ESA BATTERY DEVELOPMENT

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ESA

I should also mention that Dr. Goudot and myself are based at the Nuclear Space Agency's Technology Center at Noordwijk in the Netherlands. ESA's activities for battery R&D are confined to applied programs, that is to say, they must be directly related to future ESA projects.

There is coordination with CNES, the French Space Center in order to harmonize the R&D investment with the sole manufacturer in Europe, namely SAFT. Although having an evident disadvantage, this monopoly, in practice, permits efficient rationalization of development and gives automatic standardization and continuity in the products with consequent increase in relevant experience with them.

The ESA program for some years has been concentrated upon three main objectives.

(Figure 3-50)

First, we are interested in the development of a higher capacity family of nickel-cadmium cells in the range of 25 to 60 ampere-hours.

Secondly, we are trying to improve the existing NiCad range, which extends up to about 26 ampere-hours, the emphasis being on weight reduction and quality. That is to say, we are trying to enhance the mechanical and electrical behavior and lifetime.

Thirdly, our main development is in silver hydrogen cells. In addition, we cooperate with CNES, the French agency, in nickel-hydrogen development.

The first figure also shows the evolution of these developments. Taking the first of these three objectives, the high capacity cells are now being requested for some application satellites, mainly telecommunications, with power demands of up to 2 kilowatts during the eclipse.

In consequence, it is planned to develop a cell of approximately 40 ampere-hours in the 1980 to 1981 timeframe. It is intended to use the same technology as existing SAFT, 4- to 26-ampere hour range, following the current operating modes, limits, and so on.

It is expected to achieve an energy density of around 40 watt hours per kilogram at 100-percent DOD. It is probable that the new family will have a common footprint modifying the height as the simplest means to achieve various capacities.

This approach, which has been satisfactorily adopted for the current standard range, allows for extensions of the size with a minimum of development cost and delay.

The second of these main objectives, the improvement of the existing design, includes, first, the achievement of a better understanding of the cell thermal behavior. Following a study contract with Elektronikcentralen of Denmark, it is now possible for us to undertake realistic thermal predictions at battery level. This will be referred to a little bit later in context of the silver hydrogen cell development.

Next, the saving in weight of approximately 5 percent for the 23-ampere-hour-size cell in the current range has been made possible by reduction of the can wall thickness.

(Figure 3-51)

This is from 0.6 to 0.4 millimeters. It was found, however, that the thinner wall doesn't produce changes in the mechanical behavior of the battery level requiring a different approach to the design of the battery structure.

This figure shows the current ECS battery, which is the European Communication Satellite battery's design, using the recently qualified thin wall cell and showing the lightweight structure adopted. In fact, there were titanium rods and end plates. Next, a new mechanical design for the internal connections of cell electrodes for improvement of the vibration capability has recently been qualified at 22 grms in parameter.

(Figure 3-52)

The design will be incorporated in cells of the next ECS battery model, and it is expected to be adequate to meet the anticipated levels of both the Ariane launcher and the shuttle.

The figure shows the new leaf spring design that has been adapted. More recently, 7-ampere hour cells for the Exosat project, using this design successfully withstood a level of 28.5 Grms. We expect this design to have some reserve as well in this respect.

In fact, with this number, there is an additional nylon locking piece that goes between the top of the cell and the electrostack to push in the stack during vibration.

(Figure 3-53)

A summary of the qualification procedure applied to the ECS cells with details of the vibration spectrum is given in the next vugraph. At the 22 Grms level, development SAFT models successfully withstood about 30 minutes endurance in each axis.

Next, a study of electrochemical impregnation of the nickel electrode was completed in 1976, and subsequently a pilot manufacturing unit was built under the sponsorship of CNES. This would have sufficient capacity to meet the future European needs. This anticipates that the advantages of this technique are confirmed by samples currently in cyclic testing.

(Figure 3-54)

This vugraph shows the progress to date comparing the evolution of thickness of electrochemically and chemically impregnated electrodes to date, and the advantages of the electrochemical technique have been well demonstrated. For instance, there are some unimpregnated electrodes shown in the graph. That is the middle curve.

A study of the plastic bonded cathode, which, for the moment, completes our various improvements, is in progress with the intention of further weight reduction of NiCad cells. We hope to introduce this type of electrode in lightweight cells in the near future, and some results should be available by the end of 1980.

The third and largest of ESA's objectives is the successful development of the silver hydrogen cell. This activity started in 1974 with the feasibility study by Batelle predicting the possibility of achieving 80 watt-hours per kilogram and a lifetime of between 4 and 5 years.

(Figure 3-55)

Since that time, following systematic studies of silver electrodes, electrolyte management, and separator materials, the first generation cell was realized. This silver hydrogen cell, developed and shown in the next figure, was reported by SAFT at last year's symposium at Brighton in 1978. The figure shows it compared in size with the current NiCad and nickel-hydrogen cells of approximately a different capacity.

(Figure 3-56)

The development of a second generation hydrogen electrode is now being considered. This was seen previously to be a limiting factor in the performance of the present cell. Concurrently, following the review of all components, a detailed mechanical design study is soon to begin on a spherically shaped cell, and a working prototype of this cell is shown in the next figure. It is at 24 ampere-hours.

The present situation indicates already that better results than those predicted are achievable with an energy density of 90 watt-hours per kilogram and a comparable volumetric efficiency to NiCad cells.

(Figure 3-57)

This figure provides comparative weight breakdown of nickel cadmium, nickel hydrogen, and the two generations of silver hydrogen cells. Just in case any of you noticed, this figure here proved to be somewhat optimistic. This one is somewhat pessimistic.

I think this relates to Inconel 718 contained in that Inconel 65. As you can see here, we are getting 91 watt-hours per kilogram for the spherical cell. If you look at the volumetric efficiency, we are showing a very good capability versus the NiCad.

Prototype cells which have been in test for 2 years have been submitted to 24-hour cycles at 50-percent DOD at both 20 and 0°C. After approximately 550 cycles at 20°C, some problems are evident as shown in the figure.

(Figure 3-58)

The cause was attributed to short circuits caused by dimensional changes of the positive electrodes. The new design will avoid this feature, but up to the point of failure, no other problems were observed.

At 0°C, the test is still running, after 700 cycles without any sign of failure, as shown in the next figure.

(Figure 3-59)

In these figures we must relate the pressures to the overall capacity available. In low-orbit conditions (i.e., with 100-minute cycles), the test has been in progress at 20°C and 25-percent DOD.

(Figure 3-60)

This test is still running after 10,000 cycles. An initial variation in performance, as you can see in this figure, is so far unexplained. However, the cell continues to give very satisfactory performance. I should also explain that these graphs are average data. In fact, the spread in reality was not too great.

