REPORT OF THE U.S.-KOREA FORUM ON FUSION SCIENCE AND TECHNOLOGY

FEBRUARY 18-19, 1997

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EXECUTIVE SUMMARY

The Science and Technology Policy Institute (STEPI) of Korea and George Mason University's Center for Science, Trade, and Technology Policy co-sponsored the U.S.–Korea Forum on Fusion Science and Technology on February 18 and 19 in Tysons Corner, Virginia. The Forum was one in a series of high-level meetings between Korean and U.S. scientists, engineers, and policy makers. The meeting was designed to promote dialogue on important scientific and policy issues among Koreans and Americans interested in fusion science and technology. An Organizing Committee of 18 distinguished scientists, academicians, and policy makers provided advice and counsel concerning the organization and execution of the Forum. The agenda for the meeting and a list of members of the Committee are listed in Appendix A.

This conference was unique in that it dealt not only with specific details of a narrow field of U.S.–Korean science and technology cooperation, but also with the broad international policy environment for the field. As part of that effort, participants looked at the growing Korean fusion program and discussed, both inside and outside the formal sessions, how the American fusion community could contribute to and participate in the activity.

The Korean National Fusion Project calls for the development and construction of a steady-state-capable superconducting tokamak, the Korean Superconducting Tokamak Advanced Research project (KSTAR), with many of the same characteristics as the canceled Tokamak Physics Experiment (TPX) at Princeton. The Korean project is now in the first of three phases. The design and construction phase will last until 2001. The Koreans plan to begin operating the machine on August 15, 2002.

The Forum provided an opportunity for U.S. participants to hear more about the project. There was unanimous support for the Korean effort, and there was some discussion about the relative value of pursuing the effort for energy development as contrasted to advancing scientific knowledge. The Korean speakers explained how the KSTAR project fits into the global fusion program, especially its relationship to the International Thermonuclear Experimental Reactor (ITER), and both Korean and American participants related information about ongoing discussions between the Princeton Plasma Physics Laboratory (PPPL) and the Korean Basic Sciences Institute (KBSI) on program definition. Korean speakers also spoke of the importance of bringing industry into the project early, and an explanation of Samsung's role was provided.

Technical discussions revealed the many advances in fusion R&D that are relevant to the KSTAR project and other fusion experiments such as ITER. Enabling technologies for Fusion R&D and the applications of plasma and fusion research were also highlighted.

FINDINGS

- The KSTAR project being supported by the Government of Korea will greatly advance the world's understanding of fusion science and technology. It is science-based, flexible, world-class, and relevant, and will bring Korea into the international fusion research arena.

- Participation by Korean industry is very significant, but it remains unclear what role industry will take after the machine is operational.

- Details on foreign use of the machine should be worked out in the near future, especially with advances in remote collaboration that would allow foreign researchers to utilize the machine without being on site.

- Tokamak research was considered by the speakers to be very important plasma physics research, however, a question was raised by one speaker about the practicality of it for fusion power.

- The potential spin-offs to other areas of science and technology are very possibly significant.

- The KSTAR project provides significant collaboration potential between Korea and the United States in a number of enabling technologies, such as superconducting magnets, long-pulse neutral beam injectors and radio frequency power systems, repetitive pellet injectors, actively cooled plasma-facing components, and remote maintenance systems.

- Because the United States Government is working toward a balanced budget, spending for U.S. fusion programs is not likely to increase. Therefore, U.S. interest in the Korean program is very high. In addition, since the United States has a long history of research and development in fusion and since over 50 million dollars was spent on TPX, U.S. scientists and engineers can be very helpful to their Korean counterparts, particularly in the engineering design phases of the project. Therefore, both sides should work toward true collaboration, not just unidirectional technology transfer.

- The U.S. Department of Energy and the Korean Ministry of Science and Technology Implementing Arrangement for Fusion Research Cooperation provides a good framework for collaboration on the KSTAR project.

