYCLING (cont'd)



SAFT TEST N°511

COLUMBUS Program

Discharge:
58 mn at 130 W

Charge:
54 mn at 130 W
26 mn at 70 W

As per June 1993

No Cell removed
Cycling still running

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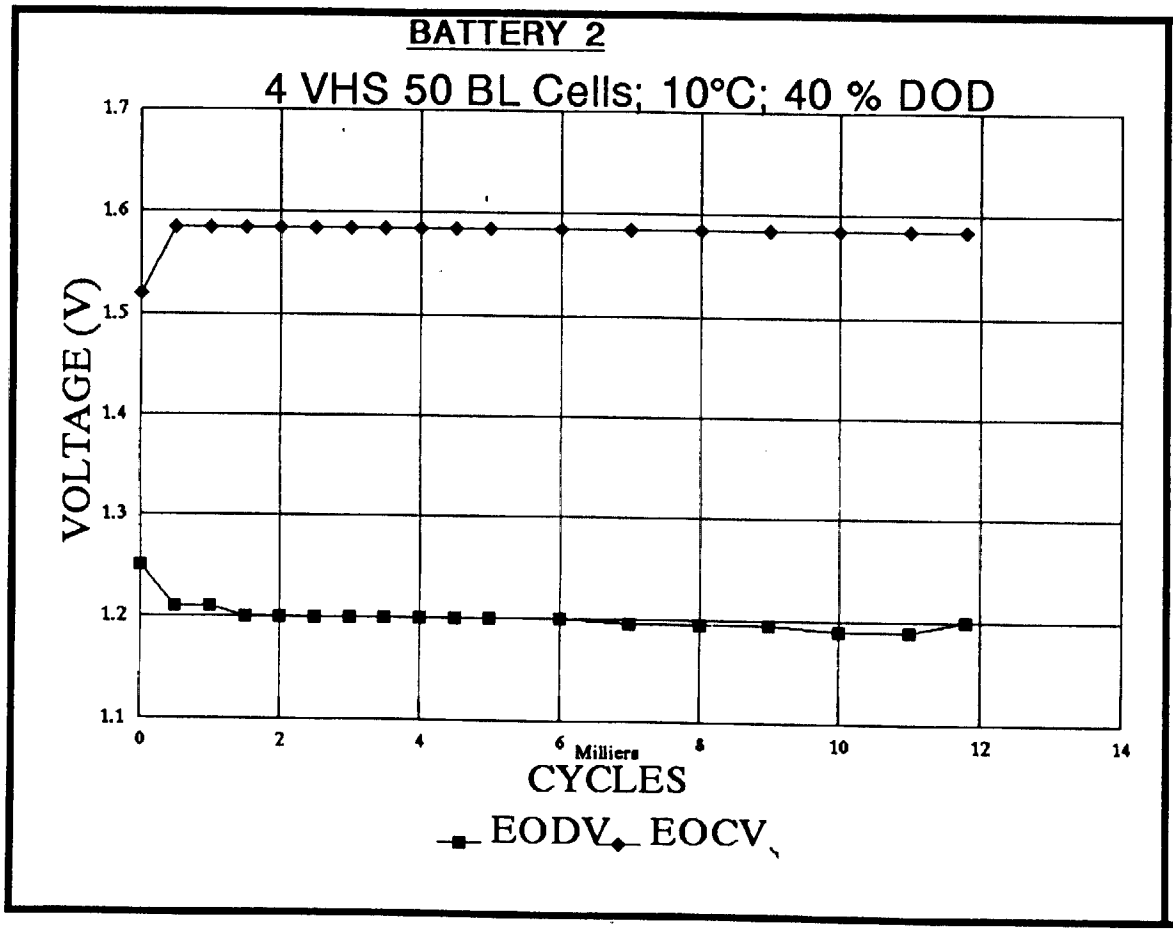
ADVANCED BATTERIES

SAFT NICKEL HYDROGEN CELL CYCLING STATUS

3-1 LEO CYCLING (cont'd)



