Minutes of the meeting of the
Fusion Energy Sciences Advisory Committee.
March 9-10, 2010.
Gaithersburg Hilton, Gaithersburg, Maryland.

Summary: March 9, 2010

There were six presentations during the day

- Dr. W. F. Brinkman on the FY 2011 budget request to Congress for DOEs Office of Science - regarding ITER, he indicated that there were enormous problems with respect to scheduling as the European Union cannot meet its obligations at this time. The first plasma in ITER is expected around November 2019, but the ITER council meeting in May 2010 will be important in determining the schedule.

- Dr. E. J. Synakowski on the emergent Fusion Energy Sciences vision. He pointed out that the immediate challenge is to establish scientific credibility, and discussed two high level goals: plasma dynamics and control, and materials in a fusion environment.

- Drs. D. Hammer and R. Rosner presenting a status report on the high energy density laboratory plasma research needs workshop.

- Dr. R. Linford on the 2009 Committee of Visitors review of the Office of Fusion Energy Sciences - a draft report of the review completed on December 11, 2009 was delivered to FESAC.

- Dr. R. J. Kurtz on the scientific and technical challenges for development of materials for fusion - fusion presents a uniquely hostile environment that poses unprecedented challenges to developing materials that meet safety, environment, and performance objectives.

- Dr. P. W. Terry on a hierarchal approach to validation experiments in magnetic fusion science - a white paper by the Validation Experiments Working Group, U.S. Transport Task Force, was delivered to FESAC.

The day’s activities were completed around 6:25 pm

Summary: March 10, 2010

On Wednesday morning, there was an annual ethics briefing for FESAC members only at 8:00 am. The public agenda started at 8:30 am.

There were three presentations during the morning

- Dr. Steven E. Koonin talked about the vision of Department of Energy and looked at the future directions of the fusion energy program.

- Dr. Jeffery Freidberg reported on the fusion-fission hybrid workshop and presented his views on the impact of a non-existent fusion technology program.

- Dr. Falcone reported on the new FES-funded activity at the SLAC National Accelerator Laboratory. In particular, he talked about the MEC instrument and the interesting physics issues that can studied using this instrument.

After these presentations there were five public comments by Dr. Wurden, Dr. Goldston, Dr. Hill, Dr. Sadowski and Dr. Stambaugh. Thereafter, the FESAC panel held a discussion on the report by Committee of Visitors. The report was approved unanimously and a cover letter was drafted and approved. The final report and the cover letter will be ready for transmittal within a couple of weeks. The sessions activities wound down with a discussion of the next FESAC meeting and topics of discussion in that meeting.

FESAC Members Attending (Institutional information for FESAC members is at the end of this report)

Kathleen B. Alexander
Riccardo Betti, Vice Chair
Richard W. Callis
Bruce Cohen
Martin J. Greenwald, Chair
Amanda Hubbard
Hantao Ji
Ramon Leeper
Rulon K. Linford
Kathryn McCarthy
Dale M. Meade
Ellen Meeks
Edward Thomas, Jr.
Nermin Uckan
Michael Zarnstorff
Thomas M. Antonsen Jr.
Lance Snead
John W. Steadman

FESAC Members Absent

John Sheffield
Steven Zinkle

In Attendance

NAME	AFFILIATION
Joydip Kudu	OMB
Paul Terry	UW-Wisconsin
Rokr Rojnea	Univ. of Chicago
David Hammer	Cornell University
Stan Milora	ORNL
Martin Peng	ORNL
Tony Taylor	DIII-D General Atomics

Mark Haynes	Concordia Power
George Tynan	UCSD
Gerry Navratil	Colombia
Jerome Hasting	SLAC
Rick Kurtz	PNNL
Miklos Porkolab	MIT
Graham Bench	LLNL
Wayne King	LLNL
Mike Fluss	LLNL
Glenn Wurden	LANL
Robert Cauble	LLNL
Lee Schroeder	Tech Source/LBNL
Kyron Williams	Florida A&M
Steve Dean	FPA
Roger Falcone	LBNL
Ron Davidson	PPPL
James VanDam	IFS-Texas
Kyron Williams	Florida A&M University
Robert Rosner	U. Chicago
Mohamed Abdou	UCLA
Grant Logan	LBNL
Walter Sadowski	
Rob Goldston	PPPL
Stewart Prager	PPPL
Ron Stambaugh	General Atomics
Bill Nevins	LLNL
Lois Buitano	NNSA/DOE
Tom Finn	NNSA/DOE
Jim Glownia	DOE SC-2, Office of Science
Ben Brown	DOE/SC
Natalia Melcer	DO/CFO
Hannibal Joma	DOE/SSO – MECI FPD
Kurt Hahn	DOE
Curt Bolton	DOE
Mike Crisp	DOE
Gene Nardella	DOE
Steve Eckstrand	DOE
TV George	DOE
Mark Koepke	DOE
Mark Foster	DOE
Barry Sullivan	DOE
Erol Oktay	DOE
Sharon Stevens	DOE
Nirmol Podder	DOE
Francis Thio	DOE
Ann Sautsung	DOE
John Mandrekas	DOE

Sam Barish	DOE
Ben Brown	DOE SC-2
Steven Koonin	DOE – Undersecretary of Energy
W.F. Brinkman	DOE - Director Office of Science
Pat Dehmer	DOE/OSC Deputy Director for Science Programs
Ed Synakowski	DOE - Associate Director for Fusion Energy Sciences
Al Opdenaker	DOE – FESAC Management Officer

Tuesday March 9, 2010

The meeting was called to order by the chair, Dr. Martin Greenwald, just before 9:00 am. The Committee members introduced themselves and thereafter the presentations started.

Dr. Brinkman

The November 2009 meeting of the ITER Council was the first one he attended. There were two issues that came up at that meeting - the first had to do with ITER management and the second was related to the project schedule. The management issues will be addressed through changes in the management structure and personnel. However, there is an enormous problem with the schedule as the European Union cannot satisfy its obligations at this time. These obligations pertain to the delivery of toroidal coils, buildings, and the vacuum vessel. Nonetheless, the first plasma is scheduled for November 2019. There is another Council meeting scheduled for later in the week and another in late May to finalize the budget. The European Union is expected to commit to about $10 billion.

The FY 2011 Office of Science budget request to Congress is up 4.4% from FY 2010. However, the Fusion Energy Sciences budget request is down by 10.8% as $46 million contribution to ITER is removed from the request. The Advanced Scientific Computing Research request is up by 8.1%. The Basic Energy Sciences (BES) has the lion's share of the request and the increase over previous year is by 12.1%.

