FESAC Meeting Minutes - February 1-2, 2017
Gaithersburg, Maryland

WEDNESDAY, FEBRUARY 1, 2017

Introductory Remarks – E. Synakowski

- Thanks to Mark Koepke for his service as the immediate past chair of FESAC. He was energetic, purposeful, and faced challenging tasks that demanded the most of his leadership. He faced things head on and worked with integrity. Thank you.
- The next chair is Don Rej. Welcome to Don for his leadership to FESAC. We are grateful that he agreed to serve. He will do so with industry and collegiality. It is his meeting to run.

Welcome and Opening Remarks – D. Rej

- Welcome and thanks to FESAC – all members are in attendance, including ex officio members. Thanks to the speakers and all who are in attendance at the meeting, and those participating remotely.
- Thanks to FESAC members whose terms are expiring – especially Mark Koepke. They handled four charges, a significant amount of work under Mark's watch. Committee members with expiring terms are: M. Koepke, A. Bhattacharjee, J.S. Kim, and E. Zweibel.
- Welcome to new FESAC members, who will serve through June 2019 (R. Maingi, T. Pederson, S. Reyes, and A. Wendt).
- Thanks to the continuing members of FESAC.

Office of Science Perspective – S. Binkley

Dr. Binkley was unable to make a presentation due to a meeting with the Secretary's Chief of Staff.

Dr. Bernard Bigot: The ITER Project Moving Forward

- Dr. Synakowski: Thanks for coming to this meeting in spite of the extraordinary demands of your position. We appreciate it very much.
- I was very pleased to attend this meeting a year ago. Thank you for inviting me again. I very much appreciate your support. You are generous to give me so much time for this talk.
- When I was appointed as Director General in 2015, we set clear priorities to manage the need for change. We have been working closely with the Domestic Agency heads. In particular, I thank Ned Sauthoff for how well we work together. The various items of the Action Plan 2015 have all been accomplished. We are now freezing all the interfaces, to help when we begin to assemble the components that will come from all over the world. Very important was the development of a resource-loaded baseline schedule.
- Our 2016 performance and follow-through have been very good. We achieved 19 of the 20 milestones. The last one was postponed three months when we found out that our welding was not in compliance with nuclear safety measures; we

had to re-qualify it, and we expect to complete this milestone by the end of March.

- In April 2016 there was an in-depth review by an independent group of experts. The members of this panel were very proactive. An important conclusion from the panel was that the sequence and duration of future activities has been accurately estimated. The ITER Council endorsed their report.
- At the request of Congress, Secretary Moniz was able to state (based on the report from this panel of experts): "The project achieves to be technically achievable, although significant technical and management risks remain." This was an important statement. We know that we are under scrutiny.
- On January 13, the Deputy Secretary of Energy officially approved the ESAAB review for the baseline for the U.S. Contributions to ITER project for first plasma.
- The ITER schedule is now structured as a staged approach. This reduces risk during assembly. This is the best achievable schedule that we could expect. First plasma is scheduled for 2025.
- The 18th and 19th ITER Council endorsed this updated schedule. First plasma will be December 2025, first physics experiments in 2028, and DT commissioning in December 2035.
- On June 27, the ITER Organization signed a contract with the MOMENTUM joint venture to serve as the Construction Management as Agent.
- Now we are entering the industrial phase with highly challenging specifications. Geometrical tolerances are in millimeters; superconducting power lines are cooled to extremely low temperatures, etc.
- There has been much progress on the workplace. The tokamak complex is a seven-story structure. The buildings are making much progress. The assembly building will be expanded to cover the tokamak complex, so that components can be assembled and installed. Everything has to be extremely well aligned so as to align with the cryostat penetrations. The tokamak complex sub-basement is now ready for equipment to be installed. 120,000 metal plates form its ceiling.
- Last June, a huge double overhead crane, one of the biggest in the world, was installed in the assembly hall. This crane will move the large components.
- The vacuum vessel sectors will eventually be assembled, like the ring on your finger, except that it weighs 70,000 (?) tons. Korea will deliver the tools for this assembly. The tools will arrive on site in June of this year.
- Next to the assembly hall is a building for the radiofrequency heating systems.
- The cryoplant is on its way to being erected. By June it should be ready to accommodate equipment.
- Work at the poloidal field winding facility has begun. The two smallest poloidal field coils are being manufactured in Russia and China. The others are too large and must be manufactured on site.
- The cryostat is also being manufactured on site, by India.
- This picture shows who manufactures what. Note that the ITER Members share all intellectual property. Not only in the U.S., but also in other countries, manufacturing is making good progress. So many parts are arriving on site that we have difficulty dealing with them. Korea has fully demonstrated its capability to build vacuum vessel sectors. The 1000-ton central solenoid is being built at

General Atomics in the US. Also, the U.S. has delivered an array of components for the steady-state electrical network and is expected to complete these deliveries in 2017.

- The role of ITER is emphasized by the 2004 National Academies study on burning plasmas and the May 2016 report of the Secretary to Congress.
- In September 2016, the ITER Organization held the first ITER Scientist Fellows Network Workshop. These Fellows will work on key physics R&D topics. This network has begun well, and we appreciate the commitment and engagement of these scientists.
- We support innovation in many technologies: e.g., superconductors (largest superconductor procurement in the history of industry), gyrotrons, cleaning methods (for cleaning windows between the vacuum vessel chamber and certain diagnostics), vacuum systems (ITER will have one of the largest, most complex vacuum systems ever built), robotics and remote handling (cutting edge, due to the large size of ITER and the presence of fusion neutrons), plus other areas.
- ITER is really moving forward. We are working day and night. In the morning, the birds gather on the fence to observe the progress. The progress is on schedule.

Q & A: Dr. Bigot

Q: Dr. Rej: This is very exciting work. It is great to hear about all the deliveries.

Q: Dr. Rapp: Impressive progress. What is the largest issue and risk on the path to first plasma? Would you consider performing early H-mode operation at lower magnetic fields?

A: Dr. Bigot: There are many challenges. It is hard to say which is most difficult. I focus on being on time. These are nuclear components, with strict regulation. To keep with the schedule is the most difficult issue. Assembly is also challenging, especially within the cryostat, which is so packed. We have to design piping, cabling, etc. so as not to conflict with each other. Concerning early H-mode operation, I could control that under the request from STAC. We are considering this. It depends on having an appropriate heating system.

Q: Dr. Reyes: What is your opinion of Test Blanket Modules? Is this still one of the missions of ITER, and, if so, when would they be installed during assembly?

A: Dr. Bigot: The TBM is on the agenda of ITER. It is key to demonstrate production of tritium. The ITER Council requested that we first focus on first plasma. With our new schedule, we postponed delivery of the TBM systems. But since these systems interface directly with the vacuum vessel chamber, we have to define the interfaces now, and hence we are working on this now, even though the systems will be delivered later. The early plan for TBM has been postponed. Manufacturing and assembly of the TBM system will occur during the staged phase, maybe 2025, and be complete by 2035.

Q: Dr. Pedersen: How do you keep your diagnostic windows clean?

A: Dr. Bigot: It is a surface treatment. But your question is too specific for me to answer - I will ask my staff to provide the answer to you.

Q: Dr. Groebner: Complex parts are being built around the world, which have to fit together. What is the protocol for ensuring this?

