N94-28113

THERMAL MODELING OF NIH2 BATTERIES

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1993 NASA AEROSPACE BATTERY WORKSHOP
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NOVEMBER 16–18, 1993

SAFT
ADVANCED BATTERIES

THERMAL MODELING OF NIH2 BATTERIES

TABLE OF CONTENTS

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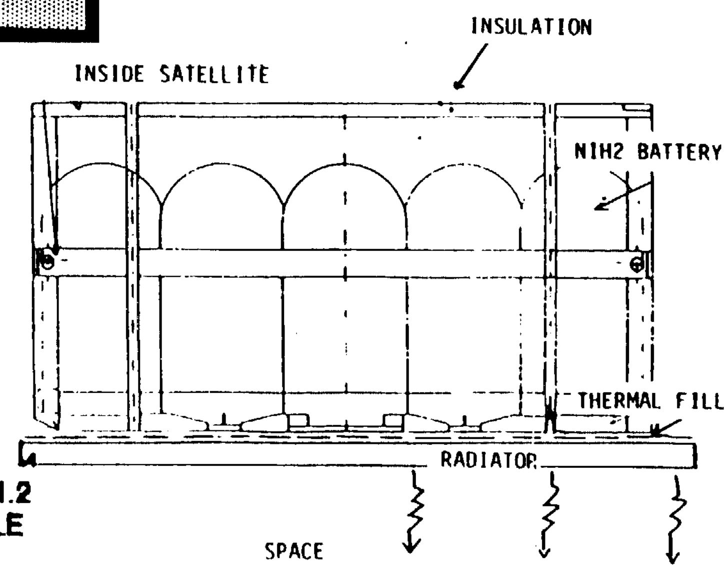
1 – NIH2 BATTERY MISSION AND ENVIRONMENT



IN GENERAL, GEOSTATIONARY AND LOW ORBIT SATELLITES :

- PRELAUNCH OPERATIONS
- LAUNCH AND TRANSFER ORBIT
- ECLIPSES
- PEAK DISCHARGE DURING SUNLIGHT

FOR THERMAL STUDIES, GEO MAXIMUM ECLIPSE PERIOD WITH :

- C/2 TO C/1.5 DISCHARGE CURRENT DURING 1.2 HOUR
- C/20 TO C/10 CHARGE CURRENT WITH RECHARGE FACTOR OF 1.1 TO 1.2
- C/100 TRICKLE CHARGE CURRENT TO COMPLETE THE 24 HOURS CYCLE

THERMAL OPERATING CONDITIONS :

- TEMPERATURE RANGE : $-5°C < T < +25°C$
- TEMPERATURE DIFFERENCE BETWEEN TWO POINTS OF THE ELECTRODE STACK < 6°C
- TEMPERATURE DIFFERENCE BETWEEN STACK AND CELL WALL < 12°C
- TEMPERATURE DIFFERENCE BETWEEN TWO IDENTICAL POINTS OF TWO CELLS OF THE BATTERY < 9°C

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2– NIH2 CELL HEAT DISSIPATION

2.1 – DISCHARGE

HEAT DISSIPATION FORMULATION :

PD = ID (U0 – UD) WITH
- PD : HEAT DISSIPATION IN DISCHARGE (W)
- ID : DISCHARGE CURRENT (A)
- UD : DELIVERED CELL VOLTAGE (V)
- U0 : THERMO–NEUTRAL POTENTAL (V)

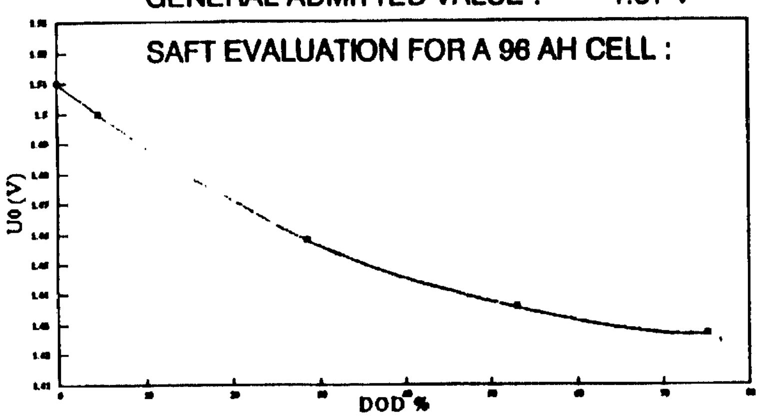
UD = u – R ID² WITH
- u : VOLTAGE AT COUPLE LEVEL (V)
- R : NICKEL TABS AND OUTLET RESISTANCE (mOHM)

PD = PSTACK + R ID² WITH PSTACK = ID (U0 – u) : HEAT DISSIPATION IN THE STACK (W)

THERMO–NEUTRAL POTENTIAL (U0) :

GENERAL ADMITTED VALUE : 1.51 V

SAFT EVALUATION FOR A 96 AH CELL :



EXAMPLES OF HEAT DISSIPATION (AVERAGE) :

	96 AH	64 AH
PD :	12	10.6
P STACK :	7.7	8.2
R :	1.55	1.7
ID :	52.5	37.7

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2– NIH2 CELL HEAT DISSIPATION

2.2– CHARGE & TRICKLE

FORMULATION OF HEAT DISSIPATION IN CHARGE :

HEAT DISSIPATION HAPPENS AT END OF CHARGE AND IS LINKED TO EXOTHERMIC REACTIONS IN THE STACK

FORMULATION RESULTS FROM ANALYSIS OF :
- ENERGETIC BALANCE OVER THE CYCLE
- CELL VOLTAGE PROFILE AT END OF CHARGE

ENERGETIC BALANCE :

$QC = Ec - Ed - Qd$ WITH
- Qc : THERMAL ENERGY LOST IN CHARGE (JOULE)
- Ec : ELECTRICAL ENERGY INPUT IN CHARGE (JOULE)
- Ed : ELECTRICAL ENERGY OUTPUT, IN DISCHARGE (JOULE)
- Qd : THERMAL ENERGY LOST IN DISCHARGE (JOULE)

CORRELATION HAVE BEEN ESTABLISHED FOR SAFT 96AH CELL AND 64 AH BATTERY, FOR C/10 CHARGE AND K FACTOR OF 1.2 AND 1.1 RESPECTIVELY

FORMULATION OF HEAT DISSIPATION IN TRICKLE CHARGE :

$P = Ut\,It$: ELECTRICAL ENERGY INPUT = HEAT DISSIPATION

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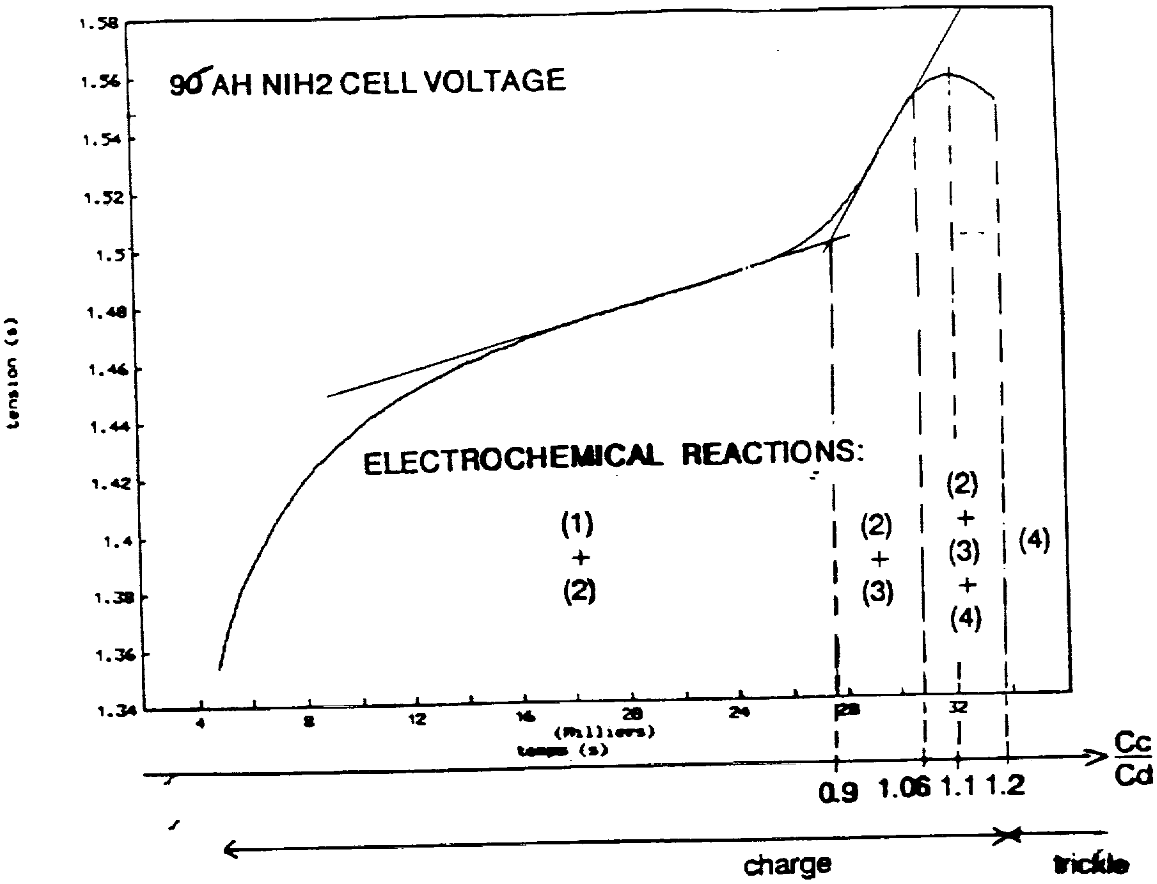