(Figure 3-61)

Storage testing first performed on samples in 1977 gives very attractive results, indicating a comparable self-discharge to NiCad cells. This next figure shows a loss of 15 percent after 1 month at 20°C and 8 degrees at zero.

(Figure 3-62)

It should be noted that this attractive behavior of the silver hydrogen couple is derived using components available some 3 years ago.

In 1978, a thermal study of nickel-hydrogen and silver hydrogen cells was carried out by Elektronikcentralen. Following a component analysis, a thermal model was constructed as shown in this next figure, and this rather complex model shows the calculated delta temperatures at specified nodal points of the cell for a constant 1-watt dissipation within the electrode stack.

The results gave good correlation with values measured in practice. The results have also shown, however, that the heat evolution is rather greater than that of the equivalent NiCad cells, and modifications will necessarily be introduced in the second generation cell design to improve heat dissipation and assist in definition of future battery structures.

It is envisaged that an egg-box like structure would be a likely solution to the encapsulation of the spherical shape. As I mentioned previously, a further contract is now planned to study this cell design.

In parallel, looking at possible effects of hydrogen embrittlement and long-term high-pressure cycling, we are conducting a contract at Ecole Centrale in Paris. The smaller volume of the spherical cell will necessitate a working pressure of 50 bars at the end of charge. The question of safety in both design and operation of metal hydrogen batteries has to be considered, and the study of safety aspects is the prime objective of this metallurgical study.

In preparation for the future, a system study contract for metal hydrogen cells will be given to one of the leading European prime contractors within the next few months. This study will analyze the problems of integration into spacecraft, looking at the mechanical, thermal, and electrical interfaces.

However, it should not be concluded that metal hydrogen will automatically replace NiCad in ESA applications. For example, the merits of nickel hydrogen at least appear to be questionable, to us at least, and historically systems with silver electrodes have not demonstrated the best lifetimes. The choice will necessarily be a question of tradeoffs, case by case.

In the near future, it is intended to concentrate our efforts in the ESA battery test center to the evaluation of both nickel hydrogen and silver hydrogen to define the cell characteristics and to determine operation modes and to assess life duration, with the eventual objective of qualifying cells.

(Figure 3-63)

This series of figures shows the test center at Noordwijk and details of some nickel-hydrogen tests that we are doing for CNES.

(Figure 3-64)

In the center we can test exactly 100 batteries if necessary, 100 different tests. We have 2000 different data channels.

(Figure 3-65)

This test done at CNES is comparing the performance and life cycling of the cells with the standard 23-ampere-hour nickel-cadmium space cell.

(Figure 3-66)

This is a closeup, a detail of the cells being tested showing pressure tranducers at the top.

I have very briefly described our program which is rather ambitious technically, but is limited inevitably by budget problems—in fact, in order to achieve our project readiness, we spend something annually like $300,000.

Finally, this last figure provides a table with details of batteries used with ESA spacecraft.

(Figure 3-67)

It is a record that appears to be comparatively good up to the present time, and we hope it will remain so. I think I can give you a few minutes to look at that. But, of course, we used the first European battery on ESRO IV, the SAFT cylindrical cell. I think I should point out it is in this HEOS 1 we have got an orbital life of over 7 years. This doesn't apply to the silver cadmium battery.

In the Meteosat 1, we have been experiencing a capacity degradation of almost 50 percent, which we attribute to bad battery manufacturing. We have a solution to restore this to full capacity in the next few weeks.

I think I will finish there. I would like to acknowledge the assistance of SAFT, who provided a lot of the data.

DISCUSSION

RITTERMAN: You pointed out some electrochemically impregnated positive data, and you showed, I think, that there was hardly any swelling or no swelling of that electrode.

Could you comment on the loading level and the nature of the electrochemical impregnation? What solution is it impregnated from, and how many grams per cc void of active materials did you have impregnated?

GOUDOT: We have no data on that question. Even SAFT has no data. But that can be provided.

GROSS: You indicated on one of your charts that for the OTS spacecraft, you had a new battery management technique. Could you discuss what it was and why it was necessary, and what it did?

GOUDOT: It's a new technique we are applying in OTS. It was based on tests we performed in the laboratory. It was based on the fact that we have a minimum of overcharge in the battery, even to keep the state of charge lower than 1. We observe, in fact, in low orbit with a test performed at 80-percent DOD at 20°C, three times expansion of the lifetime you have normally with the commercial technique.

The technique used in OTS was to let the battery choosing the recharge capacity by recharging with a low-recharge coefficient; 1.2 in the beginning, until the battery reached the lower

voltage in the charge, percent voltage, and at this moment the K factor was increasing by 3 percent, and each time by 3 percent. For the time being, after 2 years mission the coefficient is 1.05 awaiting the degrading of voltage conditions until there is volting with present forms. And this technique normally must double the lifetime, at least.

GROSS: There was laboratory data to base that operation on?

GOUDOT: Yes. We have that available for low orbit as well as geosynchronous orbit. Many years.

GROSS: Second point. It was indicated on the chart that the ISEE spacecraft had a battery failure. Could you discuss what that was?

GOUDOT: In this project, due to the change of load during this period, it was not possible to do the same technique as OTS, requesting very stable loading. There we come back to the common scenario technique having voltage limitation at the end of charge. As I remember, it is a 16-step voltage for end of charge as well as limitation. It is more common for that scene.

YOUNG: About all I can say is that the limiting factor is the current carrying capability paper, but in the second we were operating at 1.02K factor. That is the ratio of charge-discharge. It's currently at 1.05 after 4 eclipse periods.

I think your second question was, if I understood, you were asking what the failure was on ISEE? In fact, this was shorting in cells, so the battery is now disconnected in the spacecraft.

DYER: Can you comment further on the limitations of your hydrogen electrode design, the original hydrogen electrode design? You mentioned you have a second generation hydrogen electrode.

YOUNG: About all I can say is that the limiting factor is the current carrying capability of the hydrogen electrode. The next design will be a lighter weight construction, but it will also have a much greater current carrying capacity. I can't remember offhand what the density is for that electrode.

GOUDOT: We are going to develop a new hydrogen electrode, because we developed silver electrode and its performance is now so good, we are limited by the hydrogen electrode. Following that we are forced to develop a new type of electrode because what we used until now was coming from the fuel cells development more than 10 years ago.

YOUNG: As an additional comment on that, we use a thick electrode in the silver hydrogen cell anyway, which means that we are using fewer hydrogen electrodes in the silver hydrogen cell. So it has to be beefed up a little.

VAN OMMERING: I would like to mention that the data shown on the nickel-electrode expansion were actually developed with the Intelsat contract with SAFT. The loading levels that

were involved there were about standard loading level for the chemically impregnated electrodes. And under-impregnated electrodes were about 70 percent, which was standard level. The electrochemically impregnated electrodes have the same loading level as was under-impregnated chemically made electrodes.