A: Dr. Bigot: We try to precisely define interfaces. Those who design a component are less keen to think about how it interfaces with other components. Second, we have a strong quality assurance and control program. We emphasize quality control. It is a main challenge that all equipment will be properly manufactured. We have set up a team that will think about assembly. This challenge is addressed through quality control. We have a common information system to facilitate this. If you have suggestions, please let us know.
Q: Dr. Neilson: You mentioned CD-2/3 baseline approval for the U.S. and acknowledged the work of the US team. It would not have been approved except for the successful tireless work of the IO team. We owe you a debt. Burning plasma is the essential next major milestone for fusion. So it is important that we do everything possible to make this succeed. We acknowledge the efforts of the IO central team and your work.
A: Dr. Bigot: I am pleased that the USIPO is working with us in an integrated manner, and so are other domestic agencies. We set up the ITER Scientist Fellows Network, and soon we will set up an ITER Operators Network. These are the people with critical experience for operating the machine. There will be a call for this. I approved the terms of reference for ITER Operators Network. People might think 2025 is far away, but I think we have to get out in front with these things.
Q: Dr. Foster: Will your construction management team be present throughout the construction of ITER, to be available?
A: Dr. Bigot: There were 20,000 activities. This is not manageable. Now we have reduced this to a manageable shorter list of activities in our master schedule. The milestones are very helpful; they push people to move together, since nobody wants to fail. The Construction Management as Agent will be during the whole lifetime of assembly construction. They will work with the IO staff and the domestic agencies. Companies are used to working together in this way, so we made a call to get this help, rather than setting up such a team by ourselves.
Q: Dr. Maingi: Thanks for your personal vigor with this project. There is concern about the tritium plant and its ability to deliver for the DT experiments in 2035. What is the timetable for the plant, will it deliver what will be needed, and can it process the exhaust?
A: Dr. Bigot: Tritium plant qualification and full design are not yet fully ready. I will soon be meeting with a company that is expert at tritium separation, albeit not on the ITER scale. Separation in a timely manner to be fed back into the experiments is a challenge. It is a nuclear component, so the regulators will be deeply involved in the qualification of this plant.
Q: Dr. Patello: It is great to see a master schedule. What risks does the protracted timeline bring to this project? For example, staffing, succession planning, materials, etc.
A: Dr. Bigot: The ITER Council requested a thorough review of risk management this year. Working with the domestic agencies, we are now reviewing the risk register. We set aside 2.0-2.5% of the total ITER budget to assess and mitigate risk. A risk meeting will be held before the end of April. The chair has been selected. All ITER Members are eager to see ITER properly operating. We have to push hard.

Therefore. I don't want to rush and face difficulty later. Safety, quality, schedule and cost—in that order. To avoid risk, we must be very careful about safety and quality.
Q: Dr. Rej: There has been a remarkable turnaround in management and achievement since the 2013 Madia management assessment report. First plasma is important, but DT is the real goal.
A: Dr. Bigot: There are still components not yet finally designed, but we have enough float to accommodate this. For example, we are not dumping the TBM; rather we are re-planning it. For first plasma, everything is now well defined. For what comes later, there is float.
Q: Dr. Patello: So the funding profile is driving the assembly, not safety or quality?
A: Dr. Bigot: Correct. We have to build the hot cell, $500M, by 2020. What mainly drives the staged approach is money, but we also integrate safety and quality requirements.

Dr. Edmund Synakowski: DOE/FES Perspective

- Dr. Rej: S. Reyes, A. Wendt, and R. Maingi need to be sworn in at 10:30 a.m. We will take a break then even if Dr. Synakowski's talk and Q&A following are not yet finished.
- Dr. Neilson's point is absolutely correct. International risk has been sufficiently reduced for the U.S. to proceed in baselining. It has been a great collective effort.
- I know there is anxiety, which comes with any change. I wish I had more details to relate to you. I don't know what is coming down the pike any more than you do. My first encounter with the new Administration team is this week Friday, to give a briefing about ITER. In a few weeks hence, the SC programs will give briefings. We are going to press our case for the science in as sharp a way as possible and will keep you informed how it goes.
- I will present a series of highlights during the past months about the program.
- Thanks to outgoing FESAC members, whose terms are expiring. Congratulations to Ellen Zweibel for being awarded the Maxwell Prize. Thanks to those members who are joining FESAC and those who are continuing to serve.
- A year-long Continuing Resolution is possible. We are allocating resources as provided, subject to the FY17 Request and possible rescissions. We are being very conservative.
- Thanks to all who participated in the Budget Planning Meetings last year, and to our industrious FES staff that coordinated these meetings. We may reach out for more systematic feedback. We also have feedback for you in terms of what we need to hear at these meetings, since there was a wide range of types of input at the meetings last year.
- Progress continues at the ITER site. With the work of the manufacturers from around the world, ITER's progress has been impressive. If you step onto the ITER site, there is disciplined intensity, choreographed with much planning. Please try to visit ITER. Many thanks to Dr. Bigot for sharing the latest on the ITER story.
- A feature of our activities last year has been responding to Congress about US involvement in ITER. This occupied much time and attention by FES, SC, and

DOE—and even beyond, since there is a coupling with other partners (e.g., Department of State, White House). In the end, Secretary Moniz's handprint on this report was very clear. He created a homework set for the next Administration, including re-evaluation of U.S. participation. ITER remains the best candidate today to demonstrate sustained burning plasma, which is a necessary precursor to demonstrating fusion energy power. We recommend that ITER remain a partner in the program. We are about to enter into dialogue with the current Administration about ITER participation - and give sensible, technically informed advice to the incoming administration. We are now entering that dialogue with the new Administration. The National Academy study will contribute to that dialogue, and the new FESAC charge will inform the National Academy study. Without higher performance by the ITER staff and the USIPO staff, the story could have been different.

- Steve Binkley could not be here this morning. I asked if he had messages to relate. His leading comment is: Be cool. We are all learning how best to proceed. There are high quality aspects of what we do, important for the nation, so I look forward to having a vibrant conversation with the new Administration, which will hopefully resonate. There is high frequency chatter in the news today, but there is a place for enduring quality to be known. There is optimism going forward with the upcoming dialogue.
- We give credit to the USIPO, Joe May, and Tom Vanek for moving forward on the process to achieve CD-2/3. Adam Cohen was also instrumental in telling a clear story about what is required - and Deputy Secretary Randall. The Acquisitions Systems Advisory Board reviewed the project. The Deputy Secretary was the ultimate approver. She signed it on January 13. Bill Cahill, the federal project director, gave a great presentation. This was the Deputy Secretary's last meeting before leaving office. She commanded the room in a professional way. The incoming Administration can do what it wants, of course, but now we have ITER embedded in the accepted framework of project management of the Office of Science. So it is in the best possible shape for the next Administration to consider, since it is now project managed. The cost range of 2008 has been revised, and now includes the entire project.
- The Secretary's report in May also directed that the NAS conduct a study. So we engaged the NAS, meeting with Peter Blair, Jim Lancaster, and David Lang. The NAS assessment is designed to have several components, according to the statement of task developed with NAS. There will be an interim report, due in October. The statements in this interim report should feed into the final report, not conflict with it. This interim report will help inform the judgment of Congress. The final report is intended to reach beyond the FES Ten-Year Perspective that was submitted to Congress in December 2015. We need to be prepared with a plan in the event that U.S. participation in ITER suffers a setback. But the two scenarios—involvement in ITER or not—are not meant to be compared.
- The new FESAC charge will feed into the NAS burning plasma study. We offer examples in the charge, but you may come up with other examples or you may decide to not deal with the examples we suggest. We are not seeking an

assessment of various types of magnetic confinement configurations. This will be a value-added contribution to the NAS study, which will continue for about a year after the report for this charge is delivered.

- Concerning the decadal study of plasma science: I understand the anxiety. But given the other NAS study, we have to plan. There are new players who seek to be involved in the Decadal Study and who might contribute. We need to refine the charge in view of the Secretarial imperative on burning plasma science. FES recommends launching this toward the end of 2017.
- Great reports came out of the community engagement workshops held in 2015. They are being used in FES, SC, and DOE to inform programmatic decisions. The final reports are available from the FES website.
- Regarding dialogue with the University Fusion Association: There are important discussions as our program undergoes change, to consider faculty development and on-campus research activities. There have been shifts within the overall university funding level. It is also important to understand how this, and other factors, play into the university concerns. DOE data indicate that total university funding has not declined. However, we look forward to working with the university community to reconcile the understanding of funding levels, and other factors that may be fundamental to the concerns.
- The DOE position is that NSTX-U is a high priority enterprise. Terry Brog and David McComas from PPPL are approaching it in a transparent manner and will speak this afternoon. NSTX-U will be offline in FY2017. We have been transparent with Capitol Hill and briefing congressional members and have discussed the DOE perspective on this. Pursuing the remedy for the situation is a very high priority for DOE.
- We are excited to participate in W7-X from its initial stages and onward. Here is a picture of Glenn Wurden inside the vacuum vessel, long before pump down. Chancellor of Germany, Angela Merkel, attended the dedication. She talked for 15 minutes about the value of fusion research, and she also talked about the value of basic scientific research in the context of a modern industrialized society. Remote participation is not a substitute for being there, but helps augment collaboration. In addition to U.S. technical prowess developed on our major facilities and through computation, the U.S. offers expertise on framing problems and driving them home to completion, and our international partners value this. Steve Sabbagh's remote work on KSTAR has all the elements: university researcher, at a national lab, participating on an overseas facility.
- FES has a positive partnership with NSF in basic plasma science and engineering. Recent workshops celebrated 20 years of the NSF/DOE partnership.
- Concerning DOE Office of Science leadership changes, we acknowledge Dr. Pat Dehmer's leadership. She is now retired, but still active. Personally, it has been a tremendous privilege to work with her; she was a terrific mentor and a consummate professional. The program has budget challenges, but she helped us work through them. Dr. Steve Binkley has replaced Dr. Dehmer.
- Al Opdenaker had an extraordinary run of 43 years of service at DOE. He also brought marvelous and rich humanity to what we do. There is great affection for you. No replacing Al! We wish you the best.

