FUSION ENERGY SCIENCES ADVISORY COMMITTEE
OFFICE OF SCIENCE

Doubletree Hilton Hotel & Executive Meeting Center
8120 Wisconsin Avenue
Bethesda, MD
Tuesday, February 28, 2012 at 8:30 am.

Dr. Martin J. Greenwald, Chairman, presiding.

WELCOME

Dr. Greenwald thanked committee members and the audience for taking the time from their busy schedules to attend the meeting. He stated that there was a substantial agenda that includes reports from two subcommittees and a presentation from DOE on the President's FY 2013 Budget Request to Congress. As a result he asked committee members to try to adhere to the agenda. Dr. Greenwald welcomed Dr. W.F. Brinkman who was scheduled to present the President's FY 2013 Budget Request to Congress for the Office of Science (SC).

DOE/SC PERSPECTIVES INCLUDING THE FY 2013 CONGRESSIONAL BUDGET REQUEST

Dr. W.F. Brinkman, *Director, Office of Science*

- Explained that the SC was an important part of the total effort in physical sciences and represented 45% of the total funding that the U.S. government puts into physical sciences.
- Stated that the SC had supported research that led to 100 Nobel Prizes over the past six decades and 20 in the past 10 years. Noted also that the SC supports 25,000 PhDs, scientists, engineers, graduate students, undergraduate students and supporting staff.
- Noted that the national laboratories have created a very large set of user facilities that are unique and widely used. Commented on the support given to the science community by President Obama during the State of the Union Address in January 2012 and quoted: "Innovation…demands basic research….Don't gut these investments in our budget. Don't let other countries win the race for the future. Support the same kind of research and innovation that led to the computer chip and the internet, to renew American jobs and new American

industries." Added that two of the main themes in the President's address were the strong support of science and clean energy.

- Stated that it was the administration's policy and purpose to enhance American competitiveness in the field of energy. Noted that many people believe that there is going to be a major revolution in how new energy is generated and used in the next 50 years and that the United States needs to take the lead.
- Elaborated on the importance of basic research in relation to science, innovation and the DOE (Department of Energy) and SC by noting the following:
  - Science is the basis of technology and underpins America's energy future.
  - Current standards of living are made possible by science that was funded in the 20th century, and the 21st century is laying the foundations for new technologies of the future.
  - Progress in science and technology depends on advances and replenishment from basic research.
  - A highly-trained workforce of scientists and engineers with the best tools is a requirement to invent the future.
- Noted that the SC has an arsenal of science capabilities in the form of many major user facilities, national laboratories and researchers to break down barriers to new energy technologies.
- Stated that capabilities have been focused on critical national needs and detailed:
  - Bioenergy Research Centers – Now going through a renewal process going into their 5th year and noted that they have shown great progress in attracting scientific communities and have done work relating to the creation of biofuels.
  - Energy Frontier Research Centers – The centers have brought small groups together to research specific subjects, one example being a new type of solar cell based on silicon single crystal rods.
  - Combustion Research Facility – Made many contributions to understanding flames and combustion in diesel and gasoline motors.
  - Joint Genome Institute (JGI) – Played a major role in understanding the human genome. Now the focus has been changed to plants and microbes. Microbes play an important role because they help to process biofuels and also the interaction of soils and wilderness with the atmosphere.
  - Nanoscience Centers – Generated many new structures.
  - Energy Innovation Hubs – Two hubs, one dealing with the production of fuel from sunlight and the other research with batteries to make them more efficient.
- Discussed the 21st century science applications to be used in new energy technologies using nanotechnology, biotechnology and modeling and simulation:
  - Materials and chemical processes by design – The use of nanoscale and mesoscale structures for scientific advances and manufacturing innovations in solar energy conversion, clean-energy electricity generation, battery and vehicle transportation and carbon capture, use and sequestration.
  - Biosystems by design – Concentrates on the development of synthetic biology tools and technologies and integrative analysis of experimental genomic science datasets for the

design and construction of improved biofuels. This includes the fact that they can now decode DNA and understand the structure of any protein. The challenge is in relating this knowledge to function. Commented on research conducted at one of the biofuel centers on the development a new lignin by changing the DNA. The new lignin makes it easier to extract cellulose from plants.

- Modeling and simulation – The use of the Leadership Computing Facilities and production computing facilities to advance materials and chemistry by design and to broadly address energy technology challenges.

- Emphasized that this was a paradigm shift in materials science in terms of trying to do research without the empirical approach to new material. Added that he wanted everyone to understand where the pressures are and the directions that they were trying to go.
- Discussed the SC FY 2013 Budget Request to Congress and made the following points:
  - Reasonable increases for BES (Basic Energy Sciences), ASCF (Advanced Scientific Computing Research) and BER (Biological and Environmental Research).
  - Decreases in budget allocation for the remaining three areas with FES (Fusion Energy Sciences) being one.
  - The decrease in funding has posed a problem due to the obligation to move ahead with ITER. The administration had confirmed its decision to continue with ITER.
  - For ITER there was an effort being made to find ways to save money and the process was being begun with a meeting with the heads of all the domestic agencies of ITER with Professor Osamu Motojima.
  - Dr. Brinkman explained that it could be beneficial to review costs and added that facilities had been closed in the past and it will be necessary to close some in the future.
  - The shortfall for ITER has meant that Dr. Ed Synakowski has had to determine how to take $45 million from the base program and transfer it to ITER, a process that has been challenging. This budget shortfall in the base program is a recommendation by the administration; it is not yet the fusion budget because it has not yet been passed by Congress. He noted that some changes may be made to the President's request before it is passed.
  - It is difficult to know when the final version of the budget appropriations bill will be passed especially since this is an election year.
  - The passing of the Bill could be affected by the political situation in several ways. The current Congress, much maligned as a 'do nothing' Congress may want to act and pass the Bill to show that they can act before the election. Alternatively they may continue as they have and not act definitively until next January.

COMMITTEE DISCUSSION

Dr. Greenwald referred to the commitment from the SC for ITER and clean energy which they supported. He noted that there did not seem to be a commitment for fusion energy even though they

were embarking on the largest scientific initiative in the U.S. He asked how the SC would characterize their commitment to fusion energy. Dr. Brinkman responded that fusion was not thought to be a viable technology until maybe 2050 and they had a lot to do as far as CO2 and the climate situation was concerned before that time. Dr. Brinkman said they looked at it from an energy point of view and an administration point of view and believed that there were more immediate issues. He said that the fact that the administration was moving ahead with ITER showed that it was being supportive.

Dr. Dale Meade commented that in his opinion a plan was needed to move forward and to illustrate to Congress what was happening and what they were doing. He thought that there should be more interaction between the fusion community and the ITER project with regard to technical and budgetary issues. He said that as it is an international project there is a feeling of 'hands off' compared to domestic projects. Dr. Meade also said that a case should be made to Congress and the administration to ensure there was a plan for the domestic program from the present until 2021 to exploit ITER, develop broad base aspects of working with fusion and make a decision on a nuclear science initiative. He referred to 1996-97 when cuts of 40% were made to their program and within two months there was a restructuring plan. He considered the current situation just as serious and thought there should be more interaction between the department and the fusion community.

Dr. Brinkman responded that Dr. Synakowski would discuss the planning process that he would put into place and he noted that he would be working with him on that plan. With regard to his second issue of more community interaction with ITER he said that that was an interesting point. He noted that there were many reviews with regard to ITER and he thought perhaps more could be done. He agreed with Dr. Meade that a plan would have to be put into place over the next few months. Dr. Brinkman asked how they would they stay at the forefront of fusion science when ITER moves forward in 2021. He said that one thing that concerned him was that a new facility in their field had not been built for quite some time but that at the same time the domestic program could not move forward as he would like with the funds going to ITER.

Dr. Riccardo Betti noted that those were very significant cuts to the domestic program. He said that the funding profile would run up to a higher level than $150 million. He asked if the DOE had a plan of how to fund it and he thought it was important for the fusion community to know what would happen in 2013. Dr. Brinkman responded that they had several plans, they had profiles they wanted to propagate and put forward but with the current funding situation that would all have to be re-examined with the rest of the administration. He noted that they would have to develop a revised plan and this would have to be done by the next council meeting of ITER. He added that the FY2013 budget was supposed to be a stepping stone to the real budget for ITER which was an additional factor, $100 million more and so he noted that they have a major issue deciding how to go forward.

Dr. Amanda Hubbard referred to the current budget and noted that some ITER cost increases were being absorbed by the flat fusion budget and she said that that ran counter to the recommendations of multiple FESAC panels over the years. She said that he had just mentioned the sum of the $100 million and said that she hoped in the current meeting they would get some solid figures for that. She asked if

Dr. Brinkman considered it feasible or advisable to fund ITER out of a flat fusion budget. Dr. Brinkman responded that no, he did not think that he could expect $100 million from the domestic program. It was not viable as that would be a 50% cut. He said the funds would have to come from another source.

Dr. Bruce Cohen referred to the fact that Congress had been sending formal language to the department about balancing its investment in ITER with its investment in the domestic program and asking the department for a ten-year plan. He noted that to the fusion community the budget did not seem to be what Congress had in mind. He said in his opinion it was doing harm already and gave as an example, the shelving of plans to hire post-docs. He said that he felt if ITER was worth doing it was also because they had a domestic program worth doing and that ITER would have been the logical next step. He stated that it made no sense to sacrifice the domestic program in order to outsource and send their fusion research activity offshore. Dr. Brinkman responded that he agreed with him and he thought it was regrettable because there had been additional enthusiasm because of the ITER project. He added that they should wait and see what Congress decided and then put together a plan to see how they could move forward.

Dr. Christopher Keane acknowledged that decisions of this type were very difficult but he thought that transparency was an important part of how they did things both on the program side and on the project side. He asked about the ITER project and referred to its budget submission and noted that there was not a detailed project data sheet. He asked at what point they would receive the ITER project data sheet and costs. He noted that costs might be revised but he said it would give everyone more insight into how the project was being managed on the U.S. side and how they would fit in. He referred to the normal level of rigor that the SC would ordinarily do on other projects and said it might be there but was not obvious at the moment. Dr. Brinkman responded that if the community was not getting enough information regarding ITER then it was something that they would have to change.

Dr. Hantao Ji asked about budget allocations and asked what logic was used to decide which department allocations went up or down. Dr. Brinkman stated he had mentioned this earlier and those decisions were made based on the issue of what programs had the most impact or were viewed as having the most impact on energy and at the moment it was on near-term problems. He added that in his mind BES had the biggest role to play in that and he reviewed their existing facilities and their heavy use by industries. Dr. Brinkman elaborated and said that there had been a major change in the nature of their national laboratories. He said previously the national laboratories had been doing research for themselves often working with academic institutions doing experiments; they were research-oriented. Today things were different; they had synchrotrons, biofuel centers etc., these were all unique and would not be built by American industry. He said that the national laboratories had an opportunity to have a broader impact working with industry and he gave one example of GE developing a new type of battery and they had used the synchrotron extensively. Dr. Greenwald noted that in fusion they had always had that aspiration to go beyond science-driven science to industrial applications. Dr. Brinkman acknowledged that there certainly were applications that had come out of fusion.

Professor Edward Thomas referred to the FES budget allocation and noted there was not too much difference but he thought that the 'devil was in the details'. He asked how the tone was going to be changed within the SC so that those details that were having impacts on their program were mitigated. He also asked how the fusion community could maintain healthy two-way communication between the community and the SC. Dr. Brinkman responded that it had occurred to him over the last several years that few people understood the progress of the field. He added that the tokamaks had made a lot of progress over the last 50 years and he noted that all of a sudden it was apparent that everyone realized that the machines were getting out of hand as far as cost and so progress stopped. He stated that the answer was that they had no choice but to go on to build ITER and the negotiation had taken a great deal of time and he repeated that he did not feel that people appreciated that progression.

Dr. Ramon Leeper remarked that to have a viable community to use ITER they would have to push back on restructuring or spending profiles on ITER construction. He asked Dr. Brinkman if he felt this would be the outcome. Dr. Brinkman said he did not know how it would come out. He said if you try to push out ITER construction by saving $180 million a year you would be essentially shutting it off and raising the costs. Dr. Leeper said that from their perspective the U.S. program had no choice but to push back and he said perhaps it related to what had already been brought up with regard to transparency and how funds were being spent because they had to have a viable community. Dr. Brinkman agreed but said it had to be viable at both ends and emphasized the importance of ITER for the whole fusion community which he saw as its future.

Dr. Steve Zinkle referred to a comment Dr. Brinkman made about fusion as not being able to deliver electricity until 2050 and that was far off compared to some of the other options such as bioenergy and solar. He commented that the Congressional Budget Request might make that a self-fulfilling prophecy. He said that some believed it could be faster than 2050 but he asked if there was a sufficiently shorter period of time would that have changed the calculus in the discussions, in other words did it need to be 2025. Dr. Brinkman said he did not know the answer to that question. He said the most important thing was that date would need to have some credibility to it.

Dr. Cohen asked what the minimal healthy domestic program in fusion would be and he said the National Academy had weighed in on this already and noted that at the $300 million level the various projects the fusion program was working on already represented a minimal set. He added that over the last six years their budget had been flat and so things have contracted due to the reduced buying power of their money. He wondered if their research area was sustainable under that scenario, and this budget is even more difficult. He also asked if a balanced portfolio should also invest in a long-term solution to energy needs. Dr. Brinkman agreed that the program has to be sold, and they all have to work to convince people. He said that this has been a problem for the community, but he wanted to get ITER going and was not intentionally trying to change the domestic program. He said that a lot more work needed to be done to convince people that it was as important as they considered it to be.

Dr. Riccardo Betti agreed that the community had failed in convincing those outside the community due to the fact that they hadn't produced a burning plasma. He worried that perhaps the most cost-effective way of doing this – a high-field tokamak – looked to be being sacrificed in favor of ITER.

Dr. Ji asked which energy source was the greenest solution for the future, the biofuel or solar energy when considering timescale. Dr. Brinkman said it would probably be all of the above in some complex mixture. Dr. Ji asked if there was a formula that determined how much they should invest in each field. Dr. Brinkman responded that the SC asked what technology was becoming viable relative to the cheapest current technology. He said natural gas today was the cheapest source of energy and so he said they had set goals in solar to get it down to a dollar a watt installed and if it was down to that level it would be competitive with natural gas. He added that they were also looking at wind which for onshore was already down at the competitive price. He explained that they had to take into account this market determination, and they had to find things that would compete. He mentioned the fact that they are pushing enhanced oil recovery and get them started on the target of capturing CO2 but this was not economically viable at present.