As a matter of fact, a question, I wonder if you would elaborate on your assessment of nickel-hydrogen technology. It is questionable at this point.

YOUNG: Thank you for the first comment. The opinion we have about the nickel hydrogen is that when you take into account the loss of volumetric efficiency, I think that we can also make the point, the problem with the nickel-cadmium system is related largely to poor battery management on the spacecraft.

I think one should get above all the noise, discussing what we should and shouldn't do. I think one should get a well-managed battery. I don't think the differences in performance are going to be that great. So overall we don't think that the energy density and the watt-hour efficiencies will show significant improvement on the nickel cadmium.

RITTERMAN: Are you confident that the hydrogen electrode was the limiting electrode in silver hydrogen? Could you and the other gentleman comment on the other density where the limitation occurred, or the rate of discharge where the limitation occurred on the hydrogen electrode?

YOUNG: I am personally not competent about that.

GOUDOT: We have no memory, and we have no data there. But we have a report, and we can provide the data to you if you want.

OTZINGER: Are you getting favorable results from your silver hydrogen work? Can you tell me what the separation system consists of?

YOUNG: Apart from the conventional answer of various polymers, etc., I will ask the SAFT representative to answer that. What the separator constituents are with silver hydrogen.

FOUGERE: The separator constituted from the membrane associated with, number one, nylon; several layers of cellophane type membrane; plus several layers of nylon.

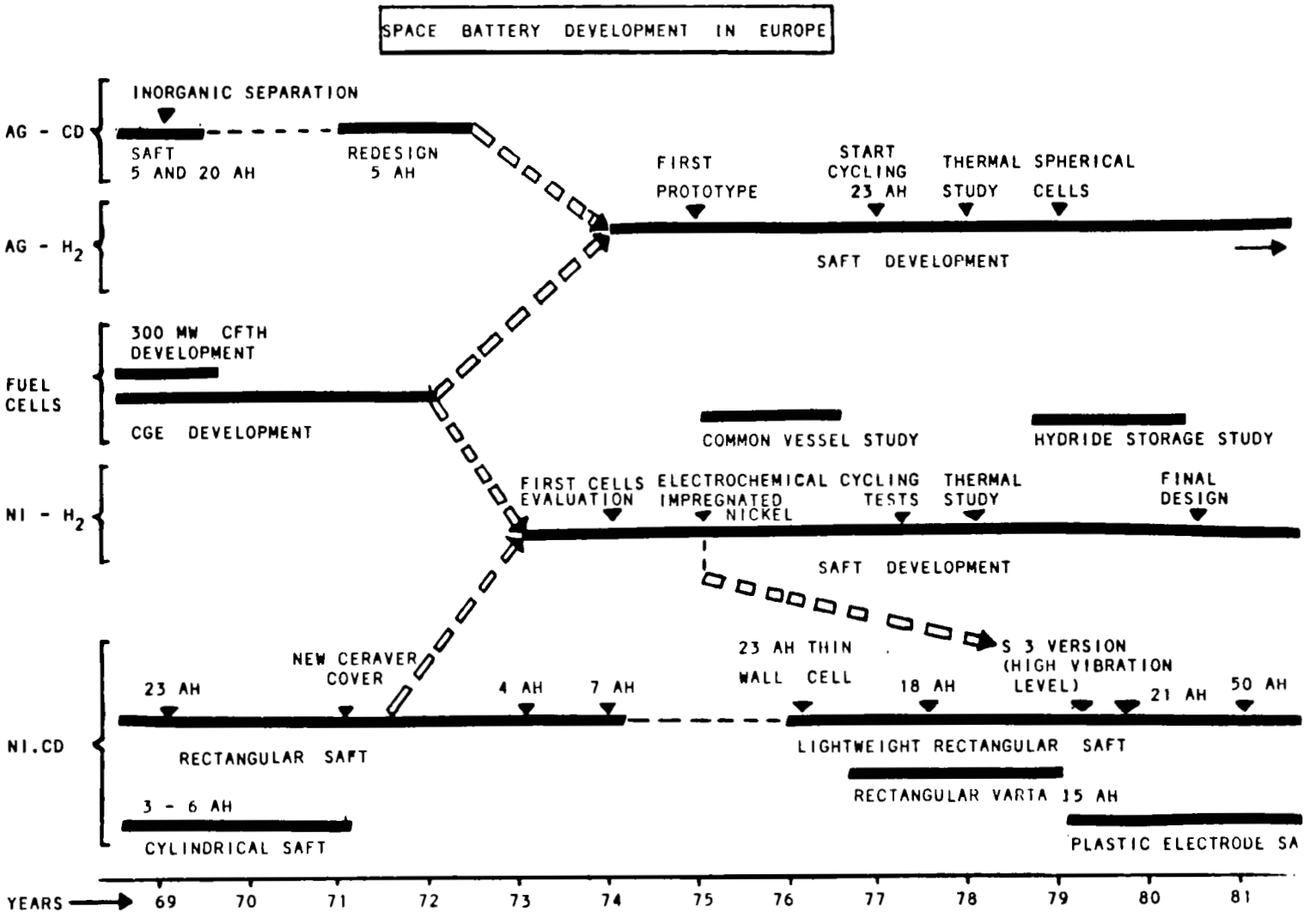

SPACE BATTERY DEVELOPMENT IN EUROPE
AG - CD
INORGANIC SEPARATION
SAFT
5 AND 20 AH
REDESIGN
5 AH
AG - H_2
FIRST
PROTOTYPE
START
CYCLING
23 AH
THERMAL
STUDY
SPHERICAL
CELLS
SAFT DEVELOPMENT
FUEL
CELLS
300 MW CFTH
DEVELOPMENT
CGE DEVELOPMENT
COMMON VESSEL STUDY
HYDRIDE STORAGE STUDY
NI - H_2
FIRST CELLS
EVALUATION
ELECTROCHEMICAL
IMPREGNATED
NICKEL
CYCLING
TESTS
THERMAL
STUDY
FINAL
DESIGN
SAFT DEVELOPMENT
NI.CD
NEW CERAVER
COVER
23 AH
4 AH
7 AH
23 AH THIN
WALL CELL
S 3 VERSION
(HIGH VIBRATION
LEVEL)
18 AH
21 AH
50 AH
RECTANGULAR SAFT
LIGHTWEIGHT RECTANGULAR SAFT
RECTANGULAR VARTA 15 AH
3 - 6 AH
CYLINDRICAL SAFT
PLASTIC ELECTRODE SA
YEARS
69
70
71
72
73
74
75
76
77
78
79
80
81