SAFT TEST N°512

COLUMBUS Program

Discharge: 34.29 A

Charge: 22.69 A

As per June 1993

1 Cell removed at beginning of life

Cycling still running

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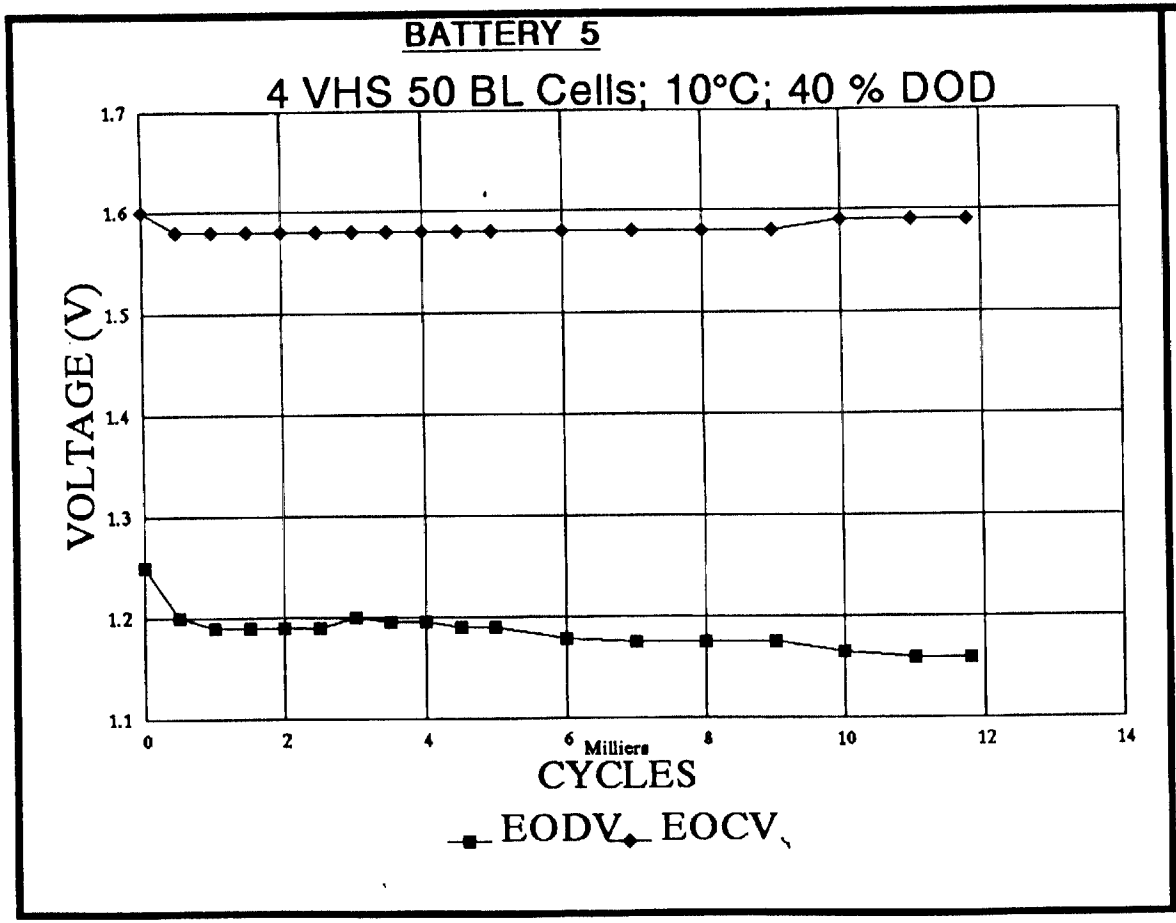
SAFT NICKEL HYDROGEN CELL CYCLING STATUS

3-1 LEO CYCLING (cont'd)