BREAK

The Fusion Energy Sciences Advisory Committee recessed for a 15 minute break.

FES PERSPECTIVES INCLUDING THE FY 2013 CONGRESSIONAL BUDGET REQUEST

Dr. Ed Synakowski, *Associate Director for Fusion Energy Sciences, Office of Science*

- Stated that he would be talking about the program, the vision and the budget.
- Noted that it was a budget coming at a time when they were entering a new era in the field and there were challenges and opportunities within the budget.
- Said that he would be talking about the challenges and introduce topics that might facilitate talking about putting ways forward in mitigating some of those challenges.
- Commented on some of their overall ambitions in the field which he considered bold and which were:
  - To contribute to energy and climate solutions by mid-century.
  - To establish the plasma sciences broadly for fusion, discovery in fusion and discovery in the plasma sciences outside of fusion.
- Stated that they were over-arching forces that governed many of the choices given some of the boundary conditions imposed by the budget.
- Noted that many members were involved with the National Academies in developing the document, "The Burning Plasma" and in the development of the "Plasma Science 2010" decadal study. Added that the "Plasma Science 2010" study was urging the SC to take on a directive dedicated role in stewarding plasma sciences more broadly. Stated that the current budget reflected both sets of values.

- Stated that the proposal was developed with a long-term view for fusion and the plasma sciences and had been framed by the administration's priorities for near-term payoffs. In particular detailed:
  - The budget was developed considering the administration's high priority of investment in research relevant to clean energy with near-term payoff.
  - The administration confirms a strong commitment to ITER and recognizes its importance to fusion and to the energy economy in the second half of the century, as well as the leading scientific role of the U.S. in getting to this point.
  - Cuts are being made in a large majority of the non-ITER parts of the program. The exceptions are where modest increases have been proposed in international research and materials.
  - The proposal in the budget maintains the program structure and this can lead to where we need to be in 10 years.
- Stated that fusion and plasma science elements are intimately linked and showed this with an illustration showing fusion on earth/discovery linked with plasma-materials, science and technology. Noted the FES program mission as: "…to expand the fundamental understanding of matter at very high temperatures and densities and to develop the scientific foundations needed to develop a fusion energy source. This is accomplished by the study of the plasma state and its interactions with its surroundings."
- Commented that FES research had been world leading in bringing us to a new era in fusion energy development and relative to that statement noted that:
  - After more than 50 years of research the scientific and technical viability of fusion on earth was to be determined.
  - The scientific vehicle for the test was ITER and it would enable the study of high gain fusion plasmas, fusion systems that release more energy than is required to initiate and control them.
  - The U.S. has had a major role in developing the scientific basis girding ITER, its design and its operating scenarios.
  - The budget proposal for FY2013 will be highly impactful for ITER construction, fusion research and the plasma sciences overall and preserves a structure that can effectively engage the world in the ITER era as well as being fiscally responsible.
- Stated that the total FES budget request was $398.3 million as opposed to $401 million appropriated in FY2012. Noted that the drafting of the proposal considered goals of where they needed to be in ten years, particularly in relation to the following:
  - The U.S. needs to lead in burning plasma science – Support is being given to the ITER project at $150 million. The DIII-D runtime is to be maintained with no upgrades and the Alcator C-Mod facility would cease operations in FY2013.
  - Position the U.S. to assert leadership in present gaps – Increases in international opportunities on long-pulse facilities, both tokamak and stellarator. In materials science continue support for the NSTX (National Spherical Torus Experiment) Upgrade project and DIII-D to enable an informed decision on an FNSP (Fusion Nuclear Science Program) later in the decade.

  - Steward the broader plasma sciences – The FES program structure is maintained and the non-ITER program sees an overall reduction of about 16% including closure of the Alcator C-Mod program. Joint programs with NNSA (National Nuclear Security Administration) and NSF (National Science Foundation) in non-MFE (Magnetic Fusion Energy) research are maintained at reduced levels.
- Noted that they could have focused on magnetic fusion but a decision was made that there was an obligation to steward the broader plasma sciences.
- Commented on some of the new super-conducting devices being constructed worldwide. Noted that many of the countries were also contributing to the ITER project at the same time. Some of these projects were discussed:
  - ITER will be constructed and the frontier of burning plasma science will be there. He likened it to the LHC (Large Hadron Collider) in high energy physics. The importance of the participation of the U.S. in ITER was emphasized.
  - The $B-class research facilities in magnetic fusion will be online in Europe and Asia and the class of physics that the facilities would enable will include and extend beyond what U.S. facilities are capable of exploring. The U.S. domestic program can and must be leveraged to take advantage of these research resources.
  - Noted the U.S. has an opportunity in the long run for a leadership in fusion materials science.
- Stated that it was important for the U.S. to pay attention to what was developing internationally and then determine how best the United States could be engaged. Added that the challenge was ensuring that U.S. researchers both senior and junior had an opportunity for access to the world's leading questions in fusion.
- Emphasized that the budget proposal made steps in engaging the changes although in a constrained environment.
- Reiterated some of the positive issues:
  - A student population of over 400.
  - Outstanding facilities in DIII-D and the NSTX Upgrade when completed would be second to none in that class of compact tokamak research.
  - Viable core elements with leverage opportunities in the U.S. which they would need to embrace and pursue.
  - A clearly-defined gap in fusion materials.
  - Longstanding international research relationships at the emerging facilities and opportunities there should be pursued.
  - Opportunities in materials science with high potential for leverage, particularly with the BES office.
- Outlined some of the issues that they would have to overcome in the budget:
  - The loss of a major facility and the student engagement at that facility.
  - Minimize the impacts on the human capital as they try to create opportunities for the research team.
  - Reductions in every area except international research and materials. Examples of what could be done to mitigate the effects of the losses include: increasing student education opportunities at DIII-D and NSTX; vigorously develop and understand the limits of research opportunities overseas; and develop leverage within NNSA, BES and ASCR (Advanced Scientific Computing Research).
- Stated that U.S. research had to evolve with respect to the international scene overall and evolve with respect to fusion materials science and extracting fusion power. Added that these

were opportunities that were well articulated in the "Priorities, Gaps and Opportunities Report" from the FESAC panel.

- Noted that for them to increase their impact in those areas they needed to lever their common interests in MFE, IFE (Inertial Fusion Energy), look to the Nuclear Energy Office, BES within the SC and NNSA.
- Stated that there was a fundamental choice to be made about the mission of a major fusion nuclear science facility that they should have the technical basis for deploying by the end of the decade. Added that one of the fundamental choices surrounding the mission space is asking what does the core of the proposed facility look like. Noted that what they had in the budget proposal was a pair of world-leading facilities which, in concert with the rest of the tokamak worldwide database should enable an important decision on this question.
- Commented that he believed what had an impact with the administration was the scientific argument that the relevance of the alpha particle physics that would be revealed on ITER in concert with advanced computation to other magnetic fusion concepts. Said the argument was what could get you the alpha particle physics quickest to inform the broad base of fusion energy concepts. Added that this was an argument developed by the community and looked at by the National Academies and this had import within the administration.
- Emphasized that the administration also understood the scientific value of the domestic program.
- Stated that he challenge moving forward was developing a plan that would strengthen the relationship between ITER as a research instrument and the domestic program. Noted that they should not be viewed as independent entities but as a partnership.
- Stated that the administration was still developing its approach as to how ITER would be supported. Added that while the administration was looking at ITER costs and coming to terms with what that would mean he could not advise them that at the present time there was a final resolution as to how that would be done.
- Confirmed once again that the U.S. path for fusion would be expressed in terms of scientific elements and would include changes of emphasis. Stated that it was his view that there would be continued downward pressure on the domestic non-ITER component of the budget and he thought it would become incredible to think about continuing a commitment to a program balance.
- Stated that in developing plans or possibilities for future years and considering reduced budgets there was a serious possibility of looking at options of reduced program scope and this might include focusing more exclusively on the scientific aspects of the plasma science or focusing on fusion materials science.
- Noted that in the current environment the leverage between domestic and international research opportunities would become more important if the U.S. was to have available access to the leading scientific questions in the coming decade.
- Discussed the overall breakdown of the total budget in a pie chart and he noted some of the following:
  - ITER was to receive $150 million
  - The MFE, major three facilities at $149,828 million
  - Enabling R&D in the budget was at $22.648 million
  - The total non-ITER budget dropped by 16% in total
  - Detailed the facility operations
- Reviewed a chart for the FESAC FY 2013 Congressional Budget and area reductions. Noted that if funds were being withheld in the sum of $26 million for solicitation then it would show up as a

reduction on that particular program and added that it would provide an opportunity to compete for funds.

- Discussed ITER with some background, the construction project, international commitments and U.S. obligations:
  - ITER is the keystone for establishing the scientific and technological feasibility of magnetic fusion energy.
  - Will create the world's first sustained self-heated plasma.
  - U.S. research has had a defining impact on ITER design and operating scenarios.
  - The designs and construction of the U.S. contributions will be done almost exclusively within the boundaries of the United States.
  - Many technologies will be at reactor scale or will enable first studies at reactor scale.
  - The budget for ITER was $105 million for FY2012 and $150 million for FY2013.
- Discussed the ITER management team changes and noted the excellent leadership of Director General Motojima supported by a strong U.S. leadership including Rich Hawryluk and Rem Haange.
- Commented on why the ITER project needed to grow in challenging budgetary times and noted that:
  - ITER is the capstone of 50 years of research in magnetic fusion.
  - The project construction is moving along and the U.S. needs to keep pace.
  - With the current budget they are at the edge of having a negative impact on the overall schedule. A further reduction in the U.S. contribution will yield a schedule slip and the political consequences would be unpredictable.
- Reviewed the international financial commitments to ITER and noted specifically the contribution from European Union, Japan, significant increases despite the earthquake and tsunami.
- Noted that the majority of the funds for the ITER project were spent within the United States to labs ($168 million), universities and industries ($171 million).
- Discussed DIII-D and noted:
  - The budget numbers had gone down in FY2013 from FY 2012 for research and operations.
  - In the area of plasma dynamics and control science referred to two specific areas concerning electron heating and fundamentals of plasma transport MHD and waves.
- Discussed the commitment to the NSTX project at the PPPL (Princeton Plasma Physics Laboratory) including the funding for research, operations and construction projects. Described some of the research being conducted at the laboratory and noted that the upgrade was going to be completed on schedule.
- Stated that the Alcator C-Mod at MIT in Cambridge was to be closed in FY2013. Noted regret about the closing of the facility considering the people and institution involved. Added in FY2013 there would be an analysis of the data from FY2012 and results would be published. Expressed a hope that the research staff would take part in collaborative efforts in other domestic and international research programs. Expressed the view that the Alcator C-Mod contributions had been exceptional.
- Outlined the need to grow their internationally-based research efforts and he included the first-of-its-kind superconducting tokamaks in China and South Korea, Germany and currently being built in Japan. Emphasized the importance of the social aspects of forming viable sustainable research teams.
- Discussed enabling technologies directed towards a materials science emphasis. Noted the

FESAC Panel report "Priorities, Gaps and Opportunities" pointed to the needs and opportunities for the U.S. in fusion materials science, including closing the fuel cycle and harnessing fusion power. Also stated:
  - An initiative in fusion materials research is proposed.
  - The level of support for design studies of future facilities and the VLT (Virtual Laboratory for Technology) would be reduced.
  - The level of support for advanced technologies for future facilities will be reduced.
- Discussed advances in validated simulation considered critical for the future of fusion. Noted that:
  - Theory and computation are important elements of every aspect of fusion and plasma sciences.
  - In FY2013 the scope of the theory program will be narrowed.
  - For SciDAC (Scientific Discovery through Advanced Computing) the scope and balance of the portfolio will be maintained but fewer centers may be selected following the FY2012 re-competition.
- Discussed the experimental plasma research portfolio and MST (Madison Symmetric Torus) and noted it was nearly flat-funded. Stated they wanted to maintain a critical level of effort to enable connections between non-tokamak and tokamak configurations and that a validation and verification emphasis be maintained.
- Reviewed general plasma science and HEDLP (High Energy Density Laboratory Plasmas) and noted they also suffered reductions. Explained that the program had significant support elsewhere with the NSF and NNSA and therefore more significant reductions were afforded there as opposed to other areas.
- Commented on program planning and advised there had been a substantial amount of discussion within the SC. Acknowledged the comments made about community engagement and agreed they were important and should be heard.
- Advised the FESAC that they did not have a charge. Added that a concerted effort was made to develop a charge but nothing emerged that they were comfortable with and they felt that the driver of doing it by the FESAC meeting would have been irresponsible unless they were comfortable with the charge in hand. Noted that they would be engaging the community at a later time.
- Stated that the path forward for fusion was with regard to scientific elements and that would include changes of emphasis and detailed some major points:
  - Burning plasma science and stewarding broader plasma science will be key elements but the program scope may be reduced due to lower funding levels.
  - Major domestic facilities will still engage in plasma dynamics and control but will shift focus towards challenging metrics relevant to fusion materials science.
  - Leverage between domestic and international research opportunities in MFE will become even more important in harder budget times. If the U.S. is to obtain access to the leading scientific questions in the next decade.
- Stated thatDOE was developing a strategic plan to be presented to Congress in December of 2012 and noted that it was mandated by legislative language from the FY2012 budget, would include technical community input and would include: ReNeW (Research Needs Workshop) reports; the "Priorities, Gaps and Opportunities" analysis; and new input from FESAC on international research and fusion materials science.
- On the development of the plan the following steps would be taken:

- FES was developing a charge and/or charges to be presented to FESAC and looked forward to receiving input from them. ITER and new elements in the program were possible components of such a charge or charges.
- With regard to timing there were two issues: the administration approach to ITER and the domestic program and the House and Senate marks this year.
- Input from individuals on any concerns regarding the program would be welcome.
- The plan would be developed by FES and shared with FESAC in the fall of 2012 for comment.
- The development of a plan for the domestic program in conjunction with ITER.
- The program must include a vigorous international component if U.S. scientists are to have access to research questions that remain inaccessible within the U.S. alone.
- Development of the capability to make major contributions in fusion materials science and harnessing fusion power.
- A priority of maintaining program breadth if budgets permit, noting that the prospect of further non-ITER program reductions may make it impossible to maintain present program scope.

COMMITTEE DISCUSSION

Dr. Greenwald acknowledged that the program up until now had been highly constrained and suffered a factor of four drop in spending power since its peak and he agreed that the budget of FY2013 presented many difficulties. He noted that looking forward knowing the scope of the requirements for ITER construction combined with the fact that the current budget is flat, he stated that it looked like the trajectory they were on was a slow dissolution of the program. He asked where the SC would draw the line.