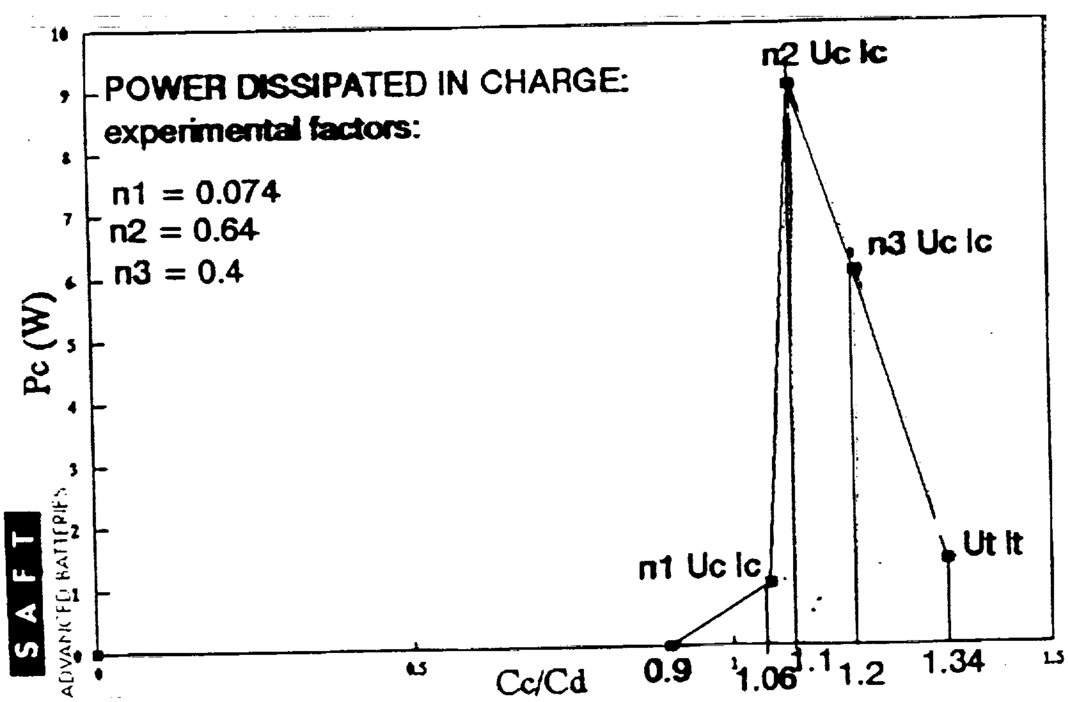

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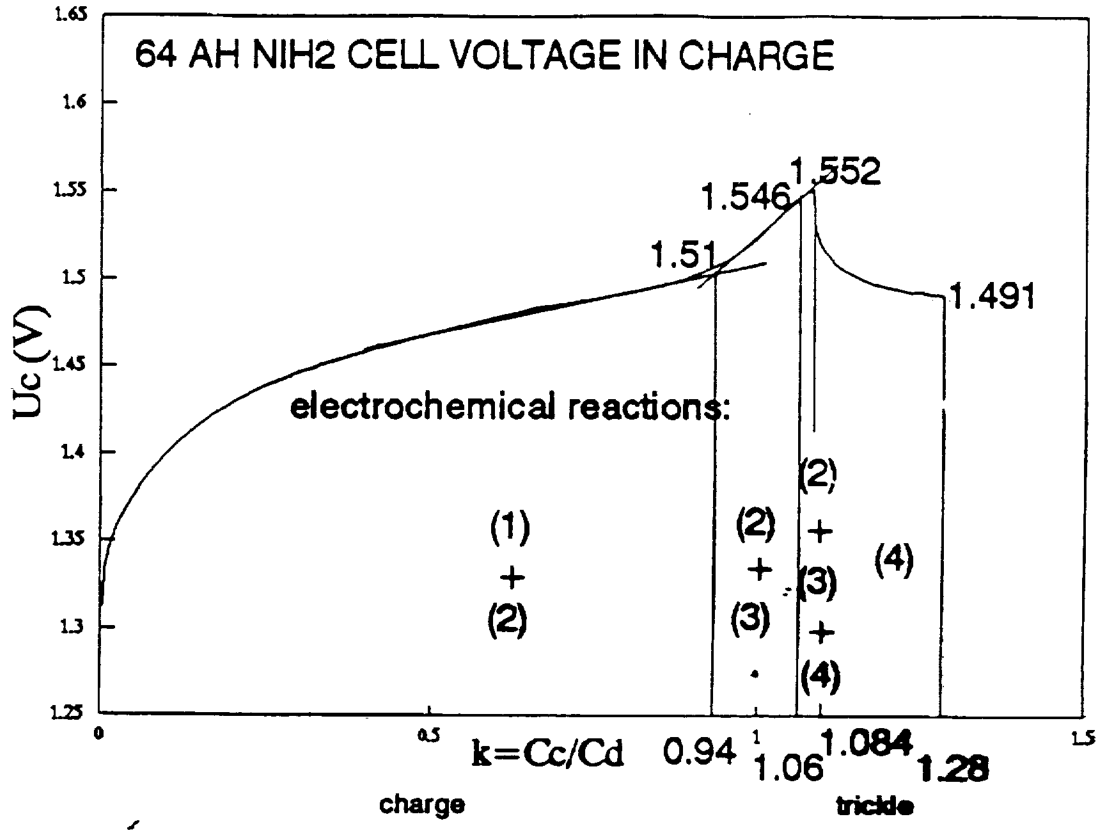

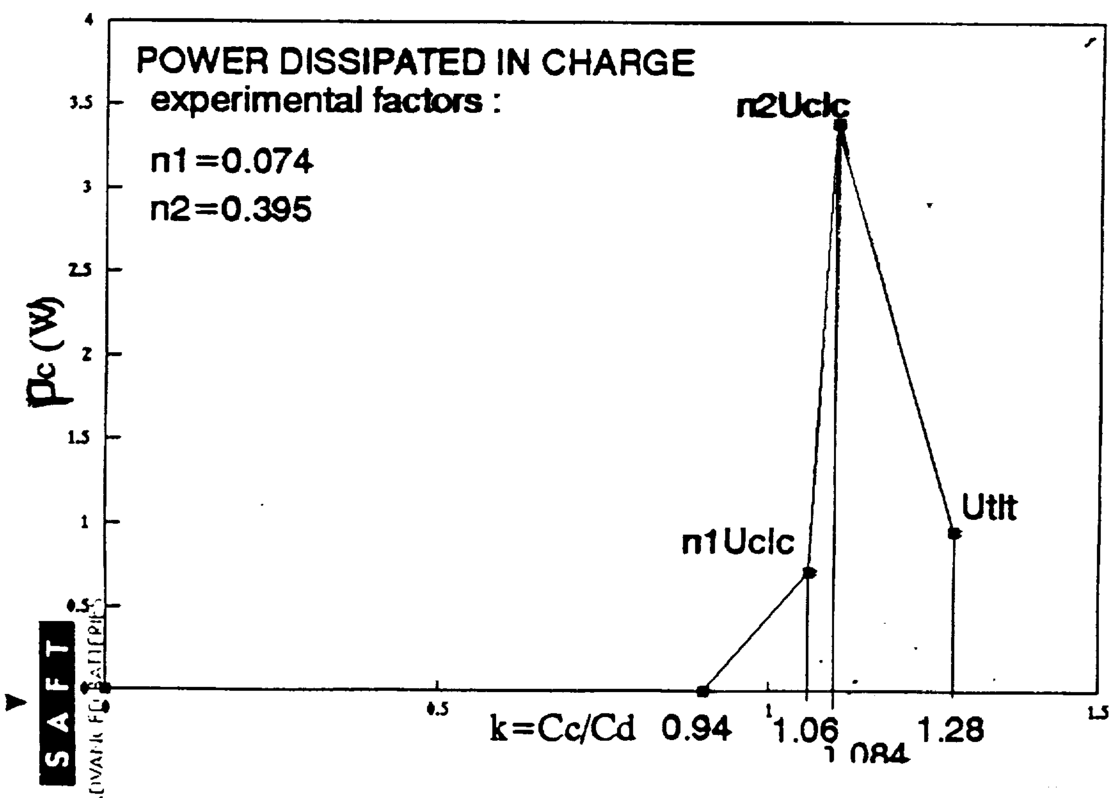

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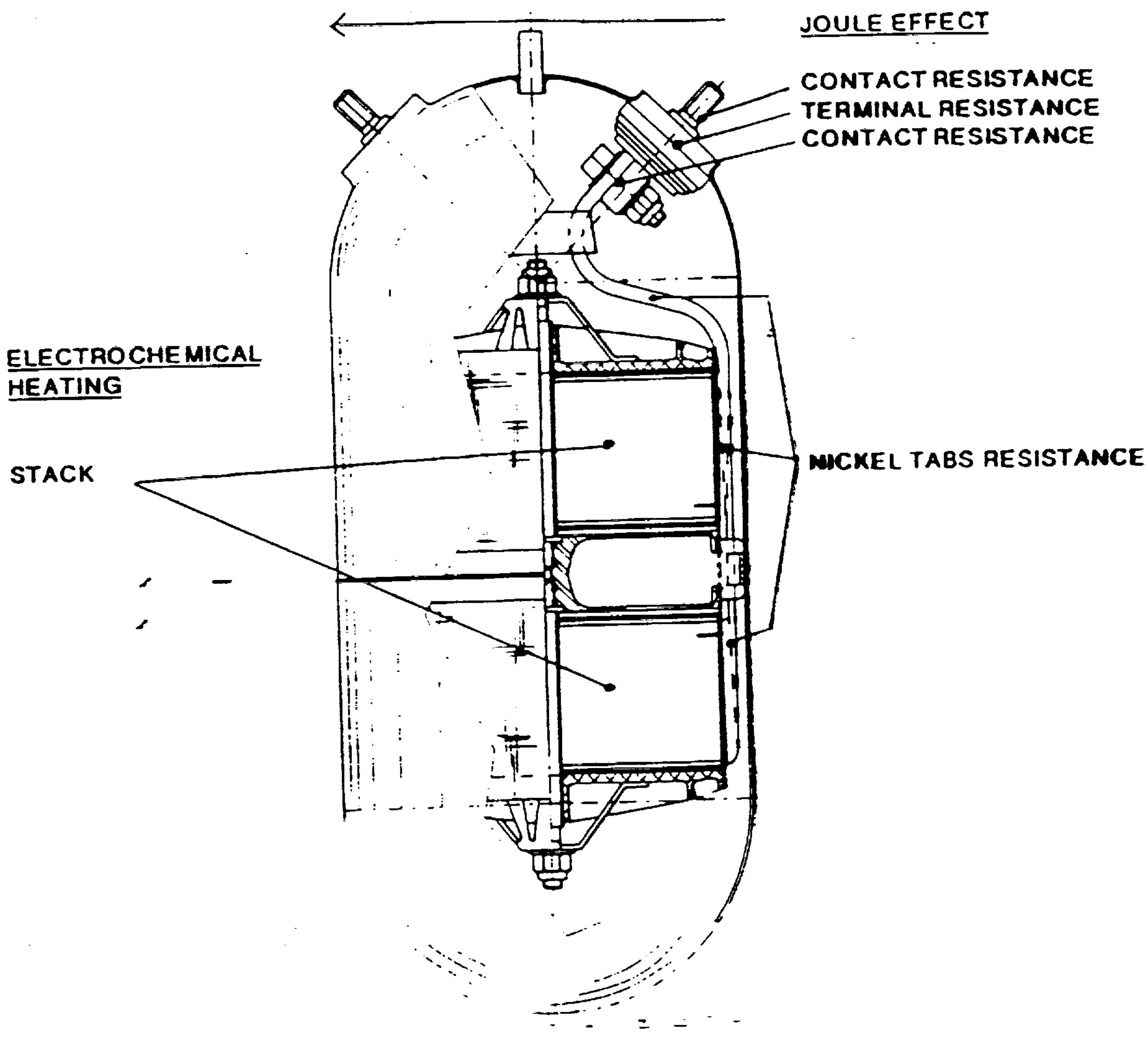
U : CELL VOLTAGE



