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THE FUTURE OF LITHIUM BATTERIES (ROUND TABLE DISCUSSION)

The Third International Meeting on Lithium Batteries concluded with a round table discussion on *The Future of Lithium Batteries* chaired by P. Bro (Southwest Electrochemical Co., USA), J. P. Gabano (SAFT, France), Z. Takehara (Kyoto University, Japan) and O. Yamamoto (Mie University, Japan). Although the full proceedings were recorded, certain editorial changes and deletions have been made in the interests of clarity, and hopefully without changing the context of the discussions.

Dr J. P. Gabano (France): We will begin this informal round table discussion on the Future of Lithium Batteries with Dr. Bro presenting the results of the survey conducted among the participants of the meeting. We hope that this presentation may stimulate questions and comments from the audience at large. In addition, we welcome discussion of any of the papers presented during the meeting.

Dr P. Bro (U.S.A.): I would like to thank the sixteen respondents who contributed to this survey. Of course, each one of us has personal ideas about where research in lithium batteries is going, but what do we, as a community, think about future prospects in this area? The first question posed in the survey was whether anything was coming along that might obviate the use of lithium batteries. The response was categorical, there was not one suggestion of any developments that might lead to their replacement.

The second question addressed the prospects for the evolution of new devices (in the next 5 - 10 years) that would need lithium batteries. The general response was vague with no clear definitions, so I conclude that this community tends to be conservative. We do not expect the emergence of new devices during the next 10 years that will require lithium batteries.

Another interesting question was: "What new types of lithium batteries will be reduced to practical reality during the next 10 years?" Polymer batteries were the first choice, with rechargeable systems a close second.

Then, we had a question about the relative importance of the following battery parameters in various market sectors.

	Consumer*	Original Equipment Market	Military
Gravimetric energy density	0.21	0.18	0.19
Volumetric energy density	0.28	0.27	0.24
Storability	0.30	0.32	0.26

*Units are arbitrary as these numbers show only the relative ratios.

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As you can see, there is really very little difference between the market sectors. It appears that the responses were random, and that there were no definite opinions on this question.

There is always the question of what should be the voltages of lithium cells. Lithium batteries can be made with practically any voltage from 0.5 V to about 4 V. We asked what should be the voltage for the memory business. Basically, a bimodal distribution emerged: one fourth of the community thought that low voltages are satisfactory for CMOS circuitry and about one half asserted that high voltages are needed. Most of us are battery people and not electronics people, so I am uncertain what value should be given to this assessment.

Next, we know that there has been some interest in ultra-thin batteries, (*i.e.*, paper-type batteries) and that Japanese workers are foremost in this field. An interesting result of the survey was that the paper-thin batteries would capture about 6% of the lithium battery market during the next ten years.

Now, we come to the rechargeable lithium batteries. We have discussed three different types of rechargeable batteries at this meeting. Most of the earlier work concentrated on organic-solvent type batteries. Since then, polymer electrolytes have been pursued in the development of an all-solid rechargeable battery. Finally, there is the other approach represented by Duracell, namely, the rechargeable Li/SO_2 battery. I would appreciate very much at this point if we could have some response from Dr Yamaki on the liquid organic electrolyte types, from Dr Armand on polymer batteries, and ask Dr Dey to defend his school of thought on the Li/SO_2 system.

Dr Yamaki (Japan): I believe that organic electrolytes and inorganic cathodes are the best choice. For example, Dr. Stiles is studying one kind, and his batteries are very good. Our cell also incorporates this system and, hopefully, is also good. There are many other satisfactory materials among organic electrolytes and inorganic cathodes. As I have pointed out at this meeting (see *Journal of Power Sources, 20* (1/2) (1987) 3 [these Proceedings p. 3]), polymer cathodes have a poor packing intensity. Even if a polymer cathode exhibits a large gravimetric energy density, the volumetric energy density will be very small. I realize that polymer cathodes have very high potentials and that there are high hopes for them in the future. However, at present, the use of polymer cathodes is not practical. I cannot comment on the performance of the Li/SO_2 system as I have not worked with it. I am given to understand that SO_2 is very difficult to handle. A special instrument would be needed to study the Li/SO_2 system, and this is a problem area. For these reasons, I believe that organic electrolytes and inorganic cathodes are the most practical and the best choice at present.

