H. W. Hendel et al. (PPPL) described the use of Bicron 720 ZnS detectors for obtaining neutron count rates on TFTR. Recoil protons from a thin plastic sheet excite the ZnS screen, and a curved light pipe leads the photons to a PM tube. A 90-deg bend shields the PM tube and electronics from the high neutron flux. The detectors have a short decay time (200 ns), so high count rates can be measured.

Several experiments use $^{235}U$ fission detector systems for measuring neutron emission rates. M. S. Derzon et al. (LLNL) are developing a high-pressure (200-atm) $^3He$ scintillation detector, which is expected to provide very good neutron energy resolution (<5% at 2.5 MeV).

M. T. Swinhoe (JET) described neutron measurements on JET. In addition to fission counters, they have a detector filled with 3 atm of $^3He$ and 6 atm of argon. It is located over a hole in a concrete floor 20 m above the torus, and it can attain an energy resolution of 60 keV, which is adequate to measure the observed 120-keV width of the deuterium-deuterium neutron peak ($T_i = 2.7$ keV).

C. A. Bunting et al. reported ion temperature measurements on HBTX-1A using a CX neutral atom energy analyzer. They measured $T_i$ up to 120 eV, for plasma currents up to 250 kA, and noted 10-kHz fluctuations on the detector signals, which appear to correlate with magnetic field fluctuations.

Several papers described neutral atom energy analyzers, using *E*-parallel-to-*B* geometry and surface barrier detectors or microchannel plate detectors. For high-density pinches, however, such detectors view only the plasma edge region.

J. D. Strachan (PPPL) reviewed methods for measuring fusion products in tokamaks. The 3-MeV protons emitted by the D($d,p$)T reaction and the 14.7-MeV protons from the $^3$He($d,p$)$^4$He reaction have been detected. The energy distribution of these reaction products is a good measure of $T_i$.

### DIAGNOSTIC SYSTEMS AND APPLICATIONS

Franz Jahoda (LANL) described the peculiar properties of barium titanate ($BiTiO_3$), which make it useful as a "phase conjugate mirror." Laser beams reflected from it produce the phase conjugate of the incident beam, which means that phase aberrations produced by going through refractive media (glass, plasma) are nullified, so that a Michelson interferometer with such a mirror would measure nothing at equilibrium. The response time of the mirror is slow, however, so rapid changes of refractivity do produce fringes. Hence, the interferometer is sensitive not to refractive index, but to the rate of change of the refractive index. Such a mirror might also be useful with an intracavity absorption experiment to get rid of unwanted phase sensitivity.

Sid Medley et al. (PPPL) and M. J. Moran (LLNL) described potential measurements of gamma rays emitted during fusion reactions. Although the branching ratios for gamma emission are very small ($10^{-7}$ in some cases), the resultant gammas can provide useful information about the plasma.

G. A. Cottrell et al. (GA Technologies, Inc.) described a technique for determining plasma profiles from a few chord measurements. Instead of assuming an approximate shape or doing a matrix inversion, an iterative process that proceeds toward the profile having the "maximum entropy" is performed; hence, it is deemed to be the most probable, given the limited data available.

The conference proceedings will be published in the *Review of Scientific Instruments*. The Sixth Topical Conference on High Temperature Plasma Diagnostics will be held in the spring of 1986. The chairmen for that conference will be John Soures, Laboratory for Laser Energetics, University of Rochester, and Ken Young, PPPL.

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## SUMMARY OF THE FUSION POWER ASSOCIATES' SYMPOSIUM ON NEW DIRECTIONS IN MAGNETIC FUSION, ROCKVILLE, MARYLAND, OCTOBER 3, 1984

### THE SYMPOSIUM

Congressional action on the FY 1985 fusion budget resulted in funding cutbacks and called for the preparation by the U.S. Department of Energy (DOE) of a new fusion program plan. This symposium was convened for the purpose of receiving a presentation from John F. Clarke, head of the U.S. magnetic fusion program, on the first draft of the new policy plan and to conduct panel discussions on several important topics related to the policy plan. The panel discussions covered four areas: the role of industry, the role of tokamak ignition device options, the role of improved fusion concepts, and the role of technology research and development (R&D).