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THERMAL MODELING OF NIH2 BATTERIES

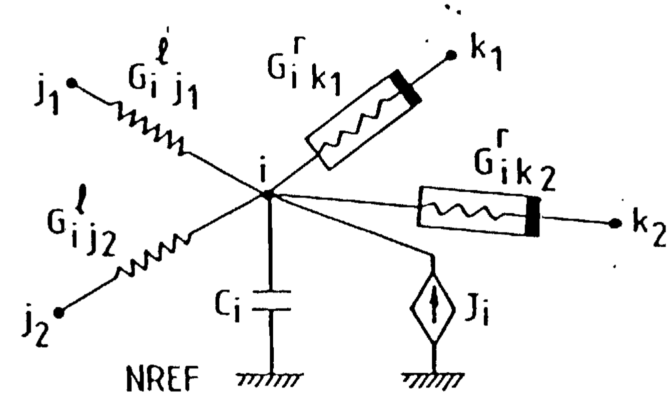
3– NODAL SOFTWARE

2.1 – THERMAL ANALYSER ESACAP

NETWORK ANALYSER FOR THERMAL AND ELECTRONIC PROBLEMS
(PRODUCED BY STANSIM IN DENMARK)

MAIN ADVANTAGES :

- EASY DESCRIPTION BY BASIC COMPONENTS
- EASY DESCRIPTION OF RADIATIVE COMPONENTS
- MODEL APPROACH
- POSSIBILITY TO INTRODUCE NEW COMPONENTS
- LARGE POSSIBILITIES TO INTRODUCE CONTROL
- TREATMENT OF COUPLED PROBLEMS (ELECTRICAL, FLUID FLOW, MECHANIC, TWO PHASE FLOWS)
- LARGE POSSIBILITY TO INTRODUCE PARAMETERS AND PHYSICAL PROPERTIES
- GEAR INTEGRATING METHOD
- SPECIAL METHODS FOR STEADY-STATE ANALYSIS



Thermal parameter	Electrical parameter
heat flux	intensity
temperature	potential
capacity	capacity
conductance	conductance
heat source	current generator
impressed temperature	voltage generator
impressed flux	current generator

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THERMAL MODELING OF NIH2 BATTERIES

3– NODAL SOFTWARE

2.2– INTEGRATING GEAR METHOD

- A HIGH STABILITY FOR ORDERS $K \leq 6$, AND AT THE SAME TIME A HIGH PRECISION,

- THE AUTOMATIC CONTROL OF THE TIME STEP, CONTROL WHICH IS PERFORMED THANKS TO THE EVALUATION OF THE ERROR,

- AN OPTIMUM MODIFICATION OF THE ORDER IN SUCH A WAY THAT THE REQUIRED PRECISION IS OBTAINED,

- BECAUSE THE CONTROL OF THE TIME STEP IS AUTOMATIC, THIS LEADS TO A GAIN OF TIME CALCULATION, WITHOUT INSTABILITY WHICH IS PARTICULARLY IMPORTANT FOR STIFF PROBLEMS.

GEAR PERFORMS THE INTEGRATION IN TWO STEPS :

- PREDICTION WITH AN EXTRAPOLATION BY A NEWTON POLYNOMIAL

- CORRECTION BY SOLVING THE IMPLICIT EQUATION RELATIVE TO THE ENERGY-BALANCE (SUCCESSIVE POINT ITERATION METHOD).

THERMAL MODELING OF NIH2 BATTERIES

4 – DEVELOPMENT GENERAL PHILOSOPHY

- TWO FUNDAMENTAL PARTS : CELL AND STRUCTURE , EACH PART CAN BE RUN SEPARATELY
- A CELL HAS TWO FUNDAMENTAL PARTS : ELECTROCHEMICAL HEART AND MECHANICAL STRUCTURE (CELL WALL, NICKEL TABS, OUTLETS)

IT'S WHY THE THERMAL STUDY IS MANAGED HAS FOLLOW :

- DEVELOPMENT OF A MODEL FOR THE ELECTROCHEMICAL COUPLE WITH THERMOPHYSICAL PARAMETERS AND COMBINATION OF CONDUCTIVITIES, HEAT CAPACITIES, TO TAKE INTO ACCOUNT ALL COMPONENTS (MATTER GRID, SEPARATORS, ...) =======> MODEL OF 100 NODES
- REDUCTION OF NODES NUMBER BUT NOT INITIAL PARAMETERS AND EXTENSION TO A COMPLETE CELL (MORE THAN 100 NODES)
- REDUCTION OF A COMPLETE CELL INTO 10 NODES ALWAYS WITH THE INITIAL PARAMETERS
- DEVELOPMENT OF BATTERY STRUCTURE AND INTRODUCTION, AT EACH PLACE, OF A REDUCED CELL MODEL
- SAME APPROACH FOR SUB–COMPONENTS SUCH AS DIODES FOR EXAMPLE

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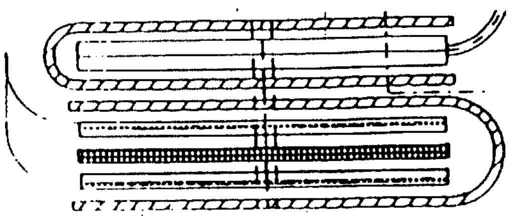
5 – NIH2 BATTERY MODEL DEVELOPMENT

5.1 – AT COUPLE LEVEL



- POSITIVE ELECTRODE
- SEPARATOR
- NEGATIVE ELECTRODE
- NEGATIVE ELECTRODE SEPARATOR
- ELECTROLYTE

→ ρC_{EQ} , $\lambda_V \downarrow$, $\lambda_H \rightarrow$

FOR EACH COMPONENT :

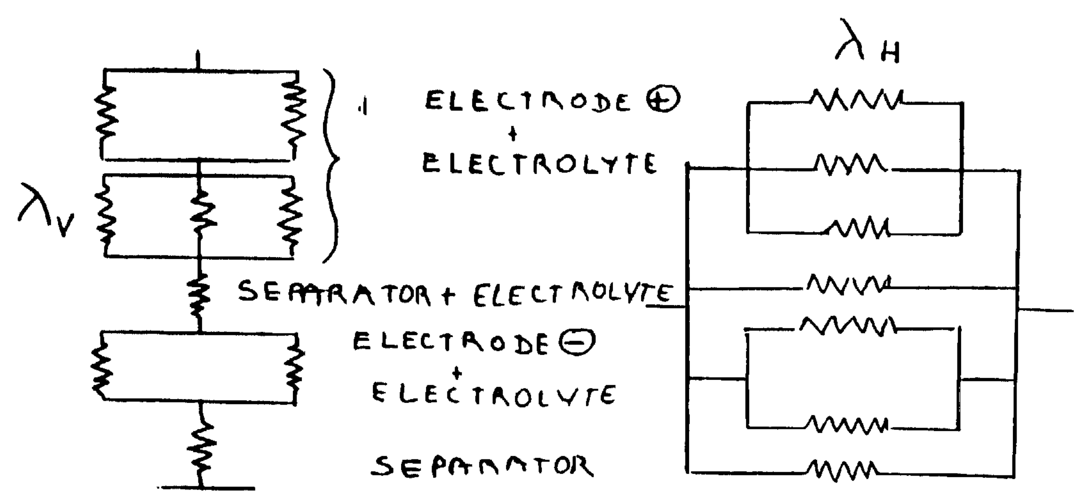
ρC , λ , THICKNESS (Ep)

EQUIVALENT THERMAL CAPACITY :

ADDITION OF EACH THERMAL CAPACITY OF THE COMPONENTS :

$$\rho C_{EQUIVALENT} = \frac{\Sigma \rho C \, Volume}{Volume \ couple}$$

EQUIVALENT THERMAL CONDUCTIVITY :



$$\lambda_V = \frac{\Sigma E_p}{\Sigma \lambda / E_p} \qquad \lambda_H = \frac{\Sigma \lambda E_p}{\Sigma E_p}$$

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5.2– AT CELL LEVEL (1/4 OF A CELL)

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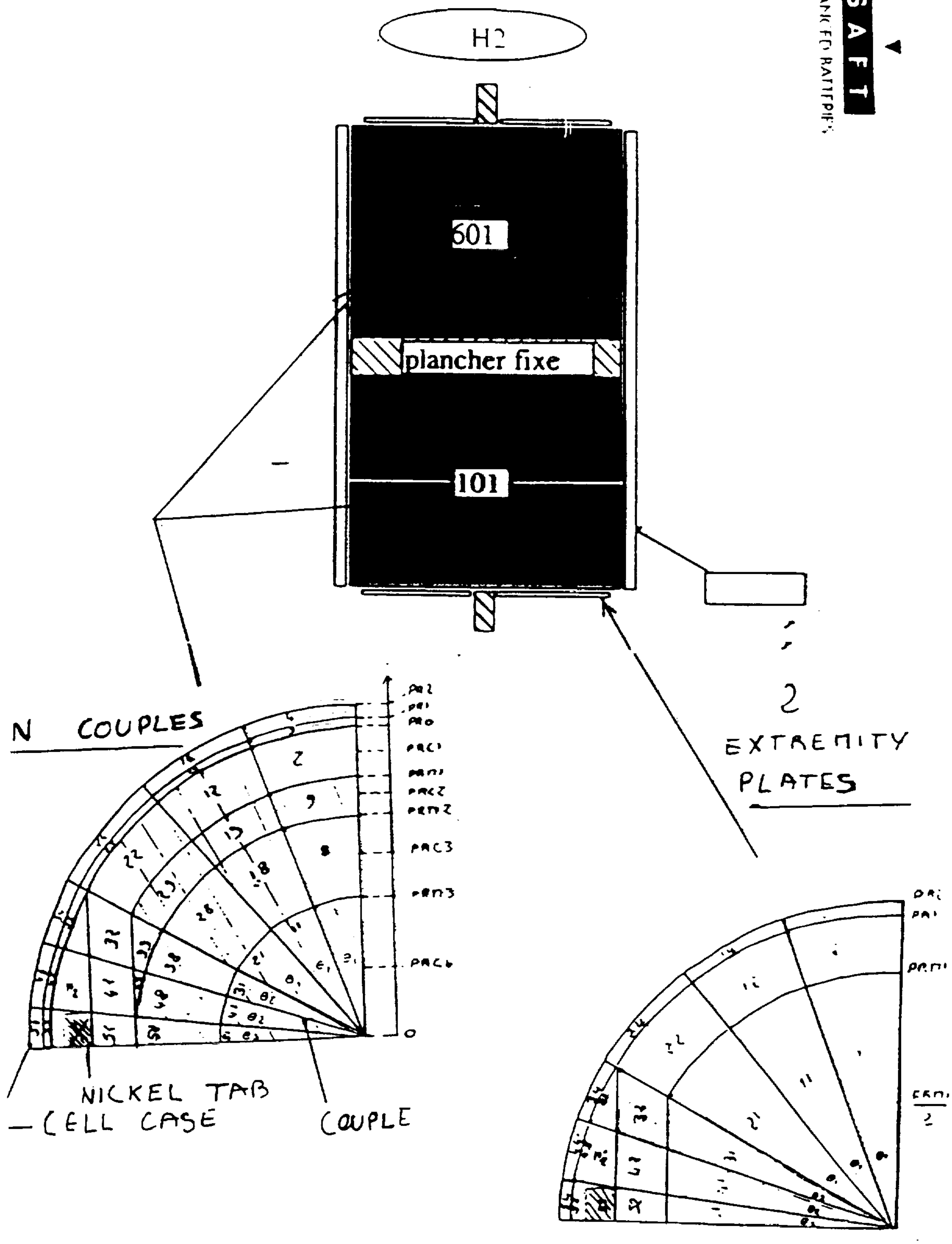