The FY 2011 budget advances discovery science and invests in science for national needs in energy, climate, and the environment; national scientific user facilities; and education and workforce development.

In BES, energy related topics include research on radiation resistant materials in fission and fusion applications and separation science and heavy element chemistry for fuel cycles.

An expanded research effort in High Energy Density Laboratory Plasmas (HEDLP) will be supported. HEDLP is enabling deeper understanding of extreme phenomena in a range of disciplines including fusion energy sciences, condensed matter physics, materials science, fluid dynamics, nuclear physics, and astrophysics. The new research awards will continue to be under the HEDLP joint program between FES and NNSA which began in FY 2009. The research is expected to provide information in assessing the viability of inertial fusion energy as a future energy source. Also research opportunities will be available for junior researchers to continue research that is closely aligned with fusion energy sciences and stockpile stewardship.

There will $16 million available in FY 2011 for the Office of Science Early Career Research Program. These funds are expected to support about 60 additional awards at universities and DOE national laboratories. The funding opportunity announcement will be issued in spring 2010 with the awards made in the second quarter of 2011. An additional $10 million will be available for the Science Graduate Fellowships program. This will support about 170 additional fellowships.

After the presentation Dr. Brinkman responded to questions by FESAC members.

Dr. Linford applauded the investment being made by the department in major facilities and scientific research in dealing with the energy problem. However, he was concerned about the drop in the fusion budget and its impact on fusion research. The fusion community has known for many years that major new facilities will be needed to answer essential scientific questions relevant to the fusion energy program. Those scientific questions will not be answered by ITER or by any existing facilities in the world. These scientific issues have been discussed by Greenwald report and by the ReNeW activities. Will the fusion community be given the opportunity to do more than just basic studies? Dr. Brinkman responded that we have to think beyond ITER. It is very important. He points out that the rest of the world is already doing that while we are not. Where is the plan? We have to think this through and also think what we are going to do internationally. We have to figure it out and put a plan together. ITER will be a tremendous drain on the fusion program for the next ten years (peaking around $350 million a year). So there will be not be a lot of new facilities being built alongside that for now. We have a lot to think about what we want to do and what we want to do internationally. We want to think about all the issues that go along with building a reactor.

Dr. Greenwald noted that the fusion community, in doing scientific simulations, makes very good use of cycles provided by the advanced computer facilities. However, there is a concern that there in not enough input from the large user communities, programs, and projects, on the decisions being made about the architectures and how to invest the funds. There seems to be a take-it-or-leave-it approach as opposed to working together and having a dialogue to determine what the appropriate investments would be. Dr. Brinkman responded that he supports the idea of a dialogue between the user community and those in charge of putting together the advanced computing facilities.

Dr. Ji asked about the connection between fusion science and other branches of science. Dr. Brinkman noted that in his mind the first wall issues and the material issues are the important topics that the fusion community should be involved in. This leads to connections with the nuclear fission community. Dr. Brinkman asked Dr. Ji if there were other connections he was thinking about. Dr. Ji mentioned astrophysics. Dr. Synakowski responded that Fusion Energy Sciences already supports plasma astrophysics and will continue to do so.

Dr. Cohen asked about the coordination between NNSA and the Office of Science, and NNSA's interest in inertial fusion energy. Dr. Brinkman noted that the two departments do communicate and try to make sure that the community is well funded. In his talks with NNSA energy is always a topic of discussion.

Dr. Zarnstorff asked about the role and balance of international collaborations. He noted that in cases where the US programs are not as strong as the international ones, there is a strong international collaboration. Dr. Brinkman pointed out that we have successful international collaborations when the work is done in different home laboratories and not by collaborative groups or by central organizations. For successful international collaborations there is a need for good management structure with a strong central organization. This is not the case with ITER.

Dr. Synakowski

The work of the FESAC panel is much appreciated and their technical advice helps develop the vision of Fusion Energy Sciences (FES). The FES ambitions are commensurate with the energy and climate challenges of our times. There is talk about fantastic science that has an impact beyond fusion energy, thereby broadening our appeal. The immediate challenge is to establish scientific credibility that is consistent with the energy goal. FES needs the best technical advice possible to make informed decisions within the present budgetary and competitive environment. There are two high level goals of FES. The first goal is related to plasma dynamics and control. This applies to science questions of magnetic and inertial fusion energy, of industrial applications and of nature. The second goal is related to material in fusion environment. This includes plasma/surface interactions, nuclear effects on materials and structures, and the extension of nuclear material science to tritium breeding and extraction of fusion power.

On ITER it was mentioned that the US contribution will cost more than anything the Office of Science has ever undertaken. This requires managing the ITER contribution within the reality of budget constraints. ITERs place in the budget translates to the need to pursue programmatic moves that can take advantage of leverage. Leverage opportunities can be found in plasma dynamics and control as well as materials.

While the materials science represents the most urgent need, the open field line science/divertor issues are quite urgent. The demands on materials for fusion overlap and extend beyond those of Gen IV fission. There is a need to develop joint initiatives on materials with BES, NE, and NNSA. What is a sensible program that advances materials science efficiently and effectively? Do we have the scientific basis for pursuing either a moderate aspect ratio or a small aspect ratio magnetic fusion device? There is a need to define the appropriate magnetic geometry and the nuclear environment that can be tolerated.

By mid-decade the vision is to be well established in international research in steady-state tokamak physics. A FESAC charge in international research opportunities in key physics areas would be appropriate and timely. Additionally, identifying the key physics elements and research needs of a coordinated program nationally and internationally in 3-D physics would be a useful topic for FESAC to address.

On validated predicted capabilities, it was noted that the Fusion Simulation Program (FSP) is part of the critical predictive science effort. FSP is only as good as the physics models that are included and the reliance on validated prediction to fill gaps will demand a high level of confidence. There will be an emphasis on validation of physics models that are incorporated in FSP. The importance of the sensible use of massively parallel computing and the role theory and experimental validation play is very high.

Following the presentation there was a discussion with the FESAC members.