### PLANNING

In his opening remarks, Fusion Power Associates' president Steve Dean stated that "there is a continuing need to develop a spirit of cooperation among all the organizations that are working on the program because we are a small community in a country that has got a lot of fish to fry.... We have a lot of work to do to get people to understand what it is we do and why it is important." Dean pointed out that, since 1976, we have not been getting the funding, nor making facility commitments, that would allow us to claim we are on a path to a scheduled endpoint of operating a power plant. "It is the burden of a plan or planning activity to explain, as best one can, how one is going to get from where one is to where one wants to go," he said. "A real plan must contain milestones, activities needed, schedules and costs." Dean noted that in addition to basic physics and technology programs, proof-of-principle experiments, and major scaleups of those experiments, it is necessary "to do some other things, like make some energy and study some engineering issues and learn what to do with fusion, if eventually we are to get to commerical fusion power.... This will require building some energy-producing experimental reactors."

### NEW DIRECTIONS

In his keynote address, describing the new draft policy plan, John Clarke said that, technically, the fusion program is ready to carry out an ignited burning plasma experiment but that, politically, there is little perceived requirement for a near-term reactor or for scheduled fusion reactor development. The program response to the situation, Clarke said, will be to increase our effort to conceptualize a better ultimate fusion energy system. "Given the changed external perception of what is needed from the program, clearly the way in which we organize the pieces has to change," Clarke said. "The changes will consist of different priorities and pacing of the research we are doing." He said new policy would result in increased emphasis on alternate concepts, university basic research and systems analysis, and less effort on reactor component engineering development, component test facilities, prototype reactor facilities, and "mainline flagship projects." "Flagship is a code word around Washington these days," Clarke said. "Just to clue you in on the code, it's bad. Flagships are bad."

Clarke contrasted his present draft policy plan with the previously issued Comprehensive Program Management Plan (CPMP). The CPMP "tried to bring major elements of the program to an early conclusion in order to free up resources, to rapidly move on to the next step in the program," Clarke said, whereas in the new policy plan "we will be emphasizing breadth in the program and innovation for the development of a more promising reactor concept.... Rather than emphasizing international leadership, it will emphasize international collaboration." Clarke said that international collaboration would be used to the greatest extent possible, "emphasizing early joint planning of programs and projects."

Clarke commented, "In this new program, we visualize the role of industry as more systems analysis. If we are indeed trying to develop a better fusion product, we recognize that we will need the help of industry and the practical engineering orientation of industry to keep us on the right track.

"In the old plan, the national laboratories were envisioned as supporting a reactor thrust, supporting the development of specific components that would be then needed for moving on to the next step in this reactor development, and the universities were perceived as basically training new people in the implementation of future programs. Now we have to put more emphasis on the development of innovative ideas in fusion because you have to produce a condition that doesn't exist in nature.

"We require large facilities. The national laboratories are a unique tool that the United States has available to carry on the kind of large science that is required to address certain problems in fusion, and these innovative ideas will eventually lead, like some of them today demand, to the kind of facilities that the national laboratories uniquely possess. On the other hand, as far as the universities are concerned, in addition to their role of providing new talent for the program, which was our perception of their traditional role, we will be looking to them for these new ideas, for developing the germinal, seminal ideas that years from now hopefully will represent major focuses and thrusts in the program."

Clarke continued, "Somehow we have to develop better, stronger working relationships between the laboratories, universities and industries in order to emphasize the contribution of their unique talents to the needs of the program."

## ROLE OF INDUSTRY

The panel on the role of industry in the program plan was chaired by Harold K. Forsen (Bechtel). The panelists were Dale A. DeFreece [McDonnell-Douglas Astronautics Company (MDAC)], T. Kenneth Fowler [Lawrence Livermore National Laboratory (LLNL)], James A. Maniscalco (TRW, Inc.), Leonard F. C. Reichle (Ebasco Services, Inc.), and Roger Gould [Princeton Plasma Physics Laboratory (PPPL)].

Forsen summarized the recommendations of MFAC Panel 7 on this subject. Panel 7 noted that "the absence of a DOE document, that describes the many tasks required before fusion commercialization, makes long-range planning for laboratories and industry difficult and may lead to false long-range planning assumptions." Panel 7 also noted that "DOE has not established a clear policy for contracting with industry for supporting R&D programs in the context of a national long-range plan for fusion development." The panel also noted that "industry prefers a role in the fusion program where specific tasks are assigned and where the total experience of a company can be applied to solve these tasks."

Commenting on the new draft policy plan, Forsen said, "What is missing is how the technology will be transferred to industry," and "how (U.S.) industry will not be shut out by selective international collaboration."