SAFT TEST N°513

COLUMBUS Program

Discharge: 34.29 A

Charge: 22.69 A

As per June 1993

No Cell removed

Cycling still running

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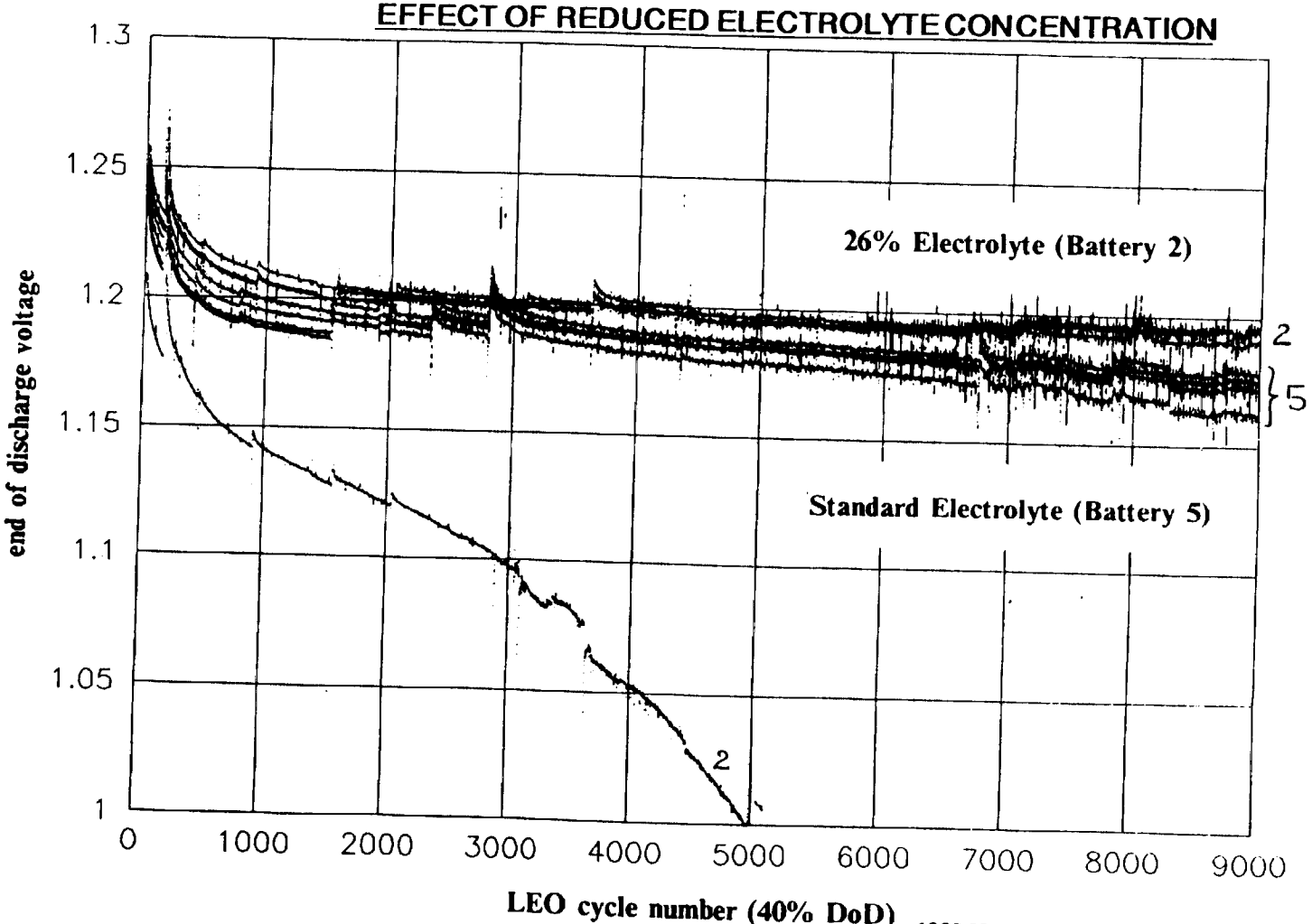
SAFT NICKEL HYDROGEN CELL CYCLING STATUS