36 NODES PER COUPLE

22 NODES PER PLATE

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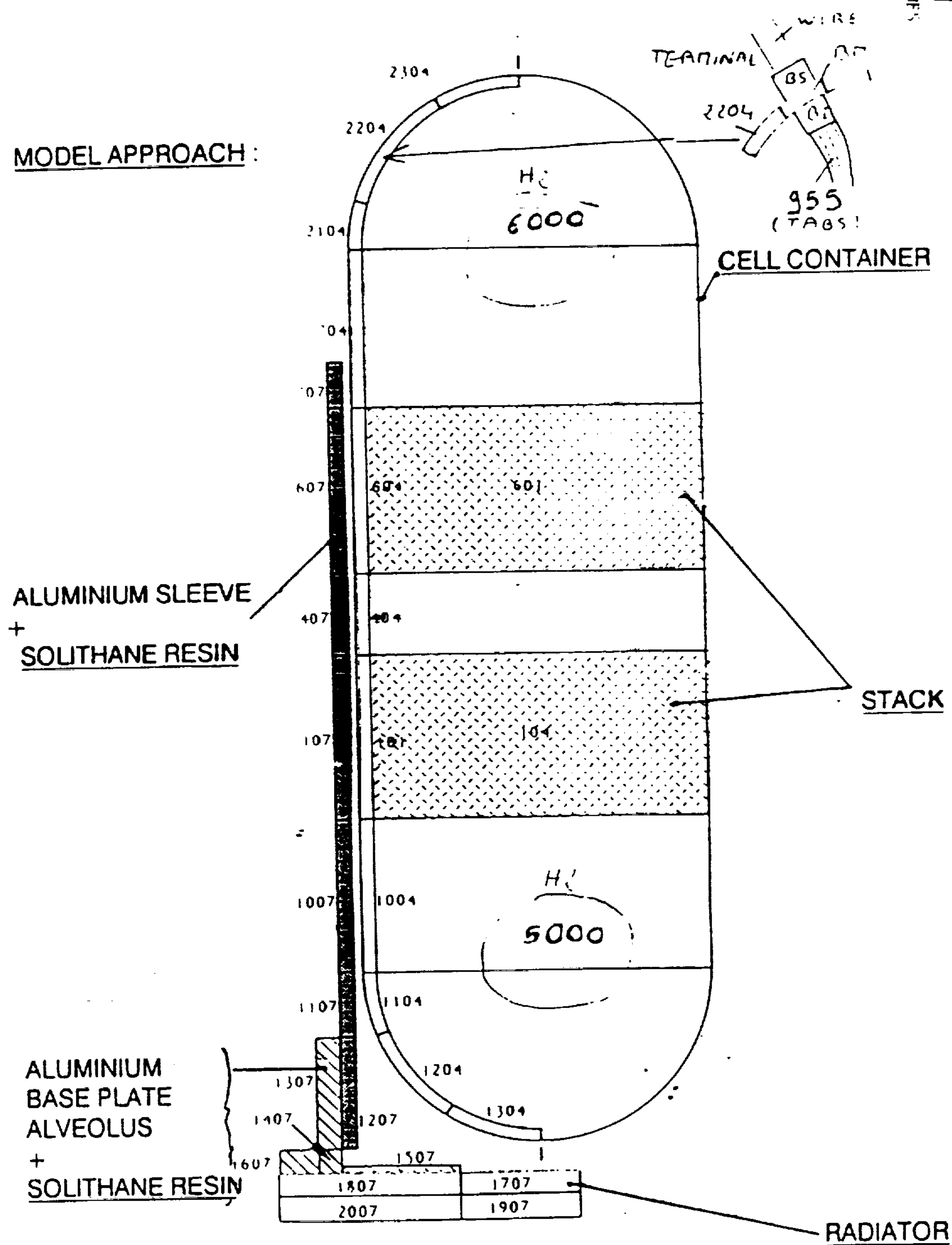
5.2– AT CELL LEVEL (1/4 OF A CELL)

INTEGRATION OF BATTERY STRUCTURE AT CELL LEVEL :

MODEL APPROACH :



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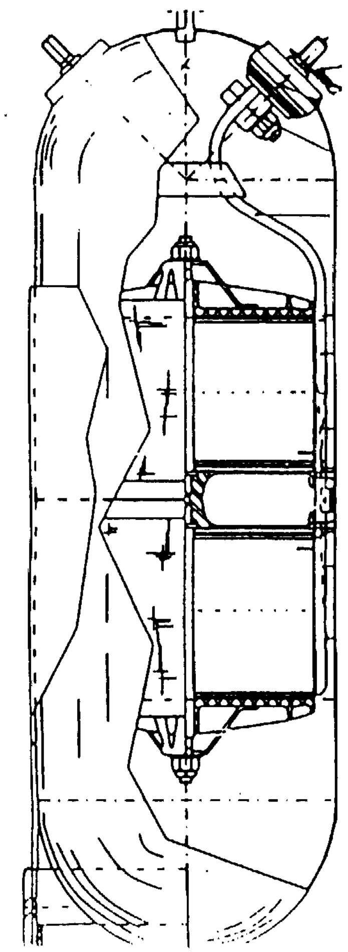
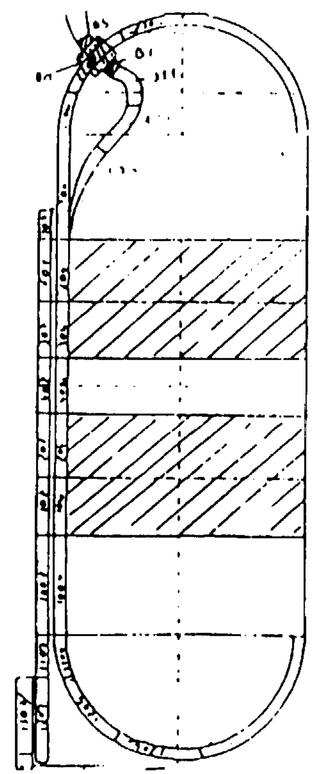
5.2– AT CELL LEVEL (1/4 OF A CELL)

CELL MODEL REDUCTION : WITH SAME BATTERY STRUCTURE INTERFACE

BASIC INPUTS :



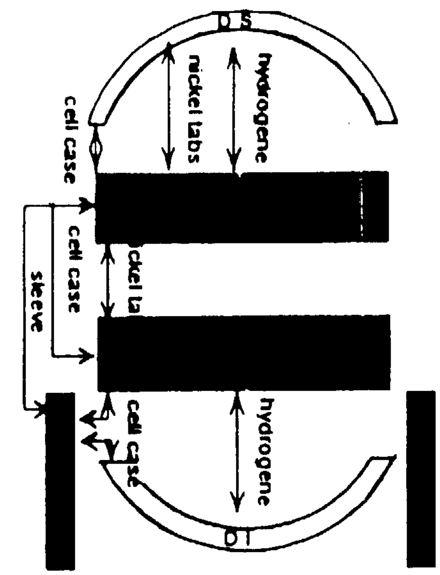
1/4 CELL
DETAILED MODEL :



250 NODES

REDUCTION

1 CELL
ROUGH MODEL :



5 NODES

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5.1 -

EXPERIMENTAL APPROACH :

--> EVALUATION OF THERMAL CAPACITY
(SPECIFIC TEST)

VHS 96 CM
WITH SLEEVE AND ALVEOLUS

--> $\rho C_{calculated} = 2333$ J/°C

--> $\rho C_{experimental} = 2330$ J/°C

--> EVALUATION OF HEAT GENERATION
(SPECIFIC TEST)

VHS 96 CM TOTAL AVERAGE HEAT DISSIPATION IN DISCHARGE :

70% DOD :	P = 12 W
80% DOD :	P = 16.5 W

--> TEMPERATURE DISTRIBUTION ON A VHS 90 CM CELL

CORRELATION WITH MODEL PREDICTIONS

(SEE THERMAL VACCUM TEST ON VHS 96 CM CELL)

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5.3– AT DIODES LEVEL

EXPERIMENTAL APPROACH :

TWO TESTS HAVE PERMITED TO EVALUATE WITH A GOOD CONFIDENCE :

. HEAT GENERATION WITHIN DISCHARGE AND CHARGE DIODES

. THERMAL CONDUCTION THROUGH THE DIODE ASSEMBLY SYSTEM

. PREDICT DIODES TEMPERATURE AT VARIOUS CURRENT LEVEL.

