



# **Communications Research Centre**

**SECONDARY BATTERIES FOR SATELLITE USE**

by

**W.D. EDWARDS**

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Department of  
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Ministère des  
Communications

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**OTTAWA, DECEMBER 1976**

COMMUNICATIONS RESEARCH CENTRE

DEPARTMENT OF COMMUNICATIONS  
CANADA

SECONDARY BATTERIES FOR SATELLITE USE

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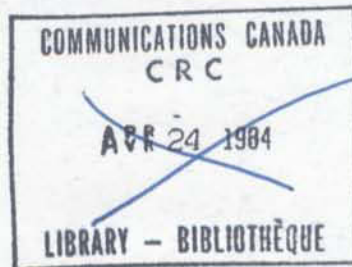
W.D. Edwards

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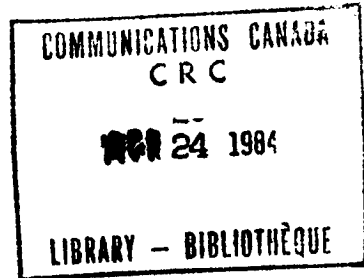
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# SECONDARY BATTERIES FOR SATELLITE USE

by

W.D. Edwards

## ABSTRACT

*The relative merits of nickel/cadmium (Ni/Cd), nickel hydrogen (Ni/H<sub>2</sub>) and silver/hydrogen (Ag/H<sub>2</sub>) batteries as sealed units for satellite use have been examined.*

*It is concluded that the state-of-the-art with respect to Ni/H<sub>2</sub> cells is not sufficiently advanced to justify their use as main power sources on Canadian satellites within 5 years.*

*At the present time it appears to be much more cost effective to improve the reliability and life of Ni/Cd batteries than to try to replace them with high energy per lb Ni/H<sub>2</sub> batteries.*

*The background, desirability and economics of manufacturing satellite batteries in Canada are discussed and recommendations made.*

## 1. INTRODUCTION

All the nickel cadmium batteries used in the Canadian satellites have come from the U.S.A. For CTS there was effectively only one suitable manufacturer of space qualified batteries. New battery systems are appearing. What policy should DOC/CRC follow to maintain a source of reliable space batteries?

In the past the expertise of the electrical power sources directorate of Defence Research Establishment Ottawa (EPSD of DREO) was used to ensure the required battery reliability. Their personnel solved many problems by working closely with co-operative U.S. suppliers. What should their future role be?

In the following pages sealed battery problems and their chance of solution are discussed. Some specific research tasks which could be undertaken by DREO are suggested. The presently attainable cycle life of Ni/Cd batteries at large depths of discharge (D.O.D.) is inadequate. Nickel hydrogen (Ni/H<sub>2</sub>) batteries have been suggested as an alternative and their relative position and impact on the Canadian Space Program are therefore examined.

The possibility of satellite battery manufacturing "spin-off" in Canada is explored. The actual course which should be followed depends upon policy decisions which have not yet been defined. The alternatives are therefore presented in the form of decision trees.

## 2. BATTERIES FOR SATELLITE USE, THEIR CHEMISTRY AND PROBLEMS OF OPERATION

### 2.1 INTRODUCTION

In batteries for satellite use we need:

- a) Reliability
- b) High energy density – watt hrs. per lb.
- c) High energy per unit volume
- d) Ability to deliver some 80% of capacity over several thousand cycles
- e) Efficiency, to reduce thermal problems
- f) A sealed system
- g) Good charge retention

The NiCd battery has been in use for some seventy years and more recently has been the first choice for satellite battery supplies. The developmental effort which has gone into this system, particularly during the "satellite period", has produced a system in which the only real problem is item (d). Continuing research has improved and is expected to continue to improve the performance in this regard. The relevant physical-chemical considerations are discussed in this section. As the depth of discharge possible for a given number of cycles increases, the effective energy density possible for a given mission may be increased. This point should be kept in mind when tables of energy density for a variety of systems are studied (e.g. Figure 4).

The cost per pound of launch into orbit is high and it is therefore desirable to maximize the energy per pound of the battery system. New batteries which offer higher energy densities per pound are needed. The nickel hydrogen system is the favoured research vehicle for satellite application at the present time. A patent by B.I. Tsenter et al<sup>1</sup> of Leningrad filed 25 February, 1971 was probably a big stimulus for a flurry of activity in the "West" – see papers by Klein<sup>2,3</sup>, Dunlop<sup>4</sup>, Font<sup>5</sup>, Miller<sup>6,7</sup>.

Whilst for large batteries the Ni/H<sub>2</sub> system does offer a greater energy density than Ni/Cd, the other properties necessary for a satellite battery--items (c) to (g) at least--must also be considered. The particular mission for which the batteries are considered will determine the relative importance of these items, e.g., a large-cycle life is not important for a short duration mission.

The battery types and their chemistry are therefore considered in some detail in order to generate an awareness and appreciation of their respective problems.

### 2.2 BATTERY TYPES

Primary batteries deliver their energy on a once only basis. When they are used on rockets or satellites it is for their high energy density and high current capabilities together with good reliability. They will not be considered further as no use is foreseen for them in the Canadian satellite program.

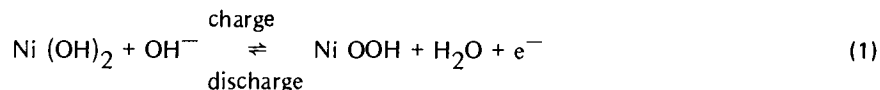
Secondary batteries which are used and then recharged are more suitable for most satellite applications.

## 2.3 SECONDARY BATTERIES OR RECHARGEABLE SYSTEMS – THEIR CHEMISTRY

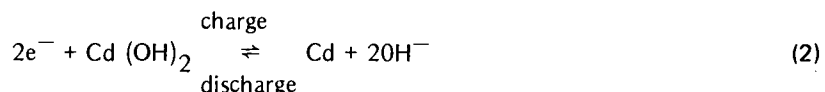
The best known is the lead acid system. Its relatively low watt hrs. per lb. and normally vented construction render it unsuitable for satellite use. The sealed Ni/Cd system is the most widely used battery for satellite power systems. The battery was patented in 1899 and manufacture commenced in 1904.

### 2.3.1 The Nickel-Cadmium (Ni/Cd) Cell

The charge/discharge reactions of the Ni/Cd cell are first considered. This is an oxidation reduction system. At the positive, nickel electrode an oxidation process occurs on charging and is usually stated as:



Ni goes from the divalent to the trivalent state on charge and on discharge the reverse occurs. At the negative cadmium electrode a reduction process occurs on charge and is usually represented by:



and on discharge the reverse reaction occurs. [OH<sup>-</sup> is an oxidizing agent and H<sub>2</sub> the classical reducing agent.]

A solution of approximately 26% KOH is used as electrolyte.

#### 2.3.1.1 Overcharge

If the charging process is continued and all of the Cd(OH)<sub>2</sub> is converted to cadmium (eq. 2) before the positive nickel electrode is used up (negative limited), water is electrolysed and hydrogen is given off at the cathode. viz:



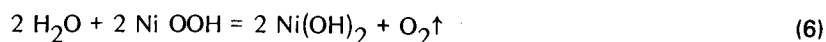
In the absence of any catalytic recombination devices the reaction is essentially irreversible and a build-up of internal pressure results if the cell is sealed. If the system is positive limiting, i.e., the nickel electrode plaque is used first, the reaction



occurs at the nickel electrode on overcharge. The oxygen may diffuse to the negative electrode and the following reaction takes place:

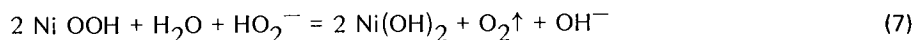


This prevents a build-up of oxygen pressure within the cell. When charging ceases, self-discharge occurs because of the decomposition of the active material:

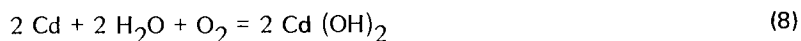




or, in the presence of peroxy ion



and at the negative electrode if oxygen is present:



This gives a reduction in  $\text{O}_2$  pressure. From equations (3) and (4) it is seen that once the active plate material is used up (fully oxidised or reduced, as appropriate) then the electrolysis of water takes place with  $\text{O}_2$  evolved at the anode and hydrogen at the cathode.

The oxygen evolution at the positive electrode is more temperature sensitive than the normal charging reaction and so oxygen evolution becomes appreciable at an earlier stage of the charging cycle as the temperature rises.

To ensure that hydrogen is not generated (reaction 3), the capacity of the cadmium electrode is designed to be much greater than that of the nickel electrode, i.e., the negative to positive plate capacity ratio must be  $> 1$ . The cadmium electrode is also designed with a large area to facilitate the recombination of oxygen.

The reactions 6, 7 and 8 continue at measurable rates until the cell is discharged, e.g. 90% of the initial charge is left after 8 days at  $20^\circ\text{C}$ . A more rapid self-discharge takes place in the presence of the nitrate ion.

### 2.3.1.2 The Nitrate – Nitrite Shuttle

A rapid self-discharge observed in some Ni/Cd batteries was traced to the presence of an impurity – the nitrate ion. Cadmium metal has been shown to reduce the nitrate ion ( $\text{NO}_3^-$ ) to the nitrite ion ( $\text{NO}_2^-$ ) and the oxidised positive plate material (nominally Ni OOH) oxidises the nitrite ion to the nitrate ion. The ( $\text{NO}_3^-$ ), ( $\text{NO}_2^-$ ) couple can conduct a shuttle between the plates resulting in self-discharge of the cell. The nitrate may remain from the initial process of forming the electrodes.

### 2.3.1.3 Overdischarge

If current is forced through the cell after discharge the cell potential reverses. Hydrogen, oxygen, or both, can be evolved. At the nickel electrode



and at the cadmium electrode



This is as expected from the previous considerations of the positive and negative limited cases, respectively, with a reversal of electrode roles. The oxygen may recombine in the subsequent charging process, but hydrogen does not recombine at useful rates without a catalyst.