SUMMARY OF PRESENTATIONS

KEYNOTE SESSION

The co-organizers of the Forum, **The Honorable Linsu Kim**, President of the Korean Science and Technology Policy Institute, and **The Honorable J. Thomas Ratchford**, Director of the Center for Science, Trade, and Technology Policy of George Mason University, welcomed Forum participants. They noted that this meeting provided an opportunity to integrate science and policy, and in the process enrich fusion science and technology. Dr. Kim noted the significance of fusion technology, and pointed out that because of its high cost and technical uncertainties it is particularly well suited for international collaboration. Dr. Ratchford and Dr. Kim presided over the first session and introduced the keynote speakers from Korea and the United States.

The Honorable Boo-Sik Yi, Vice Minister of Science and Technology of the Republic of Korea, provided a historical perspective on U.S.–Korean science and technology cooperation. He noted Korea's debt to the United States for help in training many Korean scientists and engineers and in aiding the development of the Korean science and technology enterprise. The U.S.–Korea science and technology relationship, he explained, has changed from one in which the flow of information was one-way to one in which there is greater mutuality. Citing Korea's new membership in the OECD, he asserted that Korea is now a world player in science and technology, and as such, will commit $300 million from 1996 until 2002 to develop a next generation facility for fusion research. At the same time it will develop such leading-edge technologies as superconducting magnet technology, large-scale ultra-high vacuum technology, and others.

He remarked, however, that Korea cannot accomplish its fusion goals unilaterally, but must collaborate with the United States, which, he stressed, stands at the forefront of fusion science and technology. That is why the Korean Basic Science Institute and the Princeton Plasma Physics Laboratory have been working closely under the rubric of the Implementing Arrangement for Fusion Research Cooperation signed in June 1996 between the Korean Ministry of Science and Technology and the United States Department of Energy.

He concluded by expressing his desire that the discussions at the Forum would promote common understanding between policy makers and research scientists on the major issues related to fusion science and technology.

The second Keynote speaker was **The Honorable Thomas M. Davis III**, a Member of the Committee on Science of the U.S. House of Representatives. He reported on the dramatic political changes that have occurred in the United States over the past two years. He asserted that the need for a balanced budget by the year 2002 will have an adverse impact on federal spending for R&D. He surmised that the most immediate impact of these diminishing budgets will be in the "evolving relationships between the troika that performs science and technology development in the United States—the universities, industry, and the government." The impact of reduced budgets on international collaboration in science and technology, he related, has not yet been addressed fully by the Congress. But he did note that where large-scale machines are required, such as fusion, international collaboration in construction and operation is essential.

Mr. Davis went on to explain that Congress's concern that the U.S. fusion program's near-total focus on the tokamak concept, for which practical application was well into the future and for which there were many concerns regarding economic viability and public acceptance, led the Congress to cancel the $700 million Tokamak Physics Experiment and to modify the fusion budget strategy based on "continued reduced funding levels; international cooperation and collaboration...and; greater emphasis on basic plasma science and alternate fusion concepts." He asserted that restructuring the U.S. fusion program must then lead to increased international collaborative efforts in fusion. He said that this Forum provides a useful arena to define future partnerships.

PLENARY SESSION

The Plenary session featured four distinguished physicists from Korea and the United States. The session was moderated by **Dr. Ronald C. Davidson**, former Director of the Princeton Plasma Physics Laboratory and professor of astrophysical sciences at Princeton University.

The first Plenary speaker was **Professor Duk-In Choi**, President of the Korea Basic Science Institute. He began by giving a thumbnail sketch of the Korean plasma and fusion research efforts since 1970. He went on to describe in great detail the Korean Superconducting Tokamak Advanced Research project. The mission of the project is "to develop a steady-state-capable advanced superconducting tokamak to establish the scientific and technological bases for an attractive fusion reactor as a future energy source." Dr. Choi stressed that KSTAR will be the world's first fully superconducting tokamak and that it will come on-line at least ten years prior to ITER.

He explained that there are several objectives of the project. First, when the device becomes operational it should be relevant to the world-wide fusion community. Second, the construction and operation should advance the knowledge of industry as well as academia. And third, the cost must be within Korea's capability.

Dr. Choi outlined the three research objectives of KSTAR. They are:

- to extend performance boundaries through active control of profiles and transport
- to achieve steady-state operation using non-inductive methods
- to contribute to the optimization for an attractive reactor.