Dr. Meade noted that the presentation gives a lot of food for thought. As is known, fusion needs a long range plan for the future. It would be a useful exercise to lay out a road map. A road map that starts off with the scientific issues and the connections between 5 various issues. Then for these issues identify quantifiable meaningful metrics and then seek advice along those lines. It is too often that we focus down on hardware and it is already happening. Given the road map and the scientific issues, we can talk about the best way of optimizing the combinations in a particular mission. Fusion energy faces a perception of credibility and there is a need to make the program credible to those outside the field of fusion sciences. Within the road map one could point out to some key deliverables separated out in time over a decade or so, that would make the program credible to those on the inside looking up and also for those on the outside looking in. Each of these steps, as pointed out in the presentation, will cost in the billion dollar plus range. Dr. Synakowski responded that too often we do talk about hardware. However, we do need facilities - large facilities - to improve our understanding of physics issues. In terms of a road map, the materials research program is an important issue which needs substantial facilities. There is quite a bit of overlap between MFE and ICF as far materials issues are concerned. If we could say that we have a source that generates 14 MeV neutrons, there would be a broad range of interest from outside the fusion energy field.

Dr. Thomas pointed out that we are good at advocating new programs but, in a budget constrained environment, we are not good at turning off programs. How does one go about deciding what programs to eliminate in light of the questions that need to be answered in five to ten years from now? Dr. Synakowski noted that it is not in everyone's interest to have FES ask FESAC to make decisions regarding which programs to turn off. That decision process belongs elsewhere. We will never go wrong with smartly constructed proposal. A responsible program can always be asked to delay things during bad budgetary times.

Dr. McCarthy wanted to know about the connection between DOE-SC and DOE-NE. In many discussions presented today one could substitute DOE-NE for DOE-SC and the same discussions take place in DOE-NE. The NE program is looking for ways that it can collaborate with and leverage off other programs. The materials issue is a good area for collaboration. NE is addressing the materials issue using a science based but goal driven program. In conventional fast reactors fuels are expected to last about 200 dpa (displacements per atom). But there are concepts out there that can push to twice that level. DOE-NE has been working on a road map which is due soon. There is also an implementation map which goes along with this road map. That may be something to look at when building the road map for DOE-SC. Also the NE program is a good model to look at for validating codes and models.

Dr. Zarnstorff mentioned that for materials research the Europeans and the Japanese have their next step as IFMIF. Is that an example of FNSF? Dr. Synakowski: No. Dr. Zarnstorff: Should we host or be involved in IFMIF? Dr. Synakowski: We are not likely to host such a program because of financial issues. Dr. Zarnstorff: There are other international programs that are stronger in this area than we are. They all go through IFMIF. In your thinking about FNSF is it a CTF (component test facility) type of device or for testing other aspects of the fusion system like reliability and steady state? Dr. Synakowski: Even the more modest versions of FNSF will address a variety of issues (not just as a CTF). If there is a program that is good for IFE, MFE, NNSA, etc., we can probably support it within FNSF.

Dr. Cohen had questions about international collaboration, the FSP program, and in the area of theory and predictive modeling.

The budget for international program has been relatively flat and there are no new solicitations for international collaboration. It is difficult for new domestic programs to get funds for international collaborations.

Your view of the FSP program is that it extends beyond tokamaks, e.g. 3-D extensions. There is a tension that is emerging that will FSP be everything to everyone? The project will inevitably have to be focused to get anything done. Bill Tang has been proclaiming that FSP will be a tokamak oriented code. So if we want more to be done then the decision has to be made soon. The project is being defined now.

You indicated theory and modeling as our leadership areas with significantly increased emphasis. There has been a tension in the funding stream for theory and modeling for a very long time. Funding for base theory has been either slowly contracting or remaining flat. FY 2011 is no different - theory is flat. Base theory is in pain and continues to be in pain. Dr. Synakowski responded that he has to be a little careful talking about possibilities. ITER is imposing a lot of constraints on us. We need to get more details about the kind of work that is not being done as FSP grows. Dr. Synakowski pointed out that he does not have crisp answers to the questions. In terms of a budget the whole picture does not hang together. It is worth asking how theory can grow within the validation programs. However, there is no clear answer at present and more thought will have to be devoted to the long term plans.

Dr. Synakowski agreed with Dr. Leeper that there is overlap between IFE and MFE on materials issues. Diagnostics of the the harsh fusion environment is a challenge in both fields. A new facility that serves the broader community should be considered.

Dr. Hubbard was pleased to hear of broader definition of material sciences including plasma-wall interactions and divertor designs. Has OFES decided upon FNSF? If so, what are time scales? Dr. Synakowski responded that it makes sense to him to push this program. The time scale cannot be determined now as it depends on the funding. But FNSF has to be ready in time to make use of ITER burning plasma experiments. A level of understanding of what is required is needed sooner than later and there has to be a shift in the paradigm.

Dr. Betti noted that the program would have more credibility if a burning plasma experiment was on line. Was it a mistake to not pursue the burning plasma experiment? Can a small BPX be built in the future - maybe, in collaboration with international partners? Dr. Synakowski responded that we will be well served, from a scientific point of view, by a burning plasma experiment. We did the right thing early on given the knowledge at hand. The decision was made based on that knowledge and even now he supports the decision.

Dr. Greenwald asked how to balance international collaboration without ceding our leadership role. Dr. Synakowski responded that we have a chance to be architects in the directions of international programs as we are being sought after. Maintaining leadership is not necessarily ceding leadership. There are tensions but we should welcome them.

Dr. Meeks pointed out that it is a challenge to have a goal orientated program together with a discovery program. ITER is a goal. What percent of the program has to be goal orientated? Dr.

Synakowski responded that even in a goal orientated program there is a discovery program. ITER was marketed as a discovery program. It is also a goal orientated program. It is difficult to put distinct labels. Science on Alcator, NSTX, and DIII-D is goal orientated. NSTX has astrophysical implications also - a discovery program. There is a need to shift to more goal orientated program and be prepared to move out of things that do not work. Dr. Meeks further noted that the broader aspects of plasmas being addressed by OFES (e.g., low temperature plasmas) could be taking away resources from the stated goal. Dr. Synakowski responded that broader aspects are only a small component of the portfolio. Fusion will do well if other fields related to fusion will applaud our achievements. There is a need to have more than ourselves cheering for us. The returns could be significant considering the small investments. Cross category vested interests are good for us.

Dr. Callis said that ReNeW did not establish priorities. Is FESAC being asked to do that? Dr. Synakowski said no. The Greenwald report identified priorities. The questions being asked of FESAC are more technical.

Dr. Ji noted that the fusion-fission hybrid program is an example of a joint NE-FES program that addresses material issues. This could be a future discussion point even though the science gets tangled with politics. Dr. Synakowski that one can get people from both communities in the same room to work on materials issues. However, we need to make fusion work first and keep our interest in fusion going. Dr. Ji continued that predictive capabilities are possible with understanding of detailed physics. Each step in a process has to be predictive before the complete package can be used for predictions. There is a need to do plasma science and get detailed diagnostic measurements to compare with before one can be predictive. Dr. Synakowski noted that we can to try to make predictions for ITER based on modest laboratory experiments. There could be other classes of experiments to invest in that help us.