Dr Armand (France): The polymer electrolyte battery is analogous to the liquid electrolyte system, except that it employs a very thin polymer electrolyte film to prevent diffusion of species from one side of the cell to the other. At first, we were interested in replacing the sodium/sulphur or the lithium alloy/sulphide batteries with a polymer battery operating between 80 °C and 100 °C. We met not only the energy density requirement, but also the power density requirement. The second point I want to make is that we can produce low-to-medium rate batteries operating at room temperature. In this case, the main problem is the discharge at 0 °C and lower. But what type of consumer electronics can be used at −10 °C? Most of the electronics are coupled with liquid crystals and these do not operate satisfactorily at freezing temperatures. So, the batteries are not going to be used at such temperatures. The ambient temperature polymer battery work started just a few years ago. The poster presented by the Hydro Quebec team described the shapes, designs, and capacities that can be made. I believe that the polymer batteries can replace the Ni/Cd system in certain applications. Clearly, polymer electrolyte batteries are good candidates for micro-electronics. As for Li/SO_2 cells, I think there are still some problems to be addressed. For example, what kind of safety can be obtained with the larger cells in consumer applications?

Dr Dey (U.S.A.): Dr Bro asked me to defend the Li/SO_2 system. First, I wish to discuss rechargeable batteries in general. At present, there are basically two rechargeable battery systems, lead/acid and Ni/Cd, that are in commercial use. In both of these systems, the capacity from cell to cell can be balanced by an overcharge reaction via an oxygen cycle. These cells can be connected in series to make batteries. Most applications using rechargeable batteries are not single-cell applications. There are very few systems that use the 1.2 V of the Ni/Cd battery or the 2.0 V of the lead/acid battery. Most applications require 6 V, 12 V, or more. When a series-connected system does not have an electrochemical cycle that allows the cells to be balanced, the cycle life becomes very poor. This is well known in the case of the sodium/sulphur system, for example. Although this system was discovered in the early 60s, scientists are still attempting to produce a practical version. Since the system does not have an overcharge mechanism to balance the cells, when connected in series, the cycle life is very poor. For this reason, I believe that the Li/SO_2 system, as we have developed it with an inorganic electrolyte and a Cl_2 cycle for cell balancing, allows series use. But SO_2 is a toxic material. Therefore, I do not believe that the system is suitable for any consumer applications. It has excellent prospects in military applications, however, and already the primary Li/SO_2 system is being employed in this area. The technical problems are well defined. The first is the compatibility of the separator. We have identified a material that is compatible, and I am sure we will be able to develop a separator that will stand up to elemental chlorine. The second, and much more serious, problem is safety. For primary SO_2 batteries, however, this has been solved quite effectively. I think many of the technologies that have been developed over the last ten years to improve the safety of lithium batteries will result in those batteries becoming suitable for military applications.

With regard to polymer electrolytes, these are very interesting systems but, as Dr Armand has pointed out, at low temperatures (I do not mean as low as −30 °C, but only down to 0 °C) none of the present electrolytes has a conductivity that is sufficiently high to provide the current required for most of the consumer applications of rechargeable batteries. The prospects are slim of finding a polymer with a conductivity sufficient for the cell to be useful at 0 °C. Also, I am not aware of the development of any prototype cells with polymer electrolytes. By prototype cell, I refer to a fully packaged cell from which an actual energy density can be obtained, not just a laboratory cell from which a projected energy density for the finished package is extrapolated.

Finally, concerning organic electrolyte/solid cathode systems, this type is expected to be the front runner because is has already reached commercialization. The Li/SO_2 rechargeable battery should be next into the market since it is suitable for many military applications.

Dr Bro (U.S.A.): I would like to open up this discussion on rechargeable batteries since they occupy such a large segment of the work reported at this meeting. Dr Osaka wishes to comment on these systems.

