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**TRIP REPORT: FUSION POWER ASSOCIATES ANNUAL MEETING**

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**ABSTRACT**

The Fusion Power Associates Symposium, " The Search for Attractive Fusion Concepts", was held January 31 - February 1 in La Jolla, California. The purpose of this meeting was to bring together industry, university and government managers of the US fusion program to discuss the state of fusion development and the direction in which the program should be heading, given the cutbacks in the US fusion budget. There was a strong, minority opinion that until the "best" concept could be identified, the program should be broadly based. But there was also widespread criticism, aimed mainly at the largest segment of the magnetic fusion program , the tokamak. It was felt by many that the tokamak would not develop into a reactor that would be attractive to a utility and therefore should be phased out of the program. If the tokamak will indeed not lead to a commercial product then this meeting shows the US fusion program to be in a healthy state, despite the declining budgets.

## I. INTRODUCTION

The Fusion Power Associates held their annual meeting and symposium on "The Search for Attractive Fusion Concepts" in La Jolla California, January 31 - February 1, 1985.



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The Fusion Power Associates is a US non-profit, educational and scientific research foundation. Its purpose is to foster and ensure the timely development and public acceptance of fusion as an environmentally and economically viable source of energy. Its activities include the publication of a news letter, the publication of books, the issuing of policy statements, the organization of symposia and interaction with the news media. Its corporate members, one of which is Ontario Hydro, include most of the large companies in North America that are interested in fusion.

This symposium takes place against a backdrop of declining budgets and program reorientation in the American fusion program.

The FY 84 magnetic fusion budget was $US 470 million, the FY 85 budget is $US 437 million and the FY 86 budget submitted to the US congress in February was nearly $US 50 million less. The Inertial Confinement budget proposal for FY 86 is for a 50% cut from FY85.

Along with the declining budget the program is undergoing a reorientation:

1. The program will move away from large flagship projects, such as TFTR - the large tokamak at Princeton.

2. There will be more emphasis on alternate concepts and innovative ideas.

3. International co-operation will be sought to stretch research dollars.

4. Responsibility for engineering and reactor development is being shifted to industry. The immediate consequence is that the DOE program is becomming more physics orientated as opposed to engineering oriented.

There are a number of forces at work influencing the decision to cut the program back and to gradually change its direction. There is an attempt to keep the US deficit down, the energy surplus has obviated the urgency for commercial fusion and fusion is not as short range and exciting as some of the competing projects, such as Star Wars or the Space Shuttle. There is one additional underlying factor. For some time there have been many experts in the fusion community, especially in industry and the utilities, saying that the large tokamak reactor would never be commercially viable; it is too expensive, too complicated and too fragile. The DOE and the polititians, the two groups that control the size of the budget and the program's direction, have apparently listened to this and are re-evaluating the program.

## 2. THE SYMPOSIUM

The Symposium comprised four sessions and a tour of the facilities of GA Technologies. The session titles were:

1. "Prospects for Developing Attractive Magnetic Fusion Concepts"

2. "Prospects for Developing Attractive Inertial Fusion Concepts"

3. "Industry and Utility Perspectives on Future Directions in Fusion Energy Development"

4. "Prospects for Alternate Fusion Fuel Cycles".

Each session had the same format. The panel chairman made some opening remarks followed by a ten to twenty minute statement from each member of a panel of experts from the US fusion community. This statement was either an opinion on where the program should be heading or a summary of their particular group's progress. This was followed by audience discussion.

The sessions were transcribed and will be published in the Journal of Fusion Energy.

Below are some of the highlights of each session. More complete accounts are given in Appendices A - D.

## 3. PROSPECTS FOR DEVELOPING ATTRACTIVE MAGNETIC FUSION CONCEPTS

There was a lot of controversy in this session. The large tokamak concept was under attack and on the defensive. The keynote address by Robert Hirsch (Chairman of the board, Fusion Power Associates) was very clear. He considers the tokamak program a failure. He feels that the program has had enough time to come up with an attractive concept and has not done so. The next generation tokamak experiments are just too expensive for what they will produce. He believes that the alternate concepts need more investigation. Stephen Dean (President, Fusion Power Associates) who delivered (the absent) Hirsch's talk commented that he thought Hirsch was taking an extreme stand to sharpen up the debate.