EXPERIMENTAL RESULTS :

CURRENT	DISCHARGE P	CHARGE P	DISCHARGE MAX T J	CHARGE MAX T J
50 A	30 W	/	95.5 °C	/
37 A	20 W	/	66°C	/
6 A	/	5.5 W	/	52.5 °C

MODEL APPROACH :

– DETAILED MODEL OF DIODES ON THEIR SUPPORT --> 33 NODES
– CORRELATION ACHIEVED WITH TESTS
– ROUGH MODEL --> 8 NODES

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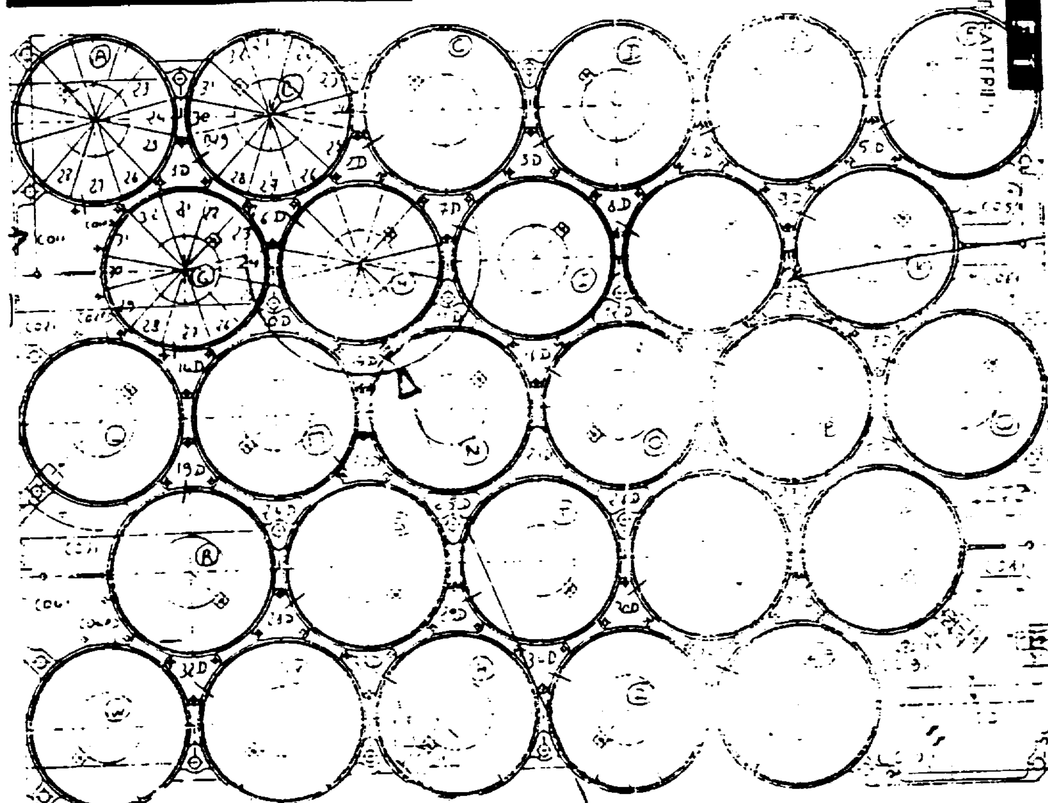
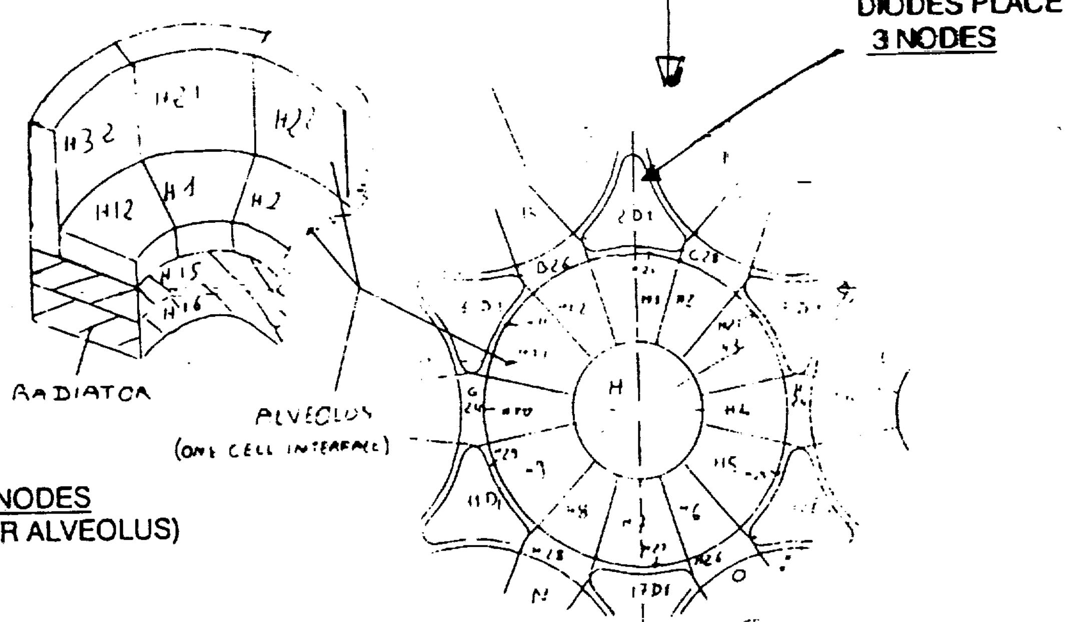
5.4– AT BATTERY BASEPLATE LEVEL

SIDE PLATE (3 NODES)



DIODES PLACE 3 NODES



26 NODES (PER ALVEOLUS)

840 NODES FOR THE WHOLE BASEPLATE

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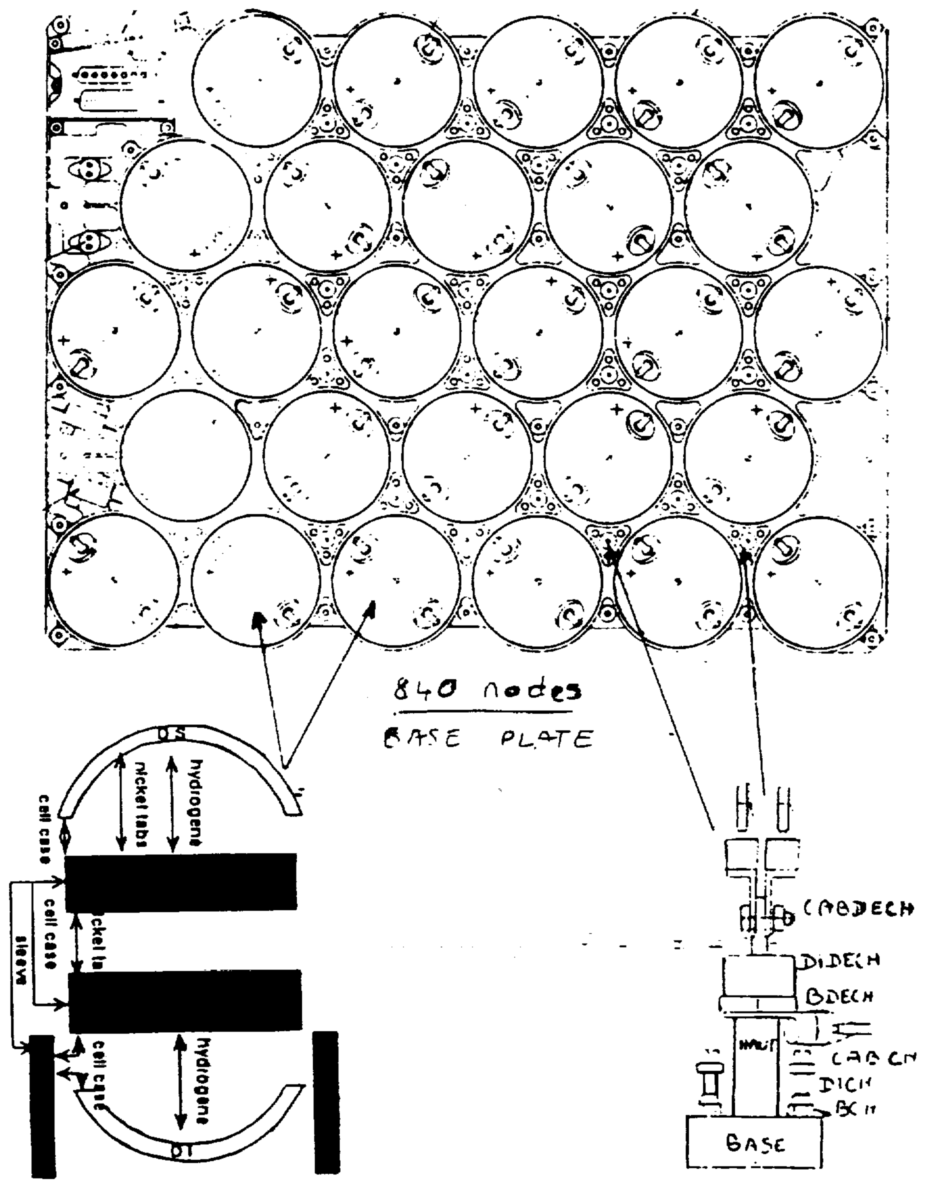
5.5– BATTERY COMPLETE MODEL

COMPLETE SYSTEM : 983 NODES



27 CELLS (5 NODES EACH)

DIODES SYSTEM
(8 NODES)

WITH ALL BASIC INPUTS

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5.1 -

WITH THIS APPROACH :

			x 27
SIMPLIFIED CELL MODEL	: 5 NODES	—>	135 NODES
SIMPLIFIED DIODE MODEL	: 8 NODES	—>	8 NODES
BASEPLATE MODEL	: 840 NODES	—>	840 NODES
COMPLETE SYSTEM :			983 NODES

A COMPLETE DETAILED MODEL :

			x 27
DETAILED CELL MODEL	: 250 NODES	—>	6750 NODES
DETAILED DIODE MODEL	: 33 NODES	—>	33 NODES
BASEPLATE MODEL	: 840 NODES	—>	840 NODES
COMPLETE SYSTEM :			7623 NODES

FURTHERMORE EXPERIMENTAL STEPS ARE DIRECTLY INCLUDED
IN THE DEVELOPMENT OF THE SYSTEM MODEL
(AT CELL AND DIODE LEVEL)

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6– NIH2 EXPERIMENTAL DEVELOPMENT