- We have two new program managers join a cadre that is a real pleasure to work with. They are closely coupled with what you are doing in the field. They are able representatives in the office on your behalf. The hallways at FES (whose color scheme leaves much to be desired) are very vibrant. Our new staff is bringing in excellent new ideas.
- The SC expectation is that FES gives four Early Career awards. But given the success of these awards particularly for gaining tenure, FES made two extra awards last year. We set aside the resources to augment the number of awards beyond the SC expectation.
- And some of the Early Career awardees have extended their reach – there are two recipients to be selected for PECASE awards. This is exceptional recognition of the quality of research being done by your colleagues.

New program managers
Kramer Akli – high energy density laboratory plasmas
Matthew Lanctot – International tokamak collaborations
Bob Bartolo – AAAS fellow – second year
Seth Aportadera – Summer intern – (from West Virginia University)

2016 early career awards from FES
Peter Bruggeman (Minnesota)
Egemen Kolemen (Princeton)
Scott Baalrud (Iowa)
Felicie Albert (LLNL)
Robert Kolainski (SNL/CA)
Devesh Ranjan (Georgia Tech)

Two PECASE winners from FES in five years
Daniel Sinars (SNL) – announced in August 2012
Stephanie Hansen (SNL) – announced in January 2017

Q&A: E. Synakowski
Q: Dr. Carter: One reporting request is the House resolution that asks for more workshops. How will that be addressed?
A: Dr. Synakowski: There is no update on the continuing resolution.
Q: Dr. Carter: I am glad to see the response to UFA concerns. Whether funding stays the same is not most important, rather research opportunities for leadership. Innovation and creativity should be used at universities to get recognition from deans.
A: Dr. Synakowski: I agree with you completely. High-energy physics has a common issue with providing leadership opportunities for university researchers. Money helps, and we wish we had more to allocate, but leadership requires more thought, not just funding.
Q: Dr. Patello: Regarding funding in a CR, you said you allocate funds based on President's request. If it turns into a full year CR, where will your budget be?

A: Dr. Synakowski: I don't know. The implications have to be clearly outlined to Congress. Then, a decision will be made. We operate at the lowest funding level, but try to do no harm. Staffers will come up with guidance for us to follow, but that has not yet happened.
Q: Dr. Neilson: There are many interesting things in the new charge. One particular thing that attracted my attention is to pay attention to the international program and advance things via partnerships. This should not be overlooked. When is final report from the NAS study due?
A: Dr. Synakowski: This is not sharply defined. The whole enterprise is about two years.
Q: Dr. Groebner: I am happy to see the FES response to initiatives. But what about ELM control?
Response Dr. J. Van Dam: We can talk offline about specifics.
A: Dr. Synakowski: DOE is serious about ITER. We should look at ideas that are enabling in the ITER era. Hence, the charge is not totally driven by the NAS study, but by what is important. It will contribute to the NAS study.
Q: Dr. Foster: Please clarify the DOE position on start of the Decadal Study. Also, please discuss funding and other agencies that will be involved.
A: Dr. Synakowski: What first gave us pause is that burning plasma science is an important element to be addressed in the Decadal Study. Hence, launching in parallel could be problematic, as said the NAS. So, the suggestion was to launch in a phased manner. That was one driver for the delay. Even if we launch the Decadal Study now, there will be a slight delay due to getting it set up. Another component in the logic is that the FESAC study, which is desired to contribute to the NAS burning plasma study, will be ongoing as well. Too much to do all at the same time. But, we want to get going on the Decadal Study as soon as possible, so to do it on a time scale aligned with the NAS interim report. Funding by other agencies for the Decadal Study is welcome. We envision launching it by the end of the calendar year.
Q: Dr. Hegna: Will the Budget Planning Meetings be a yearly exercise? Will it grow beyond the 19 meetings you had in FY 2016?
A: Dr. Synakowski: We do plan to do it this year. Whether we will expand the number remains to be seen. We are open to involving additional participants. Nineteen meetings occupied much energy of the office, so we drew the line at that number last year.
Q: Dr. Hegna: Did you get what you wanted from the budget planning meetings?
A: Dr. Synakowski: Some groups were excellent in answering the guidance letter. Some were less helpful, instead giving scientific seminars rather than budget planning information. We will recommend sharpening of the content.
Q: Dr. Dasgupta: How does inertial confinement fusion compare with magnetic confinement fusion?
A: Dr. Synakowski: ICF is a substantial effort. I don't know the overall funding level.
Response: S. Finnegan: Roughly $500M per year.
Q: Dr. Verboncoeur: SC primarily funds science, not technology. There are technology advances needed for a fusion power plant. At some point, we need to shift into a major investment in fusion technology. Is there speculation about how and when such a shift might occur?

A: Dr. Synakowski: SC had no pushback about the nature of this new charge; they regarded it as a fine and good thing. Good concepts that enable good science to be done have been supported. We have a way to go before the FES program breaks outside the charter of SC. One aspires to the day when our activities could be augmented in the way that you suggest, although even then there should be a place in SC for our science activities. Less important where the activities occur, but rather what the endeavor should be. It is hard to speculate on a timeline.
Q: Dr. Rej: Remote operation is impressive. What is the status of JT60-SA, and what is the FES plan?
A: Dr. Synakowski: A tremendous opportunity. It would be great to augment our activities there.
Q: Dr. Knowlton: First plasma for ITER is an important milestone. Dr. Moniz called it out. Is there an accepted definition of what first plasma is?
A: Dr. Synakowski: That definition exists. It involves full field capability demonstration.
Response: Mr. Joe May: The definition will be included in my presentation later in this meeting.
Q: Dr. Foster: Please clarify the NAS burning plasma statement of task, point two for the interim report.
A: Dr. Synakowski: This will update the 2004 burning plasma NAS report. It could certainly include magnetic reconnection.
Q: Dr. Maingi: You struck a balance when you discussed remote participation. I led a team to EAST in September; they promised us two shifts of operation. When they saw our positive interaction with their scientists, they gave us more time and we ended up running 150 discharges. So on-site participation is very valuable.
A: Dr. Synakowski: Correct. I just wanted to highlight the progress in remote capabilities during the past year.
Q: Dr. Maingi: JET is approaching the DT-2 campaign rapidly. What about opportunities?
A: Dr. Synakowski: The shattered pellet injector is an outstanding example. JET has been proactive in engaging U.S. scientists. I have visited JET. Their research plan has been a moving target, and institutionally they are under stress in terms of clarifying its future. We need a stable set of boundary conditions, and then we can develop a set of ideas. I know that U.S. community interest is there.
Q: Dr. Greenfield: Concerning budget numbers for USIPO in 2008 and now, you showed numbers for the construction phase.
A: Dr. Synakowski: The updated numbers are for the whole enchilada.
Q: Dr. Greenfield: The new ITER numbers go through 2035. Do they include operation?
A: Dr. Synakowski: That information will be in Joe May's presentation.
Q: Dr. Reyes: Thanks to Al Opdenaker for managing tritium blanket research. Who will handle this program management now?
Response: Dr. Van Dam: The program management is being distributed to Gene Nardella and Daniel Clark.