Figure 3-50

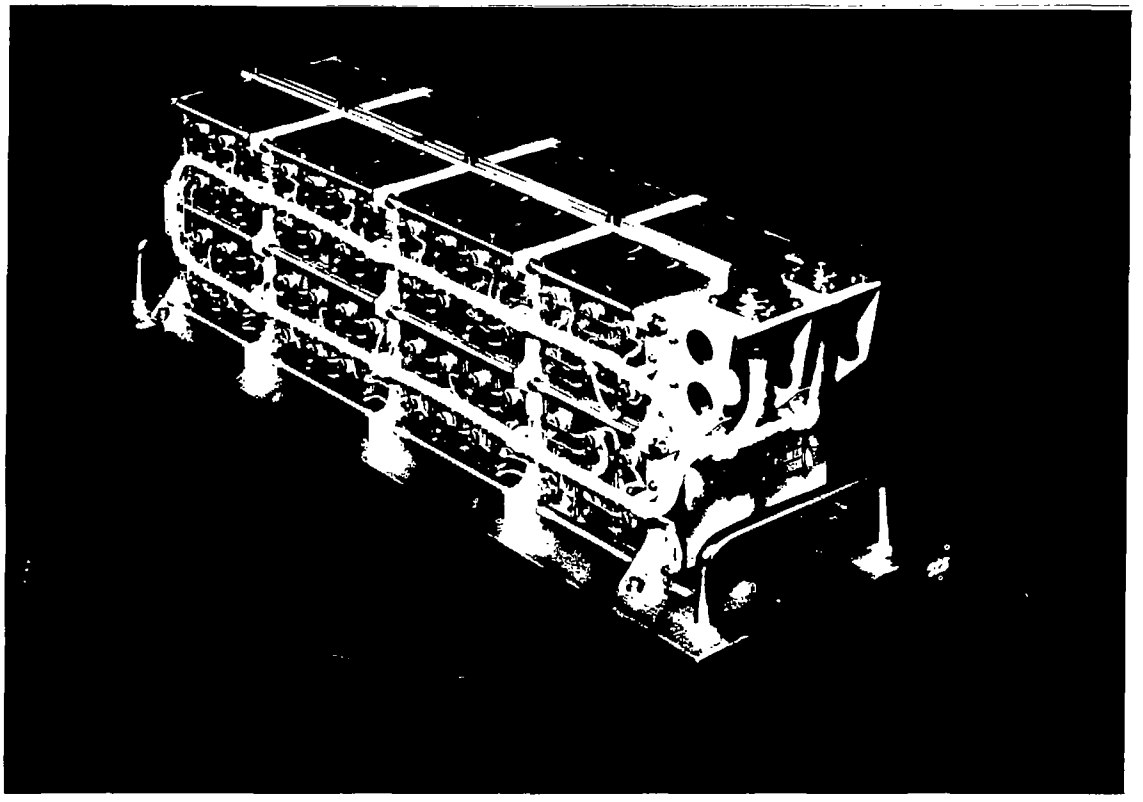


Figure 3-51

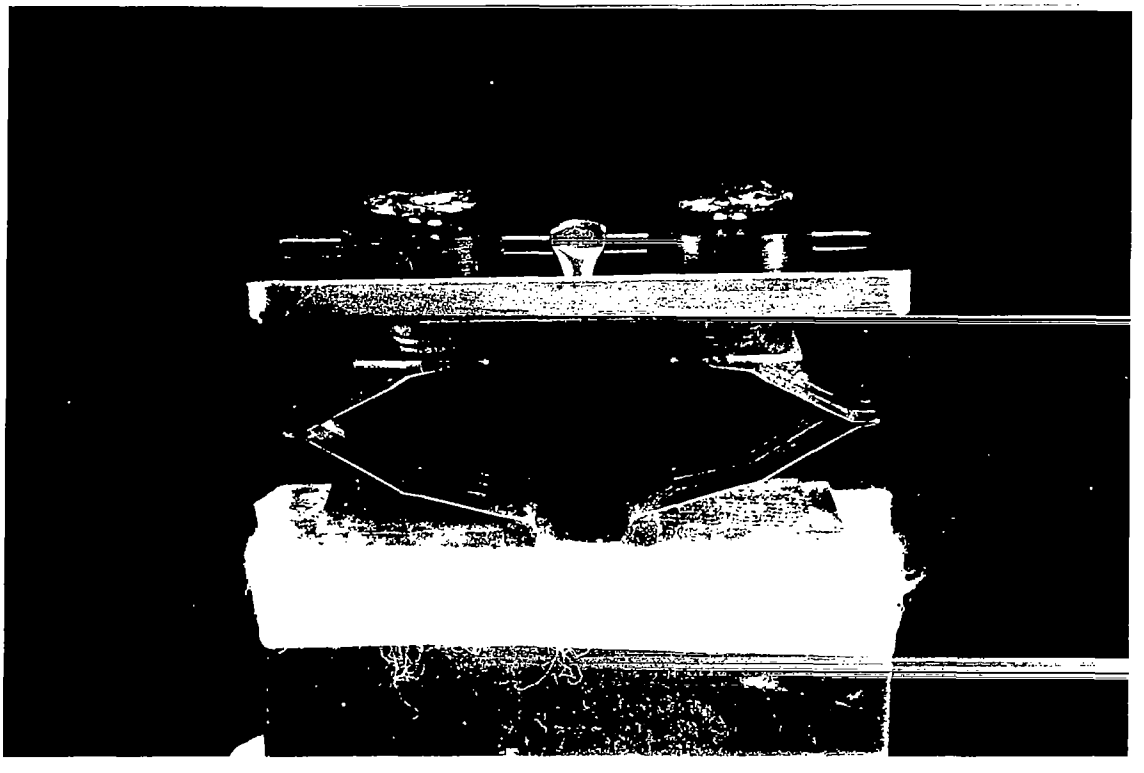


Figure 3-52

SUMMARY PROCEDURE

NI-CD CELL QUALIFICATION SPECIFICATIONS - VO S 3 SERIES

1. VISUAL INSPECTION + LEAK TEST
2. STANDARD CAPACITY
3. LOW TEMPERATURE CAPACITY (-20°C)
4. HIGH TEMPERATURE CAPACITY (30°C)
5. OVERCHARGE
6. CHARGE RETENTION
7. MECHANICAL TESTS
8. CHARGE RETENTION
9. INTERNAL RESISTANCE
10. STANDARD CAPACITY
11. LEAK TEST

NOTE : UNLESS OTHERWISE STATED ALL TESTS ARE AT 20°C.