The oxygen recombination rate depends upon the availability of reaction sites and hence also the ability of the gas to penetrate the cadmium electrode. The electrolyte is therefore just sufficient to moisten the separator as flooding would seriously reduce the oxygen recombination rate. Because of this, such sealed cells are often called 'starved electrolyte' cells.

### 2.3.1.4 The Separators

The individual electrode systems must be separated to reduce direct chemical reaction and yet there must be a low resistance conducting path across the electrolyte-separator-electrolyte layers. The separator pore size must be small enough to prevent dendritic growth between electrodes and also small enough to restrict a general chemical exchange. However, the separator must be sufficiently permeable to prevent build up of high gas pressures. Ideally, the separator should be mechanically strong, an electrical insulator and chemically inert. Nylon (Pellon) is used but oxidises fairly rapidly at elevated temperatures and for this reason polypropylene is substituted for high temperature applications. A wetting agent is used to improve the electrolyte absorption of the polypropylene. The wetting agent may oxidise slowly, leading to a loss of electrolyte from the separator and resulting in an increased cell resistance. Nylon as a separator material can absorb and retain a greater quantity of electrolyte than polypropylene and is therefore generally preferred. Methods to improve the absorbtivity and wettability of polypropylene are needed.

### 2.3.1.5 The Electrodes

Finely divided nickel is spread over a grid of nickel or nickel-plated steel. This is sintered at just below the melting point of nickel, preferably in a hydrogen atmosphere. It is then coined into a plaque to strengthen it and to eliminate sharp edges etc., which could cause shorts. The porosity is now 60–80%. The plates are then soaked in nickel nitrate (cadmium nitrate for the negative). Immersion in potassium hydroxide in the presence of a polarizing current precipitates the hydroxides. This is done in several stages. Additives are used to improve charge retention and capacity.

As discussed, the negative to positive plate capacity ratio must be greater than one in order to avoid hydrogen evolution at the negative electrode on overcharge. A second requirement is that the negative electrode available surface area be sufficient to effect recombination of all oxygen which may be generated at the positive plate. These two requirements are particularly important for sealed cells in which any gas generated causes an increase in internal pressure.

The factors which affect the negative/positive ratio are now considered in more detail and are related to the nominal value of 1.7 chosen for CTS.

- a) The negative cadmium (Cd) plate is precharged to some extent. It is difficult to obtain a good explanation from manufacturers as to why and to what extent this is done. Several reasons have been given. Precharge is used to compensate to some extent for the fact that the negative plate is not as efficient as the positive, to reduce the extent of capacity fading as the cell ages and to reduce the voltage and pressure on overcharge. The exact amount of plate oxidation during assembly also varies to some extent depending upon time of assembly, temperature, etc. An apparent ratio of 1.7 is therefore probably reduced to an effective ratio of <1.5.
- b) The variation of effective surface area with the conditions of charge/discharge cycling must be considered. This variation of surface area affects both electrodes. With an approximately 10% variation in effective capacity of each electrode the worst case can lower the effective ratio to ~ 1.3 from 1.5.
- c) The amount of electrolyte present in the interstices of the negative electrode affects the availability of the electrode surface for oxygen recombination. A weightless environment complicates calculations regarding the relative distribution of the electrolyte e.g. whether within the separators, electrode interstices or elsewhere in the cell volume.
- d) The CTS battery specification calls for a C/10 overcharge capability for 6 months in the temperature range  $-5^{\circ}\text{C}$  to  $+40^{\circ}\text{C}$ . The recombination rate of oxygen decreases as the temperature decreases; to compensate for this, more negative plate area should be provided. If not the effective plate ratio at the  $-5^{\circ}\text{C}$  end of the temperature range will be reduced.

- e) At low temperatures the reaction at the negative electrode is affected so that the charge acceptance is also reduced. At the positive electrode the formation of a higher valence nickel oxide at the lower temperatures causes an increase in positive plate capacity, i.e., at low temperature the effective negative-to-positive plate capacity ratio is further reduced.
- f) The activity (capacity) of the nickel plate may increase with time.
- g) The presence of carbonate and other impurities may also reduce the effective area of the plates. These factors, d) to g), further reduce the effective ratio to approx. unity or less.

In view of all these factors, which are unlikely to be present simultaneously, the choice of a nominal 1.7 for the negative/positive capacity ratio for CTS appears reasonable.

It is of interest to reduce the negative to positive plate ratio to as near unity as possible in order to maximize the energy density. Reduction is possible but it should be appreciated that by reducing the ratio the operating limits must be restricted if the "safety factor" is to remain the same. If the battery was maintained at a constant temperature it would ease the problem considerably — see points d) and e). If electronic control circuits were added to restrict the charge and discharge rates the ratio could be further reduced — see point b). Improved manufacturing techniques — see point a), point g) and perhaps points b) and f) — would allow for a reduction in the plate ratio without any operating penalty. That is, improved knowledge of the charge and discharge mechanisms and chemistry will lead to higher effective energy density batteries which means reduced battery weight for a given mission.

#### 2.3.1.6 Seals

At least one metal to insulator seal per cell is needed to make contact to the electrodes in a hermetically sealed cell. When the cells are used to make up a battery it is preferable to have both electrodes insulated from the case. The electrode seals must therefore insulate the electrodes from the case, they must resist attack by the KOH electrolyte and they must be leak tight. Glass-to-metal and ceramic-to-metal seals have been used.

#### 2.3.1.7 Difficulty of Predicting Capacity, Memory Effect

On discharge, at the negative electrode for example, the cadmium is oxidised and cadmium hydroxide is deposited. The reverse occurs on charge. At low temperature and high charge rates the deposits are very fine whilst at slow charge rates and higher temperatures a coarser deposit results. The discharge and charge properties depend upon the area available and so it is seen that charge and discharge current magnitudes, temperatures, etc., affect the subsequent cell operations. The cell life is increased by reducing the discharge rate and maintaining the temperature between 0°C and 25°C. It has also been observed that a relatively rapid charge rate increases the cell cycle life.

#### 2.3.1.8 Energy Density

The available capacity depends to some extent upon the charge and discharge rates used. Typical figures quoted are from 15–23 wt. hrs. per lb. The basic cells used in CTS are 12 wt. hrs. per lb. and if the weight of the whole battery pack including heaters, etc., is considered, a figure of 9 wt. hrs. per lb. is found.

#### 2.3.1.9 Low Temperature Operation

The nickel/cadmium battery may be cooled to –65°F without freezing if a 30% KOH electrolyte is used. At –40°F (–40°C) the battery retains 50% of its room temperature capacity and will still accept charge, though at a slightly reduced rate.

### 2.3.1.10 Shelf Life

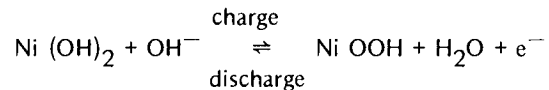
The nickel/cadmium battery has a shelf life of many years in either the charged or discharged state. For Northern use it is important to note that the battery is not damaged if frozen (not below  $-65^{\circ}\text{F}$ ) in the discharged state as is the lead acid battery.

### 2.3.2 The Nickel-Hydrogen (Ni/H<sub>2</sub>) Cell

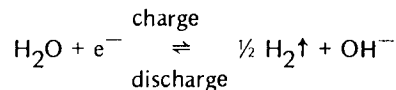
The sensitivity of the Ni/Cd battery to high over-charge and over-discharge rates is regarded as a serious disadvantage of the cell. Replacement of the cadmium electrode with a "hydrogen" electrode can avoid these problems. The hydrogen electrode has also a much greater cyclic life capability than either metallic cadmium or zinc of Ni/Cd and Ag/Zn cells.

The following reactions are usually stated as occurring in the Ni/H<sub>2</sub> cell:

At the nickel electrode

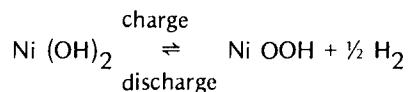


and at the hydrogen (negative) electrode

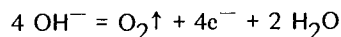


[The overcharge reaction on a Cd electrode.]

The overall reaction is written as



On charge there is production of hydrogen and the Ni/H<sub>2</sub> cell therefore operates under pressure which is typically in the range of 3–35 atmospheres (100 atmospheres in the Russian disclosure). On overcharge oxygen is evolved at the nickel electrode as for the case of the Ni/Cd cell:



in a positive limited system. The oxygen is electrochemically and chemically reduced at the hydrogen electrode so that stabilization of pressure occurs.

#### 2.3.2.1 Overdischarge

If the capacity is limited by the positive electrode, there is a possibility of continuous operation; the hydrogen evolved at the positive electrode (N.B. overdischarge) is immediately consumed at the negative electrode (this is the discharge reaction) and the pressure is constant. Limitation by the positive (nickel) electrode is assured because of the relative abundance of water in the electrolyte and the addition of hydrogen to the initially discharged cell.

### 2.3.2.2 The "Hydrogen" Electrode

The electrode carries a catalyst to help the recombination of  $H_2$  with  $O_2$  to give water. A number of variations involving platinum have been tried. The electrolyte is an aqueous solution of potassium hydroxide (~30%).

### 2.3.2.3 Loss of Capacity

Apart from the obvious mechanism of hydrogen loss from the pressurized cell there is possibility of capacity loss due to spontaneous reactions. The nickel oxides of the positive electrode and the chemisorbed oxygen on this electrode may be reduced by the hydrogen. It has been calculated that 40% of the  $Ni/H_2$  capacity may be lost in this manner – 20% in the first 24 hours due to the chemisorbed oxygen recombination. The results of Font and Goulard<sup>5</sup> showing this loss of capacity are reproduced in Figure 1. Broadly comparable results were presented at the August 1975 meeting of the Intersociety Energy Conversion Engineering Conference<sup>9</sup>. A copy of the results presented is shown in Figure 2. The mechanism is obviously not understood as Tsen<sup>1</sup> claims that the direct reduction of  $NiOOH$  by hydrogen is unlikely for kinetic reasons.