6.1 – CONSIDERATION ON TEST ENVIRONMENT

6.2 – THERMAL VACUUM TEST ON A VHS90CM CELL

6.3 – QUALIFICATION LIFE TEST ON VHS90CM CELLS

6.4 – THERMAL VACUUM QUALIFICATION ON SAFT 27VHS64CM BATTERY

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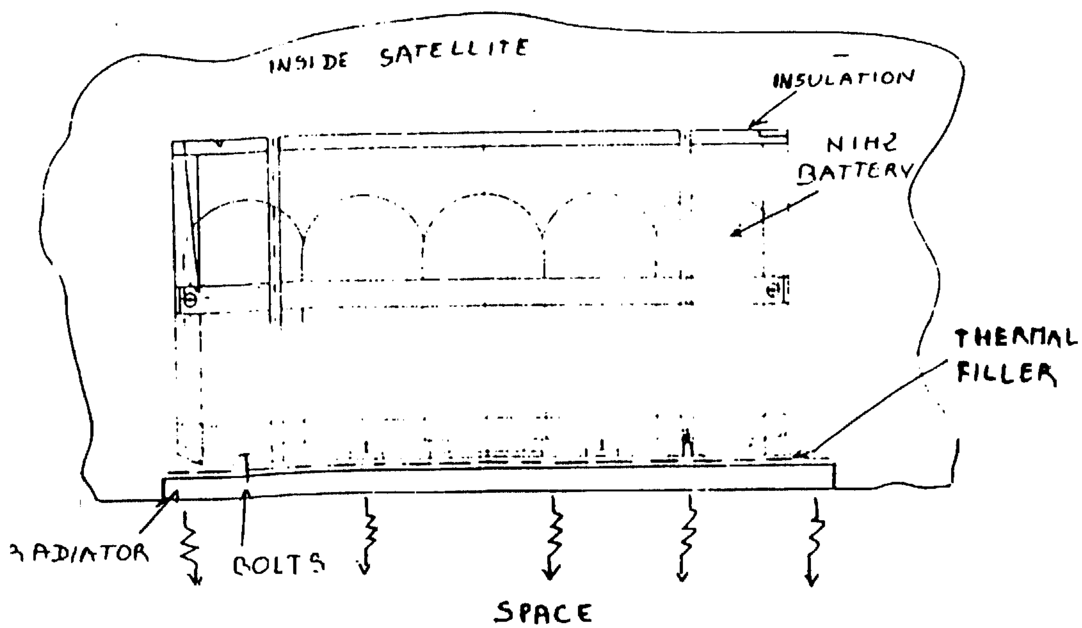
THERMAL MODELING OF NIH2 BATTERIES

6.1 – CONSIDERATION ON TEST ENVIRONMENT

IN ORBIT BATTERY ENVIRONMENT



TEST ENVIRONMENT

AMBIANT SIMULATION

- AMBIANT AIR
- THERMAL CHAMBER
- THERMAL VACUUM CHAMBER

RADIATOR SIMULATION

- BATTERY SET ON A PLATE AT CONSTANT TEMPERATURE
- BATTERY SET ON PLATE WITH PILOTED TEMPERATURE PROFILE
- BATTERY FIXED ON A PLATE VIEWING A COLD SOURCE

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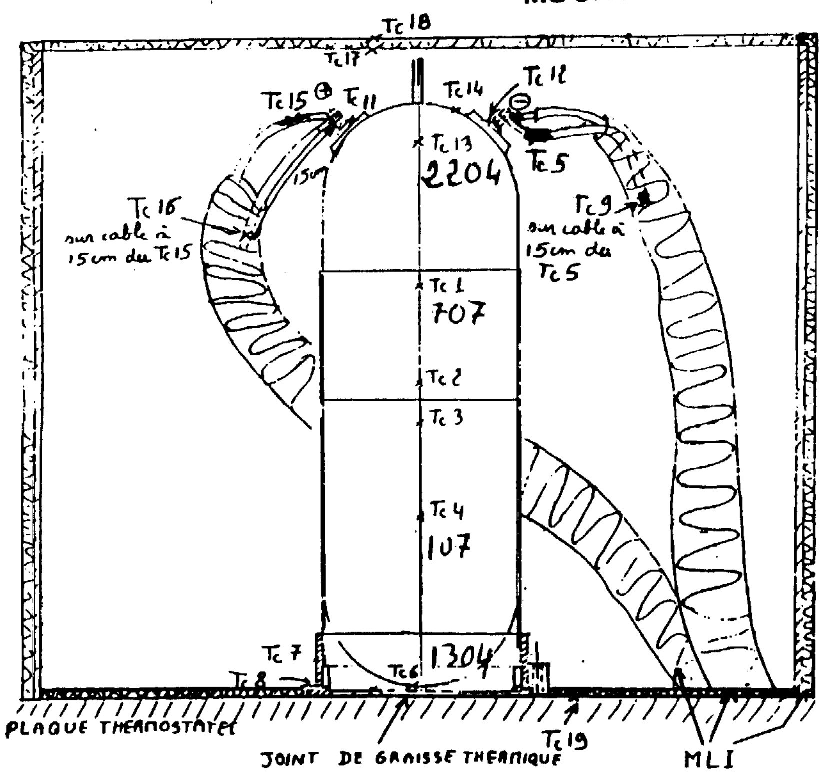
6.2– THERMAL VACUUM TEST ON A VHS90CM CELL

(SAFT POITIERS)

MOUNTING



TEST RESULTS COMPARED TO MODEL PREDICTION

	model node	max discrepancy (°C)
upper dome	2204	2.25 (measured : 13.2) end of charge (model : 10.95)
upper stack (on sleeve)	707	1.1 (measured : 26.3) end of discharge (model : 25.2)
lower (on sleeve)	107	1.4 (measured : 17) end of discharge (model : 15.6)
lower dome	1304	0.8 (measured : 2.3) end of trickle (model : 3.1)

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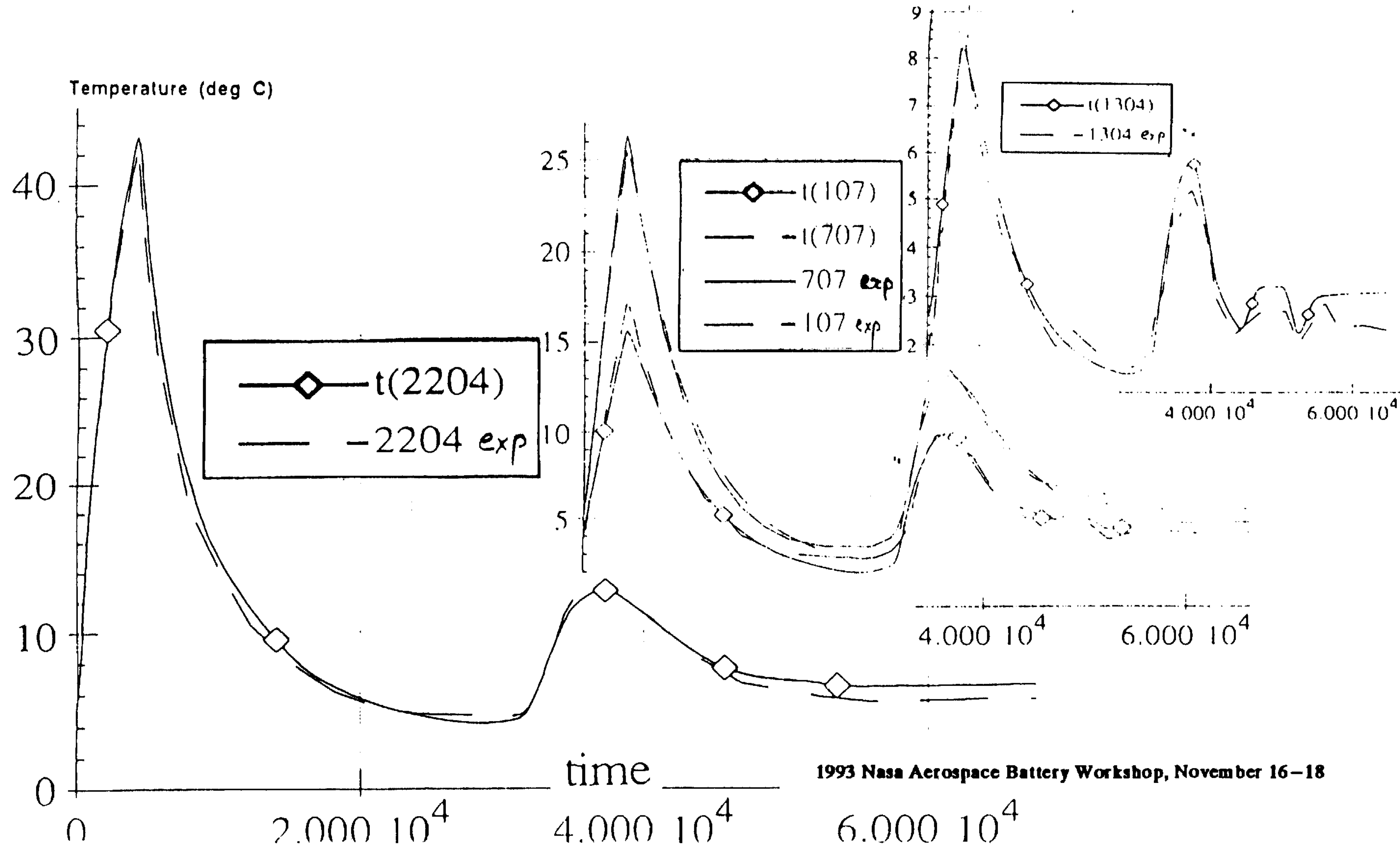
6.2– THERMAL VACUUM TEST ON A VHS90CM CELL



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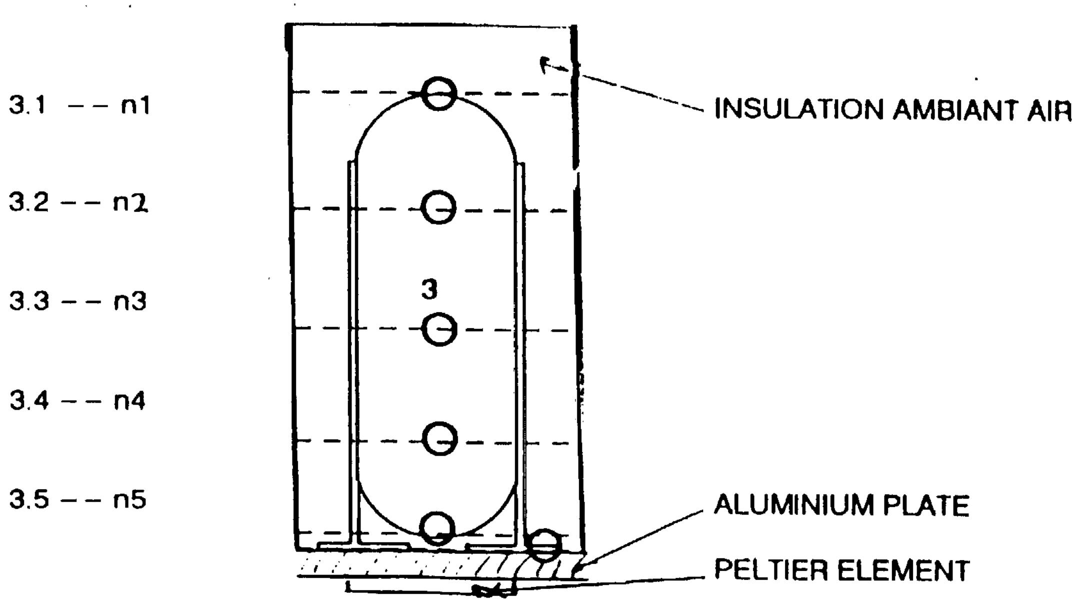
6.3– QUALIFICATION LIFE TEST ON VHS90CM CELLS