DeFreece noted that MDAC has now been in fusion about ten years and believes that industry is "absolutely essential when we think of trying to get to the point of having a data base from which you can assess whether you can go commercial or not.... Absolutely the only way that can happen is where industry has had a significant and substantial role in that development process." DeFreece noted that technology transfer to other areas is "automatic where industry is involved" and cited several examples within his company where spinoffs from fusion activities resulted in other business developments. DeFreece also noted that a close association has developed between MDAC and universities, including student internships at the company. But "in the final analysis," DeFreece said, "we have to operate it as a business and that requires an accurate assessment of just what our opportunities are in terms of the resources that we need to retain within fusion versus transfer someplace else.... We built up a view of the program that was based on milestones and a planning strategy that went along with that, and when we see things like $Q = 1$ on TFTR slipping, that was a symbol greater than the scientific accomplishment, in our planning process. And when we see a pushing off of initiation of something like TFCX that's bad news internally in terms of trying to defend our program."

Fowler advocated the formation of laboratory-industry partnerships. He stated he believed there would be opportunities for industry to work with laboratories on systems studies, experimental operations, and construction. "To me," Fowler said, "a partner is one who is interested in all of the three opportunities I've mentioned. He cares about why we're doing it. Therefore, he wants to analyze this product. He has to understand how it really works. So he wants to participate in the experiments on it, and when there is a new facility to be built, he wants to gain the experience he can from participating in the building of it."

Maniscalco stated, "I don't believe that the role of industry in the fusion program has to decrease. In fact, I'm sure that we can't afford to let it happen, because it really could have drastic consequences for the vitality of our program. For example, without meaningful industrial participation, our program could find itself heading in a ridiculous, but unfortunately not too uncommon situation, in which the U.S. could be the first to demonstrate the feasibility of fusion, only to find Japanese industry the first to capitalize on it.

"I think it's important for us to increase the intellectual involvement of industry in the program, and I think that this can be done within the existing program without requiring large budget increases or large new construction starts." Maniscalco supported the concept of partnerships of industry with both laboratories and universities. One of the advantages of such partnerships, Maniscalco said, is that "they provide rapid transfer of the technology being developed in fusion to industry.... This will accelerate the technology spinoff to commercial markets." TRW's commitment to fusion is not being justified "on the basis of near-term sales or on the profits we expect to make from commercialized fusion in the future," Maniscalco said. "Rather this commitment has been justified on the basis of technology spinoffs."

Reichle pointed out the damage caused when DOE stimulates industry by letting requests for proposals for projects like TFCX and then cancelling them. Reichle said that in view of the changed circumstances, "I think industry must recognize that the national labs and the universities have a prime role. I think we should recognize that and industry should get behind the national laboratories and the fusion-funded universities and play a subordinate role on a subcontract advisory basis for the foreseeable future, until we can get a little closer to the end goal. But I think the other side of that coin is that the national laboratories and the universities have to share their budget and involvement with industry." Areas Reichle recommended, wherein subcontracting to industry could be intensified, included systems integration, design and fabrication, component supply, management, operation, and maintenance.

Gould, Director of Procurement at PPPL, said that "it is the intent and has been the intent and will continue to be the intent of the laboratory to augment the staff with industrial participation." He listed a variety of specific examples of industrial work in progress at PPPL.

## TOKAMAK IGNITION DEVICE OPTIONS

The panel on the role of tokamak ignition device options was chaired by N. Anne Davies of DOE. The panelists were Daniel Cohn (Massachusetts Institute of Technology), Carl Henning (LLNL), Paul Rutherford (PPPL), and Thomas Shannon [Oak Ridge National Laboratory (ORNL)].

Davies stated that the objectives of the tokamak program were "to understand the behavior of stable plasma configurations with density, temperatures and confinement time that are relevant to fusion energy sources and also to identify attractive plasma configurations for such energy sources." She said that "the next step after the TFTR . . . will be to produce and study an ignited plasma.... What we are doing (now) is launching a new set of small-scale, less detailed studies to follow up on some of the innovative ideas that came out of last year's efforts.... A major new experiment such as an ignition device is really an excellent focus for international collaboration." She continued, "We invited the Japanese to join us in our design study efforts this year and they have accepted."