1. LINEAR ACCELERATION

   ± 20 G 1 MIN/AXIS X, Y, Z

2. VIBRATION SINUSOIDAL (2 OCT/MIN)

5 - 15 HZ	11 MM. DISP.	
15 - 35 HZ	10 G.	
35 - 60 HZ	20 G.	
60 - 70 HZ	10 G.	
70 - 100 HZ	7 G.	

3. VIBRATION RANDOM

UP TO 100 HZ	+ 3 DB/OCT.
100 - 240 HZ	1 G^2/HZ
240 - 1000 HZ	- 6 DB/OCT.
1000 - 2000 HZ	0.058 G^2/HZ

TOTAL GRMS = 22
DURATION 5 MIN/AXIS

Figure 3-53

(SAFT INFO)

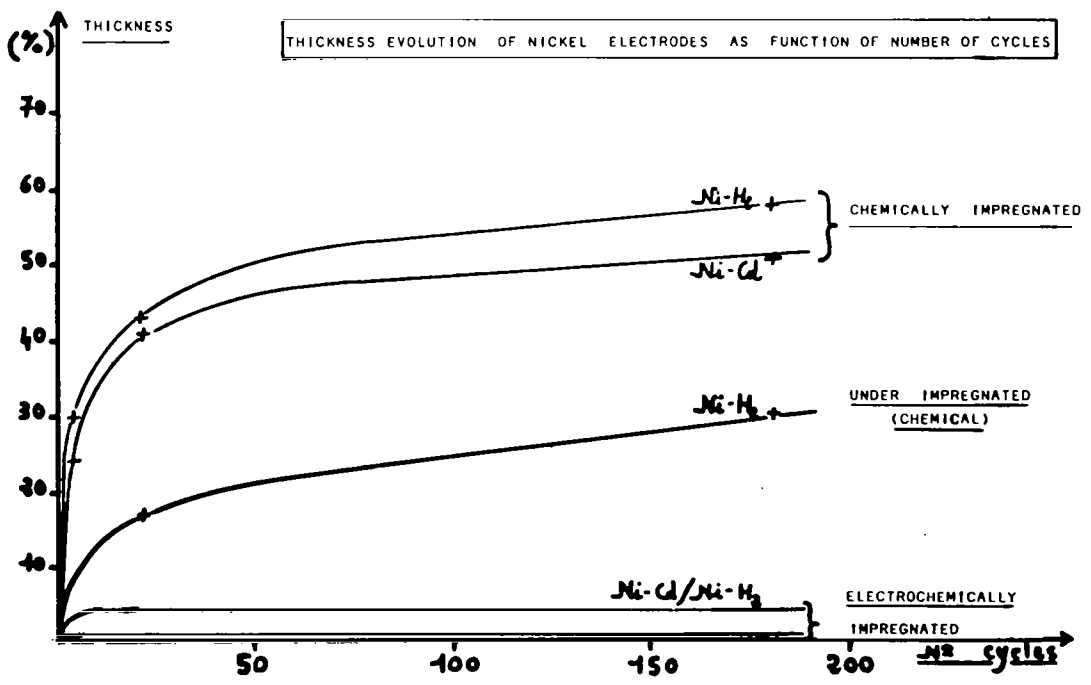


Figure 3-54

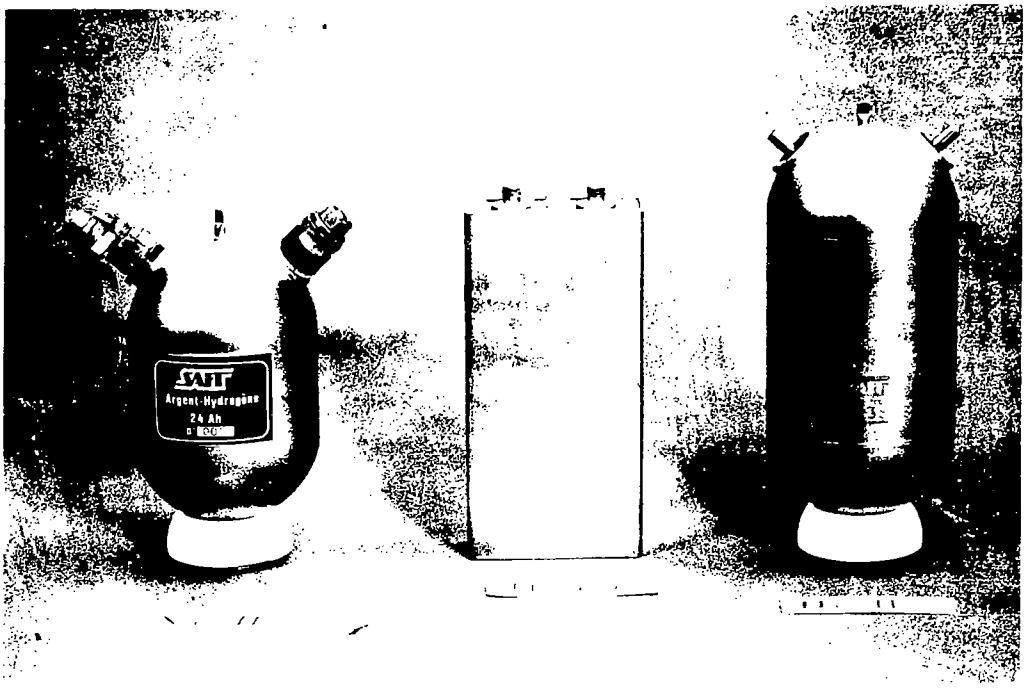


Figure 3-55

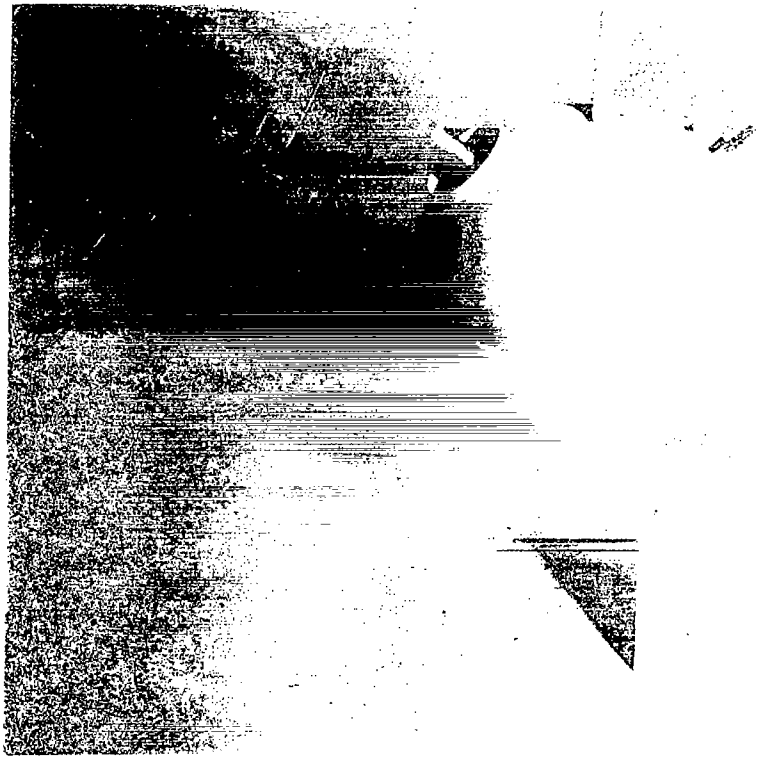


Figure 3-56

COMPARATIVE WEIGHTS - METAL-HYDROGEN AND NICKEL CADMIUM

	NICKEL HYDROGEN (25 AH)	SILVER HYDROGEN (75 Ah)		NICKEL CADMIUM 23 AH (53 TYPE)
		1ST GENERATION	2ND GENERATION	
POSITIVE ELECTRODES	250 (40.2%)	71 (18%)	71 (23.6%)	292 (29.05%)
NEGATIVE ELECTRODES	54 (8.7%)	27 (6.9%)	18 (5.9%)	390 (38.8%)
SEPARATOR	8 (1.2%)	18 (4.6%)	12 (4.0%)	26 (2.6%)
ELECTROLYTE	100 (16.1%)	78 (19.8%)	50 (16.6%)	110 (10.95%)
CONTAINER + TERMINALS	150 (24.1%)	160 (40.6%)	120 (39.9%)	183 (18.2%)
MISCELLANEOUS HARDWARE	60 (9.7%)	40 (10.1%)	30 (10.0%)	4 (0.4%)
TOTAL (GRM.)	622	394	301	1005
VOLUME (CM^3)	635	469	268	336
ENERGY DENSITY (WH/KG)	50	70	91	35
VOLUME EFFICIENCY (WH/CM^3)	49	59	103	99