(ESTEC – NOORDWIJK)

MOUNTING



TEMPERATURE PROFILE OF THE PLATE DETERMINED BY THE DETAILED CELL MODEL

TEST RESULTS COMPARED TO MODEL PREDICTIC

Node/Dt level	Temperatures Predicted	Measured	Estimated
3.2 80%	27	29	-
20%	14.4	16.1	-
Upper stack inside (hot)	29 -	- -	31 18.3
DT sleeve -dome	8.1 5.0	11.6 7.0	- -
DT radial sleeve-stack	2 1.2	- -	2 1.2
DT stack-dome	10.1	- -	13.6 8.2
DT sleeve	5.38 2.7	6.2 3.5	- -
DT stack	5.38 -	- -	6.2 3.5

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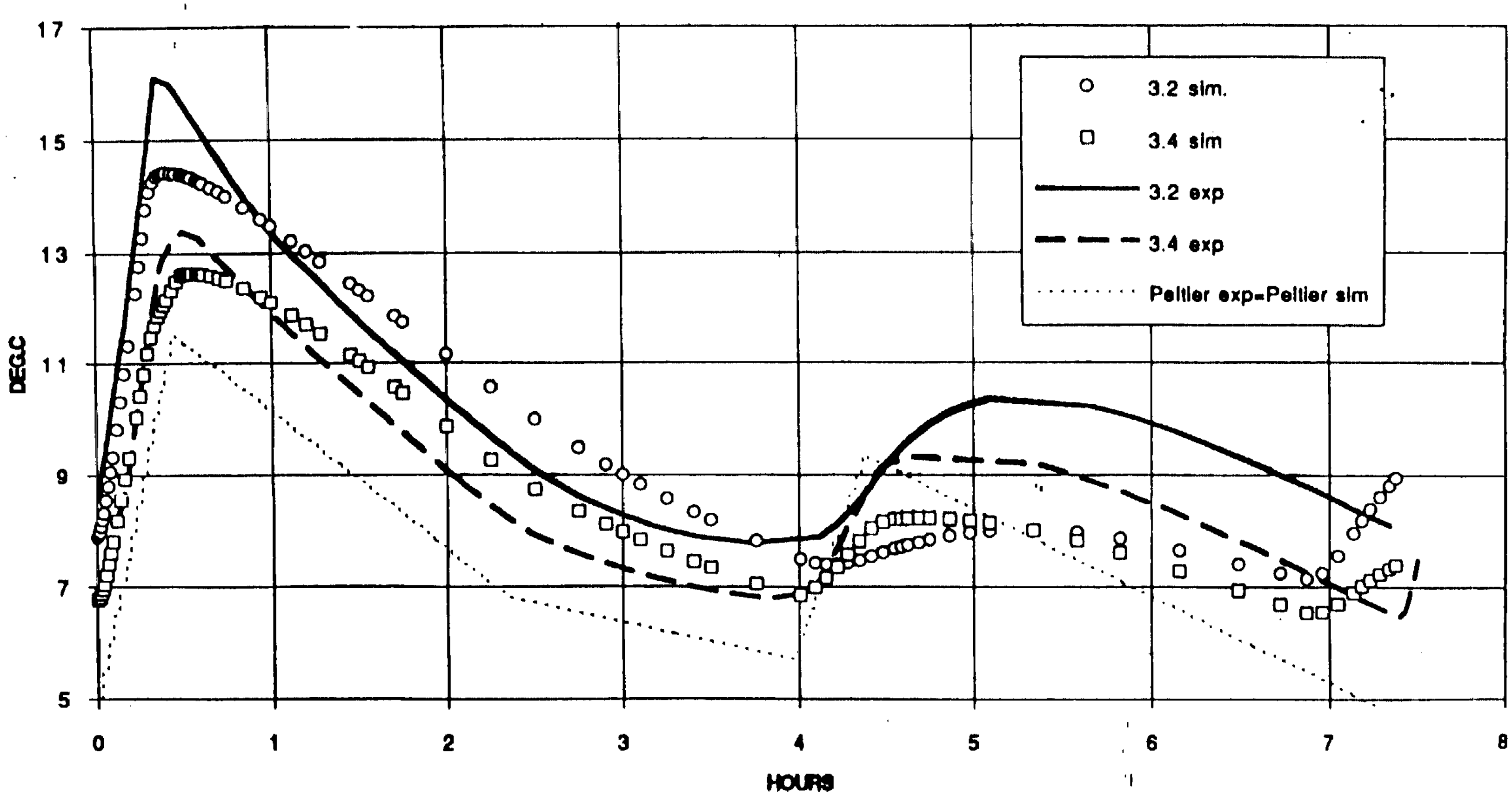
6.3– QUALIFICATION LIFE TEST ON VHS90CM CELLS



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6.4 – THERMAL VACUUM QUALIF. ON SAFT 27VHS64CM BATTERY

MOUNTING :

- THERMAL VACUUM CHAMBER
- FIXED ON A RADIATIVE PANEL
- SUSPENDED OVER A COLD PLATE AT –170°C

CYCLE :

- 80% DOD DISCHARGE OF 1.2 HOUR
- C/10 CHARGE , K FACTOR OF 1.1
- C/100 TRICKLE CHARGE
- 1.8 W HEATING PER CELL, SWITCH ON WHEN CELL TEMP. IS BETWEEN 2 AND 4 °C

ONE FAILED CELL SIMULATION :

- W CELL IS PUT IN OPEN CIRCUIT AND RELAYED BY DIODES
- DISCHARGE DIODE IS PLACED ON SUPPORT N°32 .
- CHARGE DIODES ARE PLACED ON SUPPORT N°32, 29, 30.

THERMOCOUPLES:

- 81 THERMOCOUPLES WHERE INSTALLED
- 17 ON THE BASEPLATE
- 4 ON THE RADIATIVE PANEL
- 3 CELLS COMPLETELY EQUIPPED (5 thermocouples at least)
- ABOUT 20 CELLS EQUIPPED WITH ONE THERMOCOUPLES PLACED ON THE HOT POINT
- 3 DIODES SUPPORTS COMPLETELY EQUIPPED

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6.4 – THERMAL VACUUM QUALIF. ON SAFT 27VHS64CM BATTERY

RESULTS:

	SPECIFICATION	MODEL	TEST
MAX CELL STACK TEMP.	+35°C	33.7 (X)	34.6 (X)
MIN CELL STACK TEMP.	–5°C	–4 (F)	–3.75 (F)
% HEATING USED	< 80%	70%	73%
MAX STACK GRADIENT	6°C	3.6 (F)	3.6 (F)
MAX STACK TO CELL GRADIENT	12°C	9.7 (F)	9.95 (F)
CELL TO CELL GRADIENT	8°C	7°C (N–F)	8°C (N–F)
MAX DIODE JUNCTION TEMP.	110°C	105	105.6

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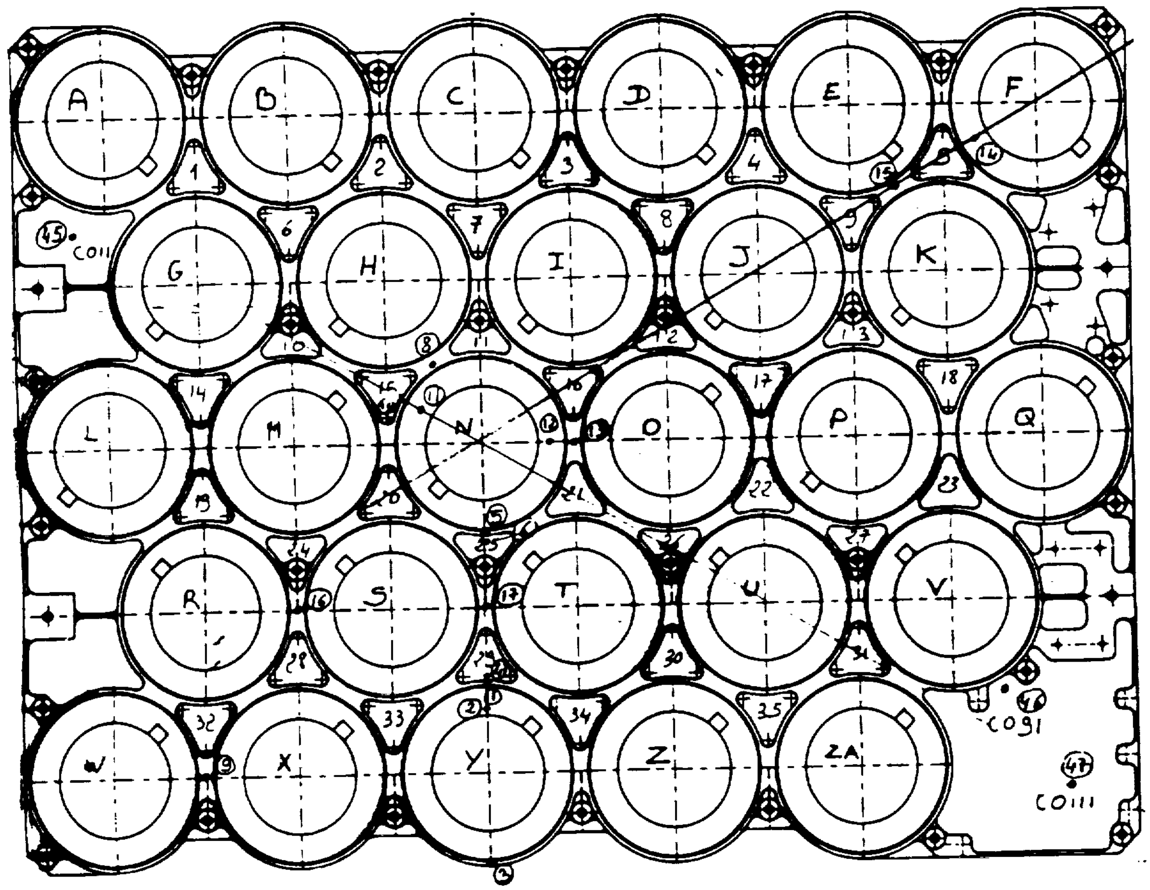
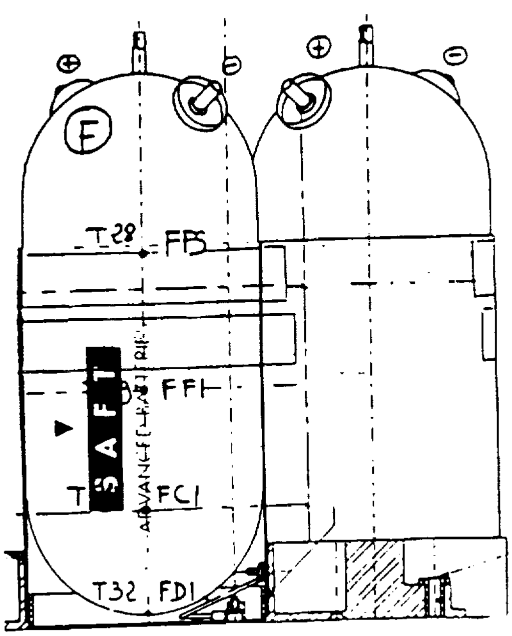
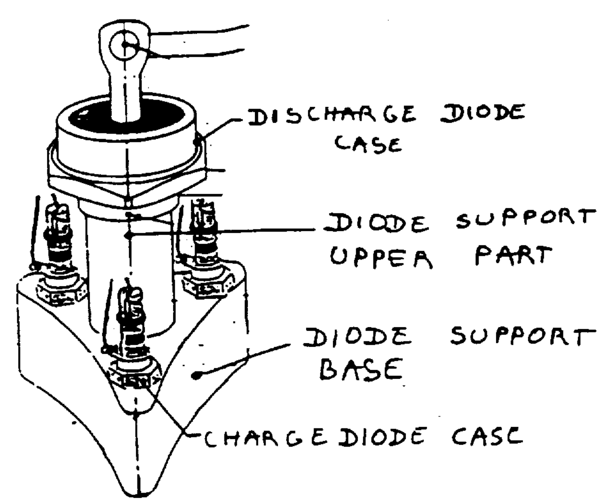
6.4– THERMAL VACUUM QUALIF. ON SAFT 27VHS64CM BATTERY