Dr. Terrence Brog: NSTX-U Assessment and Recovery

- This is my first FESAC meeting. Dr. Synakowski advised me to be myself.
- 10 run weeks in FY 2016
- Initial engineering and physics results were encouraging
- In June 2016, a failure of NSTX-U PF1A-U caused a shutdown of experimental operations. This led to a full review of all systems, sub-systems, and components.
- As part of the NSTX-U recovery effort, we have had a significant reorganization of the lab's management team, which began in September 2016. Management changes are: T. Brog – Interim Director, S. Zelick – Interim COO, V. Riccardo - Head of Engineering and Infrastructure, R. Hawryluk – NSTX-U Recovery Project Head, C. Neumeyer - NSTX-U Engineering Director, R. Nazikian – ITER & Tokamaks, H. Neilson - ITER Fabrication, M. Cohen – Interim CIO, A. Zwicker – Communications and Public Outreach, J. Graham - QA/QC (reporting to PPPL Interim Director). One of the issues we uncovered was that QA/QC was too far down in our management structure. We have elevated it; that position now reports directly to the Director. Also, the lab research council membership has changed significantly.
- DOE has challenged us with an FY 2017 Notable Outcome concerning the extent of condition. We will provide an interim progress report by March 31, 2017.
- The next two Design Verification and Validation Reviews (DVVRs) are the most important: next week is magnets (4 days), and following that, the vacuum vessel. The first three were successful.
- SC Deputy Director of Operations, Joe McBrearty, told us to tell him what we need across the DOE complex.
- A root cause analysis of several recent events shows commonalities. Les Hill is heading up this activity.
- We are not in a great position right now because of what happened to our machine. It will take much work. We are emphasizing urgency, but without going too fast. We will get there. PPPL is committed to a complete evaluation of NSTX-U (design, fabrication, construction, and operations).
- While we do this, we will excel in our other programs and activities.

Dr. Richard Hawryluk – NSTX-U Recovery Project

- The Upgrade project involved replacing the central magnet and adding a second tangential neutral beam. The new central magnet would allow physics studies at lower collisionality. The beam was for obtaining full non-inductive current drive.
- During the ten weeks that NSTX-U operated, we achieved H-mode very quickly, in only eight days. They were moving along nicely. However, the run ended prematurely, due to divertor field coil failure.
- NSTX-U had experienced a series of problems. Each event can be attributed to a variety of technical and procedural causes. This is why we are now conducting a broad investigation and taking such a comprehensive look at the facility, involving both Extent of Condition and also Extent of Cause.

- We found a breach in the cooling channel. Also, dry glass was found, not impregnated, which might be a contributing cause. The turn-to-turn fault was most likely due to poor vacuum pressure impregnation, plus other quality deficiencies, which led to turn-to-turn insulation breakdown.
- We need to address Design Verification and also Component Verification.
- The magnet DVVR will be four days. This is very important. After that, there will be a DVVR for the vacuum vessel and internal components—also very important.
- Based on the issues identified at the DVVRs, we will develop a corrective plan, and the external Extent of Condition Committee will then review this plan. It will be a very systematic approach.
- The first Extent of Condition review will be the week of March 6. It will be broadcast online. An interim report will be submitted to FES at the end of March. The second Extent of Condition review will probably be in May.
- We are taking a rigorous systems engineering approach, addressing all issues comprehensively, taking a deep dive into all systems.
- An interim report will be done by March 31, and a final report will be done by September 30.
- This plan will enable reliable and predicable operations.

Q&A: T. Brog and R. Hawryluk

Q: Dr. Rapp: What about root causes? Is this device specific, or procedure specific, or is it a culture problem, or just QA/QC?

A: Dr. Brog: I can give examples in all of those areas.

A: Dr. Hawryluk: This is a classic systems engineering situation. ITER went through the same transition. We should have done more. We are taking lessons learned from ITER and W7-X.

Q: Dr. Reyes: We need more data about failure rates of fusion components. This information would be valuable for ITER.

A: Dr. Hawryluk: Bigot mentioned creating an operations group at ITER. We will likely be actively engaged in that.

A: Dr. Brog: We need to do root cause on the coil set. We had already done root cause analysis for the preceding events. We need to get a little farther along with the reviews, and then we will start root cause analysis in a few months.

Q: Dr. Patello: Congratulations on contributing to the component failure database (joke)! Do any of the root causes overlap into other lab programs?

A: Dr. Brog: Not in ITER space. We do things differently for the ITER project. But we have to keep an eye on it. Our other major project is Scientific Laboratories Infrastructure (SLI), mostly construction. We had some challenges in that space a year ago; we have turned it around. We hired a project manager from Brookhaven Lab with a lot of experience, and he has helped greatly. We need to hire a few more project managers. We are setting higher expectations of engineering and QA/QC.

Q: Dr. Knowlton: What is a reasonable projection for first plasma? Secondly, do you have a plan for handling younger scientists who were collaborating on this project?

A: Dr. Brog: Many people want to know the date for first plasma. We need to get through the DVVRs before making that projection. It would be foolish to hypothesize.

A: Dr. Hawryluk: We are sensitive to young staff. We are working with DIII-D, which will add two weeks of extra run time for our staff and collaborators. We will also do more work on EAST and KSTAR. We are addressing this issue.
Q: Dr. Groebner: Have you found issues of concern in the DVVRs so far?
A: Dr. Hawryluk: Not anything like PF1A. But the big DVVRs are coming up in the next two weeks. So far we have found a number of things that affect reliability and availability. Each DVVR has generated about 100 chits.
Q: Dr. Patello: Are run weeks on DIII-D being increased, or redistributed?
A: Dr. Hawryluk: Increased.
Response: Dr. Dave Hill: There will be two weeks extra for NSTX-U work.
Q: Dr. Rapp: What about the previous faults?
A: Dr. Hawryluk: We did root cause analyses for them. But, those did not identify the issues that we are currently dealing with. They did not provide enough insight.
Q: Dr. Scime: How long did original PF1 fabrication take?
A: Dr. Hawryluk: Over a year.
Response: Dr. Rej: It is very good to bring in experts to help from other organizations, and share lessons learned with the community. My standard for project management was Jay Marx. But even he would say: been there, done that, screwed up.

Professor Thomas Sunn Pedersen - Recent Results and Near-Term Plans for Wendelstein 7-X

- For un-optimized stellarator magnetic field configuration, particle orbits can bring the particles far away from confinement. W7-X has been optimized to get rid of this problem: passing particles still have no issue, and magnetically trapped particles now precess on contours that are very close to the flux surfaces, thus leading to neoclassical confinement.
- The W7-X magnetic coils will operate at 2.5 T (but could be pushed up to 3.0 T).
- Measurements confirming magnetic surfaces were a collaboration with the U.S.
- We did not have very high ambitions for OP1.1. We just wanted to get plasma operation experience and integrated commissioning, and we attained all the goals for this operations phase.
- We used ECH cleaning and extended the pulse length from about 10 ms to about 50 ms.
- The confinement scaling in W7-X is consistent with that in tokamaks.
- Concerning the CNT stellarator at Columbia University, I operated this before. It was not optimized, so particle orbits were lost. But, with application of an electric field, the particle orbits remain confined.
- E X B drifts are important compared to drift velocities if the electrostatic energy is large compared to the thermal energy. But alpha particles have very high energy, so their confinement is a problem since an ambipolar electrostatic field will not be sufficient.
- We plan to have a pellet injection system in OP2, through a collaboration with NIFS and ORNL, with a repetition rate of 10 Hz for 30 minutes. We will have low field side injection (since high field side injection would be too tight).

- For diagnostics: 12 must-have systems, 23 should-have, and 11 might-get diagnostics.
- The TDU scraper elements from PPPL and ORNL have been delivered to IPP Greifswald.
- The successful first campaign produced many interesting and encouraging results.