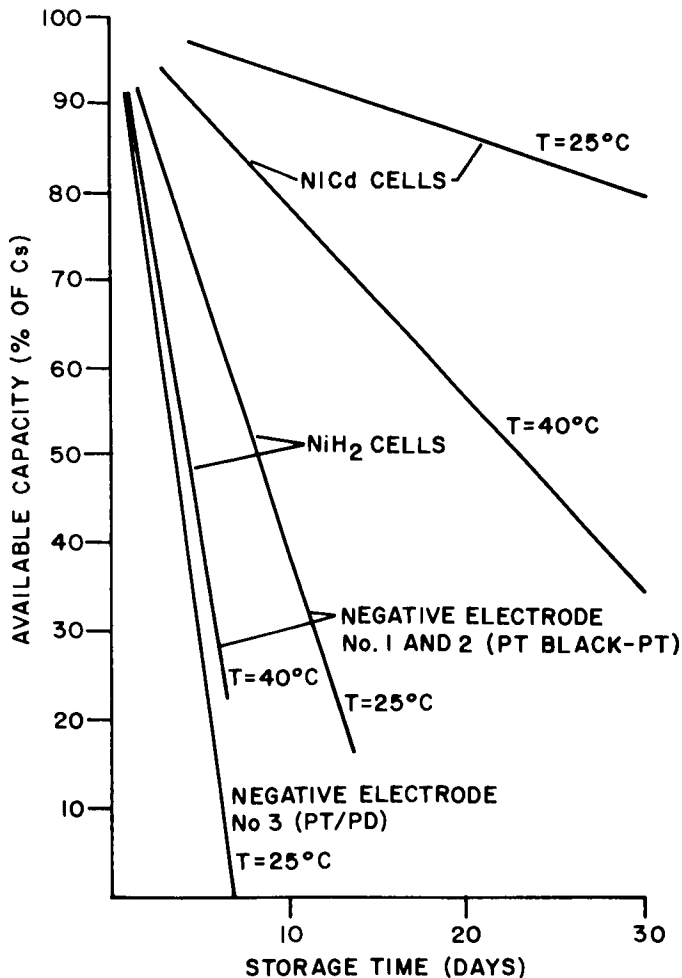


Figure 1.  $Ni-H_2$  Performance versus  $Ni-Cd$  Charge Retention vs Storage Time and Temperature for  $Ni Cd$  and  $Ni H_2$  Cells. (From Font & Goulard<sup>5</sup>)

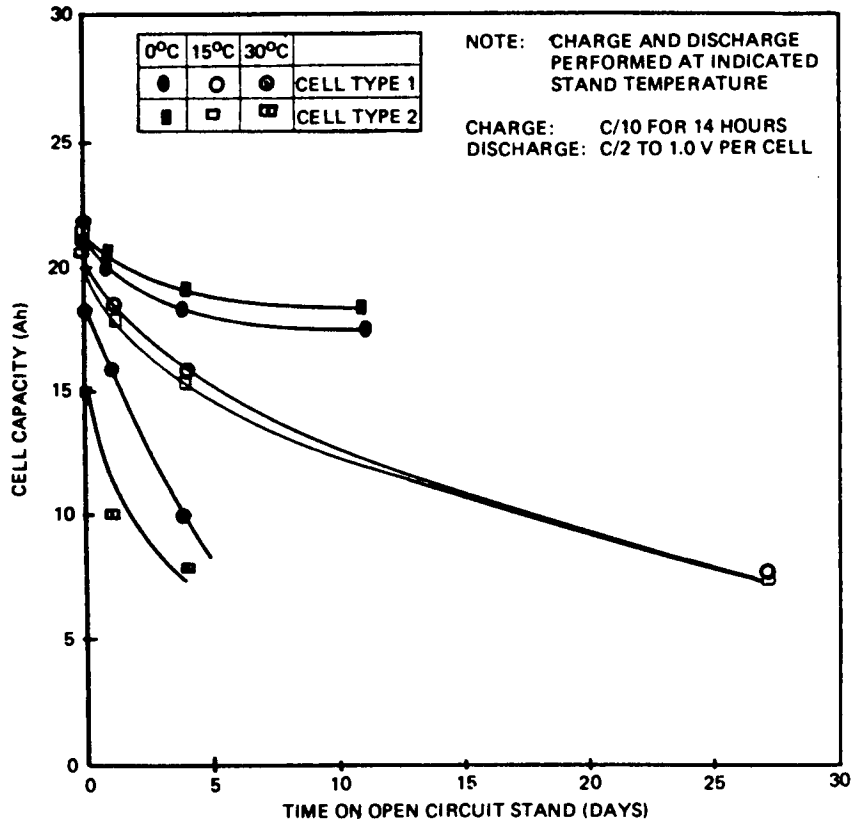
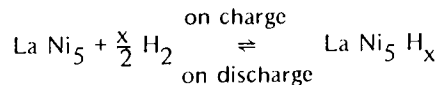


Figure 2. Nickel-Hydrogen Cell Capacity as a Function of Open Circuit Stand Time with Temperature as a Parameter (From Patterson & Sparks<sup>9</sup>)

### 2.3.3 Ni/H<sub>2</sub> with Lanthanum Nickelide (La Ni<sub>5</sub>) Absorber

The high internal pressure (~35 atmos) of a charged Ni/H<sub>2</sub> cell is a considerable disadvantage. The storage of hydrogen by chemical instead of by pressure methods leading to lower operating pressures would be a great improvement. The rare earth nickelide La Ni<sub>5</sub> offers such a possibility<sup>10</sup>:



At ~20°C the charge and discharge reactions now take place within a pressure range of approximately two atmospheres.

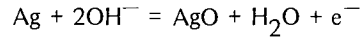
The absorption is exothermic, 7.2 kcal/mole H<sub>2</sub>. On discharge the cell generates 9 kcal/mole H<sub>2</sub> so that the heat of desorption may be readily supplied from within the cell. As far as can be ascertained from experiments reported to date, the La Ni<sub>5</sub> has been placed in a separate vessel isolated from the battery proper. There could be problems if the system were compacted since the absorption of H<sub>2</sub> by La Ni<sub>5</sub> may be inhibited by the presence of water or electrolyte.

### 2.3.4 The Silver Hydrogen (Ag/H<sub>2</sub>) Cell

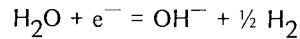
As with the Ni/H<sub>2</sub> system, there is a fuel-cell type hydrogen electrode and a high operating pressure range of 6.8 – 34 atmos. The system offers a slightly higher energy density than the Ni/H<sub>2</sub> system – ~40 watt hrs.

per lb. vs ~ 27 watt hrs. per lb., respectively. The achievable energy density is comparable with that of silver-zinc cells but by replacing the zinc with a hydrogen electrode an improvement in cycle life is obtained.

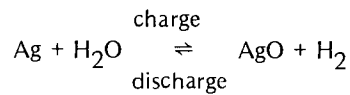
On the charge cycle we have



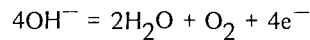
and



i.e. a net reaction



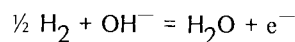
It is seen that there is a change of electrolyte concentration and a volume change of the silver electrode as the silver changes to the oxidised form. The total change is ~ 0.2 cc volume change per ampere-hour of capacity. On overcharge at the silver electrodes



The oxygen recombines at the hydrogen (platinum) electrode so that the gas pressure reaches a stable level.

#### 2.3.4.1 Overdischarge

The cell is designed to be positive limited and hydrogen evolved at the positive electrode is immediately consumed at the negative according to the reaction:



The system may be overcharged and cycled without substantial deterioration. Haas and Briggs<sup>11</sup> (Philco-Ford) are very enthusiastic about the silver hydrogen battery. They successfully carried out 600 deep discharge cycles (85%) at a 2C rate but with a noticeable drop in discharge voltage. They did not mention either the pressure problem or the possibility of shorts due to the migration of silver.

#### 2.3.4.2 Disadvantages of the Ag/H<sub>2</sub> Cell

The charge and discharge curves, i.e., voltage vs. time for a specific current are not flat and contain steps due to the changes from argentous to argentic oxide and vice versa.

Dendritic crystal growth can be a problem and may give rise to electrical shorts. The cycle life is significantly less than that of Ni/Cd cells.

Utilisation of the silver needs to be improved. Initially the utilisation of silver may be 2.4 gm/A hr. compared with a theoretical value of 2.014 gm of Ag/A hr. However, the utilisation of the silver drops with cycling and stabilizes at only 3.8 gms/A hr. The weight of a typical 25 A hr. battery described by Klein<sup>12</sup> (ERC) was 375 gms and 125 gms of this was the pressure vessel.

The battery systems just discussed are compared in Figures 3 and 4. The contents of Figure 4 are drawn from a number of sources. Some caution should be exercised in making comparisons because just what is included in a particular author's calculations of energy density is often not clear.

## 2.4 Ni/Cd AND Ni/H<sub>2</sub> PROBLEMS AND TIME FOR THEIR SOLUTION

A point of concern to this author is the extent of the validity of accelerated tests. Whilst accelerated tests of Ni/Cd batteries with emphasis on cycle life and apparently related depth of discharge are essential to obtain needed information, it should be noted that reactions taking place on a longer time scale are not properly accounted for, e.g., self-discharge effects. An additional consideration is that in comparisons of battery cycle life, etc., the number of cells involved is not always clear, i.e., the presentations imply that the reliability of a battery with one or two cells is the same as a battery with many cells in series.