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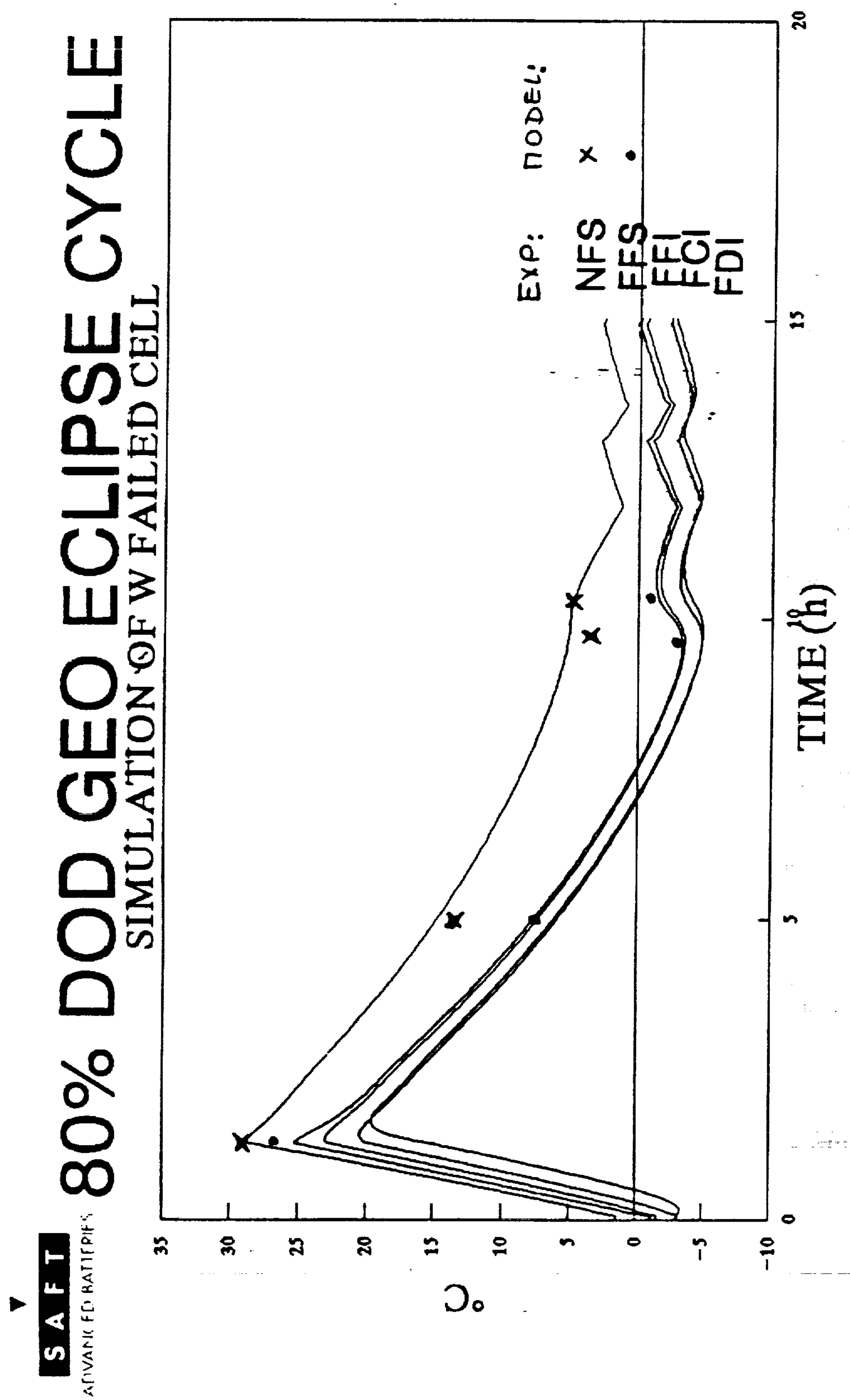
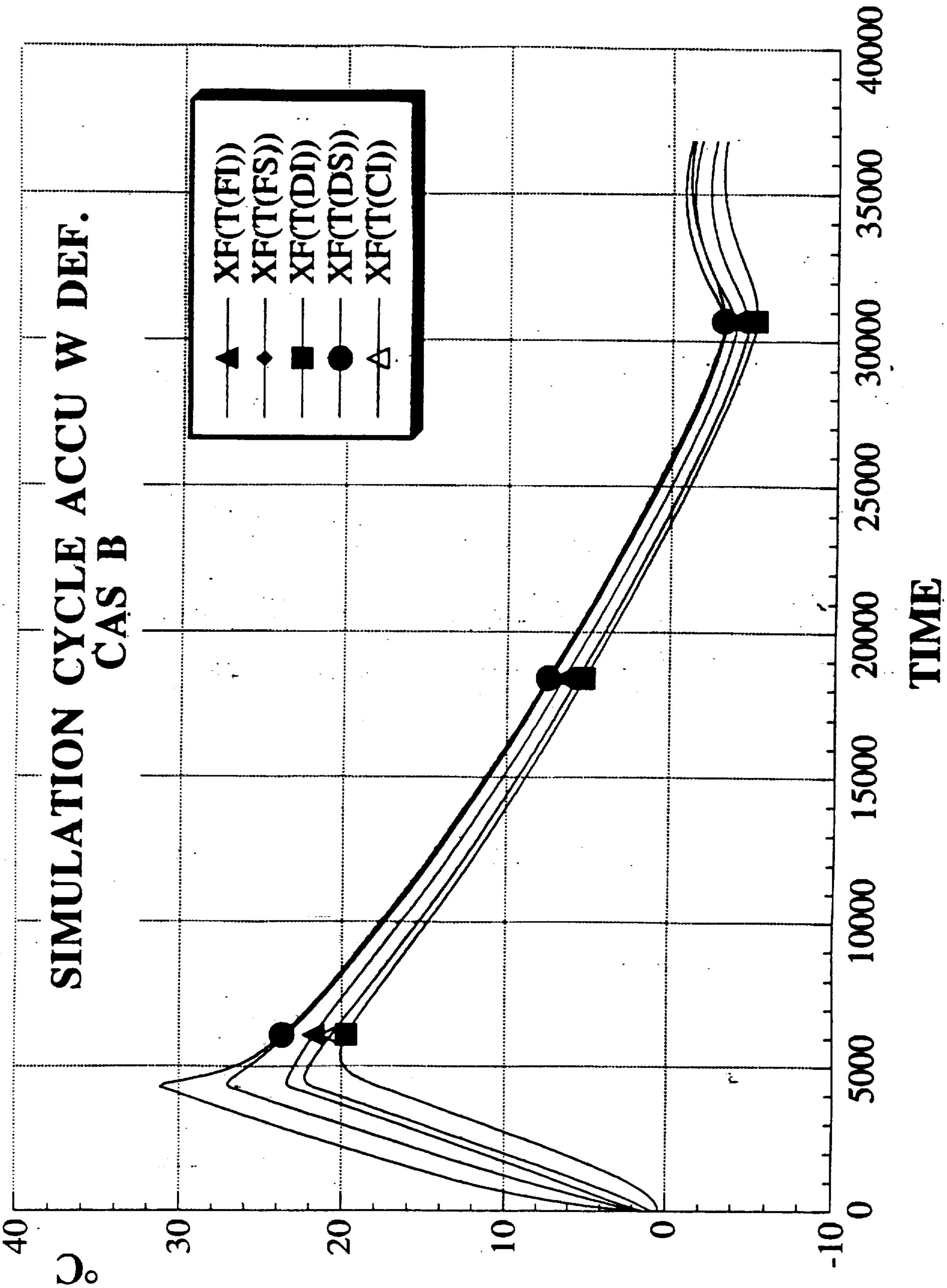

SAFT
ADVANCED BATTERIES
80% DOD GEO ECLIPSE CYCLE
SIMULATION OF W FAILED CELL
°C
35
30
25
20
15
10
5
0
-5
-10
0
5
10
15
20
TIME (h)
EXP:
MODEL:
NFS
FFS
FFI
FCI
FDI
x
•



SIMULATION CYCLE ACCU W DEF.
CAS B
XF(T(FI))
XF(T(FS))
XF(T(DI))
XF(T(DS))
XF(T(CI))
°C
40
30
20
10
0
-10
0
5000
10000
15000
20000
25000
30000
35000
40000
TIME

THERMAL MODELING OF NIH2 BATTERIES

7– CONCLUSION

NIH2 BATTERIES ARE CARREFULLY STUDIED FROM A THERMAL POINT OF VIEW

MODEL AT COUPLE LEVEL, CELL LEVEL AND BATTERY LEVEL ARE PERFORMED WITH THE SAME PARAMETERS

THERMAL MODELING IS REALISED WITH AN EASY AND POWERFUL NODAL SOFTWARE : ESACAP

TESTS IN VACUUM CHAMBER OR WITH PELTIER ELEMENTS ARE DEFINED IN ASSOCIATION WITH MODEL

GENERAL THERMAL DEVELOPMENT PROGRAM DELIVER NOW A TOOL ABLE TO ANSWER QUICKLY TO NEW REQUIREMENTS OF FUTURE BATTERIES