Dr. Linford pointed out that there is an important role for a few $100 million experiments looking at challenges in physics and engineering since the phase space is so broad. The loss of NCSX is tragic. Do you want to foster $100 million experiments to explore the phase space in the future? How do you develop and maintain management of innovative programs in fusion? Management cannot be put into cold storage and brought up when needed. Dr. Synakowski responded that leadership is needed to bring major projects along. The success of PPPL is critical and the success of OFES depends on it. We are not investing in any new facilities except for an upgrade of NSTX.

Dr. Zarnstorff noted that we need to collaborate - actually, there is a need to get into partnerships. This requires commitment and foresight. How do we maintain leadership and grow international collaborations with a flat budget? Dr. Synakowski said that one needs to identify the opportunities and make the case work.

Dr. Hubbard noted that magnet research is lacking. Dr. Synakowski said that we do need to invest in magnet research.

Drs. D. Hammer and R. Rosner

A status report from the high energy density laboratory plasma (HEDLP) research needs workshop (ReNeW) was presented. This workshop followed the FESAC report on \Advancing the Science of High Energy Density Laboratory Plasmas" that was prepared by the Betti panel. The goal of the workshop was to examine the research opportunities in depth and the research needs to pursue these opportunities as given in the report. The FESAC HEDLP identified six scientific sub-disciplines and the workshop addressed these sub-disciplines using cross cutting panels for

- connecting HEDLP research to other areas of physics and science in general;
- computing;
- diagnostics;
- research infrastructure;
- high-Z multiple ionized HED atomic physics.

The Executive Summary of the report addressed

- the five questions of HEDLP;
- the special nature of the field of HEDLP;
- the sub-disciplines of HEDLP;
- the cross-cutting subjects of HEDLP.

The five questions of HEDLP are

- How does the exotic behavior of dense collections of electrons, ions, and photons arise?
- What can creating cosmic conditions in the laboratory reveal?
- Can transient intense flows of energy and particles, unconstrained by conventional material limits, be manipulated and exploited?
- Can the interactions of matter under extreme conditions be controlled to enable practical inertial fusion energy?
- How does self-organization arise within high-energy density matter?

The point of the workshop was to show that HEDLP is an important field and can stand by itself.

At the end of the presentation, Dr. Greenwald, the Chair, pointed out that this report was neither commissioned by FESAC nor is it seeking FESAC's endorsement.

Dr. Linford

The 2009 Committee of Visitors (COV) Review of the OFES was presented along with a draft report.

There were five subcommittees to cover different elements of OFES for the fiscal years requested in the charge letters from Dr. Orbach, Dr. Dehmer, and Dr. Greenwald

- Tokamaks and Diagnostics (review period 2006-2009)
- Enabling Research and Development (R&D) (2006-2009)
- Innovative Confinement Concepts (ICC)/Plasma Science (2005-2009)
- High Energy Density Laboratory Plasmas (HEDLP) (2005-2009)
- Theory and Computation (2004-2009).

The First conference call took place on July 13, 2009 and the final draft was sent to FESAC chair on December 11, 2009. Some of the recommendations are

- Use peer review consistently across all program elements to ensure quality, balance, and credibility.
- Employ carefully designed solicitations to respond to the needs within every program element - one size does not fit all.
- Ensure that all solicitations are properly focused with clear expectations and criteria.
- Document the reasons for a selection or a declination in every folder.
- Include reasons for declination and/or some specific context for the selection outcome in the communication to the proposer.
- Employ web-based tools to facilitate reporting of progress and tracking of achievements.
- Take immediate steps to strengthen some of the hardest hit areas that critically impact the ultimate success of the domestic fusion program.
- Assure that R&D activities in the US funded by ITER use processes and documentation as close to those used by other OFES research elements as possible.
- Provide future COVs a charge that clearly includes major facility operations and construction projects, including ITER, as well as the research elements of the OFES program.
- Develop effective and streamlined mechanisms to manage solicitations that foster interactions among theory, computations, and experiment.
- Define, collect, and analyze meaningful metrics.
- Obtain and employ modern IT tools for data collection and analysis.
- Restore the staffng level of both administrative assistants and managers to levels needed to carry out their responsibilities including the collection of data needed to assess the quality of their program elements.

Following the presentation, the COV was praised for the dedication and their accomplishment by Dr. Greenwald and other members of FESAC.

Dr. Cohen said that OFES does not have a systematic way of looking at biased reviews. Such reviews should be tossed out from consideration. OFES should allow for a procedure of rebuttal and program managers should pay attention to the rebuttal. Dr. Linford responded that the dealing with rebuttals is not uniform across different program managers in OFES. They should consider outliers in the review process and eliminate them. Dr. Synakowski added that OFES is the only office in Office of Science that allows for a rebuttal process. He encouraged the development of staff that is scientifically involved so that they can make informed decisions. He noted that scores are important but they do not make up the whole review process. The program managers have to make decisions. Dr. Linford commented that the OFES staff is scientifically competent to make the type of judgements that Dr. Cohen was suggesting. The staff should be disregarding those reviews that are clearly biased or incompetent when deciding which proposals are to be funded. However, the reasoning and judgement behind such decisions was not uniformly documented.

Dr. Greenwald pointed out that as a matter of process FESAC is not going to ask OFES to respond formally today. However, it is anticipated that possibly at the next FESAC meeting OFES can respond to the COV report.

<u>Dr. Kurtz</u>

The scientific and technical challenges for development of materials for fusion are significant since the fusion environment is hostile. One needs to worry about high temperatures, reactive chemicals, large time-dependent thermal-mechanical stresses, and intense radiation. Moreover, the materials have to meet objectives for safety, environment, and performance. This is an unprecedented challenge even without radiation damage. Structural materials significantly determine fusion energy feasibility, but many other materials (e.g., breeding, insulating, superconducting, plasma facing, and diagnostic) must be successfully developed for fusion to be a technologically viable power source. The needs are as follows

- materials that serve in the fusion environment for acceptably long lifetimes;
- materials that are dimensionally stable and retain a host of performance sustaining properties in the presence of radiation damage;
- materials capable of operating at high-temperatures and maintain a wide operating temperature window;
- low-activation materials for environmental attractiveness;
- first-wall and PFC materials that are compatible with plasma requirements;
- tritium breeding and other blanket materials that meet tritium production and power extraction needs;
- blanket materials and coolants that are compatible and corrosion resistant;
- integrated and validated material/component/chamber/plant systems that can meet licensing and safety requirements during design and operating phases.