A number of speakers agreed that there was a problem with the program and suggested ways to solve it. Several panelists believe that alternate concepts, especially the compacts, which have a much higher power density than the tokamaks and would require inherently cheaper experiments to establish their viability, should be pursued more vigorously.

Some took the point of view that no one knows what a future fusion reactor will look like and no one knows what will constitute an attractive reactor to a utility. Therefore, none of the concepts, especially the tokamak, which is the most technically advanced concept, should be discarded. For example, fifty years from now, environmental concerns may be of overwhelming importance, so a different type of reactor would be attractive than if economics were the determining factor.

There was a vigorous defence of the tokamak by Harold Furth (Director of the Princeton Plasma Physics Laboratory). He believes that it is very important to establish that one fusion concept will work. This will prove that fusion is a viable option and he believes that the tokamak is the best vehicle for this.

## 4. PROSPECTS FOR DEVELOPING ATTRACTIVE INERTIAL FUSION CONCEPTS

This session was less interesting than the previous session. Most of the speakers simply reviewed their program or pointed out the potential advantages of their particular concept over the competition. One advantage that inertial fusion has over magnetic fusion and which may turn out to be very important was discussed by Bill Hogan. He said that Inertial fusion has a product (the laser) that will be useful in the short term (to the military) and this will help keep the inertial program alive.

The most outspoken talk was given by John Nuckolls (Associate Director of Physics, LLNL). He feels that the community is too fragmented and if it is bad in good times, it is suicide now. He is dismayed that money is still being spent on the $CO_2$ laser because the wave length is too long and on the KrF laser because the efficiency is too low. He wants more money put on the study of polarized fuels because it has the potential to cut laser costs in half. Nuckolls believes that the people in the fusion program should try harder to get the politicians excited about fusion.

## 5. INDUSTRY AND UTILITY PERSPECTIVES FUSION ENERGY DEVELOPMENT

This session was the most interesting and the most critical of the fusion program. Most of speakers did not have as big a stake in the fusion program as those in the last two sessions.

Christian Bolta (Combustion Engineering) discussed the point of view of a private company investing its own money. He felt, and this was echoed by other speakers, that it would be necessary to form joint ventures. He listed eleven criteria that he felt must be met for an R&D joint venture to succeed, and stated that he did not see many projects that would fulfill them in the fusion area.

Several speakers criticized the large tokamak projects, because they felt that a large tokamak reactor would not be attractive to a utility. It was criticized for being too complex, too fragile and too

expensive. Kenneth Matson (Public Service Electric and Gas Research Corporation) listed eight criteria that a fusion reactor must meet in order for it to be acceptable. They can be summarized as: simple, clean, safe and cheap.

## 6. PROSPECTS FOR ALTERNATE FUSION FUEL CYCLES

Most of the talk in this session centered on catalyzed DD reactions and proton based cycles.

The general feeling was that DD is a definite possibility with some advantages compared to DT and some disadvantages. Cost studies show that it is only marginally more expensive than DT; certainly the difference is well within the error bars. There was a general consensus that proton based fuels will never be viable and minority opinions that D-$^3$He needs more work and that DT is the most advanced fuel.

The chairman summed up by saying that the outlook for alternate fuels R&D is not very good and if the budget stays at the proposed level of about $US 390 million, there will most likely be little money for alternate fuels.

## 7. SUMMARY

There seemed to be agreement that fusion still has the potential to deliver a simple, clean, safe and cheap product. There was a widespread feeling that the present program, because of its emphasis on the large tokamak, was not aimed at that goal, and that some reorientation was required. It was felt that now is the time for the reorientation, not after the next large ($US 1.5 Billion +) tokamak experiment, because it is already clear that the tokamak will not develop into a commercial product. But there was also strong opinion that until a "best" concept was definitely established, the program should continue to examine all of the possibilities, including the tokamak. Many suggestions for modification of the program were given (usually the speaker promoted his own project) but there was no unaminity.

## 8. CONCLUSIONS

The fusion Program in the US is going through a reorientation phase. In the next few years I believe the large tokamak will decline a little as a percentage of the US magnetic fusion budget (now at 60%), the mirror program will shrink substantially from its present 20%, and the other concepts will gain. Within five to fifteen years some of the alternate concepts, most likely the compact devices, will have caught up to the large tokamak in development and will be widely regarded as the only candidates for the commercialization of fusion. At that point fusion spending will start to increase substantially.