### 2.4.1 Ni/Cd Cell Problems

As mentioned earlier this system was first patented in 1899, and the batteries have been manufactured in various forms since ~ 1904. The chemical reactions in the cell have been studied in detail but because the battery reactions are considerably more complicated than one might expect, the reactions at the positive electrode are still in some doubt (see P. Bauer<sup>13</sup> and Upton Thomas<sup>14</sup>).

In view of the long history of usage, study and apparent conservatism regarding improvements it is extremely hazardous to estimate times for problem solutions, especially from a position outside of the industry. The times obviously depend upon the motivation, talent, moral support, money and facilities available for the necessary research and development.

The possibility of solution of some of the problems is a more tangible approach. Some of the problems are considered below.

#### 2.4.1.1 The Separator

The most common separator is made of nylon. The separator must operate in an oxidising medium and as nylon oxidises slowly there is a deterioration in its properties which becomes pronounced at higher temperatures. For example at 100°C a nylon separator oxidises rapidly and fails in three weeks. The nylon separator should, therefore, be replaced in all high reliability cells and not just in high temperature cells.

Polypropylene is a possible answer; its use in long life satellite batteries has been pioneered by DREO but it is still not generally accepted. Others feel that the disadvantages of polypropylene, e.g. poor wetting, outweigh its advantage of relative inertness compared with nylon. Font and Goulard<sup>5</sup> of SAFT\* for example state that the decrease in electrolyte retention with use (time) is a disadvantage. In a recent paper (August 1975) by Kinsey and Gordon<sup>15</sup> the suspected drying out of polypropylene separators is also cited as a problem. Polypropylene separators had all failed by 17,000 cycles in a test in which nylon separators have now completed 33,000 cycles. The main problem is the choice of the correct wetting agent for the polypropylene separators. DREO personnel feel that they have the correct approach to the solution of the problem but there is still the problem of gaining general acceptance for new separators. If anyone doubts that the empirical approach is still dominant or feels that the term "witchcraft" is misplaced, it is useful to recall that some earlier Canadian satellite battery separators were made from shirt-collar stiffeners and some separators were processed using a version of an old-fashioned mangle in order to meet specifications. A relatively short term study (2-3 years) of wetting agents and their stability in the cell environment would help to consolidate the situation. The findings would be applicable to both the Ni/Cd and the Ni/H<sub>2</sub> systems. DREO should be considered for this phase.

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\* *Societe des Accumulateurs Fixe et de Traction*



Ni/Cd		Ni/H <sub>2</sub>		Ag/H <sub>2</sub>	
Advantages	Disadvantages	Advantages	Disadvantages	Advantages	Disadvantages
<p>Long life and reliable. Operates over a wide temperature range -40 to 110° F.</p> <p>Charge retention &gt;90% after 8 days at 20° C (see Figure 1).</p> <p>Can be stored in any state for long periods.</p>	<p>No reliable way of knowing state of charge.</p> <p>Electrolyte conc. varies - dilution on charge and conc. on discharge.</p> <p>Overcharge current limited.</p> <p>Overdischarge current a problem.</p> <p>Cadmium migration can be a problem.</p> <p>Present lack of large cycle life with high depth of discharge unsatisfactory.</p>	<p>Pressure is a good indicator of state of charge.</p> <p>Can overcharge or over-discharge provided that thermal limit not exceeded.</p> <p>Projected long life cycling ability at 70% DOD.</p> <p>Theoretically cell and electrodes function at constant electrolyte concentration.</p>	<p>Charge retention poor 50% after 8 days at 20° C. Pt needed for - ve electrode.</p> <p>The capacity falls off with T &gt; for Ni/Cd.</p> <p>Electrolyte movement problems. Hydrogen pressure of ~ 30 atmos increases chance of leaks and may give rise to stress corrosion problems.</p> <p>More hazardous than Ni/Cd if mishandled.</p>	<p>High energy density.</p> <p>Long life possibility with deep discharges.</p> <p>Can overcharge or overdischarge.</p> <p>Discrete charge voltage termination signal. Not subject to rapid self discharge. High power density capability [1500 watts per lb. for short times].</p>	<p>Silver electrode problems.</p> <p>Two step voltage characteristic on charge and discharge.</p> <p>The slight variations in electrode size and electrolyte conc. could be problems.</p> <p>Dendrite growth can be a problem. Operates under pressure. Cycle life &lt; that of Ni/Cd.</p>

Figure 3. Main Advantages and Disadvantages of Ni/Cd, Ni/H<sub>2</sub> and Ag/H<sub>2</sub> Batteries

Battery	Type	Watt hr/lb	Watt hr/cc	Cost \$/kwh	Volts on Discharge	Life Cycles	Comments
Nickel	Cadmium	15–25	.11→.22	~150	1.2	up to 50,000	T. range -40→110°F long life
Silver	Zinc	45–60	.29→.54	900	1.5	up to 300	Zn changes form during cycling and we lose capacity. Poor shelf life once activated.
Nickel	Iron	10–15	.055→.085	400	1.25	3000	Bulky, rugged.
Nickel	Hydrogen	25–30	~.06	~1500	1.25	1540 10K 65% 28% DOD DOD	Internal pressure up to 35 atmos. Pressure ~4 atmos with La Ni <sub>5</sub> absorber.
Silver	Hydrogen	30–60 (200 theory)	.06	~800	1.12	~1000	Lower life than Ni/H <sub>2</sub> (Dunlop)
Lithium	Sulphur	~150	.4		~1.5		High T electrolyte ~400°C. Large scale applications.
Sodium	Sulphur	~50	.02		~2.5		Operation at ~300°C
Silver	Cadmium	22–34			~1.1	~500	Poor high temp props. Used in satellites for non-magnetic property.
Lead	Acid	5–16	.07	~40	2	2000	-20°F→100°F low cost, high voltage per cell
<b>Primary</b>							
Mercuric oxide	Zinc	45	0.2	\$130	1.35		Uniform volts on discharge At 0°F. zero capacity c.f.d. 70°F value.
Carbon	Zinc	25–35	~.12	\$50	1.5		5% capacity at 20°F and 0% capacity at -20°F
Lithium	Carbon	100–250	~.4	~\$500	2.8		May explode on short circuit. Operates -60°F to 130°F
Zinc	Air	60	.18	~\$20	1.25		Temp. range -4°F→130°F

Figure 4. Characteristics of the Principle Primary and Secondary Battery Types

### 2.4.1.2 The Electrodes

These are the heart of the cell and this is where the main problems lie. The system is more complicated than might appear:

- a) It is a three-phase system — gas, liquid and solid.
- b) It is a chemical system.
- c) The main reactions are reversible.
- d) It is an electrochemical system.
- e) The electrochemical properties which are observed depend upon material (crystal) solution and regrowth. This material solution and regrowth is dependent upon time, temperature, concentration gradient, impurity, current rate, field gradient and reaction potential.
- f) The plates are porous so as to present a large surface area to the electrolyte.

From these points, and point e) in particular, one can see why charge and discharge rates, depth of discharge, number of cycles etc. become so important. A simple statement of the chemical reactions taking place is not enough. The processes occurring, essentially down to the molecular level, have to be understood. This requires the use of relatively new techniques such as X-ray microanalysis and scanning electron microscopy to approach the "form" problems, e.g., electrode material (crystal) size, shape, porosity and area, impurity gradients, interfaces, etc. In addition, the more routine cell potentials, heats of reaction and polarographical measurements must be used to study the electrochemical properties and their dependence on such "form" factors.

The assembly and understanding of such knowledge is essential for a true understanding of cell reliability, prediction of lifetime and to increase the yield of batteries made to a specification (≈ 10% only a few years ago). Some Ni/Cd's have been successfully cycled over 50,000 times and the author believes that this should be the rule rather than the exception for a wide range of charge and discharge rates, depth of discharge, etc.

### 2.4.1.3 Further Electrode Studies

The time-dependent nature of the processes sets the term of any investigation at more than three years.

The sophisticated nature of the studies and necessary equipment mean a solid research effort of at least 3 professionals plus technicians with solid moral and monetary support.

The existence of such a group is logical as a back-up for a variety of programs, e.g., satellite, aircraft, ship, northern uses, as well as for a Canadian commercial venture into the manufacture of reliable Ni/Cd batteries for such programs.

### 2.4.1.4 Protective and Charge Control Circuits

No problems are envisaged here. Present techniques may have to be modified in order to maximise battery life as more is learned about the detailed charge-discharge processes. Relatively short-term (up to 1 year) studies would be necessary to test the efficacy of new circuits.

### 2.4.1.5 The Electrolyte

As a strong electrolyte KOH exhibits few anomalies of behaviour. It has a low resistivity at concentrations near the eutectic point so that low temperature operation is feasible. The solubility of oxygen in the concentration of KOH used is quite satisfactory. The main problems are impurities and the migration of active material in the electrolyte (Cd).

The presence of carbonate either in the electrolyte or plates lowers the discharge voltage, raises the charge voltage, decreases charge acceptance, increases cell pressure on overcharge and reduces the cycle life<sup>8</sup>.

Potassium carbonate is formed when the potassium hydroxide electrolyte is exposed to air containing carbon dioxide. The inclusion of oxidisable organic spacers, etc., within the cell can also give rise to the production of the carbonate ion. Lack of sufficient awareness of these reactions led to careless battery assembly in the past, and monetary considerations lead to a careless approach in many cases today. For CTS a potassium carbonate concentration of less than 4% was specified.

#### 2.4.1.6 The Insulating Seals and Welds

No real problem exists with the seals; it is a matter of increasing the reliability of the seal through the use of better assembly techniques. Saft, France, have a French Government contract for studies on battery seals. Ontario Research Foundation (ORF) have had a contract for some four years and are looking for more funds to complete their work\*. The ORF would play an essential role as advisors regarding seals in any future Canadian commercial venture.