He also reviewed the tokamak design which includes:

- fully superconducting magnets
- long-pulse operation capability
- flexible pressure and current profile control
- flexible plasma shape and position control
- advanced profile and control diagnostics.

He next presented the parameters of KSTAR (shown in Appendix B). He gave figures for the major and minor radii, toroidal field strength, plasma current, elongation and triangularity and pulse length.

Also included in Appendix B is the cost schedule for KSTAR. Dr. Choi indicated that the total project cost is approximately $300 million. KSTAR commissioning is scheduled for August 15, 2002.

Dr. Choi gave information about the Korean National Fusion Project organization and KSTAR project structure, which can be reviewed in Appendix B.

With regard to international collaboration, Professor Choi maintained that Korea cannot design and construct the project without help from abroad. He especially noted PPPL, Massachusetts Institute of Technology, and General Atomic as being essential to the success of the project. He expressed his appreciation for help provided to date.

In conclusion, Professor Choi explained Korea's view of KSTAR in the world-wide fusion community. He stated that the KSTAR project will make critical contributions to fusion research and that it will extend advanced tokamak concepts to regimes of high-performance and steady- state operation. It also will contribute techniques for successful steady-state physics operation of ITER, and it will be able to compare advanced tokamak physics results with those from superconducting stellarators and spherical tokamaks. He expressed his desire that the project will yield many scientific benefits, such as superconducting magnet design and manufacture, high power neutral beam, microwave and radio frequency (rf) technology, and diagnostics, controls and computational methods.

The second Plenary speaker was **Dr. James Decker**, Deputy Director of the Office of Energy Research at the U.S. Department of Energy (DOE). He began by praising the Korean effort. Then he provided a detailed review of the Department of Energy's fusion energy program. Next he explained that Congressionally mandated reductions in U.S. fusion energy science R&D budgets caused DOE to revise its mission and goals and to become more focused on fusion *science* as opposed to energy development. He provided a detailed report on the history of fusion funding in the United States showing that actual spending has fallen far short of projections. He noted that the fusion budget is also affected by the country's view of energy. Energy issues are not considered a priority in the United States at this time, which affects funding for all energy programs, not just fusion. He showed, however, that world-wide energy demands are rising, as are carbon emissions.

He expressed his support for the tokamak concept and indicated that there have been significant results from various machines from around the world, and experiments have confirmed our ability to eliminate turbulence that limits energy confinement in the core of a tokamak. He stated DOE's new mission is to "advance plasma science, fusion science, and fusion technology, and to develop the knowledge base for an economically and environmentally attractive energy source for the nation and the world." The vision for the new program has three parts. They are:

- understanding the physics of plasma
- identifying and exploring innovative and cost-effective development paths to fusion energy
- exploring the science and technology of burning plasmas as a partner in an international effort.

He went on to explain the program goals, which include a focus on innovation and science, shutting down TFTR to free funds for other efforts, enhancing research on radiation-resistant materials, meeting commitments to ITER, and continuing a minimal inertial fusion energy program in coordination with the Department of Energy's Defense Program's activities in inertial confinement fusion. This restructuring has lead to the development of the National Spherical Torus Experiment located at Princeton, which is a physics experiment on a much smaller scale. Its total cost is $20 million, with an additional $100 million of facility site credits and power systems, it is highly efficient and compact, and it will sustain confinement current for very long pulses.

He concluded that while the DOE program has had deep reductions, there is tremendous scientific talent in the program and the United States will continue to make very important contributions to fusion research in the context of the world's fusion efforts.

Dr. Decker was asked whether or not it makes sense to go back and rethink old ideas that were discarded several decades ago when it was decided that the tokamak concept had the best potential. Dr. Decker responded that we have learned much over the years and our predictive capability is much greater, allowing us to explore many different concepts without building so many new machines. Dr. Baldwin added that the tokamak did prove to be our best experimental tool to teach us toroidal confinement physics, but it may or may not be the best reactor because cost and complexity issues weigh more heavily for a reactor than for an experimental device. We are bringing the knowledge we have gained on tokamaks into new and innovative concepts, Dr. Schmidt added.