Q&A: T. Pedersen
Q: Dr. Groebner: Numerical simulations show 50 keV ions will stay confined. Will you test that experimentally? How will you do these measurements?
A: Dr. Pedersen: The full optimization of orbits requires high beta, and that requires high density, which we will not yet have. So, we plan to use a three-frequency ICRH heating scheme developed by MIT.
Q: Dr. Groebner: What about optimizing at low beta?
A: Dr. Pedersen: At low beta, there is more ripple. We need beta of at least 3%.
Q: Dr. Maingi: You have nice comparisons in tomography of heat flux and temperature. What are your plans to convert temperature to heat flux?
A: Dr. Pedersen: The highest heat flux so far is 4-5 MW/m^2. It is a thesis project.
Q: Dr. Maingi: The radiation fraction is quite high (60%). Did you not expect that? What about target radiative power fraction, and how will you bring it down?
A: Dr. Pedersen: I was pleased that we did not have higher radiation fractions in OP1.1, which was only an initial phase. For future operations phases, we will do more aggressive wall conditioning—e.g., boronization and discharge cleaning, and maybe add pellets or dust grains of boron. We will have substantially cleaner plasmas in the next operations phases.
Q: Dr. Rapp: How do you define run time allocations, and the role of collaborators in program definition? Are you open to opportunities in program management?
A: Dr. Pedersen: We have a call for proposals. We have a one-team approach, so collaborators are treated as members of our groups. We look first at the merits of proposals, then later count and see if there is some institutional balance. Half of our task force leaders are non-IPP scientists. Half of our scientific program committee members are non-IPP. We don't do direct counting of who did what on which day; we hope everyone feels involved and that they are getting enough machine time.
Response - Dr. Neilson: Your collaborators agree with you.

Mr. Joseph May – First Plasma Sub Project Baseline for U.S. Contributions to ITER Project
- In his report to Congress, Dr. Moniz asked for a baseline to be done in FY17, but then he accelerated the request so that it would be finished before he left office in January.
- Because we had exceeded the original cost range by more than 50%, we had to get approval for an updated CD-1.
- We also did CD-3 because we were already doing long-range procurements for fabrication and construction.
- The DOE Deputy Secretary is the Project Management Executive.

- The OPA review was favorable. It recommended a broader cost range for CD-1 and inclusion of more contingency.
- The First Plasma subproject shall cost no more than $2.5B, with CD-4 to be achieved by December 2027. The revised cost range for the total U.S. contribution to the ITER project is now set at $(4.7-6.5)B, with CD-4 in the time frame of March 2034-2038.
- The toroidal field superconductor from the U.S. to the EU, and the steady state electrical network, will be completed this year.
- The operations phase is funded separately. It is not included in CD-1 revised.
- The high-level definition of first plasma is the ITER operational phase that includes (1) integrated systems testing at low power, and (2) achievement of first plasma and integrated systems testing of magnets at full field.
- We have baselined only the first subproject, for First Plasma. After revisiting the Secretary's decision to stay in ITER (for the FY18 budget), we will start baselining the second subproject.
- Subproject #1 for first plasma is approximately 45% complete. The actual cost to date is $885M (as of September 2016). 19% of hardware components have been delivered. There is a 46% cost contingency (about $100M) on work to go for this subproject.
- To complete the subproject by 2027 at a total cost of $2.5B, we need a certain funding profile. Note that it does not include the cash contribution to fund the ITER Organization operation. But we need to provide that annually.
- Being bureaucrats, we needed two memos (not just one) for approval. All of the signatories except Paul Bosco have moved on with the advent of the new Administration,

Q&A: J. May:

Q: Dr. Neilson: When you showed the annual funding profile, does $2.5B include cash contributions?

A: Mr. May: No. In the ITER budget from Congress, there are two line items: one for hardware and another for cash. We are on the hook for a certain amount of cash; we did not pay our cash in FY 2016. The report, being specific to hardware only, has made us nervous.

Q: Dr. Verboncoeur: In the timeline you showed, what is on the critical path and what drives the risks?

A: Mr. May: It is hard to say since these are coupled procurements. The heating systems are outliers. If we gave USIPO all the money upfront, they could complete the hardware faster. Instead, the USIPO has had to feather the procurements. We put together this annual funding profile with a certain pain threshold; we stopped at $250M/year.

Q: Dr. Greenfield: If subproject #2 starts in 2013, its cost will overlap that of subproject #1.

A: Mr. May: Yes. But it will start at under $50M/year and then ramp up. The two subprojects are intertwined.

Q: Dr. Maingi: Slide 7 states that the Disruption Mitigation System has a capped contribution. Is that only for that system? It is a critical system for ITER.

A: Mr. May: Yes, the money is capped. It was an arm-twisting by Motojima of FES to agree to take on this scope of work.
Response – Dr. Synakowski: My arm is fine. We wanted to cap the risk.
A: Mr. May: If we hit the cap of $25M without the system yet completed, the IO can take it and finish it, or give us more money to finish it. We get no credit for doing this system, different from other systems.
Q: Dr. Foster: If we can make 2025 first plasma, will it cost less?
A: Mr. May: If we could bring it in sooner, it would cost less since most of the money in the final years is actually contingency. Then, those funds would be pushed to the SP-2 budget.
Q: Dr. Pedersen: So it could be done faster if more money were provided sooner. But that would not necessarily speed up the overall ITER project.
A: Mr. May: Correct.
Q: Dr. Greenfield: At discussions at STAC meetings, U.S. procurements do not appear on the critical path until the tritium processing system.
A: Mr. May: Correct.

Dr. Donald Rej: Discussion of New FESAC Charge

- Let's do Public Comments today, just in case Steve Binkley can join us tomorrow.
- The charge letter to Don Rej from Steve Binkley is presented.
  The letter thanks Rej for accepting the task of chairing the Fusion Energy Sciences Advisory Committee (FESAC) at this important time for the Fusion Energy Sciences program. There is considerable work ahead that will require thoughtful, informed advice regarding the future of fusion and plasma sciences in the United States. It is necessary that the U.S. program be in the best position possible to lever the science and technology that will be advanced through burning plasma research on ITER. It will be important that we are involved in pursuits that give us the best chance of enabling the knowledge gained through ITER research to be effectively levered towards attractive fusion energy. Dr. Binkley is requesting that FESAC identify the most promising transformative enabling capabilities for the U.S. to pursue that could promote efficient advance towards fusion energy, building on burning plasma science and technology. The considerations should be broad, addressing advances that may occur in areas of engineering, technology, and science. The report should be submitted to the Director of the Office of Science by October 1, 2017.
- Let's seek clarifying questions. Then, we will seek your opinions about technical expertise that will be needed on the FESAC charge subcommittee. Then, let's discuss possible topics to include in the charge. Then, finally let's talk about reference documents that could be useful.

Some clarifying questions to resolve any ambiguities:
Q: Dr. Pedersen: Concerning high Tc superconductors, are you only thinking of scoping out new experiments to use these?
A: Dr. Synakowski: No, only to consider the technology itself, not its potential use. The importance, of course, is driven by potential new machines. But, we want to know the usefulness and feasibility of the technology itself.

Q: Dr. Cauble: Is this charge limited to work relevant to ITER, or more broadly to work done in the past 20 years? Dr. Bigot mentioned a number of ITER innovations, but they were mostly related to scale.
A: Dr. Synakowski: ITER was mentioned to frame the activity. Assume a successful ITER program; then, we want to be positioned to move aggressively. What kinds of technology could we have in place to enable that?
A: Dr. Cauble: It is a question of temporal framework.
A: Dr. Synakowski: But, the technology developments could occur faster than the success of ITER, and we would be interested in that as well.
Q: Dr. Greenfield: The NAS study will consider both with and without ITER participation. Is there an expectation that the subcommittee should also consider the latter case?
A: Dr. Synakowski: FESAC is being asked to consider developments that would enable fusion to proceed smartly. ITER is mentioned to frame the discussion and because the DOE position is to remain in ITER.
Q: Dr. Patello: So, if we assume a successful ITER, may we assume that technologies necessary for ITER will also be successful?
A: Dr. Synakowski: Yes, unless you think otherwise.
Q: Dr. Groebner: Some concepts would follow ITER. Are you looking for something that would change the landscape in a big way?
A: Dr. Synakowski: The DOE imperative is to get to the burning plasma class of science. Then one is open to the possibility of developments that might change the landscape for what you think a tokamak reactor would look like, or a stellarator, or an FNSF, or a liquid lithium machine. Broad, looking outside the box.
Q: Dr. Reyes: The charge language reminds me of the 2015 strategic plan charge to FESAC, in which I was involved. We heard talks about liquid lithium, but we were given a budget limitation and told to prioritize. This charge does not consider funding constraints.
A: Dr. Synakowski: Comments about the level of effort that would be required are welcome. So yes, it is different.
Q: Dr. Pedersen: Is Q=10 the measure of "success" for ITER, or is it steady state?
A: Dr. Synakowski: It does not matter. The particulars of the ITER outcome are not important.
Q: Dr. Neilson: The third paragraph is the meat of the charge. So, we are to make a list, with level of maturity assessments. This is very exciting since this charge encourages us to broaden our thinking beyond science to include technology and engineering. As fusion people, we should welcome this license. I caution about the word "transformative." A working fusion system will be the integration of many cutting edge high tech solutions. It is difficult for one thing to be transformative. The difference between a tokamak and a stellarator is not transformative, in my opinion. What would be transformative is what would jump the field forward. We will need creative thinkers, but also subcommittee members with informed skepticism.
A: Dr. Synakowski: Don't focus too much on what is meant. Let's just talk. We can even augment the intention.

