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Pulsed Power Peer Review Committee Report

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

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Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185-1190

ABSTRACT

As part of meeting the GRPA (Government Performance and Results Act) requirements and to provide input to Sandia's annual Performance Evaluation Assessment Report (PEAR) to the National Nuclear Security Administration in FY2004, a 14-member external review committee chaired by Dr. Alvin Trivelpiece was convened by Sandia National Laboratories (SNL) on May 4-6, 2004 to review Sandia National Laboratories' Pulsed Power Programs. The scope of the review included activities in high energy density physics (HEDP), inertial confinement fusion (ICF), radiation/weapon physics, the petawatt laser initiative (PW) and fast ignition, equation-of state studies, radiation effects science and lethality, x-ray radiography, ZR development, basic research and pulsed power technology research and development, as well as electromagnetics and work for others. In his charge to the Committee, Dr. Jeffrey P. Quintenz, Director of Pulsed Power Sciences (Org. 1600) asked that the evaluation and feedback be based on three criteria: 1) quality of technical activities in science, technology, and engineering, 2) programmatic performance, management, and planning, and 3) relevance to national needs and agency missions. In addition, the director posed specific programmatic questions. The accompanying report, produced as a SAND document, is the report of the Committee's finding.

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PULSED POWER PROGRAM REVIEW

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Forward

Planning for this review began in early 2004 and included meetings on logistics, committee membership, and committee charter. The following members of SNL Organization 1600 participated in the planning: Jeff Quintenz, Lisa Mattox, Keith Matzen, Doug Bloomquist, Dillon McDaniel, Craig Olson, Ed Southwell, Wil Gauster and Polly Owens. The Committee was supplied with the following reference documents: "Charge to the Panel," booklets of the unclassified vugraphs presented, and six recent publications – "Hot Dense Capsule-Implosion Cores Produced by Z-Pinch Dynamic Hohlraum Radiation," J. E. Bailey et al., Physical Review Letters Vol. 92, Number 8 (February 27, 2004); "Radiation symmetry control for inertial confinement fusion capsule implosions in double Z-pinch hohlraums on Za)," R.A. Vesey et.al., Physics of Plasmas (May 2003); "Recent experimental results on ICF target implosions by Z-pinch radiation sources and their relevance to ICF ignition studies," T.A. Mehlhorn, et al., Plasma Physics and Controlled Fusion 45 (2003); "Self-consistent, two-dimensional, magnetohydrodynamic simulations of magnetically driven flyer places a)," R. W. Lemke, et al., Physics of Plasmas (May 2003); "Near-absolute Hugoniot measurements in aluminum to 500 GPa using a magnetically accelerated flyer place technique," M. D. Knudson, et al., Journal of Applied Physics (October 1, 2003); "Density-functional calculations of the liquid deuterium Hugoniot, reshock, and reverberation timing," M. P. Desjarlais, Physics Review B68 (2003).

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Sandia National Laboratories
Pulsed Power Program

External Review Panel Report
May 4 – 6, 2004

I. Executive Summary

The External Review Panel reaffirms the positive findings of the 2000 and 2002 reviews regarding the quality of Sandia's Pulsed Power Program. Significant progress has been achieved across the entire spectrum of the Program. In the Dynamic Response of Materials area, the progress and technical performance is outstanding. The technical excellence of research is the signature of the entire Program. The use of Z as a tool to improve the reliability of the stockpile is well thought out and executed. The management of the Program remains focused on its mission and on fulfilling the needs of its customers.

Some of the Panel members who participated in the 2000 review recall that in that year the Program faced the issue of survival. The following 2002 panel remarked that the program "appears to be revitalized." Today, from the perspective of 2000, the turnaround in the Program's stability is remarkable. The Program has added the Petawatt Laser to its range of activities and is actively considering an initiative in the Z-pinch driven Inertial Fusion Energy. Sandia's contribution to stockpile stewardship – its primary mission -- is recognized as outstanding.

The Deuterium equation-of-state work is a very eloquent example not only of the tight coupling of such work to the stockpile stewardship mission but also of the value of, as well as the need for, the availability of multiple techniques to address key scientific issues.

Two other impressive scientific accomplishments are also worthy of note, both achieved using wire-array pinches on Z: significant thermonuclear neutron yield from capsule implosions driven by the dynamic hohlraum approach; and the demonstration that x-ray intensity pulse-shaping of the sort needed to drive fusion capsules to ignition and high yield is possible using nested-wire-array Z-pinches. These accomplishments exemplify the great value of the Z-machine to the advancement of stockpile stewardship science. Other experiments have demonstrated the importance of the Z-machine to the Weapons Physics class of experiments.