The vast majority of the welds made on cells are satisfactory but from time to time errors do arise in the welding techniques used. To assure reliability, the best approach for DOC as a user would be to check the seals of the particular cells delivered. It is not clear how this could be done and the problem should be kept in mind by the members of the Reliability Assurance Group.

#### 2.4.2 Ni/H<sub>2</sub> Cell Problems

The problems facing the designer of a reliable Ni/H<sub>2</sub> cell are essentially those just discussed for Ni/Cd with a few modifications

- a) As mentioned, the charge retention is poor compared with the Ni/Cd system. Not only does it mean a lack of energy when required at some later time but it is also equivalent to a continued load on the battery for which additional generating capacity must be provided. Maintenance of the battery at 0°C would significantly reduce this loss — see Figure 2.
- b) It has been observed that there is an increase with time of the pressure within the cells. Recent work<sup>9</sup> suggests that this may be avoided by using sintered nickel electrodes with electrochemical impregnation.
- c) The electrolyte apparently migrates in a zero "g" environment and at present there is no control over this. Temperature gradients across the cell are expected to compound this problem.
- d) The insulating seals: — The Ni/H<sub>2</sub> system is under pressure and the seals must be rather more leak tight than for Ni/Cd. No reliability experience has been accumulated regarding the stress-corrosion habits of the seals.
- e) The battery container and welds: — A vessel capable of withstanding ~ 35 atmos. with a factor of safety has to be provided. Stress corrosion and embrittlement due to the hydrogen may be a problem. A way to check weld integrity after assembly and delivery to the customer is needed. Inconel 718, Inconel 625 and titanium alloys have been used for the battery case.
- f) The mechanical integrity of the hydrogen electrode may be subject to failure as a result of gas evolution during charging.

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\* See proposal P-1947-G from ORF to DREO Ottawa dated 1 March, 1975.

- g) A swelling of the positive electrode is considered by SAFT to be the main limitation of the system.
- h) Low temperature operation: – One limitation appears to be the high polarisation on discharge whereas with Ni/Cd the limitation is the poor charge acceptance of the negative electrode at low temperatures.
- i) Font<sup>5</sup> and Giner<sup>16</sup> found a decrease in the electrolyte retention of polypropylene separators during testing. It is probably due to a decrease in the wettability of the polypropylene – a problem which DREO feel they have partially solved.
- j) High internal pressures ( $\sim 1000$  psi) and temperatures ( $400^{\circ}\text{C}$  and locally much higher) may be generated if the cell is shorted.

Whilst it is predicted that Ni/H<sub>2</sub> cells will have a greater cycle life coupled with high depths of discharge compared with Ni/Cd, operating experience has to be gained. There is the relatively serious rapid loss of charge with time. Whilst the solution of seal and container problems is a matter of effort and time, the charge retentivity problem is an unknown factor at the present time and may be more elusive. On the other hand it may prove to be simple: in the case of Ni/Cd cells poor charge retentivity was traced to the presence of the nitrate ion in the electrolyte.

#### 2.4.2.1 Electrical Control Circuits

No problems exist here. Patterson<sup>9</sup> has concluded that the Ni/H<sub>2</sub> system can be used in existing electrical power system designs with minor change only.

## 2.5 RELIABILITY HISTORY

One of the main concerns when buying high reliability components from a small volume manufacturer is the reliability record. To what extent is this concern justified?

If the items concerned are simple in concept and their mode of operation well understood then a dedicated team could make highly reliable devices with a high confidence factor. Repeaters for undersea cables are an example. A long reliability history for such items is additional information but not essential.

However, if the mode of operation of the items is not completely understood the lack of understanding would have to be augmented by knowledge of the components' reliability record.

In view of the problems of the Ni/Cd and Ni/H<sub>2</sub> systems just discussed, the author considers that batteries are a borderline case and probably belong to the second group just discussed. DREO personnel are more inclined to think that they belong in the first group and that a dedicated, well controlled team could produce high reliability batteries for satellite use.

## 2.6 Ni/CD OR Ni/H<sub>2</sub>

As discussed in 2.1 there is as yet no clear indication that Ni/Cd should be abandoned in favour of another system. Which system to use and when to use it depends upon many factors. To aid in selection, a decision tree is given (Figure 5).

If weight considerations are paramount it should be remembered that the weight saved will depend upon battery capacity. Because of the heavy container necessary for Ni/H<sub>2</sub> cells the smaller cells are relatively heavy. At the present time, Ni/H<sub>2</sub> batteries are weight effective if the capacity is greater than  $\sim 35$  Ah. CTS at 10 Ah is well below this figure. Even so the CTS battery weight is only  $\sim 2.2\%$  of the total craft weight and if a 1% saving were possible by using Ni/H<sub>2</sub> cells, the author does not think it is worth the consequent decrease in reliability. As Ni/H<sub>2</sub> cells are improved the situation will change and other criteria will have to be considered.

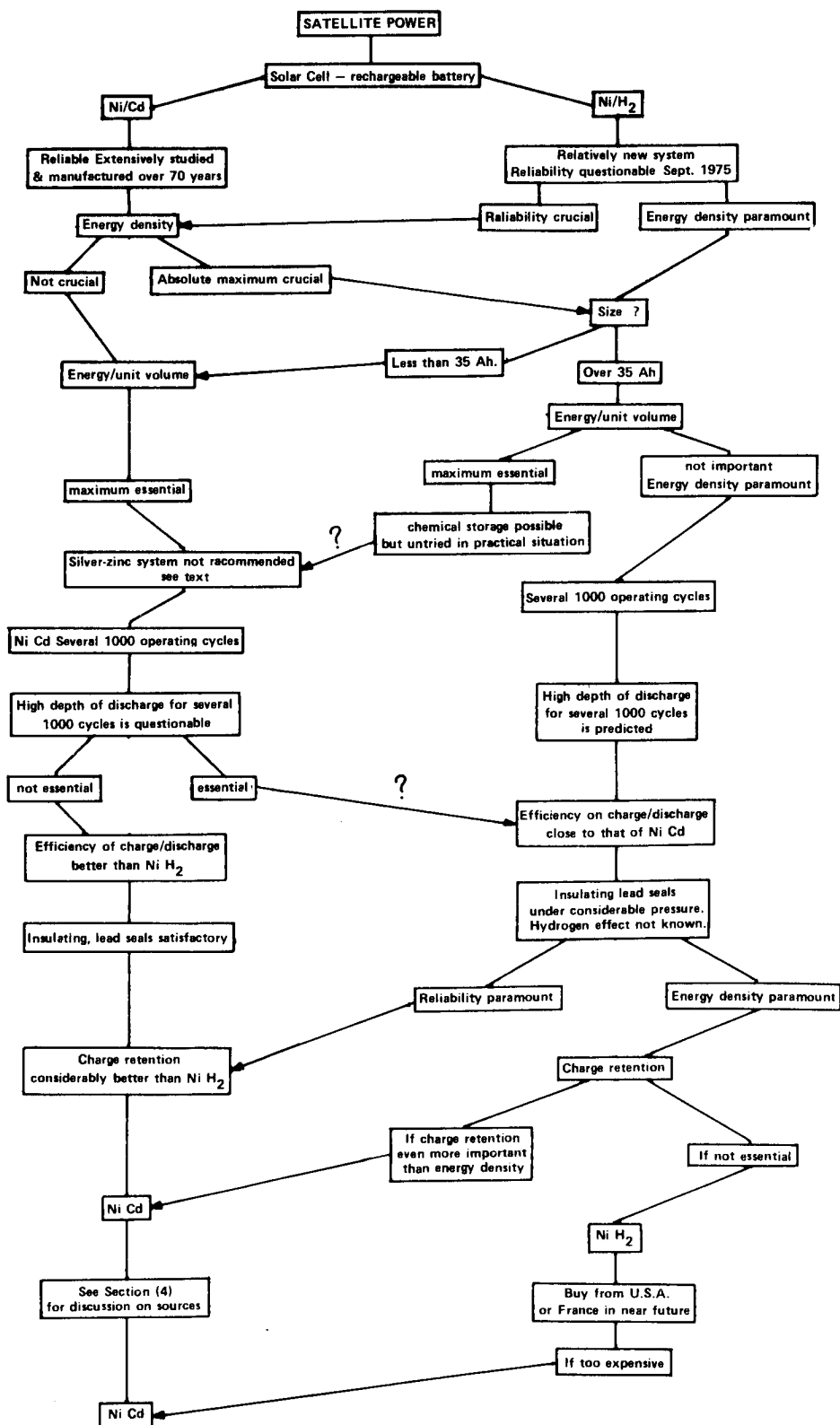


Figure 5. Decision Tree to Aid the Choice Between Ni/Cd or Ni/H<sub>2</sub> Batteries for a Specific Satellite Application

If Ni/H<sub>2</sub> cells are used to some extent as main power supplies would Canada wish to be amongst the leaders? There are more profitable ventures for Canada to carry out than pioneering the use of Ni/H<sub>2</sub> in space and unless there is an extremely good reason, Canada should stay with Ni/Cd until Ni/H<sub>2</sub> batteries have been proved out in space. Sufficient reason would be if an improved Ni/H<sub>2</sub> battery had been developed in Canada and it was necessary to demonstrate its reliability in space. However, one has not appeared and without a resident Ni/Cd battery industry it is extremely unlikely that one will appear in the next few years.

Notwithstanding the foregoing commentary upon problems, the Ni/Cd battery system is noted for its long life and reliability compared with other systems. To improve upon the present performance new approaches and the application of new disciplines are needed.

It is of interest to note here Dr. T. King's observations that Ag/Zn and Mg/AgCl cells (for torpedo use) are assembled under "white room" conditions whereas satellite cells are not. In general aerospace cells have been adaptations of available commercial cells. NASA has developed a high reliability specification for aerospace batteries and the design criteria are still being evaluated.

### 3. PRESENT CANADIAN POSITION

#### 3.1 INDUSTRY

There are some thirty-three battery manufacturing establishments in Canada and only four of them are Canadian owned. The majority make lead acid batteries and only one (SAFT) assembles nickel cadmium cells.