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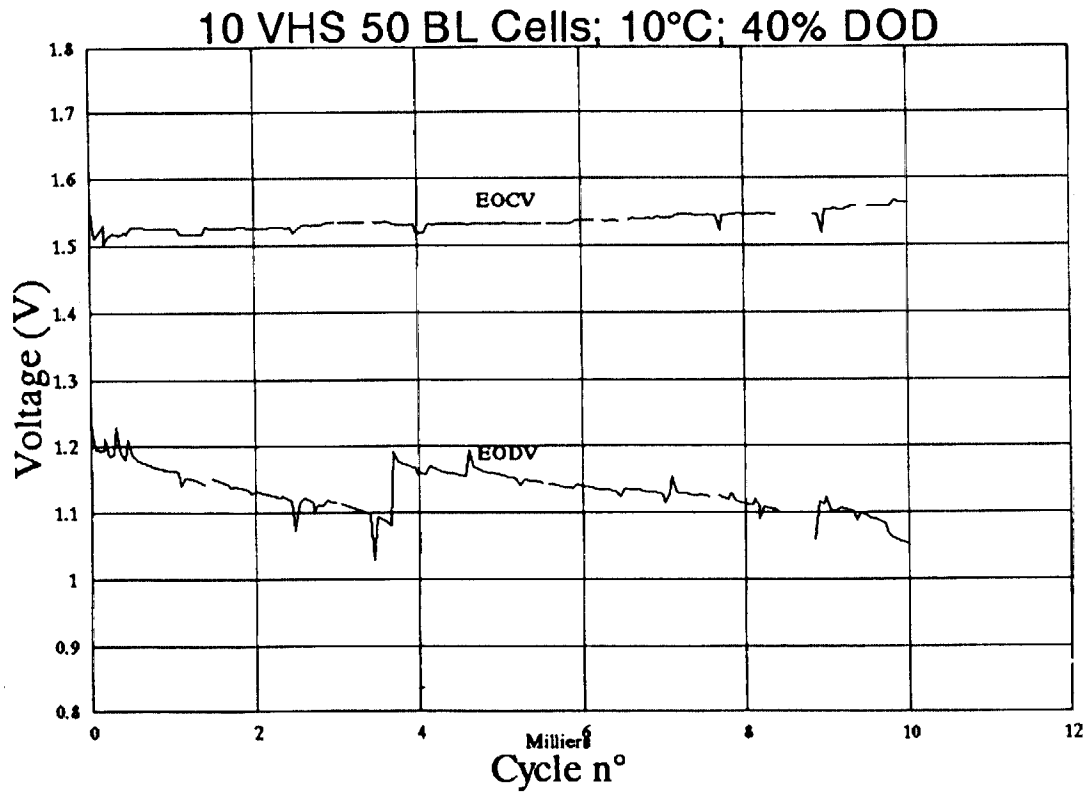
SAFT NICKEL HYDROGEN CELL CYCLING STATUS

3–1 LEO CYCLING (Cont'd)



SAFT TEST N°509

DISCHARGE:
35 mn at 34.3 A

Charge:
55 mn at 30 A
Voltage Tapering

As per April 1993

2 cells removed
(cycles 448, 3691)

Cycling still running

Test performed at SAFT

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SAFT NICKEL HYDROGEN CELL CYCLING STATUS

3-2 GEO CYCLING

3 GEOSTATIONNARY EARTH ORBIT CYCLING :

- VHS50BL CYCLING : 33 PERIODS DEMONSTRATED
  Test the suitability of VHS BL for GEO applications
  Test completed
  Accelerated shadow period

- VHS50BL CYCLING : 20 PERIODS PERFORMED
  Demonstrate the GEO life cycle with a constant DOD profile (70 %)
  Reconditionning after each season

- VHS96CM CYCLING : 7 PERIODS PERFORMED
  Compare GEO cycle life of VHS BL and VHS CM
  Test in semi accelerated conditions at 80 %
  Reconditionning before each season

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SAFT NICKEL HYDROGEN CELL CYCLING STATUS

3–2 GEO CYCLING (Cont'd)

	ESA	CNES	AEROSPATIALE SPACEBUS
CELL TYPE	VHS 96 CM	VHS 50 BL	VHS 50 BL
SAFT TEST REFERENCE	514	507	510
DOD MAX (%)	80	70	70
TEMPERATURE (°C)	10	10	10
DISCHARGE (A)	64	29.2	29
CHARGE (A)	9.6	3.7	3.7
VOLTAGE LIMIT (V)	1.53	1.5	1.49
RECHARGE RATIO	1.18	1.15	1.15
SHADOW NUMBER	7	33	20
END OF DISCHARGE VOLTAGE (V)	1.09	1.16	1.09
	RECONDITIONING BEFORE EACH SHADOW PERIOD	1 FAILED CELL AT PERIOD 28 TEST COMPLETED	RECONDITIONING AFTER EACH SHADOW PERIOD