The Panel was pleased to hear statements from DOE during the meeting endorsing the Pulsed Power Program. The Panel recognizes that it is difficult for DOE to increase its funding for this program in the short term. The result is that the Program's contributions to the Stockpile Stewardship Program are constrained by a lack of funds. Additional funding would benefit the Stewardship mission, particularly since the Program provides an opportunity for experiments that are precursor and/or complementary to those on more expensive facilities.

The Panel reaffirms its endorsement of the long-term high-yield goal as relevant to the Program's core mission, and recommends that Sandia continue to develop its rationale for a high-yield facility.

The Panel notes that two enabling activities have received additional emphasis in the past two years. They are the Petawatt Laser and the Z-Pinch driven Inertial Fusion Energy. The 2002 Panel recommended that the intended expansion of Petawatt be undertaken only after a strong programmatic need had been established. This need has been demonstrated. At this time the Petawatt Laser activities are rather well structured within the Stockpile Stewardship applications.

The Inertial Fusion Energy (IFE) activities are based on a Recycling Transmission Line power plant concept. Dr. VanDevender reported that Sandia is considering a proposal for internal funding in support of the IFE effort. The Panel cautions that these activities should not unduly divert attention away from the principal programmatic missions.

There is good collaboration in radiography. In fact, this part of the program demonstrates broad synergy with other national laboratories, industry and Russian scientists, with collaboration from AWE, Bechtel NV, MRC and PSD. Sandia has played a critical and unique role in down-hole radiography in U1a at the Nevada Test Site. This work is an excellent example of applying Sandia's Pulsed Power core capability to solving applied problems for Stockpile Stewardship.

The overall balance of the program between programmatic elements should be assessed periodically. For example, more Z-shots would be beneficial. However, some of the demand might be reduced through increased use of modeling, using both single- and multi-dimension simulation codes.

The Panel had the opportunity to interact with some of the new hires and from this interaction, although limited, received unanimous feedback that reflects both professional enthusiasm and work satisfaction.

The Campaign 4 collaboration represents an outstanding template for synergistic use of DOE inertial fusion facilities and platforms. The Panel encourages Sandia's efforts to continue to work with the other Laboratories to create and maintain a spirit of complementary cooperation. It is in Sandia's interests to work constructively to help ensure that NIF succeeds in meeting its goals. There is evidence that this, in fact, has been Sandia's practice.

The Panel recognizes the intense competition for LDRD funding. However, the LDRD funding in the Pulsed Power area that could amplify and enhance Z-pinch physics opportunities appears anomalously small.

II. Observations and Advice on the Specific Questions to the Panel

A. New Staff Working Environment

Are the working environment and the mix of applications in Pulsed Power at Sandia conducive to attracting the best new hires? Are we providing our new staff with ample opportunity to advance their careers and integrate into the ongoing programs? What changes, if any, would you recommend?

The Panel's interaction with new Pulsed Power staff presented a uniformly positive picture. These employees are excited, appear to enjoy their work and are committed to Pulsed Power and to Sandia National Laboratories.

The Panel learned that new staff members are assigned productive work while waiting for their security clearances and, during this period, they have frequent lunches with other staff members. The Panel commends the Pulsed Power management for its enlightened and pro-active approach toward its new staff.

The Panel heard no stories about why new staff leave… they say this doesn't happen.

Some employment search support for staffs' spouses, those who are new to the Albuquerque area, would facilitate the relocation experience for new staff. While this may exceed expectations, the benefit in easing hardships and concerns may exceed the resource costs while, at the same time, assist in recruiting.

Several new hires noted that an offer of a staff position, rather than a postdoctoral position, was an important factor in their choice of Sandia.

B. Additional Applications and Actions for Pulsed Power

Beyond our present research focus in inertial confinement fusion, material dynamics, secondary assessment, and nuclear survivability, are there other applications of short-pulse, high-current pulsed power generators that we should explore? If so, what are your recommendations for initial actions?

Given the importance and success of the Program's current work and the oversubscription of the facility, this Panel recommends that the Program stay the course. While there may well be additional applications for short-pulse, high-current pulsed power, it is suggested that it is important to remember that it is usually better to do a few things well. The success that the Pulsed Power effort enjoys is the result of extensive hard work and dedication. An expansion of activities should not occur at the expense of quality and timely completion of work in progress. With all this said, the Panel endorses Sandia's current practice of allocating a small portion (~10%) of its shot allotment to exploratory or high-risk concepts so as to encourage creativity and opportunity of discovery.