Some of the points that were made in the presentation

- Radiation damage produces atomic defects and transmutants at the shortest time and length scales, which evolve to produce changes in microstructure and properties through multiscale - multiphysics processes that involve many variables and many degrees of freedom.
- Fission materials issues are less serious than for fusion, e.g., for fission dpa < 0.15 while for fusion dpa ~ 200. Advanced fission reactors are beginning to push boundaries to where fusion wants to be.
- While MFE and IFE share many materials science issues and needs, IFE faces unique challenges, e.g., the first wall must tolerate intense pulses of ions and x-rays from the target, and the instantaneous neutron damage rate is much higher in IFE.
- Fusion materials research relies heavily on modeling as the fusion operating regime is presently inaccessible.

The resource needs for fusion materials development are

- Non-nuclear structural integrity benchmarking facilities to investigate the potential for synergistic effects that are not revealed in simpler single-variable experiments.
- Fusion relevant neutron source to look simultaneously at the effects of displacement damage and helium generation.
- Fusion Nuclear Science Facility (FNSF) to explore synergistic degradation modes in a fully integrated fusion neutron environment.
- There is also a need for computational capability in support of model development, materials evaluation equipment, and a facility for high-temperature materials testing.

The presentation was followed by a discussion period.

Dr. McCarthy pointed out that the presentation shows quite a bit of synergism between material needs for fusion and for fission. She recommended that the programs should work together.

Dr. Leeper wanted to compare neutron damage in IFE and MFE. Dr. Kurtz said that a different structural path is needed in IFE where the neutrons are emitted in bursts as opposed to MFE where the neutron emission rate is uniform.

Dr. Callis wanted some idea about the possible plans five years from now and ten years from now. Dr. Kurtz responded that in five years he would like to see nuclear radiation capabilities that go well beyond those in fission reactors of 5-7 dpa per year. Also he would like the ability to explore the effects of helium on radiated materials. In ten years he is hoping for a robust materials program.

Dr. Alexander said that, given the differences between the fission and fusion environments (in terms of dpa and helium), we will need to move ahead without having all the data for the design. We will be looking ahead based on predictive simulations or simulated environments. Where do we stand on assessing our predictive capabilities? Dr. Kurtz responded that it is difficult to look ahead until we can produce a simulated environment. We need to be able to benchmark models that go from nanoscale to the continuum. We also need experiments to fully validate the models. Maybe we could predict based on computational models, but experimental validity is needed to satisfy regulators.

Dr. Synakowski noted that emphasis is being placed on massively parallel computing. Do you see an evolution of the role of computations, given the developments of the past ten years, to help in predictive capabilities. Dr. Kurtz said that the key role for computations could be to help us design the kind of experiments that need to be performed. We can use computations intelligently to connect to experiments, but there are huge challenges.

<u>Dr. Terry</u>

An oral overview and a detailed white paper was presented to FESAC on a hierarchal approach to validation experiments in magnetic fusion science. The presentation was on behalf of the Validation Experiments Working Group of US Transport Task Force.

Predictive capabilities are needed for operation of ITER and Demo. This requires a rigorous validation effort. From computational fluid dynamics, verification implies that the code faithfully represents a model. Validation implies that the model faithfully represents physical reality. Fusion plasmas present additional challenges for validation. There are usual intrinsic nonlinearities and multiple scales. Also there is no single model that describes everything - there are different models with different approximations and different physics. There are serious limitations in measurement capability which makes validation difficult. In reality we do not know how to do validation in order to become predictive. Hence, new validation approaches for fusion are needed along with a hierarchy of validation experiments. Significant progress could be achieved with experiments that, for example, simplify the geometry and magnetic topology, freeze quantities that vary in general, integrate fewer disparate effects, and allow enhanced diagnostic access. The problem is that simplifications can change some of the physics in fundamental ways. The limitations must be dealt with in experimental design such as making unwanted effects less critical.

The Validation Experiments Working Group considered whether meaningful “simplified” validation experiments can be created? The case study for experiments ranged from existing devices to devices that could be built. However, the group did not develop detailed proposals or work out every issue. The case studies argued for fundamentally new approach where the validation tasks were envisioned from conception of experiments. It was integral part of design and was to tied to the physics understanding sought from the experiment. There were six case studies:

1. Validation of boundary plasma models on a small toroidal confinement device.
2. Validation of particle transport models in small magnetic confinement devices with controlled fueling sources.
3. Validation of models for linear and nonlinear dynamics of edge localized MHD modes
4. Validation of edge turbulence models via studies of turbulence dynamics in laboratory experiments with open field lines.
5. Validation of RF sheath models.
6. Validating fundamental mechanisms of turbulent transport in multiple channels.

In summary, predictive capabilities required validation at a new level of rigor. A hierarchy of validation experiments was proposed. These experiments peel back complexity in physics, geometry, interactions, and/or enhanced diagnostic access.

Follow the presentation there was some discussion.

Dr. Meade pointed that previously, case studies were carried out to explain one phenomenon: Landau damping, bootstrap current, etc. Why don't you identify specific phenomenon that needs to be checked and design experiments, theory, and simulations for that phenomenon? Dr. Terry responded that there is a need to combine things. For instance, can we simulate bootstrap current with shear flows. That is the new challenge.

Dr. Zarnstorff noted that there is a lot of data on fluctuations from previous experiment that is not understood with the present architecture. There is a need to look at old experimental results. Dr. Terry concurred. Dr. Zarnstorff continued that a lot of data is available from perturbative experiments which were carried out to stress the theories. Dr. Terry responded that we should look at that data and see if our present models can explain the observations.

Dr. Leeper said that the hope is to make predictive capabilities as one integrates various models.

Dr. Hubbard wondered if the organizational challenges had been considered. Dr. Terry responded that they have looked at physical challenges only, and not thought about organizational challenges.

Dr. Cohen noted that synthetic diagnostics maybe as complicated as the experiments themselves. Dr. Terry responded that people are looking at synthetic diagnostics. Dr. Linford asked if they can look at non-Gaussian statistics in edge physics due to atomic processes? Dr. Terry noted that case study 6 has looked at such issues. For examples, if transport is non-diffusive, how large is the deviation from Gaussian statistics.