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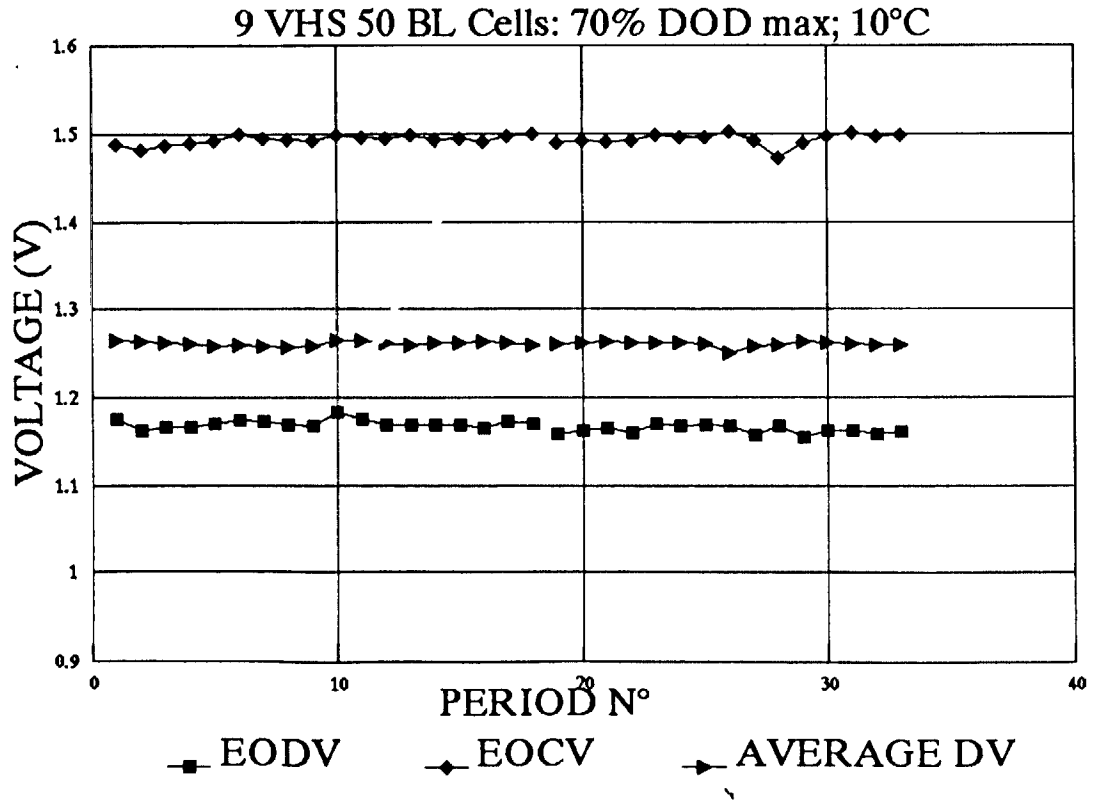
SAFT NICKEL HYDROGEN CELL CYCLING STATUS

3-2 GEO CYCLING (Cont'd)