C. Inertial Fusion Energy

There has been some recent funding for Z-pinch driven inertial fusion energy activities but, in the current climate, continued funding is by no means certain. In view of such uncertainty, have we developed the appropriate technical strategy and the appropriate balance on key issues in the existing research program? Please advise.

As a result of a FESAC meeting the Sandia ICF effort was encouraged to prepare a plan based on successful outcomes of the Z and ZR programs that could be advanced to an energy generating system. The Inertial Fusion Energy (IFE) plan, as presented, has many challenges. This year's appropriated funds will allow some systematic examination of some of these problems. Future progress in IFE will depend not only on the work being proposed under the plan, but also on the level of future government funding.

The Panel had the opportunity to interact with Dr. J. Pace VanDevender, Sandia Vice-President for Science, Technology and Engineering and discuss with him his views on the issue of Z-pinch driven IFE. In addition, the Panel heard a 90-minute presentation on the Sandia's IFE concept based on recyclable transmission lines (RTL).

The Panel was impressed with the level of dedication and creativity addressing the many complex problems identified in the IFE presentation.

Perhaps the two most important steps that should be undertaken to develop a solid scientific and technical base for Z-pinch-driven IFE are to determine the practical limits to the power flow in a mass-producible transmission line, and the demonstration that the Linear Transmission Driver (LTD) can be used to drive high-power Z-pinches. The first of these might be tested in a proof-of-principle experiment in a few years on ZR that could lead to a high-yield facility that would use easily replaceable, relatively low-cost transmission lines. This could make such a facility much more attractive because of a greatly increased shot rate for a relatively small increase in project cost.

Potentially, if LTD technology is viable and cost-effective for IFE, it could reduce both the construction and operational costs of a high-yield facility. The Panel believes that NNSA should consider the potential benefits to the main line NNSA mission that could be derived through the Congressionally mandated IFE program.

D. Possible Strategies to Increase Available Z-Shot Time for Basic Science and for Universities

Given the oversubscription of Z for the nuclear weapon mission and the evolving capabilities of Z-Beamlet and Z-Petawatt, can you recommend strategies to employ that would help to provide facility time for basic science applications and more collaborations with universities?

Sandia is a national security laboratory with a critical national mission. To the extent that involvement of and collaboration with universities and other research entities is consistent with the laboratory's efforts in meeting its mission requirements, such activities should be encouraged and implemented. Even so, these facilities are not like the "user facilities" of the Department's "Science" laboratories. The Z-pinch program does not currently have a user

facility mode of operation and the involvement of faculty or students in aspects of the program should be consistent with programmatic needs, Departmental guidance and the need to train and recruit scientists and engineers that might become involved in the program.

It appears that a good opportunity to involve outside collaborators in the Pulsed Power ICF and High Energy Density Physics Program -- without significantly impacting the programmatic mission of Z and ZR -- exists with the activation of the Z-Beamlet and Z-Petawatt lasers. These systems have a shot capacity that exceeds the needed shots for backlighting of Z. Sandia should consider utilizing these lasers as a mid- energy facility to involve university researchers as well as users from the other NNSA labs. Z-BL/PW can serve as a platform for basic HED science experiments more effectively than Z given that machine's oversubscription. The proposed Z-PW consortium could be a good start toward developing an outside use plan on the lasers.

For those Z-pinch tests that do not require exclusion of people without appropriate clearances, it might be advantageous to invite qualified investigators to be involved in experiments or theory involving observations using existing diagnostic lines. In addition, such investigators might develop or improve diagnostics of benefit to the program. For instance, Z can provide off-Hugoniot data as well as data that can be compared to Quantum Molecular Dynamics (QMD) calculations. Sandia's expertise in QMD appears to be a "natural" area to attract academic and industrial community participation. The traditional means of communication of scientific results together with creating new opportunities for outside investigators to have access to plans and programs should be considered and implemented.

E. Double Shift

The capabilities of Z (and ZR) and the demonstrated contributions to the nuclear weapon program have resulted in continuing over-subscription of the facility. We are advocating a ramp up to full double-shift operations for more optimal utilization of Z. Do you endorse this plan?