Dr Osaka (Japan): I want to discuss possible solutions to the problems of polymer batteries. The first problem is the current density: high current densities cannot, as yet, be obtained with polymer batteries. The second problem is stability: the mechanical stability may be satisfactory, but the self-discharge of cells using polyacetylene is serious. However, satisfactory open-circuit voltages and capacities are obtained when using polyaniline and polypyrrole. So, if the correct kind of material is selected, stability problems can be overcome. Finally, what about energy density? The Ni/Cd cell gives about 30 W h kg^{-1}, but what is the performance of polymer batteries? Dr Dey has claimed that it is much lower than that of Ni/Cd, but our results, for example with polypyrrole, show that the performance is strongly dependent on the nature of the film and how it is formed. In our case, if we polymerise with a PF_6 anion, we can get 1800 cycles; with ClO_4 anion we get just 200 cycles, but 150 W h kg^{-1}. If we include the packing factor, the performance figures are lower, but the systems still show promise. Toyota Central Lab. has tried polyaniline, and has claimed a service life of 1000 cycles. The current density of both polypyrrole and polyaniline is very low; this is the main problem area. There are also difficulties with lithium anode cycling. It is my opinion that a good polymer cathode will eventuate, but the critical factor is the lithium anode. It is possible that some companies have examined lithium alloys and Wood's metal alloys as a means of overcoming this performance-limiting problem.

Dr Dey (U.S.A.): The polymer batteries, polyacetylene, polyaniline, polypyrrole, and other polymer materials, have a volumetric energy density identical with that of the lithium/carbon system. Carbon is the cheaper material, so why consider the polymer materials?

Dr Scrosati (Italy): I want to answer the last question by Dr Dey: why use polymeric electrodes? Some of the polymeric electrodes may be prepared electrochemically and give very good morphologies, as we have shown at this meeting (see *Journal of Power Sources, 20* (3/4) (1987) 333 [these Proceedings] and pp. 182 - 188 Extended Abstracts). We make ultra-thin batteries for special electronic applications and optical displays. The second point is the kinetics, as pointed out previously by Dr Osaka, and I think the morphology of electroplating is important in this respect. Dr Osaka demonstrated that the kinetics of the polypyrrole electrode are quite sensitive to the method of synthesis. We must remember that this field is very young and maybe we have proceeded too quickly. Now, we are retracing our steps in order to understand the fundamental properties. After that, we can think about suitable applications for these materials. I want to make a final point about polyaniline. I share Dr Armand's opinion that this material is dangerous. The question of safety has been raised at this meeting and we must pay further attention to this subject.

Dr Moehwald (West Germany): I have a comment on the comparison of carbon and polymers. For the same intercalation reaction in polymers and carbon, the voltages are different. With carbon, higher voltages are required and these give rise to problems with electrolyte decomposition. This leads to the preference for polymers: lower voltages are encountered for the same reaction and the same capacity.

Dr Dey (U.S.A.): If the high voltage is a problem, I would say that the Matsushita batteries may be useful in many applications.

Dr Moehwald (West Germany): We should be careful here. I was talking about the intercalation process. If you use carbon, you can have a different reaction. The reaction of the Matsushita batteries is not intercalation. Their voltage during discharge is similar to that of a capacitor. When a polymer electrode is used, the voltage is not like that of a capacitor and a plateau is obtained.

Dr Iijima (Japan): In our carbon/lithium batteries, we use the electrochemical double-layer phenomenon. Thus, the capacity is less than that of intercalated polymer batteries, but the reliability and the cycling capability are very good. These batteries are used in memory back-ups.

Dr Wolsky (U.S.A.): I would like to suggest that the rechargeable lithium systems could be compared with the nickel/hydrogen system which has been highly developed in both Japan and the U.S.A. The cell voltage of 1.2 V is the same as that of Ni/Cd, and the nickel/hydrogen batteries are just as reliable and a good alternative to Ni/Cd.

Dr Belanger (Canada): Just a comment about the polymer batteries. There seems to be some confusion there. A polymer battery should be one that used both a polymeric electrolyte and a polymeric positive electrode.