SAFT test N°507

Real DOD profile

Discharge: 29.2 A
Charge: 3.7 A

Accelerated shadow period

1 Cell removed after shadow period 28

Test completed

End of life characterization:
Int. resistance: +6%
Capacity: −10%

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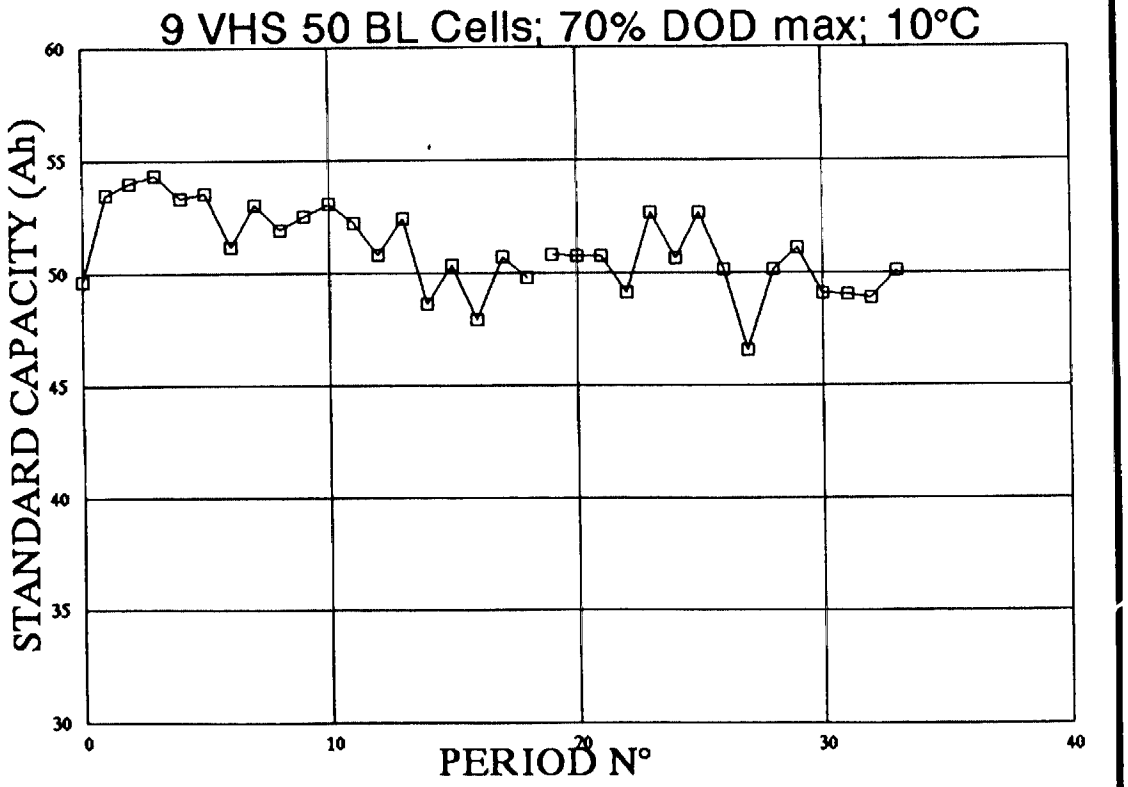
SAFT NICKEL HYDROGEN CELL CYCLING STATUS

3-2 GEO CYCLING (Cont'd)



SAFT test N°507

Capacity check between each shadow period

Charge:
7 H 42 mn at 10 A

Discharge:
25 A first Cell to 1 V
10 A first Cell to 0.5V

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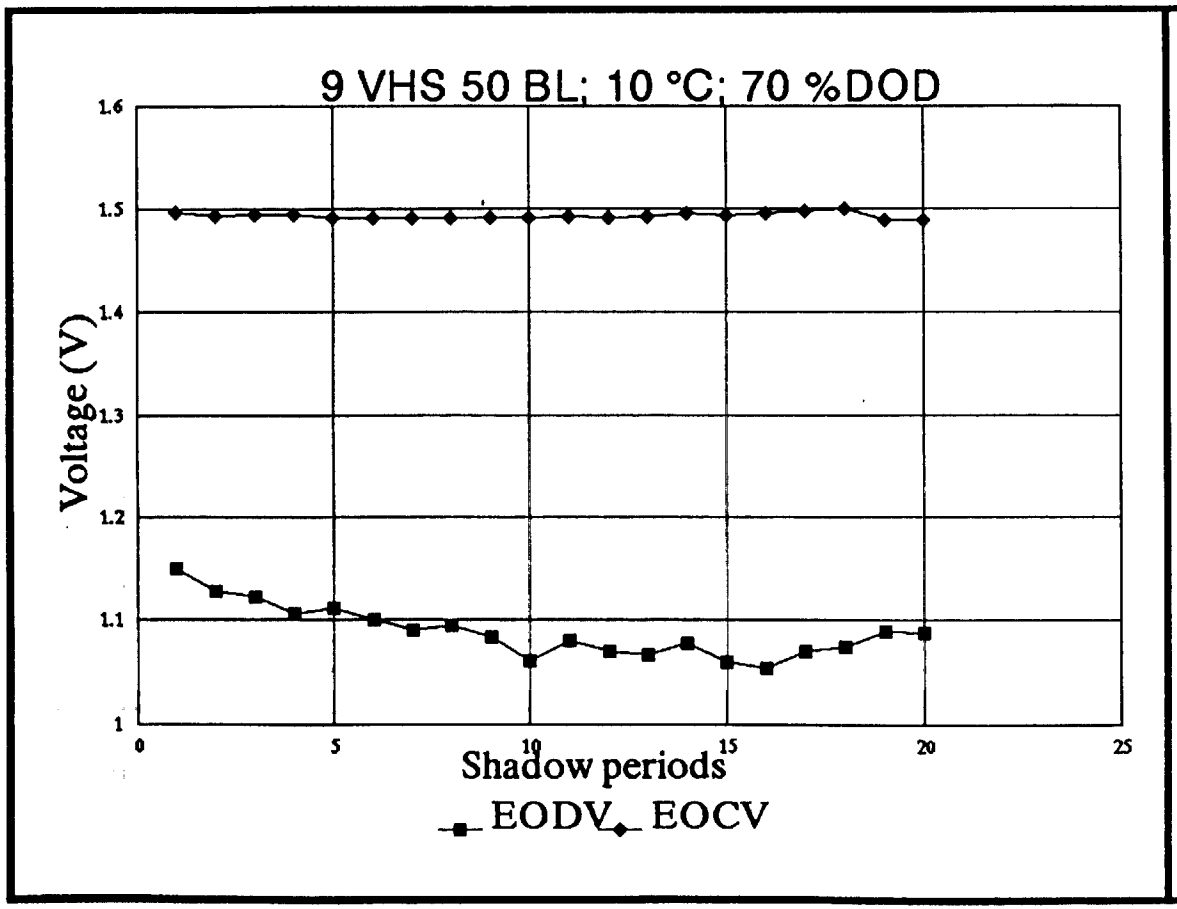
SAFT NICKEL HYDROGEN CELL CYCLING STATUS