Dr. Synakowski responded that he felt they were close to the line regarding program scope. He added that maintaining program breadth may not be viable too much further down the road. He said he didn't have an answer to the question overall but he thought the community and SC needed to be careful before considering 'throwing in the towel'. He said that the U.S. engagement was critical to ITER and he said that it was very unlikely that the administration would withdraw. He said that to say at a certain point that that was 'enough' would that mean that they would not serve the country at a lower budget level? He said there was enough flux in the ongoing discussions that it was not a foregone conclusion that dissolution was the path.

Dr. Greenwald noted that at some point it would cease to be a program, and would become foreign aid. Dr. Synakowski said this was an unfair way of characterizing it. Dr. Synakowski responded that if at some point there was a serious discussion about priorities and then the costs of the priorities were reviewed they might have a more quantitative answer.

Dr. Raymond Fonck noted that with the decisions the SC had taken there would be irreversible losses of people in the program. If facilities were reduced there would not be a significant amount of money in collaborations to recover that scientific expertise. He added that they were irreversible decisions and they would make sense if the program has a downward trajectory. However, he said that if the SC

thought that things were in sufficient flux wouldn't these irreversible decisions be counterproductive, and would the SC still make those decisions. Dr. Synakowski responded that in his judgment and that of the SC the approach that they had taken was considered the most reversible. He added that with regard to institutions and the capabilities of the institutions you could point to real loss. However the judgment was made that the decision was between something similar to what they chose or loss of program scope, and he considered that loss truly irreversible.

Dr. Fonck said that they were losing human capital which he considered irreversible because there were no resources to recover that human capital elsewhere in the program. He thought that this meant you would lose of the capability to lead. Dr. Synakowski defended the decisions made and said that such a loss would be taken if deeper impacts affected other areas of the program.

Dr. Meade thanked him for the presentation and noted that they had had difficult times before. He said in 1996 they had a 40% budget cut and went from $363 million in FY1995 to about $244 million in FY1996. He said in a FESAC meeting in 1995 two charges were developed and two panels set up. He said that within two weeks the first meetings were held and in less than two months reports were presented. He said that the one thing he wanted to impress on Dr. Synakowski and the DOE was time was of the essence and he thought it should be treated as a crisis for fusion energy and move forward with all deliberate speed. He suggested that the time to develop the charge should be short and a date be developed for two weeks. In addition he suggested another meeting of FESAC should occur so that they could start work on the charge(s). He suggested that they should have a short deadline for coming to grips and setting a plan up with priorities. He thought they should determine a way to quantify for the SC the difficulties being experienced by researchers in the field. He referred to the FY2013 budget and the $50 million that had to be found somewhere and noted that what he found distressing was the abrupt nature of the termination of a major facility which he considered wasteful.

Dr. Richard Callis referred to international collaborations and the issue of strategic planning and said that in order to have productive international collaborations especially with the Asian tokamaks they would have to engage them and train or educate them on advanced tokamak science. He added that in doing that they were planting the seeds for them to take the leadership role five or ten years out as the U.S. funding decreased. He asked if this type of strategic thinking integrated into the planning of how they would move forward with international plans. Dr. Synakowski asked if he was suggesting that by giving them knowledge the U.S. was giving them an advantage. Dr. Callis said yes. Dr. Synakowski responded that as their knowledgebase would rise then the United States would have every opportunity to rise with it.

Dr. Cohen noted that he thought that Dr. Synakowski's remarks underscored the need for strategic long-term planning. He referred to part of Dr. Synakowski's presentation and read part of it as, "with this proposal program structures maintained can lead to where we need to be in ten years". He said that surprised him because he looked at what the theory component of the program would be able to do for the mission, and believed this would be a lot less. He added that in areas where they could have had international leadership, and a huge impact on international and domestic devices, they had stopped

cold. Dr. Cohen referenced one of the priorities Dr. Synakowski identified -- the pursuit of scientific opportunities and grand challenges in high energy density plasma science -- and noted this had taken a 30% cut. He said great science was being done in that area and questioned the wisdom of cutting that area disproportionately. Dr. Synakowski asked him where he would cut. Dr. Cohen said he would not make any cuts at all to the program and he asked if they were hoping that NNSA would take up the slack. Dr. Synakowski acknowledged that that area of science was valuable and noted again that the whole series of cuts was not easy and they could not fall behind with ITER. Dr. Cohen asked him if he had a plan to go forward and engage with NNSA. Dr. Synakowski said yes.

Dr. Hubbard stated that she was dismayed by the cuts all across the board and noted that she did not share Dr. Synakowski's optimism that it was a viable path. She noted that its effect on the fusion workforce had not been taken adequately into account. She said the program would need people in ten years to work on ITER and those people would need to have ten years' experience. She added that the budget would affect the decisions of a whole cohort of students to enter or remain in the field. She said with many labs across the country laying off workers, where would the current students and post-docs go to stay in the field and she added that in her opinion it was very short-sighted. Dr. Synakowski responded that it was important to be truthful and to state that they were seeing in effect a snapshot of a process where the administration was coming to grips with the challenges and said he could not describe the outcome. He said he could only confirm that the administration was committed to ITER and a balanced portfolio. He emphasized that the cuts were not his wish but as a representative of the administration he had to find the opportunities given the overall constraints of the budget.

Dr. Ellen Meeks asked if he had the percentages of the domestic programs compared to ITER for the other countries contributing to ITER for comparison. Dr. Synakowski responded that no, he did not have that detailed data.

Dr. Keane thanked him for the presentation. He noted that he agreed with the sense of urgency heard from the other committee members. He thought it was good that the process they were using to make difficult decisions was transparent. He asked that when they were given the charge would he consider providing strawman budget profiles to help the group frame the priorities. Dr. Synakowski responded his first instinct was no but he said he was open to talking about it. He thought that it was a significant social challenge in carrying out a difficult charge of that nature.

Dr. Fonck said to him there was a difference between leadership and being impactful. He said that Dr. Synakowski had mentioned that in the FES view there were elements needed for leadership in the ITER era and he said they were not identified. He asked if at some point he would elaborate on that. He also said that Dr. Synakowski had noted that program breadth might not be viable with negative pressure on the budget. He asked then, did he have to make a choice between a plasma science oriented program or a materials science oriented program. He said, how would he go up against programs in Europe that were well funded and still expect for the U.S. programs to have an element of leadership. Dr. Synakowski said without specifics he could not answer him and he said there may come a time when

they could not. Dr. Fonck asked, how would it all be decided? Dr. Synakowski said it would start as they have described but the whole process had not been completely defined.

Dr. Betti referred to alpha physics which he had highlighted as one of the most important goals of ITER. He suggested that they could study a lot of alpha physics on smaller devices which were not as expensive as ITER. He asked at what point would the cost of ITER become so high that the SC would start to think about other options. He asked about the theory cuts and then stated that the U.S. experimental program would become so small that it would then be compared to individual European countries as opposed to Europe as a whole. He said that they still had a leadership role in theory simulations but with the large cuts they would also lose that. He thought that was harmful to the U.S. program. Dr. Synakowski responded that yes, there was an intellectual leadership loss associated with a loss of resources. He responded with regard to burning plasma options he said he stood behind where they were and that ITER would have a scientific and technical reach that they needed for fusion to be a viable option in a meaningful timescale.

Dr. Steven Zinkle stated that Dr. Brinkman's and the administration's budget built the case for basic plasma science and he noted that the scientists in plasma physics could also do great plasma science and he gave the example of the production of anti-hydrogen. He said about cuts to experimental plasma, general plasma science theory and asked if the NRC (National Research Council) recommendation was being ignored. Dr. Synakowski responded no and elaborated. He asked about the universities that were being strongly affected and asked what their role would be in the longer term and would there be a renewed activity in basic plasma physics. Dr. Synakowski agreed that many universities were being hit with the cuts and he noted it was still possible to have a high impact. He agreed that the possibility that their ability to be strong leaders might be compromised.

Dr. Rosner commented on the tension between the energy mission and science aspects of FES, and asked whether the fusion program was a fusion or plasma program. Dr. Synakowski noted that at the time the program reached the stage of a fusion nuclear science facility, it might be time to change program governance from Office of Science.

Dr. Meade asked about ITER and said on the physics and program side they were getting information but not on the project side. He stated they needed more information as FES would be called upon to provide more resources and yet they had no information on how ITER was getting into a financial predicament where more funds might be needed again. He said considering the implication for the United States where programs and facilities were affected they needed more information. Dr. Synakowski responded that if the budget was not giving enough information that there would be other vehicles they could find but he agreed with him.

Dr. Leeper noted that they were supposed to have a leadership role in ITER but if people started leaving the field he was concerned. He asked if they could push back on their contributions or spending profile. Dr. Synakowski responded that they had an independent cost review scheduled for later in the spring. He noted that total costs, integrated costs and annual expenditure were a high concern.

Dr. Greenwald thanked Dr. Synakowski for valiantly defending the indefensible.

LUNCH

The Fusion Energy Sciences Advisory Committee recessed for lunch.

BASIC RESEARCH DIRECTIONS USING THE NATIONAL IGNITION FACILITY

Dr. John Sarrao, *Los Alamos National Laboratory*

- Explained that the workshop had several aims, to explore a set of scientific directions and to explore the aspect of user science.
- Acknowledged that the FES community knows the area well and there are a number of reports that have looked at the science needs and opportunities that exist in what is generally called high energy science.
- Noted that access to NNSA facilities was emphasized in the reports and that NIF (National Ignition Facility) was developing processes and infrastructure to support the fundamental science mission.
- Provided details on the workshop that took place in May 2011 and a group that spanned a broad area that asked the question, was there science to be done at NIF that addresses both FES directions and questions of issues that are in the mission space of basic energy sciences, nuclear physics and high energy physics within the SC?
- Noted that the other two Workshop Chairs were Kim Budil of LLNL (Lawrence Livermore National Laboratory) and Michael Wiescher of Notre Dame and the many people who led panels.
- Identified the goals of the workshop:
  - To summarize key aspects of the current state of scientific research and understanding in relevant fields.
  - To define a set of related Science Grand Challenges: Identify a set of proposed research directions that address broad scientific uses of the NIF; and provide a preferred facility governance process including responsibilities of key individuals, the process for user access and allocation of NIF facility time and resources, and other policies and procedures relevant to facility users.
- Commented that it was an exciting time for NIF because it exists as an operational facility and can create extreme and interesting environments. Added it was not the first time one had asked the question, what are the science opportunities of NIF?
- Stated that the question presented the topic of the workshop but in a more structured format and using the approaches of the ReNeW workshops.
- Commented that the object was to gather 100 people from 49 institutions and 6 countries to consider some of the following:
  - Define discipline-specific challenges (The Problem)

  - That NIF can Address (The solution)
  - On a decadal scale (The Path to Success)
  - That will make a difference for science (The Impact) and
  - In Laboratory astrophysics, nuclear physics, materials and planetary physics, and beam and plasma physics.
- Described the four basic questions that were asked which included: Discipline Specific Challenge and NIF Enabled Innovation; Research Directions and Outcome and Potential Impact and noted that the structure took that shape as it was intended to generate a report.
- The results of the workshop were 16 priority research directions and he added that various aspects of fusion science and plasma science did not receive a full focus because they are topics already explored thoroughly and therefore the focus was to explore the broader questions.
- Discussed only one of the research directions and he discussed Exploring Exoplanets at NIF in detail within the basic structure of the chart format.
- Noted that user teams aligned with the priority research directions have already taken data at NIF including: Laboratory Astrophysics, Materials and planetary Physics, and Nuclear Physics.
- Stated that the initial data was exciting and was just the beginning and he gave two examples: for Laboratory Astrophysics: Radiation Hydrodynamics and for Nuclear Physics: Nucleosynthesis.
- Commented on governance models and user experience as important considerations and gave three principles which underlined their recommendations:
  - Make science on NIF successful on long-term timescales.
  - Build a sense of scientific community among NIF users.
  - Utilize best practices and lessons learned from relevant facilities at NIF.
- Stated and elaborated on their recommendations which spanned three principal topics:
  - Policy and Governance
  - Facility Operations
  - Outreach and Education
- Commented that if they were talking about decadal scale opportunities, that is a good thing as doing some of the experiments is difficult. Added that the workshop asked in the cases of Lab-Astrophysics and Nuclear Physics was it to accomplish the decadal directions? What are the things that one would need to be able to do, that one could not do today or the capability gaps.
- Considered that looking at the capability gaps could be an important part of the mix of that overall scientific agenda.
- Stated that it was encouraging that the community rather than saying here's what the facility can do today and let's tailor the science to that facility, the discussion was how do you tailor the facility to do that overall science?
- Said that the workshop identified that there are important scientific directions to explore in the domain of NIF science which embraced all that was HED (High Energy Density) and beyond.
- Recommended looking at the report which was up on the SC website.

COMMITTEE DISCUSSION

Dr. Callis noted that Dr. Sarrao was starting a new user group and he wondered if they discussed what the minimum critical size was to make a real active program. He asked if his user group was bigger than the 100. Dr. Sarrao responded that it was still under exploration and added that NIF was determining how many people they would give user time to. They picked a number of eight teams that would span both the various disciplines. He added that one of the debates was that the committee had allocated that time and had the question of how would one decide on enough capacity without scheduling people too far down the line. He said it numbered in the 100s but they were still trying to establish an appropriate working number.

Dr. Rosner offered an observation and stated that one interesting thing in the field was when you go to a users' meeting is the demographics. He added that despite the fact that the funding was still modest the enthusiasm that could be seen among young people was amazing and came from the excitement of the science and the other was the sense that there is a future.

Dr. Leeper referred to facilities like NIF where they were talking one or two shots a day and asked if there was any discussion of multiplexing on a given shot, the idea being to use a common radiation source where you would have more diagnostics of it, where maybe you could get four experiments off it. Dr. Sarrao responded that multiplexing was a good multiplier and was important in terms of how one would do multiple experiments and how did one grow larger teams. He explained and said they would both have ideas at the 80% level or similar, could we hook up and make a larger team and accomplish both goals at once. He thought that that larger integrative thinking was an important element.

Dr. Cohen said he was glad to hear that Dr. Sarrao mentioned issues such as cost of the facility, reducing the number of shots available and then diagnostics which continued to be expanded at NIF. He asked if there was any sort of cultural issue with the group trying to get its hands on just how many shots one could realistically expect for a particular campaign. He added that very often one was lucky to get a day at some facilities. Dr. Sarrao responded yes and there were at least a couple of factors and one was that researchers would go through a process of working and learning at different institutions. He also added that as one gained more experience there would be a clearer sense of what needed to be done.