Figure 3-57

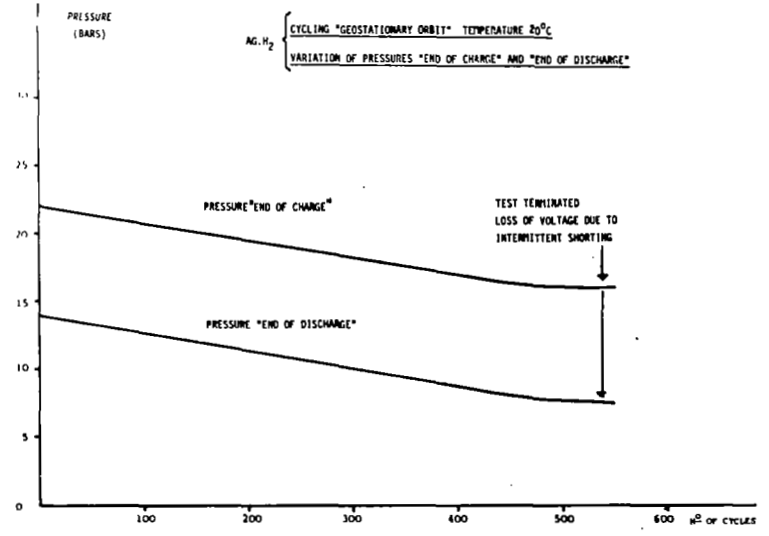


Figure 3-58

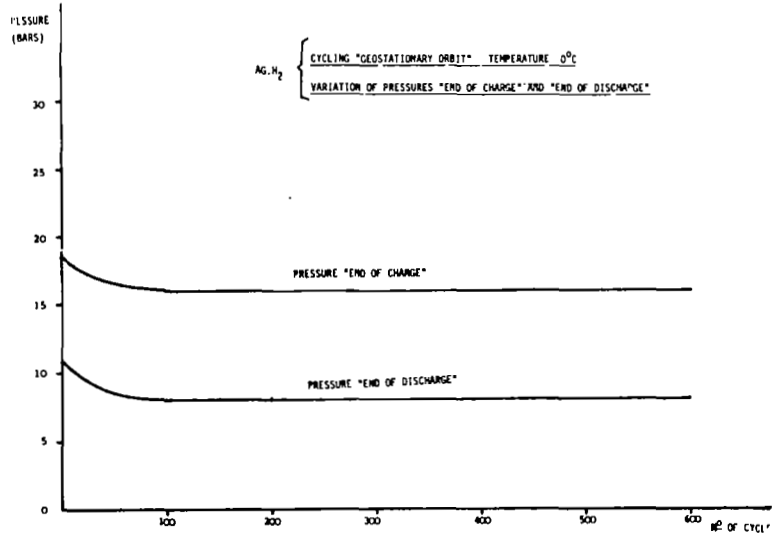


Figure 3-59

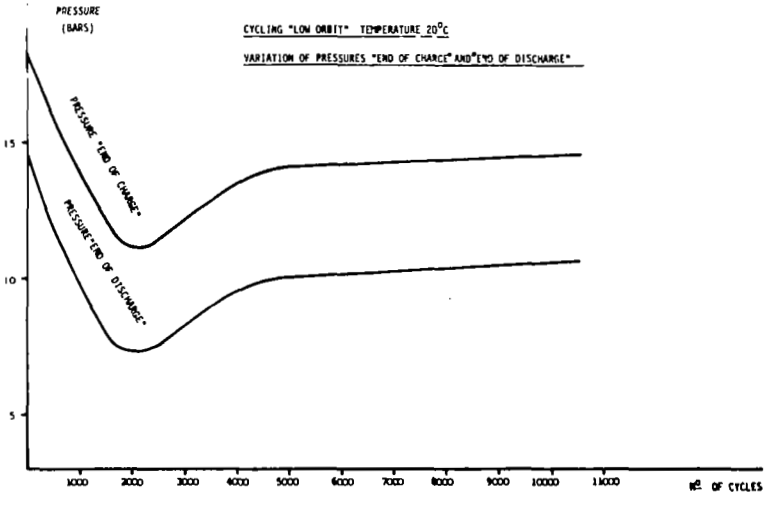


Figure 3-60

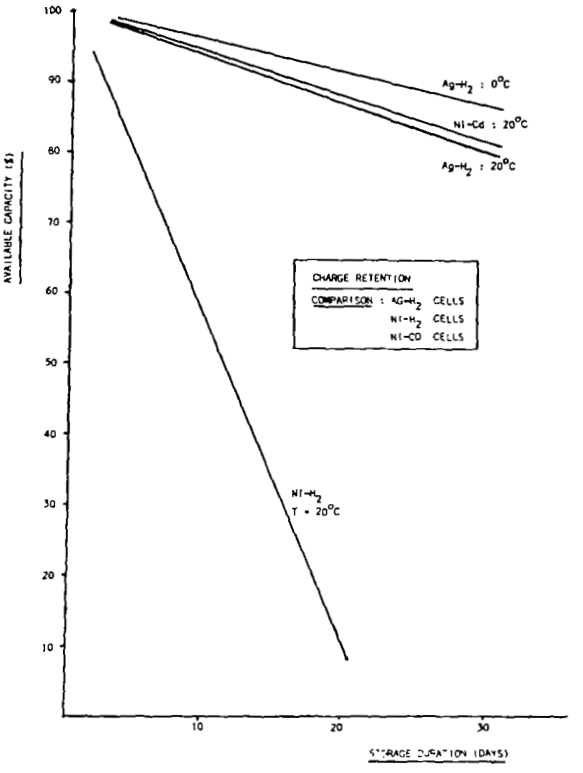
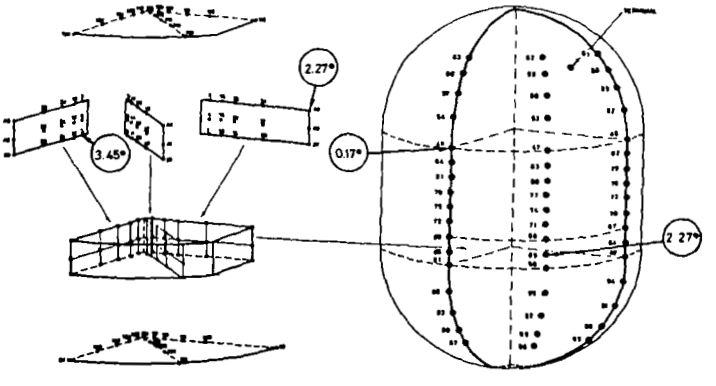


Figure 3-61



$Ag.H_2$ - CELL. TEMPERATURE EXTREMES FOR ONE WATT DISSIPATION. CELL IN CALORIMETER.