The third Plenary speaker, **Professor Sook-Il Kwun**, President of the Korean Physical Society, gave a thorough overview of Korean physics and how Korea came to begin its KSTAR effort. He stated that it is widely accepted that physics in advanced countries has played an important role for their modern industrialization process by providing scientific discoveries and technological innovations. He contended, however, that the role of physics in developing countries must be viewed differently. He provided background on the scientific and policy issues surrounding fusion research by reviewing the historical role of physics in Korea. He stated that the first physics Ph.D.s did not graduate until 1947. Then, with the Korean War, little was done to promote physics in Korea until the 1970s when physics became a popular course of study. The Korean physics community went on to play a pivotal role in the industrialization process in Korea by providing a well-educated work force and brain pool for industry.

He explained that Korean participation in big science projects has also been sluggish due to Korea's developing status and lack of funding. But Korea has proven, he contended, that it can collaborate on and develop its own big science projects. He gave as an example the Pohang Light

Source (PLS), which was built in six years for $200 million. Korean physicists and engineers worked together to design and construct this facility.

He stated that KSTAR will result in a new paradigm of interaction between physicists, engineers, and industrial partners in Korea. It requires participation by world-class industries and the physics community, and cooperation through this project will contribute to the development of high-technology industries in Korea. This interaction will cultivate the industrial infrastructure for a new advanced manufacturing capacity. The development of big science projects in Korea will also strength Korea's interaction with the world-wide scientific community. He stated that KSTAR will be open to world participation when it begins operating in 2002.

Professor Kwun concluded by stating that Korea is in the midst of tremendous change. Socio-economic development in the next century will be led by knowledge-based industries. He said that the role of science will be more important than it has ever been.

The final plenary speaker, **Dr. Robert Hirsch**, President of Energy Technology Collaborative, Inc., presented a paper entitled *Fusion: Past, Present, and Future*. Dr. Hirsch provided a contrasting view to those provided by earlier speakers about the viability of tokamak reactors for energy production. He contended that they will not be commercially viable.

He began his remarks by explaining the three optional thrusts for a modern-day fusion research and development program. They are as follows:

- pursuit of practical fusion power
- high-temperature plasma physics research
- plasma applications R&D.

In the late 1960s, he said, fusion research laboratories around the world focused their efforts on the tokamak concept because tokamaks were reasonably successful in confining high-temperature plasmas. Subsequent efforts lead to dramatic increases in tokamak plasma understanding and performance. He noted that despite these advances, tokamak research must be classified as basic high-temperature plasma physics research, not practical fusion power development because studies strongly indicate that tokamak reactors will not be commercially viable. He described a 1994 Electric Power Research Institute (EPRI) panel report that outlined requirements for development of fusion power. The EPRI report stated, "...fusion plants must have lower life-cycle costs than (the) competing proved technologies available at the time of (fusion) commercialization." He went on to show that in 1994 physicists compared the cost of the core of the then-existing ITER design to the cost of the core of a light water nuclear reactor and concluded that the ITER cost was roughly a factor of thirty times more expensive. He detailed other cost issues surrounding tokamaks and drew the conclusion that tokamaks are not practical fusion power. He did state, however, that basic plasma physics research is a worthwhile effort and that Korea's decision to build a tokamak machine is an excellent investment in furthering tokamak research.

With world markets estimated at over $200 billion per year, he concluded by asserting that another important aspect of fusion and plasma research is near-term, non-fusion applications. Accordingly, a national fusion program might profitably include a plasma applications component aimed at nearer term applications.

The discussion following Dr. Hirsch's remarks centered mostly on the economics of tokamak reactors, with several participants questioning Dr. Hirsch's reasoning. However, Dr. Hirsch stood by his opinion that tokamak reactors will not be economically viable. He argued that fusion must provide a product that is measurably more attractive than fission for fusion to be commercially acceptable.

LUNCHEON REMARKS

The Luncheon speaker, **Dr. Kwan Rim**, President of Samsung Advanced Institute of Technology, was introduced by **Dr. Erich Bloch**, Distinguished Visiting Professor at the George Mason University Center for Science, Trade, and Technology Policy. Dr Rim's remarks focused on industrial R&D in Korea.