Dr. Synakowski noted that one of the things that attracted him at LLNL was the potential use of small-scale facilities in concert with NIF. He added that there were certain classes of issues not only for which the smaller scale facilities could contribute but they could access pieces of the relevant parameter space that NIF could not. He asked if that kind of discussion was talked about or entered into in any of the discussions at the workshop, that NIF could be a keystone to a broader national effort. Dr. Sarrao responded that the short answer was yes. He said it was gratifying how deliberate some of these panels were in identifying what was or was not a credible direction.

ITER UPDATE: ACCOMPLISHMENTS, STATUS, AND DOMESTIC ISSUES

Mr. Tom Vanek, *Senior Policy Advisor, Office of Fusion Energy Sciences*

- Advised that he would be giving a presentation primarily on the international aspects of the ITER project.
- Stated that he was pleased to say that by a lot of hard work by ITER management and DOE management and many international colleagues it appeared that ITER was on the road to building a project.
- Noted that at the previous FESAC meeting the construction had just begun and there were significant questions about funding and ensuring that construction continued.
- Mentioned that in March 2011 there was a significant earthquake and tsunami in Japan which cast doubts on the government of Japan to sustain both political and financial support for the project. Added that now a year later the Japanese funding is $225 million approximately and they have also secured an additional $250 million in funding for ITER for FY2013.
- Stated that they have recently had good news and noted that the EU (European Union) had secured FY2012 funding and has a strong commitment for FY2013 funding totaling €1.3 billion which brought their total commitment for that two-year period to €2 billion (or $2.7 billion).
- Noted that during the past year they have come to an agreement that the effects of the Japanese earthquake would be limited to a one-year schedule delay. Said the initial estimates had ranged up to four years. He stated that much of the credit for the leadership of that effort was Professor SCamu Motojima and noted that he had turned the ITER organization around, streamlined it and was instrumental in moving it forward as a construction project.
- Discussed recruitment efforts and noted that all members would be asked to comment and provide candidates directly or indirectly to the ITER organization for any positions as they become available. Said that for higher level positions the members are asked to become involved in the vetting process and assessing them. Added the quality of the candidates had been improving steadily.
- Noted that the United States had worked hard to maintain strong relationships and good communications with other members of ITER which had yielded many benefits.
- Stated that the IC-10 Meeting would be held in Washington, D.C. in June 2012 and he noted that the last major meeting in the U.S. was in 2003.
- Noted that the American request for ITER was $150 million and that represented an increase in a stressed budget. Encouraged members going to the Hill and talking to members of Congress to ask for their support and to emphasize that ITER is an important part of fusion moving forward and part of a coherent program.
- Commented that it was incumbent on them in the government and at the U.S. ITER Project Office to ensure that the project is managed extremely well. Added that to not do so would make it harder to secure funding for the project and the entire fusion enterprise.

Dr. John Glowienka, *U.S. ITER Project Manager, Fusion Energy Sciences*

- Stated that his first take away message was that serious fabrication has begun. Described the PF Coil Winding Building which is the factory where PF coils that cannot be built and shipped in would be built. Stated that the PF Coil Building was completed for beneficial occupancy in December 2012. Added that it would now be fitted as a factory for the PF coils and starting in December 2012 PF coil fabrication would begin.
- Described the ITER headquarters building and said that it would also be ready for occupancy in December 2012 housing about 500 people.
- Described the tokamak pit and stated it was a concrete base mat about a meter and half deep with rebars in it and noted that the pedestals were part of the seismic isolation system. Added that the actual first floor would be built on top of that. Noted that some parts of that building would be coming from the United States including two tokamak cooling water system drain tanks that would be installed soon.
- Commented more on the construction of the central solenoid and provided details of other parts and systems.
- Noted that they had moved away from design and R&D and were now in the process of fabrication and getting industry involved.
- Reviewed the U.S. Plan and stated that the United States planned to deliver its commitments in the form of 162 deliverables in the 'Just in Time' mode meaning that as ITER needs them they will get them there. Discussed the importance of the "Early Finish Schedule" being of necessity with the other international members.
- Stated that what had been done over the last six or seven months is that they have a full and integrated drawing capability where drawings from one member are in the same format and software and can be transmitted electronically.
- Said that they also have a fully-integrated schedule with all the milestones with all the members plus the IO on the same sheet.
- Commented that the U.S. focus now was to start transitioning away from R&D and design into fabrication. Stated that the schedule calls for: the completion of the R&D; advance design with industry; long-lead procurement; and baseline domestic project in 2012. Added that this would mean that they would move away from Critical Decision (CD) 1 which was a range of costs and schedule to a fixed point estimate of costs and schedule.
- Stated that in 2012 they are starting to set up factories to build components and extra tools. Sometimes the tools comprise the majority of the cost, for instance in the construction of the central solenoid.
- Noted that in 2013 they are engaging industry to begin the manufacture of other elements.
- Reminded the members that not only did the U.S. honor its commitments within the United States but also internationally and he gave as an example, American companies contracted by other international members to engage in fabrication works to build their widgets.

- Discussed one of the commitments of the United States, the central solenoid and noted that they have contracts in place with General Atomics and outlined some of the progress steps and problematic issues with the Japanese conductor that will be used to make the solenoid.
- Described some of the testing of the conductors, the first set of which failed, and the second would be acceptable with some caveats as to its use. A new US set is currently being tested in Switzerland which shows promise. There are politics involved in making this decision, as the Japanese may not find it acceptable that the conductor is US made, but he stated it is not certain they have the capability of making the conductor. The IO would ultimately have to make this decision and they will go forward with whatever decision is made.
- The failed conductor is being tested to discover what went wrong.
- Commented on some serious oversight over the project and he noted that in the course of the ITER project starting in 2002 there had been nine Lehman Reviews or Office of Program Assessment Reviews and the last four were spaced every six months. Stated the last review was in November 2011 and the next one would be in May of 2012.
- Stated that there were strong indications that the U.S. ITER project had a functioning project team capable of executing the project and meeting the U.S. commitment and was ready for project baselining.
- Commented on the ITER project, given a fixed scope of what the cost and schedule would be. Stated that the cost could be manipulated by lengthening the term of the project but this had been deemed unacceptable by the other ITER partners. Noted that they had been looking at many different costs and profiles.
- Referred to earlier comments at the FESAC meeting and noted that with regard to transparency they had nothing to show in terms of what a bottom line would be, given the fact that they had a fixed scope but did not know what the costs and schedule were or the influence of politics.
- Stated that it was important to get benchmarking from external sources and they would have an independent cost evaluation in the May timeframe. Stated that part of the cost evaluation would look specifically at something that dealt with costs stability. Explained that that would be concerned with the issue of have they included all the items of risk in their risk registry.
- Summarized that construction of the major on-site buildings was underway and one was completed. Added that the ITER members were now in rapid transition from design and R&D to fabrication of their commitments for delivery to the ITER site and finally, the U.S. ITER project is preparing for CD-2 project baseline.
- Confirmed they were putting the U.S. in a position to establish a major project to build items to go to ITER.
- Stated that it was a U.S. project and well over 85% of the U.S. ITER funds to build widgets stay in the country and the rest is used as operating funds for the ITER organization staff comprised currently of 33 people.

COMMITTEE DISCUSSION

Dr. Synakowski acknowledged that at this time there was a level of detail that would not be available but with FESAC he noted that in the future they would like to have a sense of the number of items that are required early, the items that are being driven by the ITER need dates and how that would translate to the kind of procurements that need to be done at specific times and that are driving the ramp up in many people's minds. He added that in retrospect it would have been relevant information for the current meeting considering the sensitivity of the issue.

Dr. Ji agreed that more information was needed and said if more details could be obtained they would be willing to hear them the second day of the meeting.

Dr. Callis noted that he had been working at ORNL on the CS magnet and said that both presenters had emphasized many times that there was a strong management oversight and he said that seemed to be working well as it was consuming the upper management at ORNL and they were always preparing for reviews. Dr. Glowienka confirmed that was true and would continue.

Dr. Greenwald referred to the issue of the conductor and noted that Dr. Glowienka had said something provocative which suggested that there was a better and worse choice from a technical point of view but also suggested political influence. He said given the size of the program and possible impact on the U.S. program he noted that that was a serious assertion. Dr. Glowienka said that globally the Japanese are responsible for the conductor and confirmed that it was a project they said they could and would do. He said that the fact that someone else could provide a conductor might be viewed politically unfavorably by them. He mentioned several scenarios such as the Japanese having to pay the U.S. to build a conductor or having the U.S. train their industry how to build a conductor.

Mr. Vanek stated that the way the agreement was structured was approximately 80% of the national contributions were to be in kind with about 20% in cash. He added that one of the reasons for that approach was that it allowed countries to pick their areas of strength and interest and it would also help them to ensure that their domestic industry got some business from ITER regardless of where it was built. He said for that reason there was an extreme sensitivity and if a country had a national industry that it considered competent and prepared to deliver components that it would be difficult to find a way to take that business away from that country and give it to another member.

Dr. Meade referred to the central solenoid and asked about cost. Dr. Glowienka responded that the solenoid by itself without contingencies is about $124 million. Dr. Meade asked if that included the conductor cost. Dr. Glowienka responded no. Dr. Meade asked what the conductor cost was and noted that he was trying to get a ballpark feeling for it. Dr. Meade asked if the total was about $500 million and Dr. Glowienka said that could be. Dr. Meade expressed his concerns about the problems that had occurred with the conductor and wondered about the standard of construction, if that had been the cause of the problems. Dr. Glowienka discussed some of the testing of the conductor and explained their approaches to resolving some of the issues.

Dr. Betti commented that the ITER schedule and costs were constantly changing as he had listened to updates over the years. He asked if they were to believe now that the schedule and costs were somewhat firm. Dr. Glowienka explained that the agreement was signed in 2006, came into force in 2007 and was then subject to a design review. He also mentioned events like the natural disasters in Japan and noted that they were not giving excuses but these types of things would cause delays. He also said that they believed that the current schedule and costs were realistic. Dr. Glowienka and Mr. Vanek both explained that as the project was progressing and all the members were being made to adhere to schedules as each of their components for the project would become due. Dr. Betti asked about the initial estimates of the cost of the project which to many did not seem realistic and asked for an explanation. Mr. Vanek explained that some of the early estimates did not include many of the costs such as labor etc. He noted that the costs were considered reasonable for the context in which they were presented.

Dr. Cohen noted that there was a tension between the domestic program and ITER and he added that the domestic program was providing a lot of the R&D support funded by the domestic program for ITER. He mentioned two instances of research being done at ORNL and with one of his colleagues for the ITER divertor which had some issues. He said that in the presentation they stated that R&D would be completed in 2012 so he asked was that so, in particular regarding the divertor. Dr. Glowienka responded no, he had been talking about U.S. scope. He went on to explain some of the circumstances and decisions regarding the divertor as discussed at the last council meeting in November of 2011. He advised that from that meeting the divertor would be tungsten but design would continue on the carbon divertor until such time as they had success from existing machines that would be using tungsten as its divertor. He said the design of the ITER divertor was still vaporware. He added the Japanese were still in charge of the divertor and had spent a lot of money on the carbon divertor and were currently unhappy with the Director General's decision to move to tungsten as the primary divertor. The current position was that no one had been assigned to cast the design in the tungsten divertor.

Dr. Hubbard noted that if there was not time on the second day of the meeting could FESAC members not be sent additional information on ITER after the meeting so they would be better informed. Dr. Synakowski said they should be able provide more information and he would think about the best vehicle for that.

Dr. Keane asked if he could clarify change control, if Director Motojima decided to change the performers for the CS himself or what was the process. Dr. Glowienka responded that he would be presented with a decision package, so 'a' or 'b' and then there would be quality assurance change control procedures that would have to be followed that would trickle down based on that decision. He confirmed that the ITER organization was in control of the design and they are the design authority and are the interface with the French regulator and it would have to be that way in order to get licensed.

BRIEFING ON INTERNATIONAL COLLABORATION IN FUSION ENERGY SCIENCES RESEARCH OPPORTUNITIES AND MODES DURING THE ITER ERA

Dr. Dale Meade, *Subcommittee Chair, President FIRE, LLC.*

- Noted that there were charges given by the Director of the SC in the July 28, 2011 meeting and two of the charges related to international collaboration in fusion energy sciences research and opportunities and modes in the ITER era.
- Reviewed charge #1: "What areas of research on new international facilities provide compelling scientific opportunities for U.S. researchers over the next 10-20 years? Look at opportunities in long-pulse, steady-state research in superconducting advanced tokamaks and stellarators; in steady-state plasma confinement and control science; and in plasma-wall interactions."
- Reviewed charge#2: "What research modes would best facilitate international research collaborations in plasma and fusion sciences? Consider modes already used by these communities as well as those used by other research communities that have significant international collaborations."
- Reviewed the panel members and thanked them for all their tireless work.
- Described the panel process which included: two in-person meetings in November and December of 2011; 28 conference call meetings; a presentation made at the University Fusion Association in November 2011; and included requests made to the fusion community for White Papers related to the FESAC Panel charge on international collaboration – 18 papers were received.
- Stated that at the beginning of the process they wanted to put 'compelling opportunities' in context before they were able to address the charge. Decided to put it into the context of the vision for the U.S. fusion program as articulated by Dr. Synakowski and the Office for Fusion Energy Sciences and that has ITER as the focus for the next 10-20 years.
- Described the vision for the U.S. Fusion Energy Sciences Program to be a leader in burning plasma science to obtain the maximum benefit from participation in the ITER research program. Added that it was also the goal of the FES program for the U.S. to assert itself in long-pulse, 3D magnetic confinement science and fusion materials science research within the next decade.
- Added that there was a growing interest in the extension of the burning plasma physics to include fusion technology experience gained from ITER and then bring that experience back to the U.S. and have it interface with a Fusion Nuclear Science Program that would be established. Stated that together all of them would enable a decision on a Fusion Nuclear Science Facility.
- Stated that one of the main elements of achieving these goals was international collaboration.
- Commented that while ITER was under construction the U.S FES program would need to make effective use of limited resources and to continue to explore critical issues at the frontiers. Added that a balanced program was needed that would exploit both the strength of the domestic research program and new capabilities that would become available overseas.
- Recommended that the selection of an international collaboration should be made after careful consideration to:

  - A national goal to advance critical fusion energy science issues and
  - The need to maintain and strengthen the U.S. domestic research infrastructure that supports the ITER mission and then would position the U.S. to benefit from ITER successes and then make an informed decision on the best approach to a design of a nuclear-size facility.
- Reviewed the criteria for selecting international collaboration opportunities:
  - Importance of scientific issue to be resolved
  - Significance and distinctiveness of U.S. contributions and potential for success
  - Positions the U.S. to obtain optimum benefit from ITER participation and builds foundation for potential future U.S. development path in fusion energy.
  - Strengthen, extend and regenerate the U.S. scientific workforce.
  - Resource requirements and impact.
- Reviewed the fusion research themes and main issues:
  - Creating predictable high-performance steady-state burning plasmas.
  - Taming the plasma material interface
  - Harnessing the power of fusion.
- Listed the scientific challenges for collaboration:
  - Extending high performance core regimes to long pulse.
  - Development and integration of long pulse plasma wall solutions.
  - Understanding the dynamics and stability of the burning plasma state.
- Commented on time scales required to address issues.
- Described gaps:
  - Challenge 1 – High Performance Plasma Regime for Long Pulse.
  - Challenge 2 – Integration of Long Pulse Plasma Wall Solutions – Plasma Core and PMI are strongly coupled.
  - Challenge 3 – Dynamics and Stability of the Burning Plasma State
- Discussed capabilities for addressing high-performance long pulse.
- Reviewed the major international magnetic fusion facilities and operating plans for the emerging Asian S/C tokamaks.
- Noted the operating plans for the large super conducting stellarators.
- Identified three compelling topics::
  - Topic 1 - Extending high performance regimes to “steady-state” – Discussed these areas: Transport, stability & current drive are interdependent; Solution must be compatible with plasma facing components; Noted that timescale is a key distinguishing feature of S/C facilities; Collaboration on “Steady-state” offers strong mutual benefit; and Principal Facilities for Steady-State Collaboration.
  - Topic 2 – Development and Integration of Long Pulse Plasma Wall Solutions – Discussed these areas: Research Program Goal and Science Challenges Identified; The Science Requires an Integrated Approach; International Collaboration Opportunities and discussing in particular JET-ITER, EAST, W7-X and LHD, K-STAR, and finally JT60-SA.

  - Topic 3 – Understanding the Dynamics and Stability of the Burning Plasma State – Discussed: Good Progress in Advancing Towards Burning Plasmas.
- Reviewed the opportunities in relation to Topic 3 as follows:
  - Opportunity 1 – Alpha Particle Confinement, Heating and Instabilities.
  - Opportunity 2 – Exploration and Optimization of ITER Operating Modes
- Discussed the modes of collaboration in relation to Charge 2 and noted they would:
  - Survey the present status and modes of collaboration in use in FES.
  - Examine the experience of other fields, notably HEP and astronomy.
  - Use their criteria to determine key considerations including workforce issues and positioning the FES program for ITER and beyond.
  - Make a number of recommendations to modes which best meet the criteria and means of implementing them.
- Reviewed the current modes of collaboration and noted:
  - There were case by case opportunities, not centrally coordinated.
  - Might be focused on science topics or hardware tasks.
  - Span a wide spectrum of scales and modes ranging from: Individual Scientific Exchanges; Group or Institutional Collaborations; National Teams; and International Teams.
- Provided comments on experience in high energy physics with regard to collaborations and noted four important elements:
  - Maintain centers of excellence in the U.S.
  - Establish a culture of remote participation.
  - Maintain the ability to station personnel overseas for extended periods.
  - Establish cohesive US-ATLAS and US-CMS projects and collaborations.
- Provided comments on experience in astronomy or space science with regard to collaborations with NASA (National Aeronautics and Space Administration) mentioned specifically.
- Commented on their findings with regard to collaborations and detailed some:
  - The US-HEP collaboration with LHC is an example of a successful collaboration on a complex project overseas and it was noted that a significant overseas presence was required to acquire positions of leadership and it has to be supported by strong capabilities or a large portion of the budget.
  - The formation of national and international research teams organized by scientific topic can be an effective structure.
  - The cost per researcher sited overseas is significantly higher.
- Outlined the challenges for attracting and retaining fusion scientists:
  - Noted the greatest strength of the U.S. fusion energy sciences program is its experienced scientific and engineering workforce.
  - Retaining and renewing the workforce is crucial.
  - Challenges of international collaborations include: extended overseas assignments and how it affects families; and effects on career development.
- Detailed their recommendation of developing a team approach that would allow for flexibility and the use of remote communication tools that would mitigate some of the challenges.

- Outlined the additional challenges for university programs and noted how extended assignments would reduce program visibility at the home institution and how overseas assignments challenged PhD. Graduate education programs. Recommended that the universities be included in the international collaboration programs and solicitations and having a linked on-campus research program.
- Detailed how effective collaboration with ITER should be organized:
  - Finalize details of U.S. and international ITER research organization.
  - Should include multi-institutional national teams with laboratory, university and industry researchers. Organized so the U.S. can lead experiments and publish results.
  - A suggestion that collaborations follow the established ITER model now used.
- Reviewed their recommendations:
  1. DOE should seek issue-based, goal-driven international collaborations that are aligned with national priorities and supported by task-based work where appropriate.
  2. Mutually beneficial international partnerships should be arranged which strengthen U.S. capabilities in fusion science.
  3. Portfolio of international collaborations should include a range of appropriately scaled and structured collaborations that provide opportunities for new participants on a regular basis.
  4. For large-scale collaborations, an integrated team with a flexible mix of full time, on-site researchers and shorter-term visitors should be employed, structured according to scientific roles with support flowing directly from DOE to relevant team member institutions wherever possible.
  5. The structure of these international collaborations should be viewed as an opportunity to develop U.S. fusion program collaboration modalities and prepare for effective participation in ITER.
- Outlined issues regarding the implementation of the recommendations:
  1. Solicitations should seek issue-based collaborations but it should be recognized in the selection and award process that it may be most effective to establish separate collaborations with an overseas facility utilizing a DOE-FES umbrella collaboration agreement.
  2. The solicitation and selection process should allow for a range of modalities, partnerships and opportunities to best utilize expertise in the U.S. fusion program and should be clearly defined on the national level with open calls to establish new international collaborations or to renew existing collaborations.
  3. The division and funding of collaborations should be structured according to scientific roles with support flowing directly from DOE to relevant team member institutions where possible.
  4. DOE-FES should establish a plan to assist collaborating institutions to navigate the complex intellectual property and export control issues and ensure safety of their personnel.
  5. Capabilities for effective remote collaboration from a number of locations should be provided and expanded as remote communication technology advances.
- Summarized some of the key points with regard to collaborations and Charge 2:

  - The creation of compelling opportunities at the leading edge of fusion research will provide researchers with motivation to participate.
  - The setting up of teams with a flexible mix of on-site presence, remote participation and shorter visits.
  - Allow all types of institutions to participate at different levels.
  - Maintain strong, closely-linked programs at U.S. institutions so expertise is transferred and retained.
- Outlined his concluding remarks:
  - The panel identified a number of compelling scientific opportunities using emerging capabilities overseas that could address key scientific issues, strengthen U.S. capabilities and position the U.S. to exploit ITER and move beyond it with a strong U.S. domestic fusion program.
  - The panel has identified and assessed modes of collaboration.
  - The U.S. needs to approach these opportunities realistically, proceed step by step with detailed discussions and assessments in regard to expectations and commitments.
  - An integrated national team approach for larger collaborations offers the potential for maximizing benefit to the U.S. and preparing the U.S. for participation in ITER.
  - A plan for international collaborations should be established and integrated into the overall strategic plan for the U.S. Fusion Energy Sciences program.

COMMITTEE DISCUSSION

Dr. Greenwald noted that he had taken the weekend to review the report and was impressed by the thoroughness and thoughtfulness and thanked Dr. Meade and the panel for the work they had done. He asked members with questions to focus on broader issues. He noted there were three things he appreciated. He stated that one was that it put the question of collaborations into a strategic context and he noted he also liked the well-articulated criteria. He thought a good recommendation was for a more systematic and coordinated approach and he thought that that would help alleviate some of the friction.

Dr. Callis referred to costs of sending researchers abroad and asked about one area of extra costs which was some facilities might require an ante to have a collaboration. He asked if he had discussed that and if he had an opinion on that. Dr. Meade responded no, he added that that might be a detail for a negotiation of a specific proposal. He added that Americans should not under-value their knowledge that they would bring to a receiving institution and gave an example of American expertise.

Dr. Cohen noted that the tone of the whole study (and indeed the composition of the committee) was from the point of view of experimentalists. There was no theory component, but surely theory goes hand-in-hand with experiment. Meade admitted the oversight [with some chagrin]. I made the suggestion of adding short comments in the introduction and summary making it clear that theory and theorists are understood to be included.

Dr. Cary Forest mentioned that costs regarding sending hardware overseas should also be included.

Dr. Farrokh Najmabadi reinforced the potential difficulties posed by Export Control regulations. He also referred to researchers going abroad for several years who then may want to return to the United States. He asked what would happen if there was only a small program, in that case, what would they come back to? Dr. Meade responded that when staff is reduced at a home institution it would certainly be a problem. He said if they were going to have successful collaboration programs then people at the home institutions would have to start taking that type of situation into account, including promotion cycles. He added that when proposals were initially drawn up for collaborations that they should also consider the scenarios of the return of the researchers.

Dr. Fonck commended the committee on the report and then referred to the question of grants and solicitations. He said when universities talk about solicitations they think three-year grants but when a team goes to an international facility they think of you as becoming part of the team and many are long-term commitments. He said in high energy physics do they do solicitations or block grants. Dr. Meade said it was his understanding that big groups use block grants although he said smaller groups might be different.

Dr. Fonck referred to the expensive nature of collaborations and noted that there was an amount set aside but he asked as he had noted three areas of emphasis was there any consideration given to priorities considering the limited funding. Dr. Meade responded no, they did not. He said that EAST was a good facility to address both on the plasma control side and on the PFC side. Dr. Meade said where he had made comments about being realistic and proceeding step by step, well that situation was an example of that process.

Dr. Leeper referred to the HEP model in which it is 25% overseas and 75% domestic and he said evidently they thought that that was sufficient to exert leadership in the program. He asked about what the costs for researchers would be abroad as opposed to the cost of researchers at home and added did they have a feel for what that multiplier would be. Dr. Meade said it varied and sometimes due to circumstances where researchers might come from universities with fixed budgets and then they would have to make special living arrangements for them.

Dr. Thomas commended the report and especially its discussion of university issues. He noted that since fusion does not have a long history of international collaboration, there could be effects on tenure; long term commitments will be needed.

Dr. Cohen noted that the report focused mainly on experiments and that theory is already a key part of many collaborations.

Dr. Rosner noted the report's statement that a key difference between fusion and High Energy Physics is that in fusion, the operation of the facility *is* the experiment.

Dr. Synakowski commended Dr. Meade and his committee for their work. He said that with regard to collaborations that there was often a mindset to find something that no one else is doing and regard

that as the opportunity but his personal view was to move fearlessly in areas that are of the most vibrant interest. He noted that one reason was that there had been some important decisions already made with regard to a facility's capabilities and second that would be where the intellectual energy would be. He outlined how he would approach the process bearing those points in mind.

Dr. Greenwald made a motion that they accept this report as is with some minor changes and forward it to Dr. Brinkman. A vote was taken and all were in favor and the motion passed.

ADJOURNMENT

The Fusion Energy Sciences Advisory Committee adjourned for the day at 5:00 p.m. The committee will reconvene tomorrow, Wednesday, February 29, 2012 at 8:30 a.m.

WEDNESDAY, FEBRUARY 29, 2012

PRESENT STATE AND FUTURE PLAN OF MCF RESEARCH IN CHINA

Professor Jiangang Li, *Director, Institute of Plasma Physics, Chinese Academy of Sciences*

- Advised he would be discussing what is currently happening in China and their plans for the future.
- Two major facilities:
  - Discussed the HL-2A Tokamak, the auxiliary heating and fueling system.
  - Discussed EAST Tokamak and its physical engineering capability; main experimental results; and the research plan in the next 2-5 years. Stated they got first plasma in 2006 and two American colleagues were present, one from Princeton University.
- Reviewed slides with some of the following topics:
  - Key elements in-vessel.
  - Main diagnostics
  - Li Wall Conditioning (PPPL)
  - Fueling Effect of Gas Puff Locations
  - Effect of Ar:D2 Mixture Gas Injection into upper and lower outer divertors
  - Toroidal Flow at Edge (PPPL)
  - Long Pulse Discharges (With GA)
  - First H mode by Li coating either by oven or by lithium power injection
  - 6.5s H-mode by RF+LH (MIT, PPPL)
  - Lithized wall on HT-7
  - EAST 2012 Capabilities
  - EAST 5-Year Plan
  - Discussed Efforts Made on EAST ATSSO. Discussed scheduling.
  - PFC Strategy for ATSSO. Within two years changing totally to tungsten.
  - CN-MCF Near Term Plan (2020) with details on both ITER construction and the enhancement of the domestic MCF
- Reviewed the ITER-CN activities:
  - ITER-Conductor: Start delivery – with discussion of the schedule progress
  - Feeders: Start Construction
  - ITER Power Supply: Start Construction – details on the ITER power supply Package in CN
  - Shielding Blanket-Ready for sign PA
- Confirmed that the Chinese government was making a strong commitment to ITER and would be providing their 25 components on time.
- Noted that the government provides cash and in-kind and 11/12 Pas have been signed.
- Stated that the Chinese government was encouraging industry to get involved early providing seed money.
- Stated that DA-Vendors were working closely for QA, QC and PS.