Dr Huggins (U.S.A.): I want to talk about the future and an approach which I have not heard discussed here. This involves using low-temperature molten salts that are thermodynamically stable in the presence of the electrodes. One can find salts melting at much lower temperatures than most of the salts we know and, in some cases, these are stable towards alkaline metals. This has already been demonstrated in the case of potassium and sodium. Lithium is a more difficult problem, but I suggest that there will be some new alternatives appearing during the next ten years. Molten salts are thermodynamically stable and have high conductivities at moderate temperatures and, perhaps, even at room temperature.

Dr Matsuda (Japan): Regarding the lithium batteries of Matsushita, their charge/discharge characteristics are similar to those of capacitors. However, this battery has a lithium electrode that has been modified by the use of alloying techniques, *e.g.*, Wood's metal. So I think that the device is really a new kind of lithium battery.

Dr Wiesener (East Germany): In discussing the future of rechargeable lithium batteries, we must be careful in our comparisons with conventional batteries. The lithium cells do have some disadvantages in relation to small, sealed Ni/Cd cells, for instance, and in relation to the larger lead/acid cells. Firstly, in terms of energy density: for low depths of discharge, the energy densities are not much greater than those of conventional cells. Secondly, in terms of self-discharge: the self-discharge of lithium cells is less than that in all other types of cells, but lithium cells behave poorly both on overdischarge and on overcharge. These are serious problems in comparison with conventional systems. A cycle life of 2000 - 3000 cycles is required, that is, a performance better than that of Ni/Cd and the best lead/acid cells. I am not sure whether such a high cycle life is possible under practical conditions and with high safety. The future of rechargeable lithium cells and their applications is most uncertain.

Dr Bro (U.S.A.): Shall we go on with the results of the survey? The next question was: which are the most important markets? The original equipment market (OEM) was assessed as being the most important. Then came the consumer market, and, last of all, the military market. When looking at this, keep in mind that we are talking about the next ten years, not today.

The next question is really interesting: what controls the acceptance of lithium batteries in various markets? It appears that the safety of the lithium batteries is the most important criterion in the consumer market, second comes the price. This really means that the cost of production has to be reduced, but which comes first, cost reduction or increased sales volumes to justify the investment needed to reduce costs? Who can answer that? Rechargeability was also thought to be important. In the OEM, the price was judged the most important criterion of acceptance, second came safety and then rechargeability. That sounds reasonable. The OEM customers buy large volumes and can therefore negotiate the pricing. For the military market, safety is the most important criterion and then power density. I think we all know why the military want power and then energy density.

Looking ahead another ten years, how important will lithium batteries be in the market place? As you can see from the data below, we are looking at a very optimistic assessment, but then, we are lithium people. Notice that about three-fourths of the watch and calculator markets are going to lithium, with the photographic and pager markets at about one-half lithium batteries, and radios, tape players, and toys having a little lower share.

Lithium battery market share by 1995	
Calculators	74%
Watches	73%
Photographic	65%
Pagers	51%
Radios	40%
Tape players	40%
Toys	30%

The last question was: What system is going to make it? The following answers were received in terms of systems and markets:

Growth factors by system and market, through 1995

	Consumer	OEM	Military	Other	Total
Li/MnO_2	24.3	10.8	1.7	0.8	37.6
$Li/(CF)_n$	9.5	6.2	1.4	0.8	17.9
Li/CuO	6.9	3.9	0.8	0.4	12.0
Li/SO_2	5.3	2.2	3.8	1.2	12.5
$Li/SOCl_2$	6.9	4.8	7.5	0.8	20.0
Total	53	28	15	4	100

There is a clear preference for lithium/manganese batteries. Overall, the respondents thought that they will capture the major portion of the growth during the next ten years, about twice the growth rate of each of the other systems which individually would be expected to share about equally the remainder of the growth. You can also see that about half the growth is thought to be in the consumer market, with the OEM accounting for about one-quarter of the growth.

These responses may be complemented by, and compared with, the estimates prepared by Frost and Sullivan for the 1985 - 90 period. They concluded that the U.S. sales of lithium batteries would almost triple during the next five years, with most of the increased sales going to the military sector and only a small fraction to the consumers, the OEM lay somewhere between the two. Clearly, Frost and Sullivan and this lithium battery community are not in complete agreement, and it will be intersting to see whose crystal ball proves to be the clearer.