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## APPENDIX A

## PROSPECTS FOR DEVELOPING ATTRACTIVE MAGNETIC FUSION CONCEPTS

**Stephen Dean** (President, Fusion Power Associates) delivered the opening remarks. He began by discussing the meaning of the word attractive when applied to fusion. He believes that, since the definition is not obvious, it must be discussed and this is the purpose of the symposium. The groups who must find it attractive are the US government, the media, the general public and the ultimate customer. He said there will likely be a down trend in funding for magnetic confinement fusion and a disaster for inertial confinement fusion (he was referring to the recent submission to the US Congress for next year's fusion budget where the proposal is to cut the magnetic confinement fusion budget by $US 50 million and halve the inertial confinement fusion budget).

**Robert Hirsch** (Chairman of the Board, Fusion Power Associates and Vice President, Arco Oil and Gas Company) who was to give the keynote address, could not be there so Dean read from Hirsch's notes. (Dean prefaced Hirsch's remarks with the comment that he thought that Hirsch did not have a positive enough view of the situation). Hirsch thinks that the energy glut is a real problem for fusion and he does not think that the fusion program has come up with an attractive product. He looks at the tokamak program and is appalled. It has had enough time but has failed. The next generation tokamaks are just too expensive for what they have to do - $US 1 to 2 billion experiments don't make sense. It's time to look for something else. He feels that the alternate concepts need more effort and that the program doesn't need the large tokamak projects. He believes that TFTR should be upgraded to burn DT as quickly as possible, then turned off. People are comming to recognize these points but there has been no open debate. The criteria for fusion to be attractive are:

1. the cost should be competitive,
2. easy maintenance,
3. safe and not environmentally insulting.

Finally, he believes that knowing all of the physics isn't that important and that a window has closed on the LWR, solar power towers and is closing on tokamaks. Dean then offered the opinion that Hirsch may be taking an extreme stand to sharpen up the debate and that Hirsch thought the program should be reoriented towards a product that is wanted.

**John Clarke** (Associate Director for Fusion Energy, Office of Energy Research, US DOE) believes that fusion will be attractive if it is economically and environmentally surperior to the competition. One of the

problems that he finds is that he doesn't know what the competition will be when fusion is mature. He is not at all discouraged in comparing fusion to other concepts. He believes that both the physics and technology must be understood and only then can the possibilities be narrowed and an attractive concept developed. If the environment is more important then the program will go in one direction and if economics is more important then the program will go in another.

**John Sheffield** (Associate Director for Magnetic Fusion, Oak Ridge National Laboratory) has examined generic reactor concepts and using very conservative assumptions has found fusion competitive. But he does not know how to judge its attractiveness to a utility until he actually has the reactor. Environmental considerations may decide. For a 1200 MWe plant, 10,000 tonnes for the reactor core is about the upper limit, anything more and the LWR looks better.

**Kenneth Fowler's** (Associate Director for Magnetic Fusion, Lawrence Livermore National Laboratory) main concern was how to make it through the next five years. Because technology and the world are changing, that which makes a concept attractive is a moving target. He believes that fusion generated electricity will be economic in the same time frame that it will be feasible and it will have a slow penetration into the market. But fusion will not be so attractive that it won't need an edge such as fuel abundance, safer, cleaner etc. He believes that the trend now is towards concepts that will produce smaller cheaper reactors such as the Minimars at LLNL. It is important to find the best use for a fusion reactor, one example being a breeder. Sheffield stated that he also thought that a fusion breeder would be economic.

**Gerald Kulcinski** (Vice President, Fusion Power Associates and Professor of Nuclear Engineering, University of Wisconsin) reviewed the progress of reactor design over the last decade. Some of the areas mentioned were: reduced long lived activation, reduced reactive metal inventory, reduced tritium inventory, passive safety, high power density - small size, modularity, steady state, normal conducting coils reconsidered, advanced fuels, hybrids, synthetic fuel production and space applications. He singled out passive safety, normal coils revisited and space applications for more discussion. His main points in these areas were that passive safety, with proper design, was possible, that normal conducting coils should be re-examined in the tamdem mirror reactors and that orbiting pulsed fusion power stations offered many advantages.