- Added that all PAs were on schedule.
- Reviewed the future plan of CN-MCF program:
  - Strategy planning has begun for the next step with the creation of a national team.
  - Discussed Efforts Made in Education – reviewed both the present status and future targets. Four big ministries have come together to attempt to produce 2000 fusion scientists and engineers by 2020.
  - Efforts Made – R&D (MOST) – reviewed the present state and yearly from 2009, 2010 and 2011.
  - Next-step device design: Option 1 – reviewed types of machines and details on component testing
  - Possible Plan and Schedule
- Noted the importance of international cooperation and particularly cooperation with the U.S. as their highest priority.
- Explained that each year they have three to four international cooperation projects.
- Provided details of several colleagues working in Texas, from DIII-D & EAST on ITER.
- Noted that the Chinese think that fusion is one of the best solutions in the future for their country and fusion scientists are well respected. Added that it had the support of the top leaders all the way up to the president and the general public who visit the facilities.
- Reviewed opportunities and mechanisms for collaboration. Added that the opportunities consisted of:
  - EAST, added a third shift to collaborate with Princeton remotely in real time.
  - ITER – sharing resources from both countries and joint teams
  - Joint teams and joint facilities
  - Education
- Noted the mechanisms as:
  - Standard operation fund
  - 5-Year Plan with assessments and workshops
  - Based on present frame – administration, physics and engineering.
- Commented on the fusion budget and expressed the view that it was worth a substantial budget allocation and the importance of retaining experienced and talented staff.
- Summarized some of the main points:
  - EAST began important experiments with help from international cooperators especially U.S. EAST (ASIPP) which he noted was accessible to their U.S. colleagues.
  - By collaborating on the ITER project China will work closely with six countries for a successful operation.
  - China considered fusion one of the best choices of future energy.
  - An emphasis was made about the importance of this field to their country.

COMMITTEE DISCUSSION

Dr. Synakowski thanked Dr. Li for his uplifting presentation and for coming to the United States. He acknowledged the many suggestions made and noted that although he was not in a position to discuss them immediately he noted the things being offered with interest. He added that when he was a graduate student at Texas he had the pleasure of meeting one of the Chinese researchers mentioned and he said that he was struck by the feelings of genuineness and authenticity with regard to scientific exchange that was characteristic in Texas and he believed was also consistent throughout the program.

He asked him to comment on one aspect of the potential for increased engagement with respect to the work life of students, i.e. how U.S. students might participate. He noted that Dr. Li had commented on the importance of ITER in general and it adhering to its schedule for the Chinese program. He asked if he could comment on risks associated with ITER struggling. Dr. Li thanked him for his kind words, and responded with regard to students that they could provide good accommodation and cover all the costs when students would stay in their institute. He added that they had increased their budget for education by a large increment and that teleconferencing and other internet technology made things easier. Dr. Li addressed the question about the ITER schedule and stated that as for the technology he did not see as a problem but the budget was causing difficulty. He said that Europe, a major contributor was problematic. He added that with China there was no problem with the budget. He thought that each country, including China, had to stay on schedule to maintain its credibility.

Dr. Meade thanked him for an inspirational presentation. He said the U.S. admired what they had been able to accomplish including gaining the confidence of the government that fusion is an energy source for the future. He asked about the next-step process. He asked when they would start design and construction activities. Dr. Li stated that the designing, R&D etc. should be finished within three years. He noted that in China they have five-year plans and they are updated regularly. He said that they hoped they could start in the 2016 funding period. He added they were not ready yet and needed US help. Dr. Meade asked about the technology and testing going on at EAST with regard to high temperature plasma facing compounds. Dr. Li responded that three years ago they began R&D for the next upgrade for the PFC and he went on to detail their approach and discuss their schedule.

Dr. Hubbard said that the contrast with the US plan, or lack of a plan was striking, and that she was impressed with Chinese facilities and the opportunity for collaboration. She asked for opinions on a long term collaboration with facilities in the US and sharing of results. Dr. Li agreed this was valuable, and said they did have these collaborations with MIT, and were talking about how to get around the difficulties of dealing with data over these long distances

Dr. Chris Keane asked if Dr. Li could comment on the hybrids which formed a key part of the strategy, and secondly provide an update on inertial fusion. Dr. Li said that fission was an unavoidable choice for China because of the power needs of China and the difficulty with spent fuel. The initial directive is to think first about spent fuel, and this made their job very hard, and they haven't figured this out. The other solution was to use Thorium, and this wouldn't be as difficult, and the Thorium is more abundant

than Uranium and would not require reprocessing. The common idea is the full use of a neutron source in future for China, and perhaps the blanket developed for fusion could be tested in older machines and tested.

Dr. Cohen thanked him for a great presentation and mentioning the fusion simulation program. He noted that due to lack of resources this program had been paused but it still represented terrific leverage for anyone in the fusion area. He asked him to expand on his thoughts about the project. Dr. Li noted simulation was what they requested and added that in the Chinese domestic program, he wished that they could reserve 10% of the budget for theory and simulation which he considered important in conjunction with the theory. He gave a personal anecdote as to how he had experienced exactly how cost effective this could be, and called for continued help from the US on simulation

MATERIALS SCIENCE & TECHNOLOGY RESEARCH OPPORTUNITIES NOW AND IN THE ITER ERA: A FOCUSED VISION ON COMPELLING FUSION NUCLEAR SCIENCE CHALLENGES

Dr. Steven Zinkle, *Subcommittee Chair, Oak Ridge National Laboratory*

- Thanked all the members of his committee who had all worked hard to put the report together for the consideration of FESAC.
- Stated the subcommittee was broken into three groups: Materials Degradation; Plasma-Materials Interaction; and Harnessing Fusion Power.
- Reviewed the outline they had followed which included:
  - The Approach to Address the Charge
  - Science Grand Challenges – including the three major themes: Harnessing Fusion Power; Conquering the Degradation of Materials and Structures; and Taming the Plasma-Materials Interface.
  - Findings and R&D Options including: The Role of Technology Readiness Levels as a tool to focus R&D; and Evaluation of Roles of Key Facilities.
  - Recommendations and Evaluation of Compelling Research Opportunities
  - Summary Response to the Charge
- Outlined the actual charge given to the subcommittee.
- Noted that they set up a website and sent out a series of announcements to the community to solicit input for the panel and advised that they received 21 white papers and 5 sets of email correspondence that the panel considered as part of their deliberations.
- Stated that they had three invited talks that were part of their 15 weekly teleconference activities and two face-to-face meetings on the east and west coasts.
- Described and identified the Grand Science Challenges provided to the Scientific Foundation for the Evaluation and an example of Harness Fusion Energy is: H1- Develop a predictive capability for the highly non-linear thermo-fluid physics and the transport of tritium and corrosion products in tritium breeding and power extraction systems with the questions:

  - Can tritium be extracted from hot PbLi with the required high efficiency to limit tritium permeation below an acceptable level?
  - Can we simulate the 3-D MHD effects in flowing liquid breeders to the degree necessary to fully predict the temperature, temperature gradients and stress states of blanket components and materials?
- Two slides illustrated: Tritium Science & Technology for Fusion Reactor and MHD Forces in flowing liquid metal coolants in MFE blankets can exceed normal viscous and inertial forces by >5 orders of magnitude.
- Described and identified another Grand Science Challenge and gave examples of: Conquering Degradation to Materials and Structures: D1 – Understand and devise mitigation strategies for deleterious microstructural evolution and property changes that occurs to materials exposed to high fusion-neutron fluence (dpa and H, He transmutations).
- Described example D3 – Comprehend and control tritium permeation, trapping, and retention in neutron radiation-damaged materials. Noted the question were materials development strategies for fusion neutron radiation resistance incompatible with minimizing tritium trapping?
- Provided the third example D4 – Understand the fundamental mechanisms controlling chemical compatibility of materials exposed to coolants and/or breeders in strong temperature and electro-magnetic fields. How do MHD and ionization effects impact corrosion?
- Illustrated and reviewed examples for conquering degradation to materials and structures and materials science strategies to improve radiation resistance which may lead to enhanced tritium retention.
- Described and identified another Grand Science Challenge and gave examples of: Taming the Plasma-Materials Interface: P1 – Understand and mitigate synergistic damage from intense fusion neutron and plasma exposure. How does the coupling of intense heat flux, high temperature, and associated thermal gradients provide failure modes for plasma facing components?
- Described example P2: Understand, predict and manage the material erosion and migration that will occur in the month-to-year-long plasma durations required in FNSF/DEMO devices, due to plasma-material interactions and scrape-off layer plasma processes. Can the boundary plasma and plasma-material interface be sufficiently manipulated to ensure that year-long erosion does not exceed the material thickness – 5-10 mm anywhere in the device?

- Provided slides showing examples of multi-scale science challenges for plasma-material interactions. Outlined the importance of temperature; Temperature and PMI are coupled. Discussed importance of Tungsten “fuzz.”
- Commented that they moved to the next step and stated with that set of Grand Challenges they questioned what would the range of R&D options be to address some of the challenging options so they could move forward.
- Noted as a basis there was much discussion on technology readiness levels as a quantitative tool to assist them in mapping their current and future directions and in looking at options that would get them from a. to b.

- Stated that they were using a 1-9 scale used by NASA and advanced R&D organizations.
- Noted that using the Technology Readiness Level (TRL) scale most fusion nuclear science is at a relatively immature TRL-3 (concept exploration stage) and the panel concluded optimal progress toward higher TRLs (proof of principle 4-6) is best achieved by focusing on front-runner candidates. Stated that facility capabilities to address knowledge gaps were examined for a broad range of scientific phenomena and a series of charts were constructed to quantify the contribution of different facilities to resolving knowledge gaps.
- Discussed readiness levels identifying R&D gaps between the present status and a level of achievement and showed how they identify which steps are needed next. Explained the TRL scale was used again.
- Reviewed and explained how TRLs can be applied to components.
- Described the contribution of major facilities to PMI science and technology issues and commented on the influence that ITER was having on the TRL scale, i.e. increasing the level.
- Emphasized that the report represented the contributions from 14 members on their panel and they would welcome comments from the broader community.

- Reviewed the contribution of major facilities to PFC development and he mentioned the TRLs of the different areas.
- Described the contribution of major facilities to:
  - Diagnostics science and technology issues.
  - Plasma heating science and technology issues and discussed the levels of the TRLs.
  - Materials degradation science and technology issues.
  - DCLL chamber blanket science and technology issues.
  - Tritium science and technology issues.
- Reviewed a slide with an example of PMI-PFC facilities options assessment.
- Discussed the panel findings regarding R&D options:
  - Time to focus: Research to explore the scientific proof of principle for fusion energy (TRL>3) is the most expediently accomplished by focusing research activities on the most technologically advanced option.
  - Time to make selective reinvestments: Most existing U.S. fusion technology test stands are no longer unique or world-leading. There are numerous compelling opportunities for high-impact fusion research which may be achievable by making modifications to existing facilities and/or moderate investment in new medium-scale facilities.
- Discussed the panel findings regarding R&D options and more specifically plasma-material interactions findings:
  - P1. Power handing on the first wall, divertor, and special plasma facing components is challenging in steady state and is severely aggravated by non-steady loading – Efforts to mitigate transient and off-normal loads are critical requiring compromises between loading conditions, plasma operating modes, material properties optimization, design solutions and components lifetimes.

  - P2. Materials suitable for plasma facing components (PFCs) are limited and their performance in the fusion environment is highly uncertain. Established material and design candidates will require significant efforts in experimentation and multi-scale simulation and the coupling of plasma science, materials science and advanced engineering and manufacturing technology.
- Described some examples of plasma-material interactions.
- Discussed additional panel findings regarding R&D options and more particularly plasma-material interactions findings.
  - P3. Observing behavior at the plasma material interface during integrated month-long plasma operation requires capabilities beyond present day and planned facilities. Predicting the long-term system behavior in light of this response requires some combination of non-nuclear month-long plasma PFC/PMI linear and confinement facilities and an extensive non-nuclear (or DD) phase of FNSF in order to alleviate risk to the nuclear (DT) phase for the FNSF.
  - P4. Developing measurement systems and the launching structures for plasma heating, that can survive the fusion environment is a significant challenge. – A significant effort is required to establish viable materials, configurations, operating modes, and overall feasibility in the combined plasma and nuclear loading conditions expected in a FNSF.
- Discussed panel findings regarding R&D options and more particularly degradation of materials and structures findings:
  - D1. The lack of an intense fusion relevant neutron source for conducting accelerated single-variable experiments is the largest obstacle to achieving a rigorous scientific understanding and developing effective strategies for mitigating neutron-induced material degradation.
  - D3. Knowledge of the processes controlling tritium permeation and trapping in advanced nanostructured alloys designed to manage high levels of helium is inadequate to ensure safe operation of next-step plasma devices.
  - D4. Current understanding of the thermo-mechanical behavior and chemical compatibility of structural materials in the fusion environment is insufficient to enable successful design and construction of blankets for next-step plasma devices.
  - D5. Disruptive advances in fabrication and joining technologies may offer new routes to high-performance materials with properties that enable construction of fusion power systems that fulfill safety, economic and environmental attractiveness goals.
  - D6. The performance and economics of Magnetic Fusion Energy is significantly influenced by magnet technology.
- Discussed panel findings regarding R&D options and more particularly harnessing fusion power findings:
  - H1, H2. The ultimate attractiveness of a fusion system depends on the performance of power extraction and tritium breeding systems that surround the plasma. Also at present these systems are at a low TRL with high uncertainty as to the performance of envisioned solutions and material systems and efforts to improve current knowledge are hampered due to a lack of resources and test facilities.

  - H3. The U.S. has developed a potentially attractive family of first wall/blanket concepts and is based on the use of PbLi as a breeder/coolant, separate gas cooling of reduced activation ferritic steel first wall and structure and the use of thermal/electrical insulating inserts based on silicon carbide.
  - H4. Public acceptance and safety of fusion energy is strongly dependent upon the ability to reliably control the chemistry and permeation of tritium. Compared to fission reactors, fusion requires five orders of magnitude better control of tritium losses per unit of production; ITER represents a large step forward in the handling of DEMO scale tritium flow rate but ITER tritium systems will not be available to serve as test facilities to develop improvements still needed in processing time and system availability; and the ITER device does not address removal and processing of tritium from candidate breeder blanket systems.
  - H5. A fully integrated and coherent U.S. strategy to develop and utilize non-nuclear test facilities, irradiation facilities, and fusion devices to understand the engineering feasibility for in-vessel materials and components is needed.
- Reviewed the panel's recommendations and noted that it was an appropriate time to focus on more complex principle studies and there should be focus on R&D on front-runner concepts and moderate facility investments should be considered. Outlined the key mission of the next step device beyond ITER.
- Reviewed the panel's recommendations with regard to:
  - plasma-material interactions for sections P1, 2, 3 and 4.
  - material degradation for sections D1, 2, 3 and 4.
  - harnessing fusion power for sections H1, 2, 3 and 4.
- Commented on a panel statement on the role of computational modeling:
  - Viewed as an essential, integral component of fusion nuclear science R&D
  - Experimental research without robust modeling is sub-optimal, computational research in isolation as a proxy to experiment is not recommended.
- Reviewed the panel's conclusions as follows:
  - Focusing on breeding blanket and T2 transport/recovery options to front-runner candidates is recommended to accelerate the development of fusion energy.
  - Utilization of a systems approach is important for prioritizing scope and schedule of R& D activities.
  - Considering the large gap in technology readiness between what will be obtained from ITER and medium-scale fusion facilities, and FNSF would have a key role here.