Rutherford said, "Clearly we want to achieve ignition to demonstrate the reality of fusion power as opposed to simply the promise of fusion power. In doing so we will inevitably create a data base for a realistic assessment of the potential of fusion." He said that there were many scientific issues to study in an ignited plasma, including "optimization of MHD stability at high beta, behavior of resistance phenomena as temperature rises," and "the interaction between energetic ions, especially alpha particles, and gross MHD-like modes of the plasma."

Cohn stated that "the motivation for an ignition experiment stems from the need of the fusion program to advance to some type of new frontier in the next decade.... The (ignition) area is very rich in terms of new science." Cohn mentioned the study of self-consistent, self-generated temperature, pressure and current profiles, and stability. Cohn noted that heating by alpha particles may be the only way to get to ultra-high temperatures like 50 keV and that "the very high temperature operation may have relevance for the eventual use of advanced fuels." He said that "low cost may in fact be essential in order to proceed with an ignition experiment without an unacceptable burden on the rest of the fusion program." Cohn noted that "the performance-to-cost ratio of Alcator is one to two orders of magnitude better than any other tokamak" and concluded that "a promising approach to a low cost ignition device is to make it relatively compact and simple and use high performance copper magnets that employ little or no shielding."

Henning said, "We certainly don't want to ignore the advancement of technology along with the physics steps that are sure to happen in the next decade." He described a "high performance superconducting option.... We're just starting to explore the possibility of still more aggressive designs that might be as low as 2.6 metres in major radius." Continuing, Henning said, "Such a device might cost about one billion dollars."

Shannon said, "We were all sort of bitterly disappointed this summer to learn that we would not be able to go forward with the conceptual design of TFCX.... I have finally convinced myself that the budget problems are real.... So my suggestion is that we try to pick up the challenge. And although it's a slightly different challenge than that of the mid-70s, nevertheless it's time once again, I think, for technical solutions." He described the "spherical torus" recently proposed by Martin Peng.

## THE ROLE OF IMPROVED FUSION CONCEPTS

The panel on the role of improved fusion concepts was chaired by Dave Nelson of DOE. The panelists were Chuan Liu (GA Technologies), Rulon Linford (Los Alamos National Laboratory), Grant Logan (LLNL), Peter Rose (Mathematical Sciences Northwest), and John Sheffield (ORNL).

Nelson said that "concept improvement is a bit like the man who was told he was speaking prose when he'd been speaking it all along. We've been doing concept improvement all along." Nelson continued, "The only difference may be that we will try to give it more focused attention in order to encourage it.... I believe that the wealth of fusion ideas we already have, not to mention those that remain to be discovered, allow me at least confidently to foresee that we will have a defensible reactor.... The requirements for a competitive energy source in the next century are not perfectly known; neither are the characteristics of possible fusion reactors.... So concept improvement is as much an art as it is a science. The components of that art include the art of the desirable and the art of the possible.... Our process, and one we will increasingly focus on, is to bring those together to allow resources for identifying the desirable, to allow resources for identifying the possible. And to iterate between those to do science and technology for a purpose. In this case, the purpose is to identify an economically attractive reactor concept through the process of concept improvement," Nelson said.

Liu said, "Fusion is probably in a crisis period.... In Chinese the word for 'crisis' is composed of two characters: the first stands for 'danger'; the second stands for 'opportunity.'" Liu commented, "I think innovation and understanding are quite closely coupled for such a complicated thing like a fusion reactor.... Of course, understanding by itself is insufficient for innovation; you also need creativity." Liu cited the Ohmically Heated Toroidal Experiment configuration as an example of "a very great innovation." Liu felt that the "triad of industry, university and laboratories... must be on an equal footing." He also felt that industry "must be as innovative as the national labs and universities in order to be participating meaningfully." He noted that the competition (fission reactors) is becoming more innovative and that consequently "innovation is absolutely essential for the fusion program."

Linford listed some features that would characterize an attractive fusion reactor, including low cost of electricity, public acceptance, and being available in a range of plant sizes. He stated his belief that the reversed field pinch, spheromak, and field-reversed configurations "had higher potential for achieving all these characteristics than the other concepts under investigation." Linford pointed out that "less than 5% of the national fusion budget is spent" on these three concepts. All had needs for new facilities the total cost of which, according to Linford, "would require less than an additional 4% of the budget, which appears to be a small investment, considering both the risk and the potential benefit that could accrue from these programs."