Technical areas and needed expertise:

Q: Dr. Patello: The third paragraph lists capabilities, and the fourth paragraph mentions R&D. Are these separate?
A: Dr. Synakowski: R&D is the work required to bring the capabilities to fruition. It could be broader than just application to tokamaks and stellarators.
Q: Dr. Rapp: So R&D and the timeline?
A: Dr. Synakowski: However you wish to express that.
Q: Dr. Greenfield: R&D to develop the technology is included, but not R&D to use the technology.
A: Dr. Synakowski: Correct.
Q: Dr. Greenfield: So, R&D to build high-temperature superconductor is included in the charge's scope, but not building a device to use it?
A: Dr. Synakowski: Correct.
Q: Dr. Rapp: The charge spreads over other areas of the Office of Science. For example, materials, exascale computing.
A: Dr. Synakowski: Yes. HEP, NP, etc.
Q: Dr. Rej: Appendices in the 2015 strategic planning report of FESAC have useful information for this charge.
Response: J. Rapp: Energy converter systems might also be a good topic. Energy storage, too.
Q: Dr. Wirth: How should we organize the subcommittee? Should we keep it to members with fusion background and ask for briefings from other program offices and experts, or include them as members?
A: Dr. Rej: Good question. The big constraint with this charge is the submission date. We need to work fast to constitute the subcommittee to deliver a report to FES in nine months.
Response - Dr. Carter: It may be best to have experts come in for briefings, but keep the subcommittee membership mostly from our field. It will be challenging to organize input from other communities.
Q: Dr. Greenfield: Expertise is determined by the examples. But what might be other additional areas to consider?
Q: Dr. Sugiyama: Is there any limit on the timeline that it might take for development of these technologies?
A: Dr. Synakowski: No. But if it might take 30 years, it might be difficult for the subcommittee to intelligently comment.
Response - Dr. Groebner: We definitely want fusion people on the subcommittee who understand the problem. But, maybe for materials, we should bring on some experts so that the panel can understand briefings on this subject.
Response - Dr. Foster: We can use the web to get input for the subcommittee. Is the charge also asking for implications for facilities, e.g., high neutron flux facilities?
A: Dr. Synakowski: Facilities that help development and bring these concepts forward, yes. Confinement facilities, no.
Q: Dr. Neilson: For subcommittee members, try to choose those who will get the job done on time and who will reach out to the community so the report can withstand criticism. Get people with a long time horizon (i.e., experienced, long term stake in the program): in other words, not too old. We need to make an intelligent selection of topics. We should get input through white papers and workshops.

A: Dr. Rej: We might reach out to organized groups in the fusion community—BPO, VLT, UFA, NAS Plasma Science Committee. Leadership in those groups might have tools.
Response - Dr. Neilson: But don't neglect the fusion engineers.
Response - Dr. Rapp: We also need input from outside the fusion community.
Response - Dr. Greenfield: Speaking for the BPO, we will do what we can to help.
Response - Dr. Lumsdaine: We all represent various scientific societies and can help.

Ways to get input:
Q: Dr. Rej: Short five-minute presentations of white papers did not work well with past FESAC charges.
Response - Dr. Carter: Get white papers, then down select for presentations. Also, solicit certain people to participate. A five-minute rapid-fire approach is less useful.
Response - Dr. Groebner: Agree.
Q: Dr. Patello: So, we need to get the list straight. Should we use white papers or a survey? For some areas, like additive manufacturing, we could get an expert to brief us on the status, feasibility, and development needs. Forming the list will direct what expert testimony we need.
Response - Dr. Maingi: The timescale for this charge is about the same as what we had for the community workshops. A face-to-face meeting will need to be several days, but we could hold sessions in parallel since the topics are distinct.
Response - Dr. Greenfield: I had a similar experience with the Transients Workshop that I led. But, an important logistical difference is that we must cast our net far beyond the FES program. We will need people on the subcommittee who can identify good sources of information, and then we will need to persuade these people to talk with the subcommittee.
A: Dr. Synakowski: Broader than just technology: e.g., exascale computing.
Q: Dr. Rej: Are there items on this list that you think we should ignore? Are there other disruptive technologies to make fusion more reliable and available?
Response - Dr. Rapp: Energy conversion for nuclear systems. Also, energy storage, which is important for a true steady-state fusion device.
Response - Dr. Groebner: For the tokamak, current drive, to make it steady state and make it less susceptible to disruptions. But, perhaps this is less transformative.
Q: Dr. Neilson: Simulation of multi effect systems, such as blankets, functional structures. How far can we get with simulations?
A: Dr. Carter: I have a long list. Tritium breeding, PFCs, heating and current drive technology, high Tc, manufacturing techniques to make the next stellarator easier, spin polarization, liquid metals, etc…
Response - Dr. Reyes: Materials and licensing for advanced reactors. We need out of the box thinking. We don't have final solutions if a fire occurs in a reactor.
Response - Dr. Greenfield: In control of transients, we should have good ability to control them for ITER to be successful. But, it is not clear if these techniques will translate beyond ITER. So, we need thinking about ELM control and disruption control.
Response - Dr. Rej: It will be a challenge to keep the subcommittee size below 50 persons! I ask each of you to recommend thought leaders who could serve on the

subcommittee. Don't hesitate to nominate yourself. Include a short sentence explaining why each person you suggest would be appropriate. Please do this by next Monday, February 6. Send your input to Dr. Knowlton and me.

Public comments were presented today (instead of February 2, 2017– due to extra time in the schedule (as Dr. Binkley was not available to present today).

Dr. Donald Rej - Public Comment:
Dr. David Mauer - I represent the University Fusion Association. I am the elected President.

- I would like to inform FESAC about difficulties and widespread concern in the MFE portion of the academic community.
- I bring to your attention the UFA white paper, which makes several recommendations: engagement at user facilities, the need for long term FOAs, a vision for the university community to evolve and grow, and the scientific need for small-scale, on-campus facilities.
- Difficulties include alarming faculty hiring trend prospects, which threaten the long- term viability of academic fusion programs.
  We hope FESAC will address these concerns. We have started fruitful discussions with FES.
- University research has been and is critical to fusion research, not just training students.
- These are challenging times for UFA and all of us.
- There is a broader context for these issues: Every program in the FES portfolio is under some level of stress. The university issues discussed in the white paper are not easy to discern. They have been building for years; they are multi-institutional. We had a round table in September 2015 and a Forum in December 2015 to discuss these issues in a broader context. That led to my working group, which produced a better accounting and a quantitative statement about the situation.

COMMENTS:

- Dr. Cauble: Given that MFE has reached a steady state and will probably remain so for a while, is it surprising that there are non-positive funding trends?
- Dr. Maurer: You think that the domestic program will be static?
- Dr. Cauble: It won't go up a lot.
- Dr. Maurer: It has not been static for on-campus experimental activities. If we want to pursue ITER, we need a strong base in MFE at universities, otherwise ITER is not viable.
- Dr. Verboncoeur: From an administrative perspective, universities look for funding to support junior faculty. If funding is static, they will not support an area. This is an important aspect to keep in mind.