In the late 1960's there was an unsuccessful attempt to establish a Ni/Cd facility in Canada at Gulton Industries in Gananoque. It is understood that the Electric Storage Battery Company (ESB) have a Ni/Cd plant in mothballs in the U.S.A. and that it could be moved to Canada with the right stimulation. It should be noted that ESB is now a subsidiary of the International Nickel Company of Canada. The battery business is dominated by large multinational corporations and no R&D on nickel cadmium batteries is done in Canadian industry. In 1973, ~ \$3.1 x 10<sup>6</sup> worth of nickel cadmium batteries were imported. Further information is available in DITC reports by K. Munro<sup>16</sup> and G.F. Carter<sup>17</sup>.

#### 3.2 THE ONTARIO RESEARCH FOUNDATION

ORF has been carrying out studies on glass-ceramic-metal seals for Ni/Cd batteries for approximately four years. They were financially supported by the Defence Research Establishment Ottawa (DREO) and the Communications Research Centre (CRC). They have studied the failure mechanisms and developed improved seals for Ni/Cd battery systems. This work has direct relevance to Ni/Cd satellite batteries.

#### 3.3 THE DEFENCE RESEARCH ESTABLISHMENT OTTAWA

By far the most important battery research group in Canada is the Electrical Power Sources Division (EPSD) of DREO.

The EPSD of DREO is responsible for work on all types of batteries, fuel cells and other electromechanical devices. It has been particularly concerned with specialised high performance batteries which can operate in the rigorous military and space environments involving low temperatures, long-life-under-water operation etc. Examples are the batteries for aircraft, satellites, torpedos, sonobuoys, beacons and communications systems. The division maintains a fruitful contact with the Canadian battery industry which benefits considerably from DREO research (from "Defence Research Board - the first 25 years").

Their general goals of higher energy density, higher power density, and particularly studies of thermal problems, plate loading problems, separators and insulating battery seals for Ni/Cd are all of direct interest to CRC's requirements for satellite batteries. It is of interest to quote their objectives and goals for the project, "Optimisation Studies of Satellite Batteries for DOC".

### *Objectives*

To supply the Communications Research Centre, Department of Communications, on a continuing basis, the best information available on battery supplies for satellite use.

### *Goals*

1. Evaluate prototype satellite cells from various manufacturers for CTS applications.
2. Act as consultant on CRC-ORF study on glass-ceramic-metal seals.
3. Carry out optimization studies on separators, plates, charging techniques.
4. Provide consultative services to CRC as required.
5. Conduct evaluation tests and select cells for engineering model and flight model satellites.
6. Evaluate performance data for satellite batteries during ground test and advice on required changes to battery management plan and suitability for flight.
7. Advise and actively participate on battery conditioning prior to launch.
8. Analyze post launch battery telemetry data and provide advice to ensure optimum battery performance.

The success of DREO in the design, study, procurement etc., of the batteries used on Canadian satellites (e.g. longevity of Alouette batteries) is regarded as an outstanding achievement by the power sources community.

On the one hand there is a concern that Canada has insufficient secondary industry and yet here is a government group which *can* provide the required spin-off but is experiencing difficulty in maintaining support.

1975 was the first year that Canada was not represented by DREO personnel, due to a shortage of funds, at the Goddard Space Flight Centre Battery Symposium in November.

## **4. SATELLITE BATTERIES-POLICY AND SOURCES**

### **4.1 POLICY BACKGROUND**

#### **4.1.1 Information Necessary**

Presumably the policy with respect to satellite batteries must revolve around two main premises:

- a) To ensure that Canada obtains reliable batteries for spacecraft.
- b) To obtain all possible Canadian (industrial) spin-off and content from such satellite use.



The chemistry and the relevant battery problems have been examined. A comparison of the two main batteries has been made. This part of the work was factually based and it hopefully has some relationship to future reality. Policy, too, in order to be realistic must be based upon solid guidelines.

However, what the author considers as solid guidelines have not been available. It is necessary to have answers to such items as:

1. Is there going to be a program of "built-in Canada" satellites?
2. How many satellites per year will be involved?
3. Will Canada be in a position to define the detailed battery specifications or even the battery source?
4. Will DOC be involved to the extent that it can have a meaningful input regarding the battery source, specification and testing program?
5. If a satellite bus is bought, will the battery be included?
6. What is the DOC attitude towards research vs minimum cost hardware contracts?
7. How much money is available?
8. What is meant by spin-off?

#### 4.1.2 Spin-Off

This report is concerned mainly with batteries but "spin-off" is also a primary concern. Spin-off has been used at various times to mean employment, output or investment for the future. What are needed are real, tangible benefits to Canada from a involvement in the space program.

There is concern that there is not enough spin-off from the satellite program. Yet if a hard-nosed attitude is taken that the minimum cost be paid, a situation is created in which we pay a minimum cost for expertise and facilities gathered at some one else's expense — excellent from a bookkeeping point of view for a particular program but offering no investment for the future. Over the satellite period there were two experiences which illustrate to some extent this viewpoint.

The life of the Alouette batteries was outstanding. CRC justifiably takes credit for the exceptional life of these satellites but it should be remembered that without the dedication and interests of the people who built up the DREO battery team in pre-satellite days this would not have been possible. CRC (DRTE) was fortunate to have access to this source of advice which was extremely cost effective; this expert advice resulted in a many-fold increase in the battery life and allowed a much greater exploitation of the well-engineered spacecraft.

With CTS, on the other hand, it is understood that some research was to be performed as part of the battery monitoring contract with DREO. Questions are now asked, "What research of value to CTS was indeed done?" Is it now the view that the contract should have been let with no research content, i.e. no "spin-off" at all?

Research is one of the most valuable forms of spin-off since it is an investment for the future. Large technological programs such as CTS should be written with a fixed proportion set aside for research as another way to ensure more permanent benefits and investment in Canadian industry, etc.

To a first order, Canadian industrial spin-off will occur only if the battery manufacture takes place in Canada.

### 4.1.3 Battery Economics

Satellite batteries are manufactured as a prestige item. One reasonably might ask, "What justification is there for saying that satellite battery manufacture is a money losing business and that it is carried on for prestige only?" The assertion was made by people close to the CTS scene and by officials of DITC (see also E.J. Casey memo of 26 March, 1975, p. 2 paragraph 5). It is obviously difficult to provide concrete figures to back this up and an alternative approach is, therefore, adopted.

Suppose that a Canadian satellite is launched every two years and that the batteries are provided from a (the) Canadian source. Let us take the battery cost for CTS at \$58,000 as representative and assume a profit of 20% i.e., ~ \$12,000. To produce high reliability batteries would, at an absolute minimum, need two expert professionals and, say, three experienced technicians. Their salaries would be approximately (2 x \$25,000 + 3 x \$15,000) or \$95K per year. This is without overhead or equipment, etc. The DRED brief of 6 February, 1975 suggested a research program costing between \$130K and \$300K per year. One does not need to proceed further or to provide more accurate figures to see that a "profit" of <\$6,000 per year is not going to maintain a manufacturing organization even if we assume a ten-fold increase in battery sales.

## 4.2 OPTIONS

### 4.2.1 Do Nothing

If there were to be no future program of "built in Canada" satellites or if we in Canada have no further voice in the battery choice and design for Canadian satellites then it is difficult to justify any support for satellite battery research. The expertise would be contracted as and when needed from DRED, for example, or from the U.S.A. If this approach were adopted by DDC and others, DRED, EPSD, may well cease to exist because of the lack of continuing support. The advice would then have to come from the U.S.A. – hardly a "spin-off in Canada" position.

### 4.2.2 Canadian Satellite-Battery-Only Plant

There are two main goals for such an operation:

- a) To ensure a supply of space-qualified "batteries" for the future Canadian satellite program, and
- b) To achieve some battery technology spin-off in Canada and, to the writer, this means jobs in a self-sustaining (profitable) industry.

If a narrow view, case a), is taken that DDC consider only enterprises closely related to communications (satellites?) needs, the following picture emerges – an enterprise set up purely to manufacture batteries for satellites which would have to be funded by government.

There are advantages in having such a specialized source in Canada:

- a) Hopefully the manufacture would be receptive to our needs and be willing to implement our ideas and endeavour to meet our specifications on a "best effort" basis.
- b) If located in Eastern Canada, liaison and quality control should be much improved compared with the present (CTS) situation.
- c) A plus factor, rather than an advantage, is apparently the often-stated wish of frustrated NASA personnel that they would like the opportunity to be able to set up a Crown Corporation for satellite battery manufacture (Dr. T. King).

There are several disadvantages:

- a) The proposed Canadian manufacturer would have no reliability record.
- b) The market in Canada is limited in the extreme and one cannot realistically expect to sell many satellite batteries outside of Canada. A program cancellation means the loss of both valuable, though specialised, expertise and a considerable public investment.
- c) As previously discussed, the making of satellite batteries alone is a money losing business and it would be an expensive exercise for the taxpayer in view of the lack of spin-off into other areas.

If this route is followed the following questions must be answered:

- a) How much are we prepared to pay to set up and maintain a "tame" battery supplier in Canada and who only "might" make high reliability batteries?
- b) How much do we wish to pay to maintain an industrial expertise in Canada?
- c) How much do we wish to pay per person to establish jobs in Canada rather than pay unemployment benefits? The number of jobs created would be minimal.

As postulated in 4.1.3 the absolute minimum group size that could be established would cost with overhead ~\$250K/year to maintain.

At the present time there is a comprise in that expertise is maintained in government (DREO) where it is hopefully of use to a maximum number of enterprises. The sphere of influence of expertise maintained in an industry is almost certainly not likely to be as large.

In summary, a satellite-battery-only manufacturer would not be a sound business proposition and the establishment of such would be for essentially political reasons.