Figure 3-62

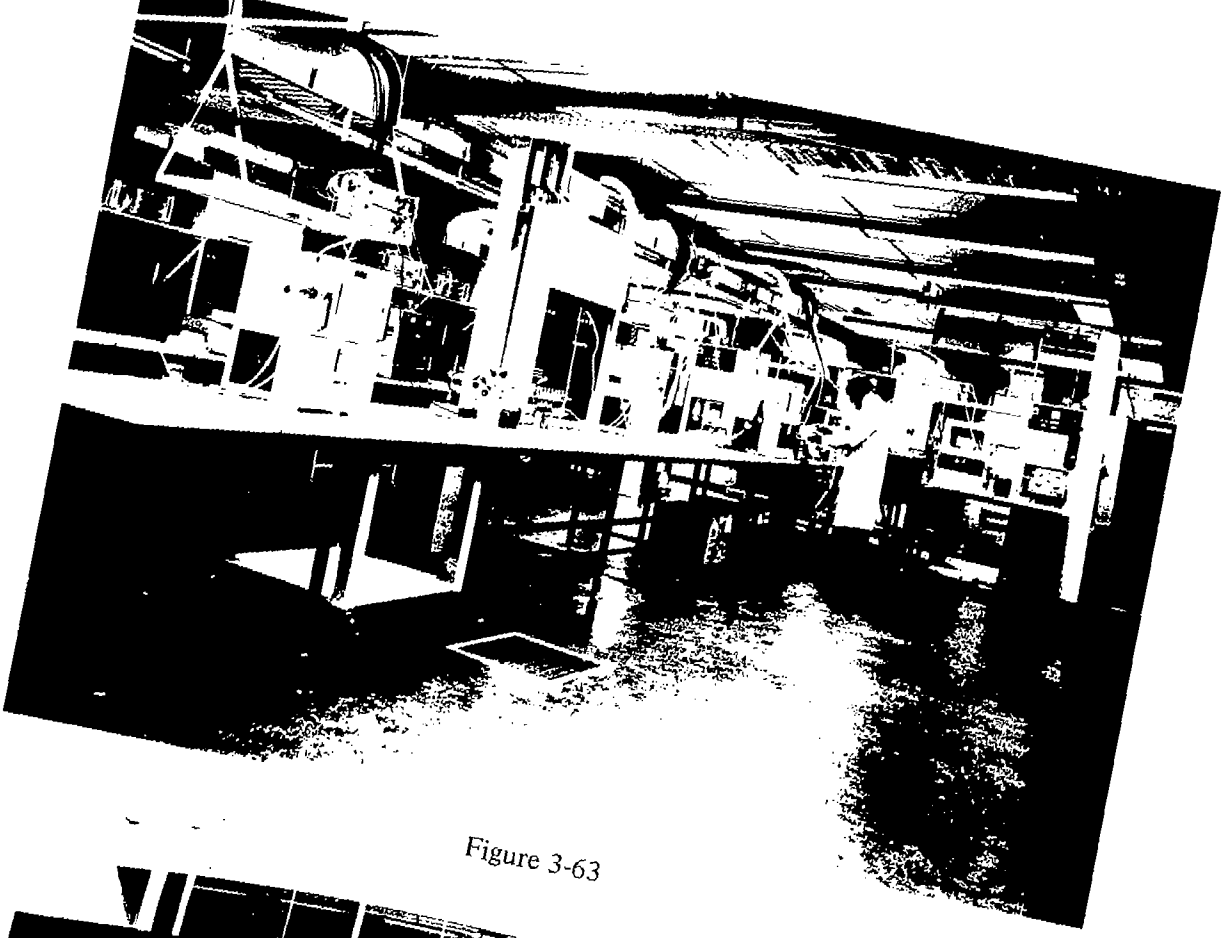


Figure 3-63

Figure 3-64

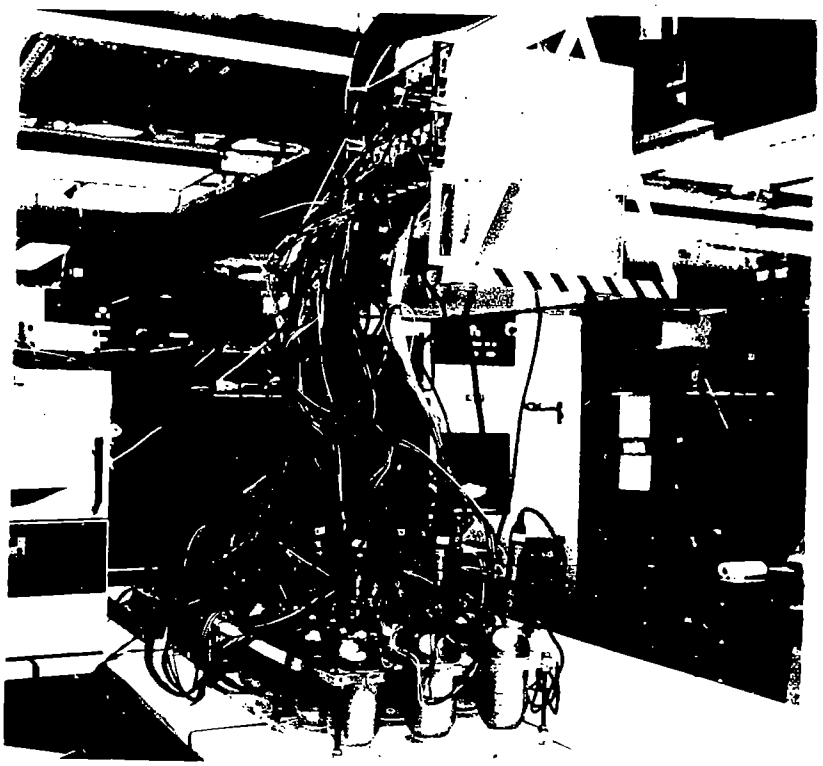


Figure 3-65

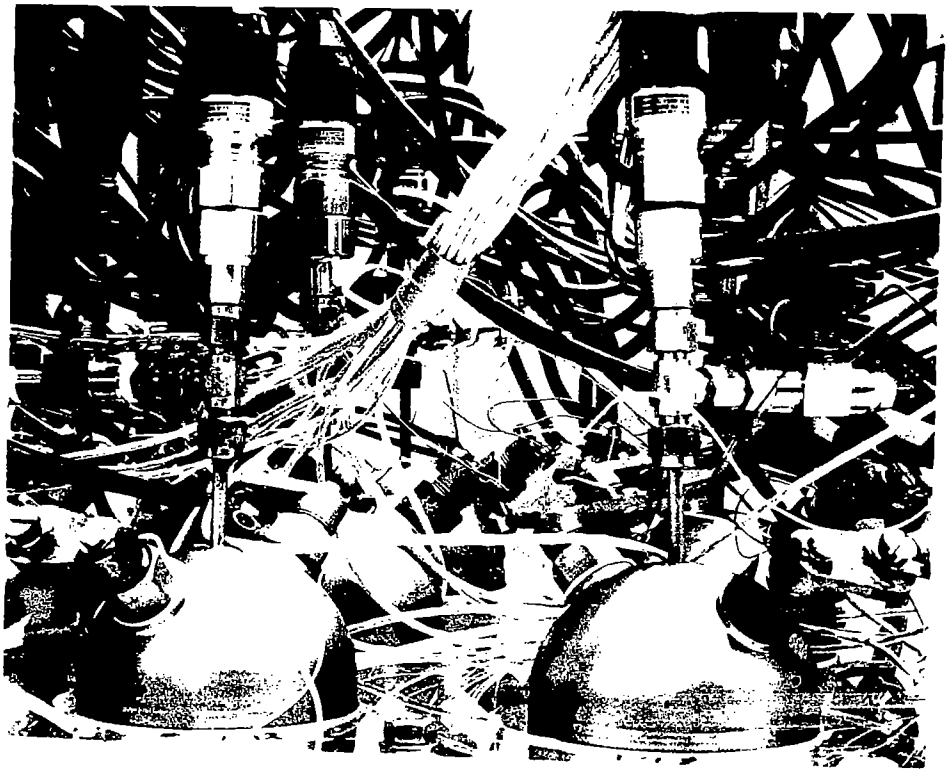


Figure 3-66

BATTERIES USED ON ESA SPACECRAFT

SATELLITE	MISSION	LAUNCH	ORB.LIFE (YRS)	BATTERY TYPE	MANU-FACTURE	REMARK
ESRO II/IIA	COSMIC RAYS	MAY 67/ MAY 68	3	1 x 16 C, 3 AH NI.CD	GULTON	3 YEAR MISSION, NO ANOMALY
ESRO 1A	AURORAL/ IONOSPHERE	OCT 68	2	1 x 16 C, 3 AH NI.CD	GULTON	2 YEAR MISSION, NO ANOMALY
HEOS 1/2	SCIENTIFIC	DEC. 68/ JAN 72	7/2	1 x 19 C, 5AH 1 x 21 C, 5AH AG.CD	YARDNEY	2 YEAR MISSION, NO ANOMALY
TD 1	ASTRONOMY	MARCH 72	2	1 x 16 C, 15 AH NI.CD	GULTON	2 YEAR MISSION, NO ANOMALY
ESRO IV	IONOSPHERE	NOV. 72	2	1 x 20 C, 6 AH NI.CD	SAFT	CYLINDRICAL CELLS
COS - B	GAMMA RAYS	AUG. 75	4	1 x 18 C, 6 AH NI.CD	SAFT	CYLINDRICAL CELLS