Dr Gabano (France): Thank you very much Dr Bro for your excellent presentation. A major problem we have seen with many of our systems is that of safety. Safety arises every time, so I ask for some discussion of this problem.

Dr Powers (U.S.A.): During his plenary lecture (pp. 1 - 8 Extended Abstracts) Dr Bro mentioned the recent improvements being made in the capacity of alkaline cells. The very early versions of our alkaline manganese cells had both high capacities and high-rate capabilities. The "D" cells could be discharged at currents up to about 90 A, but might explode when shorted. In order to come up with a safe consumer product, we had to back off these designs at the sacrifice of some capacity.

Dr Halpert (U.S.A.): Whether in space or here on earth, safety is of concern. There is even greater awareness of this issue today because of the recent shuttle accident. Therefore, insofar as lithium batteries are involved, regardless of their use in consumer, military, OEM or space applications, safety is of prime importance. The responsibilities for safety can be divided into two areas: those of the manufacturer and those of the user.

The manufacturer is responsible for producing an inherently safe cell design and building in the quality necessary to avoid defects. Many of the cells today are small and therefore contain small amounts of lithium and other materials that are considered toxic. The use of a small energy storage package is, in itself, directed toward an inherently safe cell. However, the sizes of lithium cells are growing into the 100s and 1000s of ampere hours. The design of these cells must include provision for adequate electrolyte and a proper anode-to-cathode ratio to protect against violent reactions in reversal. The materials used in fabrication must be adequate to avoid corrosion and/or mechanical fatigue. Another area of importance is to assure against external and internal shorts by providing fusing or tabs that open. A safe design is one point, assuring the quality is another. Leaks, shoddy workmanship, and non-uniformity can place a user in jeopardy. The manufacturer is also responsible for insuring that the user is aware of the limits of use and how to handle and dispose of used batteries in a safe manner. In my opinion, the manufacturers have done a poor job in informing the users of the dangers and how to overcome them.

The user, on the other hand, has the responsibility for knowing the limits of use, and proper handling and disposal techniques. Abuse can take place by the innocent placement of a battery in an environment which does not allow heat removal, or by putting the battery into a container that does not provide for expansion or for the containment of products after venting. Some cells become dangerous at low temperatures (−40 °C) which must be taken into consideration by the user. In the case of multiple cells in parallel, there must be provision for diodes to avoid the charging of one string by another. Cells can be made to vent violently or to explode if charged. This has been proven time and time again at the Jet Propulsion Laboratory in our programs on the safety of lithium cells and batteries.

In the final analysis, I believe that safety is of utmost concern to both the manufacturer and the user of lithium batteries. Much has been done to address this problem. Much more needs to be done.

Dr Takehara (Japan): In Japan, $Li/SOCl_2$ cells are produced by Hitachi Maxcell, and safety is an important problem with these batteries. I wonder if Dr Iwamaru from Hitachi Maxell would care to comment on their safety.

Dr Iwamaru (Japan): We are producing hermetically sealed $Li/SOCl_2$ batteries. Our batteries have been used mainly in sequence controllers, timers, electronic metering systems, security systems, etc. The current consumption in these equipments is usually 10 - 100 μA. However, some equipments require 10 - 200 mA pulse currents to operate the computers involved. We have conducted abuse tests such as charge, forced discharge, high temperature, vibration, shock, etc., in order to confirm their safety. It has been concluded that our $Li/SOCl_2$ batteries are very safe for use in such applications. The only potential hazard is the rupture or explosion of the cells when disposed of in a fire. There are similar products available in the market, such as gas lighters, small fuel containers, hair sprayers, paint sprayers, etc., that also have a potential of explosion by incineration. I believe that the hazard potential can be lessened by means of an effective vent. Battery engineers, including myself, are making efforts to improve the safety of hermetically sealed products, and we have already found effective and practical methods for reducing the hazard potential.