He reviewed Samsung's role in the KSTAR project. He explained that Samsung is responsible for the development and construction of the superconducting magnetic coil. He expressed his hope that Samsung would be able to find good commercial applications from what they learn.

He compared R&D spending in the United States, Japan, and Korea, showing that Korea is far behind other industrialized countries. Next he showed the proportion of R&D spending by the public and private sectors in Korea, with 80 percent of the resources being spent privately and 20 percent by the public sector. On the other hand, 10 percent of the Ph.D.s are in industry and 70 percent are in universities. He maintained that industry loses its leading researchers to universities.

He provided a snapshot of a major Korean company, which covers many different sectors. Samsung, for example, has five different groups covering different industries. Last year's revenue was 90 billion dollars.

Dr. Rim provided a description of Samsung's research system. He explained that it is a three-tiered system with a central laboratory called Samsung Advanced Institute of Technology (SAIT), which is funded by the corporation not business units. SAIT is designed to focus on five- to ten-year product development. Each of Samsung's 26 companies has a research institute funded by a strategic business unit, and finally there is the product development unit in each business unit. Samsung also collaborates with various universities and research centers around the world.

Samsung is very pleased to participate in the KSTAR project, he declared, and does so to promote Korea's standing in science and technology. At the same time, Samsung hopes to find spin-offs for the technology developed. However, market applications look scarce at this time.

During the question and answers that followed his presentation, Dr. Rim explained that Samsung's total R&D budget is $2 billion and five percent of that finds its way to SAIT. SAIT employs 850 research personnel. He also noted that Samsung is making a major effort in environmental technologies.

JOINT PARALLEL SESSION

Following lunch, the Forum continued with a joint parallel session moderated by **Dr. Saeyoung Ahn**, President of the Korean-American Scientists and Engineers Association.

The first presentation was made by **Mr. Warren A. Marton**, of the Office of Fusion Energy Science in the Department of Energy, for **Dr. Charles C. Baker**, Leader of the U.S. Home Team for the International Thermonuclear Experimental Reactor, who was unable to attend. The title of the presentation was *ITER: A Model for International Collaboration.* In his remarks for Dr. Baker, Mr. Marton outlined the objectives and schedule for ITER. The purpose of ITER, he said, is to demonstrate the scientific and technological feasibility of magnetic fusion energy by designing, building, and operating a tokamak device that will produce 1500 MW of fusion power for significant amounts of time. He noted that the engineering design activities are on schedule and should be concluded in 1998, and if the ITER parties agree, construction could begin that year, followed by the start of operation in 2008. He explained that ITER has five physics and technology goals. They are to:

- develop physics understanding of a reactor-scale burning plasma (1500 MW with long pulse length (1000s)
- explore behavior of advanced tokamak plasmas, including possible steady-state mode
- perform integrated tests of high heat flux components (1 to $5MW/m^2$)
- perform integrated tests of nuclear components of ($1MW\ yr/m^2$)
- demonstrate technologies for a reactor—superconducting coils, remote handling, diverter, exhaust, breeding blankets.

He explained that ITER was conceived of and is managed as a real international project where all of the goals were negotiated and agreed upon by the four equal parties. Appendix C contains a copy of the ITER organizational chart and a graphic showing how the four parties (or home teams) and three joint works sites centers are linked via Wide-Area networks. As an example of the international nature of the project, he showed how the four home teams are sharing responsibilities in the magnet area.

He concluded his remarks by stating that ITER can be a model for future mega-science collaboration in other fields. When asked whether other countries will be able to participate in the next phases of ITER, Mr. Marton responded that provisions for such participation are being addressed now by the four parties.

The second speaker in this session was **Dr. Won Namkung** of Pohang University of Science and Technology, where the Pohang Light Source (PLS) is located. The title of his presentation was *Technology Development for the KSTAR Project in Korea.* He began by explaining the history and capabilities of the PLS, which is a dedicated synchrotron radiation source. He showed the achievements of the PLS and plans for the future (Appendix D).

Dr. Namkung then defined some of the design features of KSTAR and some of the necessary related technologies. These include chamber components, cryogenics, power conversion, computer controls, large-volume vacuum, survey and alignment, conventional facilities, and large-scale project management.