**Harry Dreicer** (CTR Division Leader, Los Alamos National Laboratory) prefaced his talk with an observation about the 1984-5 ERAB report. They examined TFCX (a large tokamak, proposed to be the successor to TFTR, and since cancelled) and noting the high capital cost said that this would make fusion non-competitive, if available today. He went on to say that he thought the program should focus on the potential for the smallest capital cost. He introduced the mass utilization, $M_u$, (mass of the reactor core/MWth produced) as a figure of merit and compared various

fusion reactor concepts. The CRFPR (Compact Reversed Field Pinch Reactor) had the smallest value of $M_u$, comparible to the LWR. The ORNL generic fusion reactor study indicated that the threshold value of $M_u$ needed for fusion to be competitive with fission is about 2.3 tonnes/MWth. At $M_u$=2.3 the core is sufficiently small that any reduction doesn't reduce the COE (Cost of Electricity) but smaller values give the following advantages: (1) reduction in the impact of changes in the core ( ie the introduction of new technology, or simply replacement at the end of life); (2) faster fabrication of the core; (3) multi-unit plants become possible. He believes that a target of 1000 tonnes for the core mass is desireable. Dreicer then examined the prospects of achieving $M_u$<=2.3 and found it to be highly concept dependent. Tokamaks, stellarators, tandem mirrors and ELMO Bumpy Squares, all with superconducting coils and auxilliary heating, just might possibly make it, but would have a minimum mass of about 2300 tonnes (excluding coils) and would be difficult to fabricate. Those with the predicted potential to have $M_u$ < 2.3 are the spheromak, the RFP (reversed Field Pinch) and OHTE. All of these would have normal conducting magnets and ohmic heating. Those concepts with the potential to have $M_u$ less than that of the PWR value, which is less than 0.3 are the HDZP (High Density Z Pinch) and the FRC (Field Reversed Configuration). He concluded by saying that he thought the program should be diverse enough so that the concepts which have the potential for low $M_u$ get a more detailed look.

**Tihiro Ohkawa** (Vice President, GA Technologies Inc) examined the nature of fusion R&D from the perspective of a private company. If an investment in R&D requires many times a companies' net worth then it will not be attractive. The difficulty with fusion is that the cost of the experiments is rising steeply with time (or stage of development) and even though the cost of a commercial reactor may eventually be much less than the experiments, getting over the hump is very difficult. He feels that ways should be tried to lessen the cost of the experiments. He said that the way to do this is highly judgemental. A review of GA Technologies' programs (Doublet III-D, a large tokamak, and OHTE, an RFP device) was given.

**Harold Furth** (Director, Princeton Plasma Physics Laboratory) started by saying that some of the key technical issues were the identification of the optimal configuration, exploration of the burning plasma state and the development of fusion technology. He addressed the first issue and split it into two parts:

a) identify several viable options and

b) identify the best option.

He pointed out that identifying a viable option is a significant step since we then know that we are on the right track. He then addressed the absent Hirsch by saying he thought that the large tokamak was the best vehicle for determining if fusion is viable. Step b, the tokamak as the best reactor candidate, was then examined. As a specific example he discussed a 350 MWe high beta tokamak with a bean-shaped plasa. He went over the characteris-

tics of the design and pointed out the advantages of this particular concept especially with regards to the easy maintenance. An illustrative candidate for step a was then given - a ten year project to build a medium to high beta tokamak of moderate unit power (500 MWe). He gave illustrative examples of other potential step b devices: tandem mirrors, RFPs, Compact Tori (spheromaks and FRCs) stellarators and advanced tokamaks. In summary, he listed the following advantages to the two step approach of the identification of the optimal configuration:

1. The technical data base for step a can be available sooner (10 years instead of 20) if the physics is satisfactory.

2. Demonstration of one or more viable solutions would advance fusion research from the 'wildcat drilling' phase to the 'development drilling phase' ie get some oil first then look in the neighborhood for the best well - don't drill at random. (Furth said that he wanted to phrase this in a way that Hirsch could understand).