COMMITTEE DISCUSSION

Dr. Greenwald noted that he thought the presentation was excellent, comprehensive and well organized. He said that he thought it would be a resource as well as a planning tool for the SC.

Dr. Synakowski thanked Dr. Zinkle and said the efforts of the panel were of a high quality. He asked about computation and asked Dr. Zinkle to speak about the last couple of decades of development of computational capability. He asked how the changes in computing would change the path of development. Dr. Zinkle responded that if the charts had been made 10-15 years ago they probably would have had many more facilities or perhaps higher-risk types of facilities. He noted that they had built in an expectation of a strong modeling component, and this assisted both with the science and the regulatory hurdles. As compared to fission, they could be a lot more efficient in terms of the number of demos required.

Dr. Keane asked what the vision was for the use of the codes, was this one of many tools or a key integrating strand over time, a key unifying capability. Dr. Zinkle underscored yes, having truly predictive unifying capability was the ultimate goal, and this would make building demo easy. If a model wasn't there to fill in the gaps, there would be too much risk.

Dr. Rosner noted that in talking about computing that the report was silent on the challenges that modeling and simulation face in dealing with problems that were discussed. He asked why that area was missing from the report Dr. Zinkle responded that it may have been an issue of time management and said they may not have had a specific enough focus on that important question.

Dr. Ji noted it was a very comprehensive study which would be useful for a long time. He asked about the niche for the United States to make a contribution within the whole picture for fusion. Dr. Zinkle responded that the parts where they had the recommendations were intended to be specifically areas that would be prioritized. They applied the TRL levels to quantify the inquiry and then asked if there was an opportunity for the U.S. to be among the world-leading countries for that area. He added he recommendations focused on the areas where the U.S. could be at or among the world leaders. Dr Zinkle said they didn't describe the international landscape in terms of what countries were doing what in terms of world leading activities in the way that Dr. Ji was indicating, but they did identify the opportunities available.

Dr. Hubbard referenced study of structural materials at high temperature, and asked more specifically what temperature ranges were required. Dr. Zinkle indicated that mobilities had exponential dependencies with temperature. He detailed the Tungsten and Lithium temperature ranges and noted the required temperature was above 500 C.

Dr. Uckan asked if he could comment on the systems analysis approach. Dr. Zinkle responded that they didn't want different elements of the program to make an exquisite mousetrap that would be incompatible with the broader fusion energy system and he elaborated with an example.

Dr. Meade asked if the recommendations took into account contributions expected from international programs and progress made in other parts of the world. Dr. Zinkle responded that yes it did take those considerations into effect. He said the U.S. was one of the world leaders although their budget was modest compared to some of Europe and Asia. He noted that the U.S. was able to take advantage of its developed facilities which advanced its knowledge.

Dr. Greenwald proposed a motion that they accept the report and forward it to Dr. Brinkman. A vote was taken and all were in favor and the motion passed.

BREAK

The Fusion Energy Sciences Advisory Committee recessed for a 10 minute break.

PUBLIC COMMENTS

Dr. Greenwald noted that six people had signed up for public comment and they would receive five minutes each.

Earl Marmar, MIT Plasma Science and Fusion Center

We are at a crossroads in the fusion program. The FES budget plan for FY2013 is a complete disaster. Pressure to increase funding for ITER construction, combined with a declining total budget, puts us firmly on the path to dismantling the domestic program, starting with the proposed shutdown of Alcator C-Mod, and accompanied by significant cuts to most other parts of the program.

Just a few among so many key C-Mod contributions: the discovery and elucidation of the physics of intrinsic rotation; understanding plasma-wall interactions with solid molybdenum and tungsten plasma-facing components with intense Radio Frequency heating; physics of Lower Hybrid Current Drive at reactor magnetic fields and plasma densities; intermittency in cross-field scrape-off-layer particle transport; and the first detailed experimental comparisons of particle transport with non-linear gyrokinetic modeling. We are constantly responding to urgent ITER research requests; two recent ones are tests of disruption mitigation using multiple toroidal massive gas puff locations, and the first real field tests of the proposed ITER grounding system.

C-Mod is the only world-class program to study interactions between the hot plasma and the surrounding walls under plasma conditions and power densities required for ITER and for proposed fusion reactors (Power per unit area = 1 MW/m^2). C-Mod is developing a promising new plasma regime, the I-mode, aimed at high-performance, steady-state plasmas without transient heat flux to the first wall. This is a possible solution to perhaps the most critical physics issue for ITER and reactors, having huge implications for the success and cost of ITER and for the ultimate development of fusion as an energy source. C-Mod is developing the science and innovation in technology for Radio-Frequency heating and current drive systems operating at the ITER magnetic field, plasma density and RF frequencies, all prototypical of a fusion reactor. C-Mod is about to implement the first hot tungsten divertor, recognized by both FESAC panels reporting at this meeting as a critical step on the path to the development of fusion energy. The Plasma Facing Component and RF research that would be done on C-Mod are required for design of a Fusion Nuclear Science Facility, a stated aim of FES.

In the last 2 years, more than 200 scientists and students from all over the US and around the world have participated in C-Mod experiments and utilized C-Mod data in their research. Abandoning Alcator would mean the loss of decades of accumulated expertise, and of an experimental facility worth approximately $200M.

Alcator is the largest single U.S. training facility for students in the field, with intimate ties to the academic departments at MIT, particularly Physics and Nuclear Science and Engineering; at any time, the lab is home to approximately thirty graduate students, who are integral to our research planning and operation, and 15-20 undergraduates who also participate in research projects each year. Shutting down this laboratory would result in the loss of future generations of scientists - tomorrow's leaders in energy research.

Fusion Nuclear Science, now a stated priority of the US FES efforts, exists at a unique "intersection" of nuclear science & engineering, material science and plasma confinement physics. It will be necessary to develop a new generation of personnel conversant in all three of these areas, and represents a very large re-orientation in US fusion education. This workforce development is NOT OPTIONAL. We are faced with multiple realities: the roughly 2 decade timelines of ITER and FNSF, the aging demographics of the fusion community, and a particular dearth of US expertise in Fusion Nuclear Science. MIT is not the only University with a Nuclear Engineering Department working in fusion, and C-Mod is not the only US confinement device with ties to Nuclear Engineering, but the synergy at MIT is a powerful and precious resource. The strong C-Mod emphasis on boundary and material science, with high-Z metals, results in a majority of our NSE students working at the Fusion Nuclear Science "intersection".

The abrupt recommendation to close the C-Mod program comes in the absence of peer review, community input, or a FESAC plan. In the FY2012 funding legislation, Congress has mandated that DOE provide a ten year plan for the fusion program, including how ITER will be funded without destruction of the domestic program. The community has seen nothing of this plan, and to my knowledge, has so far been asked for no meaningful input for its development. The actions taken in the FY13 budget proposal indicate to me that there is currently no rational plan; if the proposals are implemented, we will be well along on the path of destroying the domestic program to pay for ITER construction.

I recommend the following. FESAC should immediately be given a charge by the Office of Science to examine options and plans for the next 10 years leading up to ITER operation. This charge should not prejudge options. The schedule for the FESAC study should be consistent with having input in a timely fashion, before the mandated report to Congress is due, and before irrevocable decisions are made concerning FY14 funding proposals. While this study is ongoing, there should be a moratorium on irreversible decisions concerning facility shutdown.

Professor Miklos Porkolab, MIT

- Stated he was a professor in the Physics Department at MIT.

- Made some additional points on the tokamak program and elaborated on many technical points.
- Stated that programs that were being shut down would affect students and technical staff.
- Noted that cutting the base budget would make it beyond the point of maintaining a healthy and competitive workforce, and would do permanent damage to the program.

Dr. Glen A. Wurden, LANL Fusion Energy Sciences Program Manager

Ok, what can I add to that? Let me start by saying it is all about the plan. We do not have a viable plan to fund our proposed programs...that includes ITER...and especially it is driven by ITER's (funding needs). We have seen this coming for years, this is not a new thing. In a sense this (the FY13 budget) is exactly a disruption, without a precursor.....because when you call up the provost at 8:30AM on the same morning, and tell them at their university that their main project is going to be shut down. ....this is exactly a disruption. And in fact, there is no mitigation system for this disruption. And we don't have a way out of it, without other consequences. So, ...a...people talk about ITER being the "capstone of the American fusion program". I do not want ITER to become the "tombstone" of the American fusion program. And if we go down this pathway, where we can look at the out-year numbers that we need for ITER, the obvious conclusion is that there is another machine down the road (DIII-D) that will have the same problem that C-Mod is now experiencing.

I've been through the disruption of a program, back when alternates were killed in Los Alamos in 1990. We lost our machine, ...actually multiple machines, our groups and our entire division. It took ten years to recover from that, and even then we probably haven't recovered. We can't do this to our human capital. It is our human teams that are the most important thing here. I don't care about the $200M investment in hardware (at C-Mod)...that is not the issue. Because you know, every person has a career plan, every person has an education plan, they have an investment plan, and they even have a retirement plan if they are lucky. (In the same way) we should think about our programs too. I mean, every machine will turn off. I have no doubt. I have worked on many machines. The will turn off (at some point). But you need to do it in a way where it is not a disruption. You need to do it in a way that you have a plan. And whether it is a 5-year plan, or a 10-year plan mandated by our friends in Congress.....and we must deliver that plan.....if we don't deliver that plan there are even bigger consequences to our program.

But it is actually a good thing to have a plan. It is not a bad thing. You can see where you are going (with a plan). And if you see where you are going, and you have talked about it with the community....then you can, you can tell your students what the future is. When there are disruptions, you have no future. And we can't let our premier tokamak team in this country, with a premier education mission, disappear overnight. And even when they are told that their research money is ok for next year at some reduced level .....what about FY14? If their number is zero, how can they plan? They can't plan. By the way, my budget at Los Alamos is down 48%, or even more, from $5.3M in FY11 to $1.88M in this god-awful plan for FY13. We can not go down this course - by the way, a vision without a plan, is a nightmare.

Dr. Stephen O. Dean, President, Fusion Power Associates

First, let me say that I endorse the recommendation just made by Dr. Earl Marmar of MIT that no irrevocable decisions be made relative to reductions in the fusion program, as proposed in the President's FY 2013 budget submission to Congress, until a vetting of such reductions occurs within the U.S. fusion community. This should be done by FESAC, or otherwise, to seek community consensus relative to priorities identified previously by FESAC.

Much of the discussion has been focused on the proposed termination of the Alcator C-Mod program at MIT. The proposed termination is of serious concern, since that program has made, and is making, important contributions to our understanding of tokamak physics and, furthermore, is important to the training of the next generation of fusion scientists. Termination of Alcator C-Mod would mean a "double whammy" for the MIT fusion program, since DOE terminated the other significant experimental facility there last year, the Levitated Dipole Experiment (LDX). Without these two facilities, MIT will lack the facilities to continue providing experience to students doing experimental fusion research.

But the problem with the proposed reductions is much broader and more serious that just the role and future of the MIT program. Reductions in other areas, such as High Energy Density Laboratory Plasmas (HEDLP), theory, and systems studies will result not only in a loss of valuable talent and expertise throughout the U.S. fusion program, but will also mean that research results these people and facilities would otherwise provide in the coming years will not obtained. On that subject, I would note that the practice of requiring many fusion programs to compete for renewal periodically via open solicitations is not working well, especially if those programs are imbedded in larger institutions having upper layers of management. One example is that of the heavy ion fusion effort at the Lawrence Berkeley National Laboratory. Using "stimulus" funding, LBNL has finally been able to complete a new facility with which to study warm dense matter physics. However, they were notified that they had to compete against other proposals, not yet received by DOE, after DOE advertises broadly for proposals in HEDLP. These solicitations often get delayed for months beyond the date expected. Upper management at LBNL, understandably, has to make plans to possibly layoff many personnel in case there is a funding lapse or no funding at all in FY2013. So, unintended consequences can result from these procedures.

The reductions proposed in the domestic fusion program were deemed necessary by DOE in order to increase funding for the U.S. contribution to ITER from $105 million in FY 2012 to $150 million in FY 2013. As several FESAC members noted yesterday, we have not been told by DOE how much is really needed in FY 2013, how much will be needed in future years to meet the November 2019 ITER first plasma target date, or where these funds will come from. We were told yesterday that Japan plans to spend $250 million in 2013 to maintain their ITER commitment. Since the U.S. has the same one-ninth share of ITER commitments, it would seem logical that the U.S. may really have needed roughly that

amount in order to meet the ITER schedule. Thus, even with $150 million in FY 2013, the U.S. may not have the funds it really needs for ITER in FY 2013.

In July 2002, approximately 280 fusion scientists assembled in Snowmass, Colorado, to assess our options for a burning plasma experiment. Three were identified: Ignitor (a short pulse, copper high field magnet tokamak), FIRE (an intermediate-length pulse, superconducting tokamak), and ITER (a long pulse, superconducting tokamak). In August 2002, a special FESAC panel met in Austin, Texas, and identified ITER as the preferred choice, but under certain assumptions. At the time, ITER was estimated to cost about $5 billion and the U.S. share was estimated to be ten percent of that, or $500 million. I was a member of that panel. I believe the panel would have chosen the FIRE concept except for the fact that we were being offered a bargain: for $500 million we could have a much more capable facility, since we only would have to pay ten percent of the cost. The full FESAC adopted the panel's recommendations in September but emphasized that the U.S. ITER contribution had to be provided on top to the existing domestic (or base) fusion program. The FY 2003 OFES budget at that time was $241 M. The U.S. was not an ITER participant at that time, but rejoined about one year later.

In spite of the FESAC proviso, in FY 2004 and 2005, the President started requesting funds for ITER by reducing the domestic fusion budget, but the Congress largely (but not completely) rebuffed these efforts. The OFES fusion technology efforts were largely terminated to accommodate these conflicts. FESAC, on its own initiative, wrote a strong letter to Office of Science director Ray Orbach saying, "Devastating cuts in certain program elements are alarming; this note expresses our most serious concerns."

The President's request for FY 2006 contained a $17 million increase for OFES, but also a proposed $51 million increase for ITER. Congress refused to go along with this, cutting the ITER request by $30 million and directing it into the domestic program, stating, "As in previous years, the conferees direct the Department to fund the U.S. share of ITER in fiscal 2007 through additional resources rather than through reductions to domestic fusion research or to other Office of Science programs." For FY 2007, the President, for the first time, requested an increase in the total OFES budget that was approximately equal to the proposed increase for ITER (there was a $4 million decrease proposed for the domestic program). The Congress eventually went along with this budget through an omnibus appropriation that did not pass until 5 months into the fiscal year.