Logan urged that we "innovate both the reactor concept improvement itself as well as the balance of plant.... We should beware of thinking that innovation is the sole province of plasma physics; engineers have their part to play in the innovation process also...." He felt that "we can do much more than we have done in the past to exploit fusion's unique potential for less hazardous waste...." He listed specific examples of possibilities for improvements in magnets, heating, and refueling systems. Logan concluded, "So we've got a lot of promise and we'd better not wait too long to show the rest of the world outside the fusion program what is, after all, the potential of fusion that we all have believed in."

Rose said that "to me, the truth is that the first experimental fusion reactor will probably have a relationship that the Model T Ford has to your present car or maybe that the Wright brothers' airplane has to the 747." Rose felt that "if you can really have a small plasma that's translatable or can stay stationary, you have a whole range of new options." He added, "If we could get to that place with experiments that are a much lower investment in cost, I think our political problems, in terms of selling this kind of a program, would be very different." Rose used the field-reversed configuration as an example.

Sheffield said that "we should think in terms of 'building blocks.' I think it's a mistake to get so hung up on your own configuration that you say 'this is it'... and miss the point that maybe it has a fundamental building block that's contributed to fusion, which coupled with other building blocks, would lead to an even better device."

## TECHNOLOGY R&D

The panel on the role of technology R&D was chaired by Ray Beuligmann (General Dynamics, Convair Division). The panelists were Greg Haas (DOE), Charles Baker (Argonne National Laboratory), and Mohamed Abdou (University of California, Los Angeles).

Haas said, "What is a desirable, attractive reactor option probably will be decided by people who are either very young today or who aren't even born.... Conducting a long-term technology R&D program requires making some assumptions about what the product may look like however." Haas suggested "classifying the issues into two general categories: those which probably are not going to be very sensitive or almost independent of the kind of confinement device we end up with; and those which probably are going to be device-dependent." He discussed optional ways of looking at various areas such as plasma/wall interactions, auxiliary power systems, safety, materials, and tritium breeding. To conduct a technology R&D program, "we have to define at least some boundary conditions," Haas concluded.

Baker asserted that all of the following notions are typically present in fusion program documents and "all these notions are wrong": that "fusion science is identical with plasma physics; that technology's primary function is to support that plasma physics, and that fusion engineering refers to the mundane standard things that you do when you just have a straightforward application of existing knowledge." Baker said that "much of what we do now, and have done in the past in fusion engineering, is true research by anyone's definition of the word 'research.'... And while much of our technology must be set by the real world requirements of our near term confinement experiments, there's an awful lot of technology that should and must stand in its own right." Baker concluded, "The magnetic fusion policy plan should not attempt to draw such a sharp distinction between science and technology. The fact of the matter is, in what we call plasma physics, it has a lot of technology and engineering in it (and) what we tended to call technology has a lot of science in it."

Abdou looked at the role of fusion technology based on his ongoing study called "FINESSE." Abdou stated that "the fusion environment experienced by nuclear components is unique." To get data needed "will require new knowledge and the new knowledge can be acquired only through new experiments, theory and models," he said. "In the 1985 to 1995 time frame we can, and we should, use new and existing small-scale test stands, point neutron sources and fission reactors. But in the mid to late 1990s, there is a critical need for a fusion engineering research facility." Abdou said, "Now, the plasma goals have been eloquently stated as 'understand the plasmas and improve reactor concepts.' But the technology program can have similar goals: 'understand the fusion engineering sciences and learn the materials engineering limits in the fusion environment and also improve reactor concepts.'" Abdou stressed that engineering tests only required a device with $\sim$20 MW of fusion power. Abdou thought that technology facilities would be "particularly economical and viable areas" for international collaboration because they "tended to be user facilities.... Therefore, several countries can share costs and benefits without necessarily agreeing on a common path."

Beuligmann said that "this emphasis on science has got vague goals.... [The] new emphasis on science... creates a spectre out there that has sure gotten our (industry's) attention.... The issue now with fusion is 'how far out is that future market?" Beuligmann continued, "As we have seen it in the past, it appeared to be viable and we could sell it. It is more difficult now to sell that to management.... What helps is to have multiple applications." He noted that General Dynamics, having developed magnet expertise for fusion, was applying that expertise to isotope separation and could apply it in other areas such as accelerators or magnetohydrodynamics. He noted that DOE seemed to have no plan to maintain the capabilities that had been developed in industry. He noted that "the younger people like to be associated...with an ongoing, very dynamic program" and that there were other well-funded opportunities that were beginning to draw these people away from fusion.

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