Wednesday March 10, 2010

Dr. Koonin

Dr. Koonin gave his presentations without any slides. Some of the points he made in his talk follow.

- He thanked the FESAC committee for its work - committees are institutional memories.
- Dr. Brinkman consults quite a bit with him. Dr. Koonin's role is to weigh in on strategic issues and work on issues of conflict.
- The department (DOE) is going through a strategic planning exercise.
- There are several themes within the department:
    - Jobs and competitiveness. A number of programs within the department are stimulating the job market through the stimulus funds. On competitiveness, the privileged status of US is under stress as the rest of the world advances.
    - Nuclear security. Issues dealing with non-proliferation; stockpile stewardship (need science and technology for nuclear weapons); strengthening of science within NNSA.
    - Energy. Energy security associated with dependence on foreign supplies; greenhouse gas emissions. We want to change the energy supply and consumption.
- There are themes that extend across the department; knitting the department together and look for synergies; shift science more into the applied direction; open up NNSA - NNSA has a couple of crown jewels and it is not easy to get them out in the open.
- Some of the program themes are:
    - simulations - a mix of experiments, data, and modeling; and then do design optimizations.
    - need to focus on what has been done in ASCR etc. to help foster energy goals;
    - materials for energy applications: fission and fusion (partnering with NNSA).
    - high performance computing facilities - determining the best technology path for exascale computing (10^{18} flops).

– IFE - NIF is operating and in Fall 2010 there will be a serious campaign for ignition; we should think about IFE as an energy production source; assume that NIF ignites then the National Academy could be asked about what needs to be done to get fusion energy.

Discussions followed after the presentation.

Dr. Greenwald mentioned that the department and the Government have an aversion to risk. Dr. Koonin responded that the department is struggling with the issues of risk and discovery. On the demand side for energy, we need to consider the ways we use energy and set up the right policies that help solve the demand issues (e.g., better cars, etc.). On the energy supply side we need to worry about risks. In this case technology evolves slowly. The government has to assume risk in order to get industry involved. ITER is about $10 billion. A good fission reactor is about $7 billion - and that is a proven technology. However, it is not easy to get industry involved because of the expense. So cost is an important criterion.

Dr. Linford noted that research is needed to turn ICF into a practical fusion energy source. What can done within the department to encourage this research? Dr. Koonin responded that NNSA is not against ICF being an energy source. NNSA is happy to see the energy initiative. OFES has a lot on its plate - so no new agenda items can be added unless more money comes in. Ignition at NIF will change the thinking of people.

Dr. Cohen said that in yesterday's presentation by Drs. Hammer and Rosner on HEDLP, it was indicated that classification issues restrict the building of codes in environments which do not have strict security. Do you have any thoughts? Dr. Koonin pointed out that physics know no boundaries. So other countries will likely take over the development of such codes.

Dr. Meade noted that you have challenged fusion by demanding economic feasibility. During the past decade significant progress has been made in MFE and ICF. We have to look beyond ITER. Many of us feel that additional major activities are needed in parallel with ITER to establish the basis for a fusion DEMO. We feel that eventually we will have less costly machines that will be cost competitive based on systems studies carried out over the past decade. In order to assess economic feasibility we need to understand more about fusion technology. There should be a high level review of fusion (MFE and ICF) as a viable energy source. There could be an internal assessment as well. Dr. Koonin agreed. The National Academy will review ICF. One has to ask how does one technology do against another competing technology.

Dr. Zarnstorff pointed out that other countries are putting in more resources into fusion than we are. They may beat us to achieving fusion energy. We may be mainly following them and could likely come in second or third. Dr. Koonin responded that the same could be said about other things - solar, fission, wind power, etc. We need to worry about things every one or two years. They have more money, newer facilities, and longer view.

To another question, Dr. Koonin said that he supports large scale computing. It is an incredibly rich area.

Dr. Meeks noted that in assuming risk and taking on technology challenges, how does one separate government funded research from industry funded research? We do not want the government to impede the research in industry. Dr. Koonin responded that work is in progress within the department. This has to be done case-by-case.

Dr. Betti noted that Dr. Koonin had said that ignition in NIF will change peoples' mind. But, there is a long way to go to energy relevance. You feel that people will pay attention to ignition even if it occurs once a day. Why does it matter? Dr. Koonin responded that scientists worry about scientific issues while the rest of the world cares about simple things that make headlines. So that is why ignition is important.

<u>Dr. Freidberg</u>

A status report on the ReNeW workshop on Fusion-Fission hybrid was presented. The goals of the workshop were to determine if hybrids are sufficiently promising to motivate DOE to initiate an R&D program; and to determine the research needs to move the hybrid concept forward. The workshop activity took place over five months and was sponsored by OFES, NE, and NNSA. There was a three day workshop which had about 100 attendees from universities, laboratories, government, and industry. The final report on fusion-fission hybrids contains ten chapters.

The proponents of the hybrid concept feel that it combines the best of both worlds (fusion and fission). The skeptics feel that the concept the worst of both worlds.

The present biggest fission industry problem is economics. The fission solutions for sustainability are fast burners for waste management, and fast breeders for fuel supply. The potential role of hybrids is fuel supply, electricity production, and waste management. There were four fusion-fission hybrid concepts that were presented.

It is not fair to compare pure fission solutions with those using the fusion-fission hybrid concepts. Hybrids assume advances in materials technology and new fuel forms. Pure fission assumes existing technologies.

There are active hybrid programs in Russia, South Korea, China, and India that are leaving us in the dust. The proliferation risks are much greater for a hybrid than for a pure fusion reactor.

There are high level research needs in fusion technology. The US fusion technology program has been decimated and we will not be able to make hybrids or pure fusion in 50 years unless we restart technology. Of particular importance is materials research. If we maintain our present strategy then our international colleagues will be leaders in fusion and hybrid energy applications while we become the followers. However, it is not clear at present whether we do need hybrids.

After his report on the hybrid ReNeW workshop, Dr. Freidberg gave his thoughts on the US fusion program and hybrids. He pointed out that after numerous workshops there is nothing new that has been built or is under serious consideration to be built in the US fusion program. Two programs, NCSX and SSPX, have been shut down and the US fusion technology program has been decimated. The effect of a lack of a technology program was illustrated using magnets as an example. The current tokamak strategy focuses on advanced tokamaks where all issues are alleviated by a higher magnetic field. However, there is no magnetic technology research program in US.