3. Successful achievement of step a would justify the vigorous long term support needed for step b.

**DISCUSSIONS**

**Clarke** (to Furth): What about the problem that we will be stuck with the tokamak?

**Furth**: At the beginning we were afraid of the breeder, but one of the worst things to happen to fusion was the passing of the Clinch River breeder. The threat today is that no concept will be demonstrated and that the government will loose faith that there is any viable concept.

**Fowler**: Remember the Balance of Plant costs. Its the total system costs that are important. The more compact the Fusion Power Core, the cheaper the R&D.

**Kulcinski**: I am a little troubled about using mass utilization. An area of concern is the use of ceramic blankets vs lead lithium blankets - the cost is not critical between these two but mass is. I suggest that volume be used instead of mass.

**Rose**: We should look for concepts that don't have the cost barrier (of Ohkawa).

**Furth**: Both my steps a and b could be accommodated in the present program.

**Ohkawa**: One way for a company to cross the hump is to form joint ventures.

**Question**: Does the window for tokamaks exist?

**Furth:** Yes and its open.

**Fowler:** The window is sliding because the tokamak is evolving.

**Kulcinski:** The real question is: Is this a window for fusion? We've made a lot of progress in the last ten years and this should be sold to the people who say we don't have something attractive.

**Furth:** The next step ignition experiment has shrunk by two orders of magnitude in mass or volume over the years, which shows that the shrinking window pressure has been felt by the community.

**Clarke:** To sum up:

1. Sheffield, Kulcinski and Fowler were positive in that there were good prospects.

2. Furth and Ohkawa gave strategies for getting over the financial barriers.

3. We are in hard times now but that won't last forever.

4. I personally think that we have an oscillating, not a closing, window and as long as fusion is attractive, there will be a program.

## PROSPECTS FOR DEVELOPING ATTRACTIVE INERTIAL FUSION CONCEPTS

**Eric Storm** (Deputy Associate Director for ICF, Lawrence Livermore National Laboratory) began this session with a discussion of the need for fusion. He then listed the uses for inertial confinement fusion (ICF) devices in the order in which he thought they would become viable: nuclear weapons design, simulate nuclear weapons effects, production of special nuclear materials, fissile fuel production, electric power, synfuel production and propulsion - both space and marine. Storm then went on to discuss laser drivers, in particular describing the Nova laser system at LLNL. He said that the target is to get the cost down to < $US100 per Joule. Solid state lasers have tremendous technical potential and may be the drivers of the future.

**Bill Hogan** (Lawrence Livermore National Laboratory) then talked about inertial fusion reactor concepts. The big advantage that ICF has over magnetic fusion is that the driver can be placed far from the reaction chambre. ICF does have an advantage now over magnetic fusion in that it has a product (the laser ) that can help it along. He agreed with Storm that the solid state laser may be the driver of choice. One of the big problems with ICF is that a lot of the work is classified and cannot be discussed.

**Michael Monsler** (Vice President for Fusion Programs KMS Fusion Inc) thinks the prospects for ICF are good because three factors are favourable: high performance, acceptable safety and competitive cost. The highest development risk is the low cost high efficiency laser. As far as cost is concerned he said that he does not have a reactor design that he thinks can be costed out with confidence. However his gut feeling is that a 10% efficient laser can get down into the competitive regime.

**Steve Bodner** (Head, Laser Plasma Branch, US Naval Research Laboratory) listed the advantages of ICF as: the high technology equipment is away from the neutrons, if the containment could be made from aluminium then a man could go in after 2 weeks and do repairs, and classical fluid theory may be all that is needed for the physics. He believes that all the constraints in driving the pellet (symmetry to 1 or 2%, stability, little preheat and high efficiency) can be met.

**David Cartwright** (Los Alamos National Laboratory) discussed the LANL program in ICF covering both the $CO_2$ and KrF lasers. The KrF laser looks like the best but the $CO_2$ is so nice to work with that they are trying a number of things to keep it in the running.

**William Herrmannsfeldt** (Accelerator Physics Department, Stanford Linear Accelerator Centre) discussed the heavy ion ICF prospects. The three main elements of the program are: the accelerators, beam transport and focussing, and beam target integration. He thinks that 500MW plants may be possible. Their program does not do any work related to target design; they are leaving that up to the laser ICF people. Their long range plans include a $US 100 million proof of accelerator facility to examine all the beam - target issues.