Dr Peled (Israel): Everybody is discussing the safety of lithium batteries. The general opinion is that safety problems are due to the low melting point of lithium and to dendrites that short the cells. My recommendation is to use an alternative anode, that is, calcium. Calcium has a high theoretical energy density, a high power density, and it melts at 850 °C. We have improved the plating of calcium so that no short circuits occur and the cells can be heated safely to 200 °C. Therefore, I think that the lithium battery community should give more attention and more effort to change the lithium anode to calcium for the larger batteries in order to gain in safety. Leak-proof, sealed "D" cells with a capability of 0.5 A or more can be made and are completely safe.

Dr Levy (U.S.A.): I was very surprised by the results of Dr Bro's survey. No-one mentioned reliability as an important factor. I think that reliability is essential in many applications. We feel that a reliable battery needs a hermetic seal. No one is looking at hermetic seals. Crimp seals are used and everybody claims they are reliable, but we never see any reliability data. My feeling is that for the military, and probably for the consumer market, crimp seals could be a problem in various applications as the equipment is exposed to variations in temperature — particularly in the military sector where temperatures between −40 and 70 °C are witnessed. As crimp seals are exposed to temperature cycling, the seals expand and contract and may develop leaks. Much work needs to be done in this area. I want to hear the manufacturers' opinions on this subject and what steps they are taking to improve the reliability of their products.

Dr Yamamoto (Japan): Dr Bro highlighted the price of batteries for the OEM as being very important. I look forward to comments from the manufacturers of lithium batteries. Especially in Japan, we produce many lithium batteries for the OEM. I would like to hear if Dr Furukawa and Dr Iijima have any comments on this.

Dr Furukawa (Japan): Originally, Dr Ikeda was scheduled to speak at this Round Table Discussion, but unfortunately he has an urgent business commitment and cannot be present. Therefore, I shall present both Dr Ikeda's and my own opinons on the future trend in lithium batteries.

Today, several types of 3 V lithium systems with solid cathodes or liquid cathodes are commercially available. Materials, such as MnO_2 and CF_x, have been selected as solid cathodes, and materials, such as SO_2 and $SOCl_2$, have been chosen as liquid cathodes. Recall the situation as it was 10 to 15 years ago, however. During the early 1970s, many cathode materials were proposed, *e.g.*, MnO_2, CF_x, $CuCl_2$, CuS, MoO_3, Ag_2CrO_4, V_2O_5, SO_2, $SOCl_2$, and $POCl_3$. Of these materials, some have been selected and have survived to the present time, based on cost and performance considerations. Epoch-making innovations would be necessary to develop new materials now.

As Dr Ikeda mentioned in his keynote lecture (pp. 28 - 35 Extended Abstracts), lithium batteries are currently supplied mainly to the OEM. To sell them through distribution systems such as those set up for zinc/carbon or alkaline manganese cells, further improvements in their discharge characteristics will be necessary. In talking about cell structure, the inside-out structure will be the best for cost. From a basic point of view, it is very important to increase the rate of lithium ion diffusion for improved performance. If we could succeed in these areas, new applications would result, and these improvements, together with the new applications would contribute to the acceptance of lithium batteries. The situation is similar for 1.5 V lithium batteries as it is for 3 V batteries. Again, it is necessary to improve the performance as well as the cost in order to meet manifold needs.

As with primary batteries, the next ten years for secondary batteries will be the time for proposing and evaluating new systems. Among the many new systems, a few will be selected and developed into practical products. Our Li/MnO_2 secondary battery and conductive polymer battery, discussed at this meeting, are among these new systems. Lithium secondary battery development is one of the most interesting areas, because the intercalation of lithium ion is a very smooth reaction. Finally, the solid-state lithium battery is an ideal battery. So, the search for solid electrolytes with high ionic conductivities will become more important, but it may take some time to achieve this type of battery. The 3 V lithium system was the first to be put to practical use. Together with the development of 1.5 V secondary and solid-state lithium systems, the position of lithium batteries will become more and more important in the near future.