In sending the FY 2007 request to Congress, the President re-estimated the cost of the U.S. contribution to be $1.122 billion, as follows:

FY 2006	19.3 M
FY 2007	60.0 M
FY 2008	160,0 M
FY 2009	214.5 M
FY 2010	210.0 M

FY 2011	181.3 M
FY 2012	130.0 M
FY 2013	116.9 M
FY 2014	30.0 M
Total	1122.0 M

This is the only out-year projection ever made publicly available by DOE. However, in 2008, DOE stated that the total required had been increased to a "range" of $1.4 to $2.2 billion. The total appropriated for ITER and the domestic program (third column), starting with FY 2006, is as follows:

FY 2006	25.0 M	263 M
FY 2007	60.0 M	259 M
FY 2008	10.7 M	276 M
FY 2009	124.0 M	282 M
FY 2010	135.0 M	291 M
FY 2011	80.0 M	287 M
FY 2012	105.0 M	296 M
FY 2013	150.0 M	248 M (requested)

Thus, if US ITER receives the requested $150 M in FY 2013, it will have spent $690 M. If ITER is to operate in November 2019, essentially all needed construction funds must be spent by end of FY 2018. Since the latest (informal) estimate of the total US contribution to ITER has risen reportedly to $2.6 billion, the President will need to request, and the Congress will need to appropriate, an additional nearly $2 billion over the five fiscal years 2014-2018, or an average of nearly $400 million per year. Clearly this cannot come by continuing to decrease the US domestic fusion program. Something needs to be done.

On January 30, 2003, the U.S. decided to rejoin the ITER project. The decision was made at the highest level of the U.S. government, an announcement from President George W. Bush stating, "I am please to announce that the United States will join ITER, an ambitious international research project to harness the promise of fusion energy."

To ensure the successful completion of the ITER project, without destroying the U.S. domestic program, requires that we regain the high level U.S. government support for the project that seems to have been lost in the FY 2013 budget submission. the ITER project must be again recognized as a presidential commitment that cannot be funded by reducing the U.S. domestic fusion effort.

There has been much talk at this meeting of making a new plan for fusion; in fact, Congress has requested it. Some feel that preparing such a plan could be the vehicle for getting the issues of ITER and domestic fusion funding resolved. I doubt that.

Next summer, I will have been working in fusion for half a century. I have seen and/or been involved in preparing many fusion plans over this time period. While all have been exemplary in their logic and

content, they have all essentially been ignored after completion. Furthermore, plans take time to prepare well; and we are in a crisis situation with respect to the funding of the US domestic fusion program. I do not sense that the DOE wants to proceed on an urgent basis with a new planning activity. So I suggest that the fusion community should self-organize to do the required vetting of the FY 2013 budget proposals and not depend on, or wait, for a DOE-initiated planning activity to begin.

Yesterday, Dr. Brinkman told us that when he arrived at DOE Secretary Chu told him, with regard to ITER, he needed to "fix it or kill it." I think now is the time Dr. Brinkman should respond to the Secretary, "I have fixed it. Now help me pay for it."

The U.S. domestic fusion program does not have sufficient funds to pay for the U.S. contribution to ITER construction. SC

Richard Buttery, General Atomics

- Noted his concern of what the budget would do in impacting their ability to benefit from ITER physics in terms of what could be learned from ITER and U.S. leadership.
- Stated that an example was the transport and performance area and noted that he would expect to encounter new processes in burning plasma's new physics regimes, they would need to be well equipped intellectually to understand these lessons.
- Stated that ITER should be funded as well as funding that should ensure that the U.S. can make a proper contribution to ITER.

Arnold Kritz, Professor of Physics, Lehigh University

- Commented about international collaboration a subject he noted he believes in strongly and has over his whole career.
- Stated that he spent more than three years working at foreign institutions.
- Noted that Dr. Meade's panel had done an excellent job.
- Stated his concern was 1. Concerned about the brain drain from the U.S. program and trying to balance that with international collaboration and 2. Concern regarding costs with regard to collaborations.

Dr. Synakowski responded that the administration's role in the FY2013 budget was over and he noted that he supported the budget. Added that the decisions were difficult and the federal government had a specific role in the process. He stated that the administration as far as planning was concerned often had no choice and often decisions were given on short notice. He added that personally he had a high regard for the science at MIT and he found the current circumstances unfortunate. He thanked Dr. Greenwald under the circumstances for chairing the committee meeting in a highly professional manner and by doing so had served his institution extremely well.

PREPARATION OF LETTER TO DOE TO COMPLETE THE CURRENT CHARGE

Dr. Greenwald reviewed the letter addressed to Dr. Brinkman in response to the two charges given to the Fusion Energy Sciences Advisory Committee. In the letter he outlined the charges and noted some details regarding the two subcommittees chaired by Dr. Meade and Dr. Zinkle. Dr. Greenwald asked committee members their opinion.

Dr. Rosner said that he did not feel that the subcommittee chaired by Dr. Zinkle addressed the computational issue. Dr. Greenwald suggested that he include a sentence that said "future studies of the impact of computation in this area would be valuable".

Dr. Greenwald asked if he could retake a vote to accept the letter. He noted no objections and the letter was approved with the one change regarding computations.

FESAC STATEMENT TO THE DOE WITH REGARD TO LEVEL OF IMPACT FROM FY2013 BUDGETARY CUTS

To avoid any institutional conflict of interest, Dr. Greenwald deferred to Dr. Fonck in leading the discussion regarding the statement. He stated that the points represented the viewpoints of committee members concerning about the impact of the FY2013 budget.

The final version of this letter is attached, click to open:

Dr. Martin Greenwald
Senior Research Scientist

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February 29 , 2012

Dr. William F. Brinkman
Director - Office of Science, SC-1
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

Dr. Brinkman,

First, I want to thank you for your continuing support and for the frank discussion we had during this week's FESAC meeting. The reports from the two panels responding to your charge of July 2012 were discussed and approved. I will be forwarding those to you in the next few days.

It is clear that the community is upset about the current budget trajectory and the potential impact on our domestic program. At the end of the meeting, a statement to that effect was prepared and approved unanimously (17 for, 0 against, 2 recusals, 1 absent). While this statement will be found in the minutes of our meeting, I felt it was important for you to understand the views expressed by the committee without delay.

The statement reads:

1) The committee objects to the theme/impression that these cuts leave the program relatively unscathed and strongly cautions against claims of impactful potential at this level or lower without real study and discussion.
   a) Specific impacts on the domestic program were noted during the meeting, these include many aspects of fusion science, plasma physics, and HEDLP research.
   b) The damage is real.
   c) The portents for the future are even more threatening.
2) If this whole discussion is in flux inside the Administration, this does not appear to be the time to make termination decisions that cannot be reversed. We are not clear on the wisdom to do lasting changes to program based on an undefined ITER profile and in the absence of an overall plan for the program.
3) Buy-in, cohesion of community is critical as we confront hard decisions – we don't want community to give a message different from DOE/OSC/FES
4) Thus we encourage FESAC charges covering

Dr. Fonck opened the floor for discussion. Dr. Meade noted that he had captured the issues they were concerned about and he thought it essential that a statement be made to the administration. He added that he supported the idea that it go forward with a separate letter to the Director of the SC.

Dr. Ji said that if they felt strongly it was their duty and obligation to express their concerns as FESAC members and also members of the broader community.

Dr. Keane made a suggestion and it was suggested under specific impacts that they add on fusion science, plasma science and HEDLP.

Dr. Cohen added that to him it made no sense to support ITER and not support the base program.

Dr. Synakowski said that he was aware that the cuts did have significant impact on the program but he thought it was also accurate to say that it was the administration's position that the program could still be impactful.

Dr. Fonck proposed that they give the statement to Dr. Greenwald in the wording that they have to be put into a cover letter to Dr. Brinkman. Dr. Greenwald confirmed that the statement would go into the Minutes as it stood. Dr. Fonck agreed the content would remain but the format and style would be edited. Dr. Fonck moved that they accept the statement from FESAC to be sent forward. A vote was taken and the motion was passed unanimously.

The formal letter dated February 29, 2012 from Dr. Martin Greenwald, Chair, Fusion Energy Sciences Advisory Committee was sent to Dr. Brinkman, Director of the Office of Science outlining the points made in the FESAC statement. For record purposes this letter was copied to Dr. Patricia Dehmer, Dr. E. Synakowski and Mr. Al Opdenaker. The letter is attached below:

ADJOURNMENT

The Fusion Energy Sciences Advisory Committee Meeting was adjourned for the day at 12:00 p.m.

APPENDIX A - AGENDA

Agenda Tuesday, February 28, 2012

Time	Topic	Page	Speaker
9:00	Welcome, Meeting Agenda and Logistics		Dr. Martin Greenwald, FESAC Chair, Massachusetts Institute of Technology
9:05	DOE/SC Perspectives including the FY 2013 Congressional Budget Request		Dr. W.F. Brinkman, Director, Office of Science
9:50	Break		
10:05	FES Perspectives including the FY 2013 Congressional Budget Request		Dr. Ed Synakowski, Associate Director for Fusion Energy Sciences
11:45	Basic Research Directions using the National Ignition Facility		Dr. John Sarrao, Los Alamos National Laboratory
12:15	Lunch		
1:30	ITER Update: Accomplishments, Status, and Domestic Issues		Mr. Tom Vanek and Dr. John Glowienka, Fusion Energy Sciences
2:30	Break		
2:50	Briefing on and Discussion of the Results From the Subcommittee Dealing With Research Modes That Best Facilitate International Collaborations		Dr. Dale Meade, Subcommittee Chair, President FIRE, LLC
	Briefing on and Discussion of the Results From the Subcommittee Dealing With Opportunities for Collaborations on New Tokamaks and Stellarators Overseas		
5:00	Adjourn		

Agenda Wednesday, February 29, 2012

Time	Topic	Page	Speaker
8:30	The Chinese Fusion Program		Prof. Jiangang Li Director, Institute of Plasma Physics Chinese Academy of Sciences
9:30	Briefing on and discussion of the results from the subcommittee dealing with materials science and technology research opportunities in the next 10-		Dr. Steven Zinkle, Subcommittee Chair, Oak Ridge National Laboratory

	20 years		
10:50	**Break**		
11:05	**Public Comment**		**TBD**
11:35	**Committee Discussion, preparation of letter to DOE to complete the current charge**		**Dr. Martin Greenwald, FESAC Chair Massachusetts Institute of Technology**
12:00	**Adjourn**		

APPENDIX B – ROLL CALL

Committee Members Present:
Dr. Martin J. Greenwald, Chair (MIT)
Prof. Riccardo Betti, Vice-Chair (Univ. of Rochester)
Dr. Richard W. Callis (General Atomics)
Dr. Bruce Cohen (LLNL)
Prof. Raymond J. Fonck (Univ. of Wisconsin)
Dr. Amanda Hubbard (MIT)
Dr. Hantao Ji (PPPL)
Dr. Christopher J. Keane (LLNL)
Dr. Ramon Leeper (SNL)
Dr. Kathryn McCarthy (INL)
Dr. Dale M. Meade (Princeton)
Dr. Ellen Meeks (Reaction Design)
Prof. Farrokh Najmabadi (UC San Diego)
Prof. Robert Rosner (Univ. of Chicago)
Prof. Edward Thomas, Jr. (Auburn Univ.)
Dr. Nermin Uckan (ORNL)
Dr. Steven Zinkle (ORNL)

Committee Members Absent:
NONE

Ex-officio Members Present:
Mr. Lee C. Cadwallader (ANS/FED)
Professor Cary B. Forest (APS/DPP)

Ex-officio Member Absent:
Dr. John W. Steadman (IEEE-USA)

DOE DOE/SC Attendees:
Dr. W.F. Brinkman, Director, Office of Science
Dr. Patricia Dehmer, Deputy Director for Science Programs
Dr. Ed Synakowski, Associate Director for Fusion Energy Sciences
Mr. Albert L. Opdenaker III, Committee DFO
Dr. Sam Barish
Mr. Ben Brown
Dr. Curtis Bolton
Dr. Corey Cohn
Dr. Dave Crandall
Dr. Steve Eckstrand
Dr. Sean Finnegan
Mr. John Glowienka
Dr. Jim Glownia
Dr. Marcos Huerta

Ms. Kathleen Klausing
Dr. David Lane, NRC
Mr. Dan Lehman
Ms. Sue Lesica
Dr. John Mandrekas
Mr. Gene Nardella
Mr. Peter Pappano
Dr. Nirmol Podder
Ms. Ann Satsangi
Mr. John Sauter
Ms. Ivrie Smith
Mr. Edward Stevens
Dr. Francis Thio
Dr. James Van Dam
Mr. Tom Vanek

Other Attendees:
Dr. M. Abdou, UCLA
Dr. David Anderson, Univ of Wisc
Dr. Dave Babineau, SRNL
Mr. Gerald Blazey, OSTP
Dr. Richard Buttery, GA
Dr. Mike Crisp, DOE/Retired
Dr. Steve Dean, FPA
Ms. Maria Dikeakos, DOE-PSO
Mr. Mark Haynes, Concordia Power
Dr. David Gates, PPPL
Dr. Bill Goldstein, LLNL
Dr. Charles Greenfield, GA/USBPO
Ms. Julie Groeninger, Princeton Univ
Dr. Arnold Kritz, Lehigh Univ
Dr. Grant Logan, LBNL
Dr. Vyacheslav Lukin, NRL
Dr. Earl Marmar, MIT
Mr. Stan Milora, ORNL
Dr. Hutch Neilson, PPPL
Dr. Brian Nelson, Univ of Wash
Dr. Erol Oktay, Retired/DOE
Dr. Miklos Porkolab, MIT
Dr. Martin Peng, ORNL
Dr. Stewart Prager, PPPL

Dr. Juergen Rapp, ORNL
Dr. Michael Roberts, RI, LLC
Dr. Henry Shaun, LLNL
Dr. Philip Snyder, GA
Dr. Tony Taylor, GA
Mr. Les Wagner, Consultant
Dr. James R. Wilson, Princeton Univ.
Dr. Glen Wurden, LANL
Dr. Leonid Zakharov, PPPL
Dr. Mike Zarnstorff, PPPL

Signed by Martin Greenwald, Chair of the Fusion Energy Sciences Advisory Committee on March 30, 2012.

Martin Greenwald