**Pace VanDevender** (Director, Pulsed Power Sciences, Sandia National Laboratory) gave an overview of the Light Ion Fusion ICF program at Sandia. He listed the main physics issues that they are now addressing: scaling, voltage gain, pulse shaping, and how to channel the beam to the target.

**John Nuckolls** (Associate Director of Physics, Lawrence Livermore National Laboratories) also feels the onset of the Hirsch disease and shares many of the same concerns. It seems that after you have been away from fusion for awhile, you loose the vision. He addressed ICF only, not magnetic fusion. He feels that the community is too fragmented and this is bad even when budgets are going up and suicide when budgets are going down. ICF must have considerable advantages over coal or fission, not just be a little cheaper, before the utilities will buy it. He's dismayed that money is being spent on $CO_2$ lasers because the wave length is too long and he's more dismayed that money is being spent on KrF lasers because the efficiency is too low. The breeder reactor idea is excellent and should be pursued. He is also dismayed that the target physics between LLNL and LANL are so different. He wants more effort on polarized fuels since it has the potential to cut laser costs in half. A lot of the reactor design studies are a waste of time - we don't need the 31st study showing that ICF is too expensive. Nuckolls then addressed some larger issues. He wondered if fusion might not be a technology before its time. How would a fusion program launched in 2020 differ from the one ongoing today? He ended his talk with a discussion of vision. He wondered why Reagon and his science advisors do not have a vision of fusion. They are obviously men of vision, all you have to do is look at their commitment to the Star Wars program. He thinks the reason is that no one has tried to sell it properly. Something is wrong if we are quibbling over a few hundred million either way. Two to four billion is being spent on Star Wars and five billion on NASA. Either its worth doing or lets drop it. And if we are quibbling like this its probably not worth it. His last remark was that Edward Teller is a passionate fan of fusion - fission hybrids and perhaps he could help.

## APPENDIX C

## INDUSTRY AND UTILITY PERSPECTIVES ON FUTURE DIRECTIONS IN FUSION ENERGY DEVELOPMENT

**Christian Bolta** (Director, Technology Strategy Development, Combustion Engineering) feels that industry has not been fully utilized in the management area. He discussed joint ventures because he felt that they were necessary in the fusion area. Based on his personal experience in observing upper management and their opinion on R&D he sees the following as being prerequisites for a recommendation for R&D, joint ventures: responsible management, defined concept and approach, known risks and costs, system integration responsibility, needed technical advances identified, a reasonable timetable, market analysis, a partner that brings added value, a possible early return on investment, no other better opportunities available in another area, budget commitment by partners and a clear proprietary benefit to the partners if successful. In the area of fusion he does not see much that would have the above prerequisites but if there were some near term benefits, it might be more attractive.

**Robert Scott** (Fusion Program Manager, Electric Power Research Institute) thinks that fusion is shooting itself in the foot with respect to conceptual designs and economic studies. The outside world misunderstands and does not realize that they are done to provide clues to what should be done next. Utilities are interested in fusion because they do not want the same thing to happen to fusion that happened to fission. EPRI, who developed the blanket module for TFTR, was very interested in the Tritium burn and lost interest in fusion when it was delayed. He discussed EPRI's wind program and said that EPRI spends 4 times as much on wind as on fusion because of the small size of the wind experiments.

**John Cutting** (Manager, Energy Systems, Gilbert/Commonwealth Inc) gave the A/E (Architect/Engineer) point of view of fusion. By 2050, 1000 1GW plants will be needed in the US. In order for fusion to be acceptable, the following points will be examined: cost (capital, operations, maintenance and fuel), environmental impact, licensing, size, flexibility and duty cycle. No utility will even consider a fusion plant until a successful DEMO is proven. Other necessary factors for fusion development are: a co-ordinated public relations campaign, a unified fusion community behind the selected option(s) and early utility participation.

**Howard Drew** (Executive Vice President, Texas Atomic Energy Research Institute) gave the point of view of a utility manager. He said that utility managers are very conservative and it will be difficult for them to plunge into a new technology such as fusion. Most managers feel that fission must come back because it has been so successful in Europe and this is a problem that fusion must address. They are negative on tokamaks because it is a new technology and because of the superconducting magnets and the liquid lithium. It is expected that there will be a lot of unplanned outages. He agreed with Nuckolls that the government leaders need to be

sold on the idea of fusion and he agrees with Hirsch that everything possible should be done with TFTR. He feels that the market place will choose the best concept not the scientific community and it is time that this was recognized.