GEOS I/II	MAGNETO-SPHERE	APRIL 77/ JULY 78	1+	1 x 14 C, 16 AH AG.CD	YARDNEY	NO ANOMALY
OTS I/II	EXPERIMEN-TAL COMM.	SEPT. 77/ MAY 78	1	2 x 14 C, 18 AH NI.CD	SAFT	NEW BATTERY MANAGEMENT TECHNIQUE
ISEE - B	MAGNETO-SPHERE	OCT. 77	2	1 x 16 C, 10 AH AG.CD	YARDNEY	BATTERY FAILED AFTER PREDICTED 2½ YEARS
METEOSAT 1	METEO. (GEOST.)	NOV. 77	2	1 x 16 C, 7 AH NI.CD	SAFT	SEE NOTE
MARECS A, B, C	MARITIME OPERATIO-NAL	80/81/82	(7)	2 x 28 C, 23 AH NI.CD	SAFT	NOT YET LAUNCHED
ECS 1/2	COMMUNI-CATION OPERATIO-NAL	81/82	(7)	2 x 28 C, 23 AH NI.CD	SAFT	
METEOSAT 2, 3	METEO. OPERATIO-NAL	80	(5+)	2 x 16 C, 7 AH NI.CD	SAFT	
SIRIO 2	EXPERI-MENTAL	81	(2)	1 x 23 C, 4 AH NI.CD	SAFT	
EXOSAT	GAMMA RAYS	81	(2)	2 x 16 C, 7 AH NI.CD	SAFT	

NOTE : CAPACITY REDUCED FROM 8 to 4.5 AH AFTER 2 YEARS IN ORBIT : CAUSE OF DEGRADATION LIES IN BATTERY MANAGEMENT APPROACH (RECOVERY POSSIBLE)

Figure 3-67