The third and final speaker of the Joint Parallel Session was **Dr. John A. Schmidt** of the Princeton Plasma Physics Laboratory. He was Director of the Tokamak Physics Experiment and is intimately involved in the current collaboration between KBSI and PPPL. He explained that the canceled TPX and KSTAR have similar project structures, and that the United States can make many contributions to the Korean effort.

He asserted that the TPX project developed a management approach and associated management systems to execute a highly technical project that incorporated a strong and geographically distributed design and construction organization. This organization established the technical infrastructure (e.g., technical expertise and computer codes) required to execute the TPX project. The TPX conceptual design was completed and successfully reviewed. The responsibility for most elements of the magnet systems preliminary design (PD) was assigned to industry. The industrial elements of the magnet PD were completed and successfully reviewed. Key R&D tasks were completed to support the TPX design activity. Both the management expertise and technical knowledge gained during the TPX design process are important inputs to the KSTAR project.

He described a U.S. team which has been organized to support the KSTAR design and construction activity. This team is led by PPPL and includes the institutions and individuals responsible for the very successful TPX design activity. The U.S. team will contribute management and technical expertise, specific design knowledge and mentoring on advanced design code applications. These contributions will be a significant factor in expediting the development of a high quality KSTAR design and implementing the construction of this design. (Appendix E shows U.S. KSTAR team contributions in systems engineering and design codes).

Following the Joint Parallel Session, a session on Technical Issues in Fusion Science and Technology and a session on Policy Issues Related to Fusion R&D were held concurrently. **Mr. R. Thomas Weimer,** Staff Director of the Subcommittee on Basic Research of the House Science Committee, presided over the Technical Issues session and introduced the three speakers.

Speaking first in this session was **Dr. Michael J. Saltmarsh**, of Oak Ridge National Laboratory, on *Enabling Technologies for Fusion R&D*. He explained that technology development has played a vital role in the world-wide effort to harness fusion as a viable energy source. Extraordinary advances have been built on a foundation of progress in certain key technologies that have enabled the creation, confinement, and control of hot, dense plasmas. For example: high-power neutral beam systems for plasma heating; high-field magnets for plasma confinement; high-speed pellet injectors for plasma fueling; and materials, coatings, and cleaning techniques for plasma-facing components.

He maintained that as we approach fusion reactor conditions, the demands on our technologies will grow, particularly in three key areas. These are: manipulation of the plasma, particularly through profile control techniques; extending pulse lengths toward steady state; and the nuclear technologies need to support burning or ignited plasma operation.

He went on to state that the KSTAR project brings the potential for significant collaboration between Korea and the United States in enabling technologies related to these three areas, e.g., in superconducting magnets, long-pulse neutral beam injectors and rf power systems, repetitive pellet injectors, actively cooled plasma-facing components, and remote maintenance systems.

He concluded that many of the technologies have applications beyond fusion. Therefore, research in these areas can both benefit fusion and act as a technology driver for other fields.

The second speaker in the technical issues session was **Dr. Hyeon-Keo Park** of the Korea Basic Science Institute, who presented a paper entitled *Advances in Tokamak Physics and the Goal of KSTAR*. Dr. Park began his presentation by stating that progress in fusion plasma science has been significant during the last decade. He pointed to achievements with TFTR DT experiments, the DIII-D high performance discharges, and recent optimized current profile experiments in JET and JT-60U. He stated that many of these advances have been due, in part, to advances in plasma diagnostics and computational physics that have provided an opportunity to understand better the physics and to provide comprehensive scalings and the physics basis to project the performances of future fusion reactors such as ITER. He described the major parameters for the KSTAR tokamak, as seen in Appendix F. He also showed the KSTAR auxiliary system parameters, beam fueling profile, and plasma current modification of KSTAR (See Appendix F).

He asserted that KSTAR shall fill the gap between the fading present generation of tokamaks and future devices. KSTAR can be a test bed for advanced physics concepts and engineering issues developed to assist ITER design and operation scenarios. To fulfill this mission, KSTAR will be equipped with physics tools and programs relevant to these issues, he said.