The rest of the world seems to like stellarators along with tokamaks. NCSX was a clever quasi-symmetric stellarator which required first of a kind magnets that are complicated. But NCSX was shut down due to cost overruns. The real time R&D needed during construction generated delays and cost overruns. So a contributing factor to NCSX shutdown was the lack of a base technology program. So there is a need to restart the fusion technology program now - pure fusion and hybrids have similar technology needs. Otherwise, we have to decide whether to buy our fusion and hybrid reactors from China or Korea.

The discussion period followed the presentation.

Dr. Betti said that he agrees pretty much with everything that Dr. Freidberg presented. But, unfortunately, we are boxed in due to budget constraints. We have no credibility and so we cannot ask for more money from Congress. So what do we cut in order to fund the technology program? Dr. Freidberg noted that this is a good question - however, he will punt on it.

Dr. Meade thanked Dr. Freidberg for an entertaining talk. He said that the hybrid report is a good one and it was a good exercise to go through. The technology program needs to be revamped - this also in light of Dr. Koonin's comments about making technology more competitive. During the construction of TFTR, the $100 million R&D program for neutral beams was done with project funds. So the way to drive the technology program is through a project. Thus, Dr. Meade disagreed with Dr. Freidberg regarding the comment on the termination of the NCSX project.

Dr. Linford wondered if there were any people from the French program on breeder cycles attending the workshop? The French are more experienced than us on breeder technology. Dr. Freidberg there was someone from the CEA in France. He was the most knowledgeable person at the hybrid workshop. At the end this French scientist agreed that a fair comparison between the hybrid approach and the fission approach had not been made. There were representatives from China and Korea as well.

Dr. Ji agreed with Dr. Freidberg that further studies are needed to assess the feasibility of the fusion-fission hybrid concept. Dr Ji continued that there is a need to do systems studies and reactor design studies to critically assess the tradeoffs between different requirements on different components in a fusion reactor before a technology program is established. Dr. Freidberg agreed with the general thrust of the comment but pointed out that setting up priorities on a budget of zero is difficult.

<u>Dr. Falcone</u>

The presentation was on the new FES-funded activity at the SLAC National Accelerator Laboratory. The Linac Coherent Light Source (LCLS) free electron x-ray laser is now operating at SLAC. It uses the particle accelerator on the SLAC site. It takes the electron beam at 14 GeV and puts it through an undulator to create a true coherent x-ray laser beam. The beam energy is about 1 mJ per pulse at nominally a 100 Hz. This is an x-ray laser on demand at one Angstrom and tunable around that. The x-ray beam can be put through a matter in extreme condition (MEC) instrument at LCLS. This instrument is one of several constructed in association with LCLS.

MEC at LCLS is an open access general user facility funded by DOE-BES and focusses on best science. The study of high energy density matter is interesting because it occurs widely - hot dense matter occurs, for example in supernova, Z-pinches, and IFE, while warm dense matter occurs, for example, in cores of large planets and x-ray driven inertial fusion experiments. The high energy density science (HEDS) experimental program at LCLS will cover a broad range of such applications.

For warm dense matter creation experiments, the XFEL can be used to uniformly warm solid density samples. For experiments on equations of state, one can heat/probe solids with XFEL to obtain material properties. For experiments on absorption spectroscopy, one can heat solids with optical laser or XFEL and use XFEL to probe. For experiments on high pressure phenomena one can create high pressure with high-energy laser and probe with the XFEL. For experiments on surface studies one can probe ablation/damage processes. For experiments on XFEL/gas interaction one can create exotic, long-lived highly perturbed electron distribution functions in dense plasmas. For XFEL/solid interaction studies one can use the XFEL to directly create extreme states of matter. For experiments on plasma spectroscopy, XFEL can be used as a pump and as a probe for atomic state. For diagnostic development, one can develop Thomson scattering, SAXS, interferometry, and radiography

In summary, LCLS is a general user facility providing open access with operations fully funded by BES. FES ARRA funding is being used for constructing the MEC instrument which focusses on high energy density science. FES funding is being requested for a strong in-house research group and proposal driven peer reviewed single investigator grants, and for laser systems upgrades.

A discussion session followed the presentation.

Dr. Cohen complimented the presentation and asked as to where does LCLS stand in the hierarch of SLAC? Dr. Falcone responded that it is the highest priority of the director. BES is paying for the LINAC and is essentially the owner of it.

Dr. Betti noted that an impressive list of science activities that can be carried out on the MEC station was presented. Are there are one or two activities that can be considered as revolutionary and breakthroughs? Dr. Falcone responded that the study of materials transformation and failure at high energy density will be revolutionized. The fact that one can visualize nano scale defects and structure in materials under high energy density conditions is very revolutionary. One can study the role of defects in material failures at short time and nano space scales. The other revolutionary topic will be the measurement of electron distribution function using the laser as a Thomson scattering diagnostic.

Dr. Hubbard asked if the research is classified and also when there will be a call for proposals? Dr. Falcone said that Stanford has a policy of not doing classified work. DOE has not yet decided on when the call for proposal will go out.

Dr. Meade asked about FES related activities that can be carried out on this facility. Dr. Falcone listed studies on materials failure (first wall), on spatial and temporal imaging of hydrodynamic instabilities in ICF, and on non local thermodynamic equilibrium.

Dr. Alexander asked if the facility is restricted to only those users who are funded by BES? Dr. Falcone responded that even NIH funded researchers can use the facility. In fact, any user funded by any agency is welcome.

Dr. Betti wondered about the difference between LCLS facility and the NDCX-II facility? Dr. Falcone noted that NDCX-II is an ion beam facility which LCLS is not. Also, NDCX-II operates in the nanosecond regime while LCLS is in the femtosecond regime.

Dr. Synakowski asked if other countries were interested in research on warm dense matter evolving from cold dense matter? Dr. Falcone said that the Europeans have lots of interest. In five years there will be a program in Hamburg, Germany. The United Kingdom is connected with the MEC facility.

Public comments and additional notes

Public comments: The committee heard five public comments. These were: Glenn Wurden on his disagreement with the new directions for the ICC program; Rob Goldston promoting a "Pilot Plant" as a pathway toward fusion commercialization; David Hill on experimental validation; Walter Sadowski on opportunities and offers of collaboration from Russia and China; and from Ron Stambaugh on common requirements for materials from fusion and advanced fission approaches.

Discussion of COV: Several minor amendments were discussed and approved by the committee. The sub-panel FESAC then voted and approved the COV report unanimously. A cover letter was drafted and approved. The final report and cover letter should be ready for transmittal in 1-2 weeks.