3-2 GEO CYCLING (Cont'd)



SAFT test N°510
SPACEBUS program
AEROSPATIALE

Shadow periods
1 to 18 at constant
DOD profile and
19 to 20 at real
DOD profile

Discharge:
1 H 12 at 29 A

Charge:
10 H 48 at 3.7 A

No cell removed
Cycling stopped

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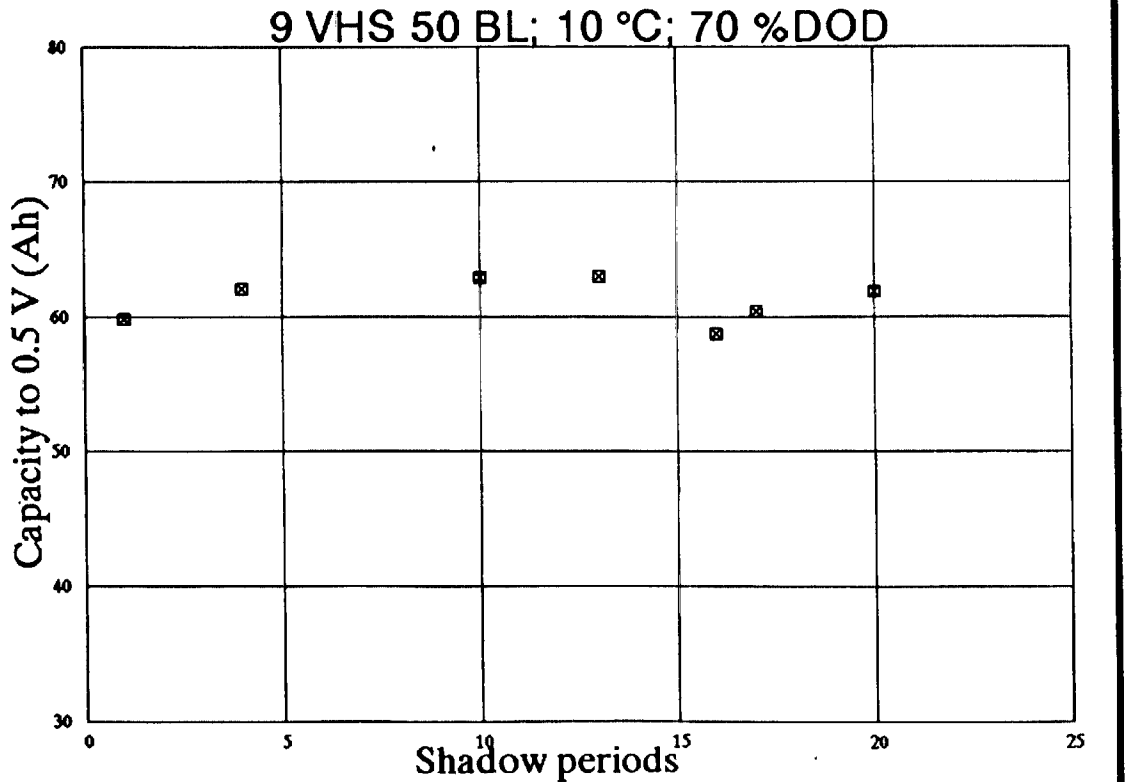
SAFT NICKEL HYDROGEN CELL CYCLING STATUS