Dr Iijima (Japan): First of all, I want to summarise some historical aspects of our research and development efforts on lithium batteries, and then mention the future of lithium batteries. In our laboratory, we began research on lithium batteries for consumer applications in 1967. Among various kinds of cathode materials, we found $(CF)_n$ to be the most promising. The $Li/(CF)_n$ battery system was first developed in 1971. Then, we introduced Li/MnO_2 batteries and 1.5 V lithium batteries using an improved CuO cathode. At present, we are studying mainly rechargeable lithium batteries and solid electrolytes.

As to the future of lithium batteries, much more effort should be devoted to rechargeable batteries. However, before such systems are developed, consideration must be given to the position that these batteries will occupy relative to conventional rechargeable batteries such as Ni/Cd and lead/acid.

Initially, rechargeable lithium batteries should be regarded as high voltage and high reliability systems rather than as high energy density units, since the batteries will have the advantages of good cycle life and good storage life. During this phase, the market will not be large. However, rapid progress in electronics will bring an increased demand for these kinds of batteries for volatile memories and other applications. For these applications, polymer film and solid electrolyte batteries should be given prime attention.

The second phase of development should aim for an improved, rechargeable lithium battery with a superior energy density and discharge performance relative to conventional batteries. It is hoped that conventional batteries will be replaced by lithium batteries in the future. This will be difficult to achieve unless the following problems can be solved:

(i) rechargeability of the lithium anode
(ii) finding a suitable cathode material
(iii) developing a high rate electrolyte
(iv) improving safety.

I believe that the first point is very important. As is well known, Ni/Zn batteries have a higher energy density and a better discharge performance than Ni/Cd batteries, but Ni/Zn has not yet reached commercialization because of the poor rechargeability of the zinc electrode. Similar problems, such as dendrite formation and shape change, occur with lithium electrodes. In order to solve these problems, we have attempted to use alloy electrodes.

We must also reflect on the reasons why we had to make both cylindrical type batteries with spirally wound electrodes and large diameter (coin type) cells during the first phase of our work. Electrolytes are needed that are more conductive and more stable because a rechargeable battery must have a high rate charge/discharge capability comparable with that of primary batteries. It is necessary to solve the trade-off problem between a high rate capability and safety. I hope that break-throughs in these areas will be achieved in the near future, and I would be very happy if our efforts were to contribute to the progress of science and to the emergence of an improved battery technology.

Dr Yamamoto (Japan): Lithium batteries will have new applications in Japan, especially for telecommunications, and I would like to ask Dr Yamaki of NTT if he has any comments on these applications.

Dr. Yamaki (Japan): NTT's "pocket bell" is now in service in telecommunications systems. The user is made aware that someone is calling when the bell sounds. The unit uses an AAA size alkaline manganese battery. The power consumption is very low in this application and the alkaline cells appear to be quite satisfactory; rechargeable batteries are not needed.

Next, the portable car telephone: one section of the car telephone can be removed from the car and used elsewhere. This section uses Ni/Cd batteries that are heavy, and therefore not very portable. I consider that the Ni/Cd batteries will be replaced by lightweight secondary batteries when they become available.

Batteries are also used for back-up power during electricity supply failures. All NTT branches use lead/acid batteries to maintain an uninterrupted service. These batteries are very large, occupy large areas, and are idle for most of the time. Because secondary lithium batteries have very low self-discharge rates, these systems may prove suitable as back-up batteries. However, safety is a problem.

These are the near-term prospects. What about the more distant future? Society will be a high information-oriented one. Portable telephones and other portable devices will be used commonly by many people. I think that rechargeable lithium batteries are suitable for such portable applications. This is the reason why we need light weight and high energy density batteries.

Dr Gabano (France): We must now close our discussions. I thank all our speakers and the participants in these discussions and expecially Dr Bro. Thank you very much for your co-operation.

Dr Takehara (Japan): This is the end of the scheduled program for this meeting. The Scientific Committee has reached general agreement that the next meeting will be held at Vancouver, BC, Canada, in 1988. Professor Haering of the University of British Columbia will be our Chairman and Dr Stiles, of Moli Energy, his Co-chairman. Thank you all very much for coming to our meeting in Japan and for your generous contributions.