- Dr. Maurer: That has impacted hiring prospects, even at institutions with a past history of fusion involvement.
- Dr. Sugiyama: In past years, we have been helped to survive by low interest rates. The price of graduate students and post docs is going up. Please consider this for the future.
- Dr. Rapp: Looking long term, ITER will operate sometime. ITER will open up fellowships. Starting junior faculty takes a while. Also, we will need to replace retiring faculty.
- Dr. Maurer: Some new hires have occurred. But two of the 14 institutions we surveyed count for two-thirds of all new hires. Age demographics show a high average age. Who will be left to argue for new fusion faculty?
- Dr. Pedersen: I support the UFA analysis. In Europe, there has been more support for the non-direct-ITER part of the program. The U.S. is suffering a bit. There is a lack of perspective for university hires. Departments are reassessing whether to stay in fusion. Can we find a solution that will not require extra money? The U.S. is certainly supporting fusion. Is there a scheme for universities to be more directly involved in the channels where money flows?
- Dr. Rej: Your white paper has articulated that well, e.g., leadership positions on user facilities.
- Dr. Maurer: We see this as part of the university portfolio that must grow. A separate working group was formed in August to address precisely this question. Mike Brown of Swarthmore is leading it. It includes both lab and university representatives. When done in the early spring, we plan to visit FES and discuss it and move forward.

Dr. Synakowski: The conversation last week at FES was very educational. My primary point therefore is one of gratitude. This is a complex issue. We would like to see funding grow, but it is more than that. It is about university cultures, and success includes both sides engaging with leadership, faculty and students. We are looking forward to working with you and having a sensible conversation.

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The meeting was adjourned 5:04 p.m and will reconvene at 8:30 a.m. tomorrow morning.

THURSDAY, FEBRUARY 2, 2017

Professor Joel Fajans – Plasma Physics and Antihydrogen

- Researchers have wished to study properties of antihydrogen since at least the 1980s.
- Interest in antihydrogen stems from tests of fundamental physics.
- Concerning parity and charge-parity violation, the immortals have been wrong before.
- For the whole of 2010, the ALPHA project trapped 38 antiatoms. Now they can trap 50 antiatoms in only twenty minutes.
- In 2012, ALPHA started hyperfine splitting measurements of positron spin flip frequency in antihydrogen.

- In 2013, ALPHA started measurements of the gravitational acceleration of antihydrogen.
- In 2016, we measured 1s to 2s transition energy of antihydrogen. This is important as a test of the charge-parity-time invariance paradigm.
- The connection to plasma physics is through the use of a Penning-Malmberg trap to synthesize antihydrogen by mixing antiproton and positron plasmas in the trap. We use a Surko-style positron accumulator; we need about 20 million positrons. The antiprotons come from the AD at CERN. Then, to trap antihydrogen, we need to apply additional magnetic fields. The bulk of the ALPHA effort is producing the antihydrogen. It involves manipulating nine high field magnets, with millions of fine adjustments. Most of the difficulties with trapping antihydrogen are directly related to plasma physics. Reproducibility is absolutely key in these experiments.
- Antihydrogen has a small magnetic moment. We take advantage of this to trap it in a magnetic minimum. We use mirror coils to create an axial minimum, and then octupole coils to create a radial minimum. These extra magnetic fields, especially the octupole, affect plasma confinement because they violate the O'Neil plasma confinement theorem for non-neutral plasmas. The quadrupole field is no good; the plasma distorts into a bowtie shape and is quickly lost. So, we went to an octupole magnet, and PIC simulations do show distortions and some particles are lost, but the confinement is much better. The octupole was the essence of the ALPHA trap. With an octupole, the plasma forms a bread-loaf shape.
- When antimatter particles escape confinement, they annihilate, so we can exactly determine where this happens and how many.
- Application of rotating voltages to sectored electrodes helps to control the radial profile of antihydrogen plasmas, but only if mixed with electrons. Antiprotons, being heavier than electrons, are pushed toward the outside.
- The octupole creates a shallow magnetic well of only about 0.54K or 40 micro eV. Hence we had to produce very cold positrons. Positrons cool by cyclotron radiation. But the cooling is arrested at about 100 K; it does not cool to the temperature of the walls. We are unsure about the reason.
- Non-neutral plasmas are almost perfect—but they do expand. Expansion converts electrostatic energy to kinetic energy, thus leading to self-heating. We need temperatures much below 100 K. So we use evaporative cooling, in which the hottest positrons are allowed to escape. But, this is a temporary effect: as soon as we finish the evaporation cycle, the plasma starts to heat up again. So, we need to operate within the first second or so. Recently, we have been exploring cavity cooling as another technique.
- A graduate student figured out a method for stabilizing the electrons. It led to an immediate improvement in trapping. It also allowed simple mixing, rather than needing to use auto-resonance.
- Is antihydrogen charge neutral? This test is a novel physics experiment. First we searched for deflection of antihydrogen atoms by an electric field. The bound obtained this way was better than the previous superposition technique. So we went to another technique, well known to plasma physicists, namely, stochastic

acceleration (well known in nonlinear dynamics whereby a charged particle is accelerated by a randomly-timed varying electric field). High-energy physicists on our team were unfamiliar with this technique and resisted. It took two years. It gave a much more accurate measurement, in 2016.

- Plasma physics, funded by NSF/DOE Partnership, has been the key to the success of the ALPHA collaboration's effort to trap and study the properties of antihydrogen atoms.

Q&A: Dr. Fajans

Q: Dr. Maingi: You showed calculations for quadrupole and octupole fields. What about using even higher order fields?

A: Dr. Fajans: They would be better, but get diminishing returns from the fact that they would need lose too much of the magnitude of the field going into the plasma. The field would be too localized near the wall. The octupole was a good intermediate solution. We have competitors, who said that the octupole was stupid, but now they just installed one.

Q: Dr. Maingi: You talked about a failed moderator. What is that? Also, it looks like you have better stability, but fewer particles.

A: Dr. Fajans: We are testing tradeoff for the sake of stability. A failed moderator has to do with positrons passing through tungsten, but now we find that solid neon is better—but solid neon eventually degrades. So, we have to replace the neon moderator.

Q: Dr. Pedersen: Could measurements of charge neutrality and of gravity interfere with each other?

A: Dr. Fajans: That is a good point, not properly appreciated. We comment on it in our first paper (2014). You are correct that we needed to worry about it. Fortunately we have the answer.

Q: Dr. Foster: How did you measure the transition? Do you have to measure the whole Balmer spectrum?

A: Dr. Fajans: We now get on the order of 15 or so antihydrogen atoms trapped per trapping attempt. Now we can stack them, 15 at a time. There appears to be no limit. So far, we have gotten up to 50, at which point the magnet started to overheat. We use a laser to measure the transition. It is easy to get the laser cavity to work. The laser mirror can get poisoned.

Q: Dr. Groebner: Are you using theoretical models to assist your research?

A: Dr. Fajans: The decision to use the octupole was based on PIC code results. Also, simulations and theoretical results showed that using an auto-resonance technique would not work too well; fortunately, a collaborator showed that antiprotons would act coherently. So the effort is mostly experimental, but there is significant input from calculations. Jonathan Wurtele's graduate student ran simulations showing that simple mixing would work effectively, and experiments then demonstrated that.

ACCOUNCEMENT BY DR. REJ:

Some public comments were made yesterday afternoon. If you would like to make a public comment, please inform me before the break.

Dr. Harriet Kung – Perspectives from the Office of Basic Energy Sciences

- Dr. Synakowski: Thank you to Dr. Harriet Kung for advancing our field and promoting the physical sciences, and for taking the time to talk to us today about the BES enterprise.
- Dr. Kung: A unique aspect of the BES program is the large suite of scientific user facilities, probably one of the world's largest such collections.
- We have actively engaged our advisory committee to help us chart our course: science for discovery, science for national needs, and national scientific user facilities.
- Science for Discovery: Let me highlight two grand challenge reports, published in 2007 and 2015 by BESAC. These reports emphasize the transition from empiricism/observation to actually being able to exercise control.
- Science for National Needs: We produced many Basic Research Needs (BRN) workshop reports, concerned with the general theme of assuring a secure energy future.
- We established Energy Frontier Research Centers (EFRCs) in 2009, after a decade of BRN planning, and after unsuccessful attempts with single-investigator awards. A BESAC report called for a new modality, namely, funding dream teams at $(2-5)M/year for five years each. In the next round, we switched to four-year terms, with new solicitations every other year, for more rotation. This was very impactful in terms of publications, awards, patents, student careers, and benefit to companies.
- We track publications with line-circle diagrams, which shows that there are many partnerships.
- We need to communicate the outcomes of the EFRCs. We just released a booklet about this. Communication of the importance of basic energy research is critical to show that we are contributing to the DOE mission.
- EFRC workforce development is successful. We have a newsletter, a network of early career staff, a video contest, 1001 word contest, and a poetry of science contest.
- We have a technical highlight about healing of defects in silicon carbide by means of ionization (viz., ionization-induced annealing).
- The U.S. trails other countries in the development of computational codes for chemistry and materials science. In 2015, BES started funding teams to develop open source research codes and data for the design of functional materials.
- We have two Energy Innovation Hubs: One of them focuses on discovery science to enable next-generation batteries (beyond lithium ion) and energy storage.
- We have two facilities of particular relevance to fusion energy sciences: (1) The Linac Coherent Light Source at SLAC. The Matter in Extreme Conditions (MEC) end station is in the far hall. The MEC represents a very strong partnership between BES and FES. (2) The High Flux Isotope Reactor at ORNL. The principal mission is neutron scattering, and also isotope production for industry and medicine, as well as materials irradiation experiments (in which FES participates).