The final topic was a discussion of the timing and topics for the next FESAC meeting. Dr. Synakowski told the committee that he would aim for a meeting in 4-6 months, that is, in the August-September time frame. The committee brought up a number of issues which might be covered at that time. These included: A status report and discussion of the strategic planning process; the vision for an FNSF (fusion nuclear sciences facility) as a long-term program target and as an organizing principle for shorter term plans; the proposed material program especially interactions with other DOE offices and divisions (it was noted that this would be timely given the release of the nuclear energy research road map); an update on ITER technical status including U.S. participation in the TBM (test 21 blanket module) program; and a discussion of the role of laboratory scale experiments in validating models for non-FE plasma physics (particularly space and astrophysics.)

Respectfully Submitted
Dr. Abhay Ram
Recording Secretary
May 4, 2010

Reviewed by FESAC members, speakers
and the DFO and certified as correct by Dr.
Martin Greenwald, FESAC Chair
May 17, 2010

Signed by Martin Greenwald, Chair of the Fusion Energy Sciences Advisory Committee on May 17, 2010

Martin Greenwald

FUSION ENERGY SCIENCES ADVISORY COMMITTEE
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Dr. Kathleen B. Alexander
Division Leader
Los Alamos National Laboratory
MS P912
Los Alamos, NM 87545
Phone: 505-665-4750
Fax: 505-665-2326
Email: kbalexander@lanl.gov

Professor Riccardo Betti, Vice Chair
Director, Fusion Science Center for Extreme States of Matter and Fast Ignition Physics
Laboratory for Laser Energetics
University of Rochester
250 East River Road
Rochester, New York 14623
Phone: 585-275-8586
Fax: 585-273-1014
Email: betti@me.rochester.edu

Dr. Richard W. Callis, Director
Heating and Current Drive Division
General Atomics
Room 34-107B
P.O. Box 85608
San Diego, CA 92186
Phone: 858-455-3554
Fax: 858-455-4190
Email: callis@fusion.gat.com

Dr. Bruce Cohen
Associate Program Leader
for Magnetic Fusion Theory and Computations
Fusion Energy Program
Lawrence Livermore National Laboratory
P.O. Box 808, L-630
Livermore, CA 94551
Phone : 925 422-9823
Fax : 925 423-3484
Email : bcohen@llnl.gov

Dr. Martin J. Greenwald, Chair
Plasma Science and Fusion Center
Massachusetts Institute of Technology
NW17-107
175 Albany Street
Cambridge, MA 02138
Phone: 617-253-6053
Fax: 617-253-0627
Email g@psfc.mit.edu

Dr. Amanda Hubbard
Principal Research Scientist
Plasma Science and Fusion Center
Massachusetts Institute of Technology
NW17-113
175 Albany Street
Cambridge, MA 02139
Phone: 617-253-3220
Fax: 617-258-0627
Email: hubbard@psfc.mit.edu

Dr. Hantao Ji
Principal Research Physicist
Princeton Plasma Physics Laboratory
P.O. Box 451
Princeton, New Jersey 08543
Phone: 609-243-2162
Fax: 609-243-2418
Email: hji@Princeton.edu

Dr. Ramon Leeper
Department Manager
Inertial Confinement Program
Sandia National Laboratories
P.O. Box 5800, MS 1196
Albuquerque, NM 87185
Phone: 505-845-7185
Fax: 505-845-7820
Email: rjleepe@sandia.gov

Dr. Rulon K. Linford, Consultant
Lawrence Livermore National Laboratory
1055 Aquarius Way
Oakland, CA 94611
Phone: 510-597-1017
Email: rulonkl@comcast.net

Dr. Kathryn McCarthy
Deputy Associate Laboratory Director
Nuclear Science & Technology
Idaho National Laboratory
P.O. Box 1625
Idaho Falls, ID 83415-3860
Phone: 208-526-9392
Fax: 208-526-2930
Email: kathryn.mccarthy@inl.gov

Dr. Dale M. Meade
Head, Fusion Innovation Research and Energy
48 Oakland Street
Princeton, New Jersey 08540
Phone: 609-921-2882
Fax: 609-243-3301
Email: dmeade@pppl.gov

Dr. Ellen Meeks
Vice President of Product Development
Reaction Design
6440 Lusk Boulevard, Suite D-205
San Diego, CA 92121
Phone: 925 447- 2223
Fax: 925 215-8430
Email: emeeks@reactiondesign.com

Dr. John Sheffield
Senior Fellow
Joint Institute for Secure and Sustainable Energy
314 Conference Center Bldg.
Knoxville, TN 37996-4138
Phone: 865-974-3939 (770-643-8556)
Fax: 865-974-4609
Email: jsheffi1@utk.edu

Professor Edward Thomas, Jr.
Professor of Physics
Physics Department
Auburn University
Auburn University, AL 36849
Phone: 334-844-4126
Fax: 334-844-4613
Email: etjr@physics.auburn.edu

Dr. Nermin Uckan
Distinguished Research Staff/
Program Leader for Advanced Studies
Fusion Energy Division
Oak Ridge National Laboratory
One Bethel Valley Road
Oak Ridge, TN, 37831
Phone: 865-574-1354
Fax: 865-241-8231
Email: uckanna@ornl.gov

Dr. Michael Zarnstorff
Principal Research Physicist
Princeton Plasma Physics Laboratory
P.O. Box 451
Princeton, NJ 08543
Phone: 609-243-3581
Fax: 609-243-2662
Email: mzarnstorff@pppl.gov

Dr. Steven Zinkle
Materials Science and Technology Division
Oak Ridge National Laboratory
P.O. Box 2008
Oak Ridge, TN 37831-6132
Phone: 865 574-4065
Fax: 865 574-4066
Email: zinklesj@ornl.gov

Ex-officio Members

Thomas M. Antonsen Jr.
Professor of Physics and Electrical and
Computer Engineering
Institute for Research in Electronics and Applied
Physics
University of Maryland College Park, MD
20742
Phone: 301-405-1635
Fax: 301-405-1678
email: antonsen@glue.umd.edu

Lance Snead
Oak Ridge National Laboratory
Metals and Ceramics Division
P.O. Box 2008, MS 6087
Oak Ridge, TN 37831-6087
Phone : 865-574-9942
Fax :
Email : z2n@ornl.gov

Dr. John W. Steadman
(Institute of Electrical and Electronics
Engineers)
Dean of Engineering
University of South Alabama
307 University Blvd., EGCB 108
Mobile, AL 36688-0002
Phone : 251-460-6140
Fax : 251-460-6343
Email: jsteadman@usouthal.edu