#### **4.2.3 Commercial, Rechargeable Battery Manufacture in Canada with an R&D Arm Capable of Supplying Satellite Batteries**

The R&D operation of such a company would still cost the taxpayer a substantial fraction of the previous case (4.2.2). In this instance the company and other departments, e.g. DITC, would share the overhead and equipment costs. Company sponsored research personnel would strengthen the minimum nucleus proposed in 4.1.3. However, the full benefits of the research done would flow through to a profitable Canadian manufacturing operation that could employ many people – approximately one per \$50,000 of sales (see para. 4.2.3.4 and ref. 18).

The assumption is made that the battery considered for commercial development would be Ni/Cd. Considerable R&D is needed on the Ni/H<sub>2</sub> system before it would be suitable for the commercial market. Apart from this the high cost, the hazards involved because of the high pressure within the cell and the explosive nature of the hydrogen if it leaked are deterrents to its commercial use. A sealed lead-acid battery has recently been announced<sup>20</sup> and could be a considerable challenge to the Ni/Cd battery for general, commercial use.

##### **4.2.3.1 Market**

The rechargeable battery market is expanding rapidly. Nickel-cadmium batteries are found in aircraft, scientific, medical and communication equipment, power tools, household items, emergency lighting, toys, tape recorders, etc. In the future there is the possibility of large scale use to power the transmitters and receivers of optic fibre systems and mobile personal communicators. The present Canadian commercial market is in excess of  $3 \times 10^6$ . The U.S. Ni/Cd market is ~\$60 x 10<sup>6</sup>. The U.S. government market in aerospace, military etc., is ~\$200 x 10<sup>6</sup>. The total Canadian battery market is ~\$100 x 10<sup>6</sup> per year vs. \$1.5 x 10<sup>9</sup> for the U.S.A.

There is probably just enough room in the Canadian market for a Canadian manufacturing company but their products should be sufficiently different and specialised to gain an advance with which to create an export market. The market is not big enough to allow a company to finance much in the way of R&D; the research funding or ideas would have to come from government sources.

If a multinational corporation were involved, the possibility of a rationalisation of products between the U.S.A. and Canada or France and Canada should be explored.

DOC/CRC puts a high premium on reliability and has an excellent reliability assurance group. DREO has wide experience in the design of high-reliability batteries both for satellite and low-temperature use. The Canadian manufacturing effort should go after and build a reputation in the high-reliability and low-temperature battery areas for such fields as high-reliability data storage, aerospace, medical, remote communications, military, nuclear, crash position indicators, low-temperature commercial use, emergency lighting, etc. It is in these areas that the Canadian experience with high-reliability satellite and low-temperature battery design could best be utilised. A number of battery shapes and sizes would be necessary to cover such markets. A logical extension therefore, would be to cater to the specialty battery market. The exercise is to provide spin-off and jobs in Canada and by looking at the broader commercial picture one may obtain valuable, profitable spin-off. It would not be merely another secondary industry but one based upon our primary material suppliers, e.g. nickel and cadmium, which should "upgraded" and our wealth of reliability and low-temperature battery expertise that should be utilized.

#### **4.2.3.2 The Marketing Position**

If a Canadian nickel-cadmium battery manufacturing facility is established, some thought must be given at the inception to the final, marketing position.

A market study would be necessary, particularly in view of the challenge from the sealed lead acid system. If DOC/DREO are seriously interested it is understood that DITC would carry out the market survey. The Federal Government customs, excise and tariff branches must be involved from the outset as well as marketing people to ensure that the infant created will live and flourish. This type of co-operation between government, industry and marketing people has in no small way contributed to Japan's success in maintaining a good export/import ratio – why not in Canada?

#### **4.2.3.3 The Industrial Interest in Such a Venture**

The probable participants are discussed in a memo by Dr. E. Casey<sup>15</sup>. The choice is between:

- i) Establishing a Ni/Cd facility and interest at Mallory of Canada where there is already a competent research group.
- ii) Establishment of an ESB Ni/Cd operation in Canada with the now inactive plant stored in the U.S.A.
- iii) Reactivating the Gulton Industries plant at Gananoque. Since SAFT now controls Gulton and also has a Ni/Cd assembly plant in Toronto, it is possible that SAFT will consider manufacture in Canada.
- iv) Establishing a completely new battery enterprise. One of the first three alternatives would offer the best chance of success.

At the moment it appears that the establishment of any Ni/Cd battery facility in Canada without DREO participation in one way or another is unrealistic.

#### **4.2.3.4 Investment per Job Created**

Attempts to get an average figure for this were unsuccessful. Mr. D. Quarterman Director of Planning and Analysis, IT&C, said that no average value had been calculated for the electronics industry and he pointed out that one could start with almost no invested capital, e.g. rent. At the other end of the scale lies heavy electrical

engineering, e.g., generator manufacture, which has a relatively large capital investment per job. A profitable battery operation would lie in the mid range between these extremes and so would not be unreasonable from this point of view. The amount of investment necessary would depend upon the equipment necessary to perform individual fabrication functions at an economical rate. Dr. I. Henderson of DREO explored this area a few years ago.

In a 1966 report<sup>18</sup> on the Canadian battery industry the sales per employee and value added per employee were given at \$25,000 and \$12,000 respectively.

#### 4.2.3.5 Probability of Success

The demand for secondary batteries is in a growth period. Batteries for high-reliability applications and low-temperature use could be made. The problem is the marketing: the demand, the pricing, the tariff protection and above all the attitude of the multinational battery companies.

#### 4.2.3.6 The Patent Position

The basic patents were filed in 1899, 1900, 1901 and should not now be a problem. DREO have already pioneered and demonstrated superior battery separators and ORF have designed superior seals which can be made by a Canadian company. Particular ways of preparing and processing the electrodes are still subject to patent.

#### 4.2.3.7 Timing

If the company established is to make satellite cells and, secondly, if it would be expected to tackle Ni/H<sub>2</sub> cells some 5–10 years hence, then it is important that a start be made as soon as possible.

Even if the establishment of a Ni/Cd manufacturer is considered inopportune at the present time, DREO should be supported to ensure that expertise is available for what could be crucial advice regarding Ni/H<sub>2</sub> cells . 1980–81.

### 4.3 RESEARCH & DEVELOPMENT STUDIES

#### 4.3.1 Role of EPSD of DREO

The management of any satellite program must have access to battery expertise to help in the decision-making process. This is true whether the management is government or industrial, and the battery source Canadian or foreign.

Canada is not likely to make actual use of Ni/H<sub>2</sub> main satellite power supplies before 1985 in view of the presently perceived difficulties, the weight considerations and the undesirability of Canada using Ni/H<sub>2</sub> batteries before they have been well-tried in space. This means that DOC may need to write Ni/H<sub>2</sub> battery specifications in approximately 1980. Expert advice would be necessary and may well prove crucial as this would be a new battery system for Canada. No such knowledge now exists in Canada and, unless the advice is to be obtained from the U.S.A., the ground work must be laid now to ensure that the advice will be available in Canada when required.

One can choose to rely on paperwork studies or, alternatively, make a proper investment for the future by supporting a modest research group working on this system and perceived problems.

DOC has a responsibility to help support the competent battery group that was of immense help to, and extremely cost effective for, the earlier satellite programs. Tight management and advice by contract may look good on paper at the immediate moment, but when the battery expertise and facility is needed in the future it may not be there. There must be an investment for the future in terms of talent, interest and facility.

Future programs of CTS magnitude should perhaps be established with a fixed proportion of the cost set aside for related research. Hardware programs spur technological development but rely on, and eat into, previously established knowledge reserves.

EPSD of DREO should be supported now as an investment in the future success of Canadian satellites. Two main problems could be defined for them:

### *1. The Separator and Wetting Agent*

DREO pioneered work on these items for the Canadian satellite program. Neither full understanding of the problem nor full acceptance of DREO's ideas has occurred. Chemical characterisation of the wetting agent and its decay mode in Ni/Cd and Ni/H<sub>2</sub> cells should be carried out. The permeability, wettability and stability of polypropylene should be further studied.

The program might well absorb two professionals and two technicians for a period of two years. The cost per year would be approximately \$125K including equipment and overhead at 50%.

### *2. The Significance of Electrode Structure Changes*

The main problem is the electrode "surface" and exactly what takes place on the charge/discharge cycle. The key to long life, deep depth of discharge, high cyclicality, retention of capacity, etc., lies here. It may be time for the introduction of new techniques (disciplines?) to unravel the problems; the scanning electron microscope comes to mind and suggests an area for cooperative research between DREO and CRC. Knowledge gained about the nickel electrode structure is essentially applicable to both the Ni/Cd and Ni/H<sub>2</sub> cell.

A solid research effort would be needed. At least three professionals plus two supporting technicians for five years initially. Their expertise and facility would be established ready for the possibility crucial period of introduction of Ni/H<sub>2</sub> cells to Canadian satellites. The cost per year would be approximately \$200K.

#### **4.3.2 Considerations Regarding the Level of Support**

Some \$190K was paid to EPSD of DREO for advice regarding batteries for CTS. This represents 0.3% of the total cost. This is a very small price to pay to improve/ensure the reliability of what is a key component of any satellite. The battery life of this particular satellite, CTS, is not critical as long as it exceeds approximately 2 years. However, in the case of other satellites, — Alouette, Anik's, etc. — the battery life is a major life-determining element. If by gaining another 25 to 100% increase in satellite life and productivity by improving the life of the batteries, then battery improvement is extremely cost effective. For example if a  $40 \times 10^6$  satellite with a battery-limited life of 4 years was upgraded to a 6-year life, the cost would drop to  $6.6 \times 10^6$  per year instead of  $10 \times 10^6$  per year. In fact, it is probably more cost effective to increase the life of satellite batteries than to increase their energy per unit weight.