**Alan Kolb** (President, Maxwell Laboratories, Inc) gave his impressions of the magnetic fusion session. The two main points are: fusion remains as attractive as ever and the fusion program is in big trouble - he senses confusion and some panic. Kolb's summary of the magnetic fusion talks is:

1. Clark: we need a broad program like the 50s and 60s.

2. Sheffield: how small do we have to make it? He doesn't know which is best so pursue them all.

3. Hirsch: Accelerate TFTR then turn it off because the physics is irrelevant.

4. Furth: Furth's career has been : pinches to stellarators to tokamaks. Two years ago Furth argued against compacts but yesterday he argued for them. Furth seems very elastic so find out which direction he resists the most and go that way.

He summarized by saying that the fusion community does not have its act together so it is not sincere about a change in direction. The payoff remains large but the ability to sell it is terrible. Good luck and God speed.

**John Landis** (Senior Vice President, Stone and Webster, Inc) was more positive in that he proposed a Formalized Industrial Participation Program (FIPP) in which a large number of companies would participate in the development of fusion. He felt that 500 to 1000 companies would be a desirable target for the number of participating companies. He said that competition would be a problem but that he thought it could be overcome.

**Kenneth Matson** (Vice President, Public Service Electric and Gas Research Corp) gave a utility point of view on fusion. He said that the holy grail for fusion is not breakeven but competitive cost - fusion will have to compete with advanced coal and nuclear. He feels that the cuts and the shift in emphasis should be turned into an opportunity to identify the best concept. Most of the concepts now are unattractive because they are overly complex. A future fusion reactor must meet the following criteria:

1. Publicly acceptable. This is extremely important. He said that a recent survey showed that fission and fusion were strongly linked in the public mind. He quoted from the Forbes article (Nuclear Follies, Forbes Magazine, February 11, 1985) : "The truth is that nuclear power was killed, not by its enemies, but by its friends." and said that a lesson should be learned.

2. Economically competitive

3. Standardized and pre-licensed design. Utilities will not buy a fission plant now unless it is prelicensed.

4. Inherently safe

5. Easily sitable

6. Relatively simple design

7. Relatively simple maintenance. This is a very important item. If it cannot be maintained then it will not be bought.

8. Easily constructed with experienced companies available.

He finished by saying that we need to get a perspective from fission and make sure that the same things don't happen to fusion.

**Leonard Reichle** (Executive Vice President, Ebasco Services Inc) predicted that if fusion does not get its act together then the budget will continue to be cut - it could go a lot lower, like solar, MHD and breeder and turn into a physics program. He said that congressman are action orien ted and that the postponement of the tritium burns in TFTR made fusion a dull area. He thinks that the next step should be a small ($US 400 million) copper coil tokamak ignition experiment. Reichle feels that international joint ventures will take too long to get going. He also feels that we should not get caught up in the alure of high power density but should stick with the most advanced concept. In summary, fusion should get political support and move ahead quickly with a mini-flagship tokamak ignition experiment.

**Peter Rose** (President, Spectra-Technology) feels that it is industry's role to propose and promote innovative concepts. He then went on to describe Spectra-Technology Inc's FRC project, proposing a $US 100 million ignited FRC experiment.

**Peter Staudhammer** (Manager, Energy Systems Operations, TRW Inc) examined the external view of fusion. He felt that the issues were: is there a window for fusion and how can the program get through the next 5 years. An attractive concept must be found and concentrated on. It must have an impact in 15 years. The examples he gave were the hybrid, and breeding tritium for the military. He thinks that an ignition experiment is needed to capture the imagination of supporters.

**Starnes Walker** (Fusion Program Manager, Phillips Petroleum Inc) gave the energy companies' perspective. He said that their company has looked at fusion from both the short and long term point of view. He said that there is considerable money ($US 100-250 million per year) available from the energy companies for R&D. Fusion has to compete with other projects for this money. Equal importance is given to time and money. He

believes that the fusion program needs more emphasis on engineering. He described their OHTE program, phases I and II. In summary he said that a cost analysis shows a considerable edge for the compacts (such as OHTE) over the large tokamaks.