3–2 GEO CYCLING (Cont'd)



SAFT test N°510

SPACEBUS program
AEROSPATIALE
Capacity check

Charge:
7 H 42 mn at 10 A

Discharge:
25 A first cell
to 0.5V

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SAFT NICKEL HYDROGEN CELL CYCLING STATUS

4– DPA RESULTS

LEO CYCLING

Cell Type	CYCLING	Saft test reference	Number of Cycles completed	Reason of Removal	DPA Observations
HRN42 n°4	ESA	504	15694	Study of the ageing of electrochemical components	. 9.5 % positive thickness increase . KOH distribution evolution due to the positive expansion
HRN42 n°5	ESA	503	31629	Short circuit	. Short due to too small insulator part compared to the positive swelling : **Old design limitation : no positive expansion accommodation system** . 15.2 % positive thickness increasing . Small loss of positive capacity (9%) . No critical ageing of the separator : only 10 % hydrolysis of polyamid

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SAFT NICKEL HYDROGEN CELL CYCLING STATUS

4– DPA RESULTS (Cont'd)

LEO CYCLING

Cell Type	CYCLING	Saft test reference	Number of Cycles completed	Reason of Removal	DPA Observations
VHS50BL n°7	ESA	512	5500	EOD Voltage below 1 V Low EODV since the beginning of cycling	Ageing of electrochemical components: – high internal resistance – high positive swelling – totally modified KOH repartition **due to acceptance test deviation :** **H2 leakage on test equipment**
VHS50BL n°1	CNES at SAFT	509	448	EOD Voltage below 1 V Low EODV since the beginning of cycling as cell n°7	– high internal resistance – FET positive capacity stable – flooding of negative plates and gaz screen **due to acceptance test deviation**

FAILURE LIMITED TO REWORKED CELLS

564,000 HOURS OF LOW EARTH ORBIT CYCLING SIMULATED

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SAFT NICKEL HYDROGEN CELL CYCLING STATUS

4– DPA RESULTS (Cont'd)

GEO CYCLING

Cell Type	CYCLING	Saft test reference	Shadow Number	Reason of Removal	DPA Observations
VHS50BL n°11	SAFT	507	28	Short circuit	. Degradation of the rilsan sleeve around the tie rod inducing the short : **Problem of test battery insulation** (at season 27) leading to oxygen evolution by electrolyte electrolysis along the tie rod . Very small ageing of electrochemical components : – 2.1 % positive thickness increasing – FET positive capacity stable – no modification of KOH repartition

NO FAILURE BY POPPING , ELECTRODE SHORTS OR HYDROGEN LEAKAGE

15 YEARS GEO CYCLING : – 6% INCREASING OF INTERNAL RESISTANCE
– 10 % MAXIMUM LOSS OF THE CELL CAPACITY

4.3 MILLION HOURS OF GEOSTATIONNARY ORBIT CYCLING SIMULATED

SAFT
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SAFT NICKEL HYDROGEN CELL CYCLING STATUS

4– CONCLUSION

GEOSTATIONNARY EARTH ORBIT SIMULATED CYCLING PERFORMED ON VHS50BL:

– REACHES 33 SHADOW PERIODS WITH SMALL PERFORMANCES EVOLUTIONS

– VALIDATES THE SUITABILITY OF THE VHS CM FOR GEO MISSIONS

LOW EARTH ORBIT SIMULATED CYCLING:

– REACHES 35,000 CYCLES FOR HRN42

– DEMONSTRATES 10,000 CYCLES ON VHS50BL

– GIVES CONFIDENCE ON THE CYCLE LIFE OF THE DM DESIGN

THE CYCLING AND DPA RESULTS DEMONSTRATE THAT SAFT NiH2 IS CHARACTERISED BY :

– HIGH RELIABILITY

– VERY STABLE PERFORMANCES