- BES is proud to support world-leading facilities. To maintain leadership, we engage BESAC in setting priorities; we are mindful of international competitors. We take a long view (ten years) in planning, scoping out technical specifications for the future, community vetting, fitting in the funding profile, and looking for opportunities. Dr. Pat Dehmer, my predecessor as SC associate director for BES, was a master in getting projects ready.
- The 2013 BESAC report led to redirection of LCLS-II and APS-U. The report said directly that both projects were on the wrong track. It was a painful decision for us to make to redirect both laboratories in shifting their scopes. However, that decision has enabled us to maintain world leadership.
- We appreciate the trust of the community in our job as stewards of the program.

Q&A: Kung

Q: Dr. Wirth: FESAC might ask your office for assistance with its new charge. Is your perspective ensuring support for university research?

A: Dr. Kung: The university community is integral to our program. BES sends 45% of its research funding to academic institutions. We are sensitive to instrumentation needs. In the EFRCs, a large fraction of them is led by universities. The university community is vital.

Q: Dr. Verboncoeur: At my university, I am dealing with a project that was renewed, but conditions were added for international collaborations regarding export control. It requires that DOE approval be received, and that has taken several months.

A: Dr. Kung: This could be at the Chicago office. I am not aware of anything in our office. I will check.

Q: Dr. Rapp: Is funding for BES sufficient to maintain international leadership of signature facilities?

A: Dr. Kung: At this point, yes. But, our leadership is being challenged. Light sources are being developed at a number of facilities in other countries. How do we maintain facility leadership without skimping on support for research? Hence, rigorous vetting by the community and BESAC is vital. We cannot compete with every new facility coming online; we have to strategically select our position. So far, we have been successful.

Q: Dr. Sugiyama: How much of university support is intentional by BES or was it historical?

A: Dr. Kung: Historically, our university support has always been strong, albeit not quite at the 45% level. In recent years, when we have competed universities and labs together for the EFRCs, we have seen a trend of strong university proposals that are supported through the peer review system. Also, we made sure that core competencies at labs are not lost. We keep a keen eye on these balances. But, we are blind in terms of quality, with respect to labs and universities. Both are quite complementary.

Q: Dr. Neilson: A fusion system has plasma, and then materials in a challenging environment. Historically, we are strongly plasma-centered. But in the future, and with the new FESAC charge, we have to think beyond the plasma to issues that are

underpinned by materials science. Does the system allow stronger partnerships with FES?
A: Dr. Kung: Opportunities exist. We can co-fund investigators. There could be more opportunities for leverage. Possibly, knowledge being generated by the EFRCs could be relevant to fusion. DOE formed an advanced material working group recently; inviting FES to join would be beneficial—it was an oversight on my part not to contact Dr. Synakowski. Linda Horton is co-leading that group. To start with, this group represents a good information exchange opportunity.

Dr. James Lancaster – Overview of Plans for the National Academies Committee on a Strategic Plan for U.S. Burning Plasma Research

- In May 2016, DOE released the report, entitled: "U.S. Participation in the ITER Project."
- We worked with the Plasma Science Committee (PLSC) and BPA members from the plasma science community.
- We prepared a white paper, and held several rounds of discussion with DOE.
- We submitted a proposal to DOE in August 2016.
- The project was funded by DOE in December 2016.
- A committee of about 15 experts (from the plasma, fusion science and engineering communities, other physics disciplines, policy experts, and international researchers) will be formed to address the charge from DOE.
- The committee will meet about six times over 20 months.
- There will be significant engagement of the domestic and international plasma science and fusion research communities, including site visits and town hall meetings.
- The committee will study the state and potential of magnetic confinement-based fusion research in the U.S. and provide guidance on a long-term strategy for the field.
- The committee will prepare a final report.

Q&A: Dr. Lancaster and Mr. David Lang:
Q: Dr. Rapp: Do you consider input from industry about magnetic fusion research?
A: Dr. Lancaster: We will have a focus on research, but we know that industry should be a factor.
Q: Dr. Rapp: Including Tri Alpha?
A: Dr. Lancaster: I imagine.
Q: Dr. Lynch: I am on the Plasma Science Committee. What about overlap of various reports? We have three on the table: the FESAC charge, the Decadal Study, and the Burning Plasma Study. The last two have different audiences, but much overlap. How do you run parallel studies?
A: Dr. Lancaster: We have done that, albeit on only an occasional basis. Communication channels will exist. There might be common members on both committees. They might meet together and deliberate together. There is a provision in our proposal about overlap.

Q: Dr. Lynch: There was discussion yesterday about the FESAC charge and its emerging definition. Where is the division of labor, and how do we hand it over to the burning plasma study?
A: Dr. Synakowski: We have talked with David Lang about this. My view is that FESAC will get into a greater degree of detail than NAS. We regard the FESAC charge and the report as value added for the NAS study, not in conflict with it.
Q: Dr. Lynch: Let me poke a little harder. An NAS study convenes input from the community; it has rules about collection of public opinion. Will FESAC provide information and hand it off, or will this be a freestanding community white paper effort?
A: Dr. Synakowski: It has standing value on its own, and that is how we initially constructed the charge. But, it should contribute to the burning plasma panel as well. It should interleave fairly well.
Q: Dr. Lynch: But, there is time urgency for the FESAC report to be used by the NAS. Perhaps, that caused me to misunderstand its purpose.
A: Dr. Synakowski: The FESAC charge is worthwhile even if the NAS study were not occurring. Yes, we might relax the time constraints if it were not for the NAS study.
Q: Dr. Lynch: FESAC could possibly just collect private information, and leave town halls and solicitation of public comment to the NAS study.
A: Dr. Synakowski: I am skeptical of modifying the way that FESAC subcommittees usually operate.
Q: Dr. Carter: The second phase (final report) of the NAS study has two scenarios, but it will come after a potential decision on ITER by the Congress. Might a Congressional decision cause the second charge to be modified?
A: Dr. Lancaster: Possibly, but right now the goal is to provide a strategy for DOE to use, regardless of what happens. Congress and DOE might make another interim decision. But, if a final decision to leave ITER were made, it might now matter to handle that charge.
Q: Dr. Hegna: How does one consider budget implications, but not make recommendations?
A: Dr. Lancaster: The panel needs to recognize budget constraints in what it might recommend. But, it will not go from there and make specific budget requirements.
Q: Dr. Hegna: Will there be prioritization in the conclusions?
A: Dr. Lancaster: That will be up to the committee.
Q: Dr. Neilson: This charge has been out for a few months. The community has parsed every sentence. How can we help you? The community is trying to organize itself to help.
A: Dr. Lancaster: Providing the interim report in fairly short order that addressed important issue means that the committee will first have to decide how to collect input—e.g. town halls, white papers. We have run many such studies.
Q: Dr. Neilson: When could you give us some guidelines?
A: Dr. Lancaster: We plan to form the committee in a month. We will have the first formal meeting a few months later, but will meet informally before that.

No additional public comments were received.

The meeting was adjourned at 11:04 a.m.

Certified as Correct by:

Dr. Stephen F. Knowlton, Acting FESAC Chair

Aug. 14, 2017

Date