**DISCUSSION**

**David Register:** A big problem is 8-10 year programs with 1-2 year funding cycles.

**Sheffield:** And even small projects take 5-10 years. To address the question that we should choose one option: we don't know which option to choose. He would be reluctant to chop out an option that might work and agrees with Furth that a viable option must be identified now.

**Miley:** (commenting on Landis' suggestion) I am concerned about getting 100 companies together without something to rally around.

**Dean:** Reagan despises what Carter tried to do with fusion, ie turn it into a big government program. He thinks that Reagan's imagination could be captured if a way were found to induce the energy companies to put up money (eg. tax write offs) and government did not manage the program.

## APPENDIX D

## PROSPECTS FOR ALTERNATE FUSION FUEL CYCLES

**Donald Dobrott** (Director, Applied Plasma Physics and Technology Division, Science Applications International Inc) gave the keynote address: An Assessment of the catalyzed Deuterium and Proton-Based Fusion Fuel Cycles. In comparing DD with DT reactors he gave the following advantages and disadvantages of DD:

Advantages of DD : no tritium breeding; lower tritium inventory; simpler blanket; higher thermal efficiency; lower power density; lower after heat; lower neutron flux; greater first wall and blanket lifetime.

Disadvantages of DD: lower reaction rate; larger size; higher capital cost; higher magnetic fields; higher temperature; synchrotron radiation and lower mass utilization.

Dobrott then compared DT and DD mirror reactors. The cost of electricity is about 20 % higher for DD but the tritium inventory is 2 orders of magnitude lower. He said that in his opinion proton based fuels will not be practical without a major breakthrough. He also noted that moving to DD reactors is moving in the opposite direction to the current trend towards compacts.

**Robert Conn** (Professor of Nuclear Engineering, University of California, Los Angeles) stated that he had looked at p-$^{11}$B as a fusion fuel and found that there was not much promise. Similarly, proton and lithium cycles look very, very difficult.

**George Miley** (Professor of Nuclear Engineering, University of Illinois) thinks that the community should be looking more at advanced fuels. Serious consideration should be given to burning D-$^{3}$He in the next ignition experiment.

**John Nuckolls** (Associate Director of Physics, Lawrence Livermore National Laboratory) thinks that proton based fuels for inertial confinement fusion are hopeless But he likes the idea of a direct conversion process and the use of polarized fuel. He has started a program at Livermore in catalyzed fusion.

**Charles Baker** (Director, Fusion Power Program, Argonne National Laboratory) compared the Wildcat (DD) and Starfire (DT) conceptual designs. Most of the energy coming out of the DD reactor is in the secondary DT neutrons. He found that there was not much difference between the shielding for the two reactors but the vulnerable tritium inventory was 30 times less and the non-vulnerable inventory was 55 times less. The cost of the tritium systems was about the same because the vacuum systems in the DD machine are much larger. In summary Baker believes that DT is the most advanced fuel and the best because it has a much higher power density and 80% of the energy comes through the first wall.

**Bruno Coppi** (Professor of Physics, Massachusetts Institute of Technology) likes D-$^3$He because it is neutronless and has characteristics that are quite different. He said that it is possible to build a compact high field density D-$^3$He experiment for about $US 46 million at the right site. He is afraid that if the cutbacks continue that the program will have to start afresh in 10 years.

**John Glancy** (Senior Vice President, Science Applications International Corp) thinks the catalized DD reaction is the most technically feasible in that it allows a real simplification of the blanket design. The best system power density would be that of the Starfire design.

**Robert Krakowski** (Group Leader, Reactor Systems Studies, Los Alamos National Laboratory) said that the main advantage to DD is in eliminating the need to breed tritium in the blanket. As far as the cost goes, DD is only 25% more expensive than DT, and that this is insignificant compared to the uncertainties. Environmentally, there is no difference between DD and DT but as far as safety is concerned DD is better because of the smaller tritium inventory and not having a liquid metal coolant.

**William Dove** (Chief, Advanced Fusion Concepts, Office of Fusion Energy, US DOE and Panel Chairman) Summary: the outlook for alternate fuels is not too good. The only way that they will become more attractive than DT is for a reason such as public safety. The liklihood of significant amounts of money being allocated to alternate fuels if the budget stays at $US 390 million is small.