The final speaker was **Dr. David E. Baldwin,** of General Atomics, who spoke about recent advances in fusion R&D. He stated that the Fusion Energy Science Advisory Committee identified six key fusion plasma physics areas and that scientists have made important progress in all of them. He provided details of advances in each of the six areas. The areas and goals for each are as follows:

- Advances in *equilibrium, stability and dynamics* translate into a predictable, reproducible ability to set up and control tokamak plasmas, enabling experiment into less mature aspects.
- Advances in *transport processes,* where our goals are a "first-principles" understanding of transport and, thereby, the means for its reduction and control.

- Advances in *plasma-wall interactions,* where the goal is to disperse a large fraction of thermal power through radiation while protecting the hot plasma from damaging gas loads.
- Advances in *wave- and particle-plasma interactions,* where the combined goals are low required current drive (CD) power, controlled fueling, and effective ash removal.
- Advances in *burning-plasma physics,* where the final tests of alpha-heating physics, and especially ignition, must await ITER.
- Composite issues await future attention because such issues integrate all of the earlier technical issues to address fusion power-plant requirements.

Dr. Baldwin showed progress in developing tokamak physics understanding both past and future. (See appendix G). He maintained that fusion research has contributed to broader scientific knowledge and said that fusion science has been at the very core of fusion energy development.

The second concurrent session covered policy issues related to fusion R&D and was moderated by **Dr. Sung Chul Chung**, Director of the Center for International Science and Technology Cooperation of the Science and Technology Policy Institute. Four speakers presented a variety of policy issues, as summarized below.

First **Dr. Michael Roberts**, of the Office of Fusion Energy Sciences at the U.S. Department of Energy, made a presentation entitled *International Collaboration Activities in the U.S. Department of Energy Office of Fusion Energy Sciences*. He stated that "international collaboration is the key to successful fusion energy development." U.S. objectives for international collaboration in fusion are to pursue fusion energy S&T as an international partner in a valued partner approach that provides for mutually beneficial collaboration. He noted that fusion energy activities take place in the context of the ITER Engineering Design Activity and in other collaborative S&T activities.

Dr. Roberts provided a thorough overview of DOE's activities in fusion, including the U.S.-Russian Federation bilateral signed in 1974, the U.S.-Japan bilateral initiated in 1979 and the U.S.-European Union bilateral begun in 1986. Other bilateral arrangements exist between DOE and its counterparts in Canada, China, and Korea. The U.S.–Korea Implementing Arrangement for Fusion Research Cooperation, under which PPPL and KBSI are conducting their talks regarding KSTAR, was signed in 1996.

Dr. Roberts also provided a summary of various multilateral agreements under the auspices of the International Energy Agency and the International Atomic Energy Agency. Finally he described the ITER Engineering Design Agreement, for which his office is responsible.

Dr. Roberts concluded by stating that international collaboration is our future in fusion energy science. Joint programs, data linkages, and a culture of sharing all lead to a win-win strategy for partners in collaboration.

Following Dr. Roberts' presentation, **Dr. Gyung-Su Lee**, of the Korea Basic Science Institute and Project Director for the KSTAR project spoke, about *Korean International Cooperation Objectives.* Dr. Lee began by quoting a 1982 paper published by The Honorable KunMo Chung, Former Minister for Science and Technology in the Republic of Korea. Dr. Chung said "Fusion Research is too big for a single country to handle by itself, and international cooperation is imperative." He went on to say, "International collaboration in fusion research has been a positive-sum game, and will most likely continue until commercial feasibility is demonstrated." Dr. Lee indicated that Korea has followed this path, and by doing so has been able to pool expertise and talents, which has assisted Korea in building its fusion expertise.

Dr. Lee said that Korea studied the international schedule of fusion projects carefully and decided where Korea could best enter the process. By building KSTAR to come on line early in the next century, it will fill the gap left by the older machines and before ITER is operational. (See timeline in Appendix H).

Dr. Lee reported that KBSI is working with PPPL, the Plasma Fusion Center at MIT, the National Institute for Fusion Science of Japan, the Institute of Plasma Physics in China and the Kurchotov Institute in Russia. Cooperation with other institutions around the world is being studied.