#### **4.3.3 Industrial Research & Development**

The tasks suggested for DREO relate to the cells themselves rather than to the packaged battery. As the energy density is increased, non-uniformity of battery internal temperature will increase. A study of the optimum thermal and mechanical packaging of a given type of satellite battery would be a good task for an industrial R&D laboratory.

A small contract to produce seals for high pressure Ni/H<sub>2</sub> cells might also be considered with Quality Hermetics of Toronto. However, the attractiveness of LaNi<sub>5</sub> chemical storage elements to reduce the pressure in Ni/H<sub>2</sub> cells reduces the drive to study high-pressure seals. Late 1977 would be soon enough to consider this if the LaNi<sub>5</sub> approach is found to be unsatisfactory.

#### 4.4 THE IMMEDIATE FUTURE 1976 – 1980

If one can assume that money will continue to be provided for research, then reliability, defined as a deeper and better understanding of the chemical-physical problems and design criteria, will improve for both the Ni/Cd and Ni/H<sub>2</sub> systems. The Ni/H<sub>2</sub> is the newest and a much sought-after system and one can reasonably assume that the information necessary to provide an acceptable, reliable system will be gained. The information available to the writer indicates that the acceptable level has not yet been attained. It should also be borne in mind that the main NASA thrust is now towards a shuttle system in which weight and therefore energy density are not quite so critical. This takes some of the pressure off finding quick solutions to the Ni/H<sub>2</sub> battery problems. In view of the lead times involved before launch of a satellite, one can reasonably predict that Ni/H<sub>2</sub> will not generally be used as the main battery source aboard satellites for approximately 5 years.

#### 4.5 THE MORE DISTANT FUTURE 1980 – 1985

With the same assumption regarding research as for the 1976–1980 period and barring unforeseen problems, then one can see from Figure 3 that, having achieved an acceptable reliability, the problems of charge retentivity and relatively low energy per unit volume remain. The latter problem can be alleviated by chemical storage of the hydrogen or a significant increase in operating pressure. At least one of the approaches should be successful enough to remove this as a disadvantage during this period. Until the reasons for poor charge retentivity, electrolyte movement, and hydrogen pressure increase with time are known, one cannot speculate upon the time frames for solution. If these problems turn out to have easy solutions then the guesstimate is offered that Ni/H<sub>2</sub> satellite batteries will be made use of as main batteries late in the 1980–85 period, particularly for large batteries, where energy density is important and is felt to be a worth-while trade-off for possibly reduced reliability compared with Ni/Cd.

Much progress is being made in the battery industry, particularly with respect to energy density and battery life. The situation should be kept under review at all times. The latest Intelsat proposals do not suggest the use of Ni/H<sub>2</sub> and as far as is known NASA has no definite plans at present to use Ni/H<sub>2</sub> as the main power source. As a trial, Ni/H<sub>2</sub> batteries will be used as main power source with Ni/Cd back-up on board the U.S. Navy NTS-2 to be launched about September 1976.

#### 4.6 CONCLUSION AND RECOMMENDATIONS

- a) The state-of-the-art with respect to Ni/H<sub>2</sub> cells will not be sufficiently advanced to justify their use as main power sources on Canadian satellites within 5 years. The relative position of Ni/H<sub>2</sub> in the period 1980–85, i.e. 5–10 years away, is more difficult to forecast. The publications of the proponents lead one to believe that Ni/H<sub>2</sub> batteries will play a larger role in this period but there are several problems.
- b) No other system is likely to be sufficiently advanced or reliable enough to replace Ni/Cd for the longer missions before 1985.
- c) Ni/H<sub>2</sub> batteries are most weight effective compared with Ni/Cd for large capacity batteries. If the use of modest size batteries on Canadian satellites continues then the Ni/Cd battery will continue to be the preferred system. There is therefore no reason for Canada to pioneer the development of Ni/H<sub>2</sub> batteries for space.
- d) At the present time it appears to be much more cost effective to improve the life of Ni/Cd batteries than to try and replace them with high energy per lb Ni/H<sub>2</sub> batteries which have not yet been shown to have a long lifetime.

- e) If a narrow interpretation of DOC's objectives is subscribed to, the best policy is probably to buy from the U.S. and pay DREO a retainer fee as advisers, i.e., essentially as we have done in the past.

As an investment in the reliability and life of future batteries aboard Canadian satellites, some support for the EPSD of DREO should be provided on a continuing basis. If DREO and/or CRC are to maintain their knowledge (and expertise) at "state-of-the-art" with respect to satellite batteries, then some research should be funded and attendance at relevant conferences should be provided for, e.g. the annual NASA Battery Workshop at GSFC.

If we are prepared to take a wider view and co-operate with DREO and others, then perhaps some spin-off could be achieved. Many factors must be taken into account when considering the establishment of a Ni/Cd plant in Canada to manufacture satellite batteries. Some information, which is essential, is not available and the alternatives are therefore discussed in the text and summarized in Figure 6.

- f) The large amount of interesting, historical material, regarding the battery program for Canadian satellites, needs to be collected together and published. With the latest satellite complete this is the opportune time for the people concerned to publish their findings.

Dr. Wernher von Braun of NASA said that "The Space Program is the cutting edge for science and technology. Man needs a cutting edge as he hunts for truth". We have our modest high-technology cutting edges in Canada and we expect them to be blunted occasionally although not as disastrously as is the case of the Microsystems collapse. We must resharpen and try again — should a high reliability nickel cadmium plant be a new edge?

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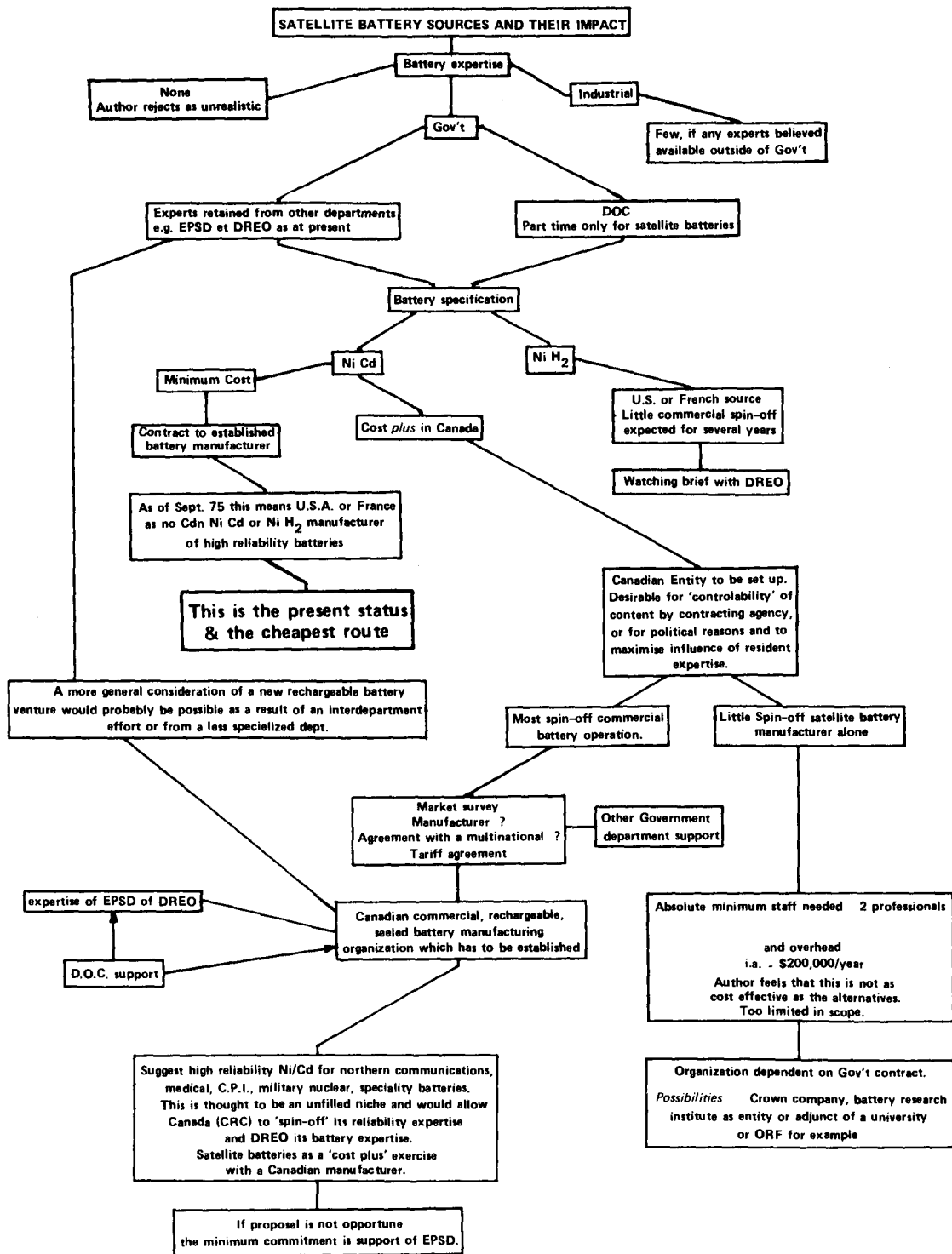


Figure 6. Decision Tree to Aid in Making a Policy Decision as the Necessary Background Policy Information Becomes Available

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8. ABSTRACT:

The relative merits of nickel/cadmium (Ni/Cd), nickel hydrogen (Ni/H<sub>2</sub>) and silver/hydrogen (Ag/H<sub>2</sub>) batteries as sealed units for satellite use have been examined.

It is concluded that the state-of-the-art with respect to Ni/H<sub>2</sub> cells is not sufficiently advanced to justify their use as main power sources on Canadian satellites within 5 years.

At the present time it appears to be much more cost effective to improve the reliability and life of Ni/Cd batteries than to try to replace them with high energy per lb Ni/H<sub>2</sub> batteries.

The background, desirability and economics of manufacturing satellite batteries in Canada are discussed and recommendations made.

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