He concluded by declaring that KSTAR will be open to the world fusion community for international collaboration.

Dr. Steven L. Davis, of the Princeton Plasma Physics Laboratory, discussed *Experiences with Remote Collaboration in Fusion Research.* He began by explaining the benefits of remote collaboration, stating that it permits physicists to continue their work without having to move to where the machines are being built. Communication, he said, is the most important part of collaboration.

He provided some examples where remote viewing of operations with control of selected instrumentation and analysis tasks has been done. He provided an overview of some of the technology currently being used to facilitate remote collaboration, like Cu-seeMe, which provides point-to-point and multipoint viewing, and the Web Controlled Multicast Backbone (MBONE) view, where scientists can move around the control room and operate some of the controls electronically. He indicated that there needs to be wider acceptance of remote control within the community and that remote control collaboration needs to be built into the original plans of a facility.

Dr. Stephen O. Dean, of Fusion Power Associates, provided a review of the *Applications of Plasma and Fusion Research*. He showed that plasma and other technologies developed in part by fusion energy research programs are being used in a wide variety of commercial and other applications. For example, applications include efficient production of advanced semiconductor chips and integrated circuits; deposition of anticorrosion and other types of coatings; improvements in materials for a wide variety of applications; new techniques for cleaning and detoxifying waste; plasma flat panel displays, and so forth. In an overhead (copied in Appendix I) he showed the results of a survey of the applications of plasma and fusion technologies. He noted that many applications are developed privately, without government support.

CLOSING SESSION

During the Closing Session, the moderators, **The Honorable KunMo Chung**, Former Minister of Science and Technology of the Republic of Korea, and **Dr. Barrett H. Ripin**, Associate Executive Officer of the American Physical Society, summarized the discussions which had taken place throughout the day. Mr. Weimer and Dr. Sung-Chul Chung, presiders of the parallel sessions, provided summaries, and Dr. Ripin related his views of the meeting.

Dr. Ripin noted that success from collaboration between Korea and the United States on the KSTAR project is likely. He said that Korea can greatly leverage the U.S. TPX design and the United States can ensure that a key facility is built. He encouraged both sides to work for true collaboration, not just one-sided technology transfer. He raised the issue of the nature of collaboration beyond the design phase. He also asked what the nature of industrial participation would be after the machine is built. Dr. Ripin explained that there is a triad of the nature of efforts that go into any successful fusion projects. One part of the triad is the experimental facility including the diagnostics and hardware; the second is the theory, concepts, and understanding that is developed; and the third is the computational modeling that tries to predict or confirm understandings. There are connections between these components. He observed that Forum discussions dealt almost exclusively with the first part of the triad with little discussion of the theory, computational modeling, or collaboration that might involve those components.

KunMo Chung gave his remarks from the context of "father" of the KSTAR project. He noted that Korea wants to contribute to the world pool of scientific knowledge and there is now a vision to do so. The Korean Fusion Program is a long-term vision where KSTAR will serve as a major experimental device for world-wide R&D prior to ITER. He agreed that it is an ambitious program, but one that he believes Korea can achieve. He said that when he made the decision last year to proceed with KSTAR, he was not sure whether or not it would succeed because he was not sure of Korea's technical capabilities nor how much cooperation would be forthcoming from the international community. But after a workshop held at Princeton last November, he felt confident that Korea could succeed. He emphasized that Korea is enthusiastic about the KSTAR project.

He said that the Forum discussions proved that there is a "meeting ground" for Korean and American scientists, not just in fusion but in many fields of research. He contended that R&D decisions should not be made only on the cost of projects, but on the capabilities of people. When there are committed people, progress can be made. Korean scientists have made this point time and again with the establishment of the Korean Advanced Institute of Science and Technology, with the design and development of the first Korean model nuclear power reactor, and the establishment of science and engineering research centers.

The future for KSTAR and the future for U.S.–Korea science and technology cooperation must be based on compassion, commitment, and competence. With those three attributes, much can be accomplished. He thanked the organizers of the meeting and stated that this meeting will be remembered as a significant step forward in the KSTAR project history.