Yes! The rapid growth of demand and need for the capabilities of Z has led to a backlog that needs to be reduced. There are specific stockpile stewardship needs that should be addressed as a matter of national interest. The Panel did not observe "fat" in other parts of the Pulsed Power program that could be reduced to provide funds to support double shift operation. Therefore, a clear and unambiguous case for full double shift operation based on the backlog should be documented and forwarded to the appropriate NNSA program office. It would seem like the unanticipated success of Z has led to a situation where the lag time in the budget process has worked to constrain the available time on the facility to the point of creating this serious backlog. The overall benefit to NNSA programs resulting from the funding to go to full double shift would be a most cost effective step.

III. Additional Technical Observations and Inputs

A. Inertial Confinement Fusion

Inertial Confinement Fusion (ICF) is at the core of the Pulsed Power program. The experiments in which neutrons produced by capsule implosions using the dynamic hohlraum approach were very well done and are very exciting, as indicated by acceptance of a Physical Review Letter on the subject. Experimental agreement with code predictions of how much the neutron yield should be reduced by adding trace xenon gas to the hydrogen fuel, to test the effect of radiation cooling, is also encouraging. The Panel was impressed at the volume and quality of the backlighting data acquired using the Z-BL backlighting diagnostic. These data clearly illustrate how use of laser driven backlighting has augmented Z's capabilities. They also point to the potential importance of backlighting in the future with the Z-Petawatt laser at shorter x-ray wavelengths.

Since inception, a lack of pulse shaping capability has imposed severe constraints on achieving high gain implosions. However, the recent demonstration that x-ray pulse shaping can be achieved using nested-wire-arrays with different inner and outer wire array masses is an important development and should be pursued. The few-percent foot pulse for 10-15 ns and few ns rise time to peak power achieved with nested arrays is very attractive for driving capsules.

As has been the case for many years now, the diagnostics that have been developed for use on Z are generally excellent and indicate great skill in working in a difficult environment. In particular, the strong support by the preceding Panel (2002) for Z-Beamlet has been fully justified by the reported results. (Recent publications in the Physical Review Letters and other journals speak to the quality of the work.)

Demand for shots continues to exceed supply. Adding more shots would be desirable and cost-effective, while optimization of currently available shots would benefit by more analyses and pre and post-shot modeling. For example, more modeling of potential shell break-up due to hydrodynamic instabilities for the high in-flight aspect ratio (IFAR) low- temperature drive implosions is recommended.

The increased integration of Sandia's work into the larger national ICF program that we have seen over the past two years has been beneficial. The Sandia capability being developed to drive NIF-scale ICF capsules will undoubtedly contribute to achieving the national goal of ignition. The Panel encourages Sandia to support the 2010 ignition goal for NIF and urges NNSA to provide appropriate support.

Again, we reiterate our support for activities that lead to the high-yield, long-term objective of the Sandia pulse power program.

B. Z-Pinch Physics

Recent work presented on Z-pinch physics was intriguing, and showed that there is still much to learn about Z-pinch mechanisms, energy coupling to the plasma after implosion on axis, and wire x-ray yield scaling with pulse duration. These phenomena have a strong effect on the scaling of the dynamic hohlraum to ignition and high yield, as well as on weapons effects simulation capabilities. Therefore, Z-pinch physics deserves high priority on Z.

C. High Energy Density Physics

The Program's high energy density physics is outstanding work that supports weapons physics and efforts to achieve ignition. The progress is impressive and the contributions valuable to the National program. The Panel recommends that Sandia's understanding of the weapons program requirements for high energy density physics be more closely aligned with the need for, and precede planning of, future facilities.

There is excellent exploitation of the detailed, quantitative and experimental results of the Double Hohlraum designs. This work should be continued.

The Panel applauds the application of diagnostic development and encourages efforts to continue to improve precise measurement techniques. This work should also be of substantial benefit to the NIF.

D. Petawatt Laser

A hard x-ray backlighting capability greatly improves Sandia's ability to perform quantitative measurements for both the stockpile stewardship program and ICF.

The Pulsed Power Program has provided good mission-need justification for this capability. In addition to diagnostic uses of a petawatt-class laser, the possibility to study Fast Ignitor-relevant laser and electron transport physics is intriguing, particularly if ultimately coupled to a high density core provided by Z/ZR. However, the Panel recommends that a detailed analysis be performed on the specific system requirements before commitment to such a project. For example, could some fraction of a petawatt meet most needs, rather than a full PW or multi-PW capability? The cost ramifications for increasingly powerful systems are large. This is a complex and not well understood area in which increased collaboration with others could bring great benefit. For instance, AWE has access to time on the PW laser at the Rutherford Appleton Laboratory in the UK and collaborative experiments could scope out this issue. Gratings used in the pulse-compression system are both costly and sensitive to damage. At this time, large gratings with sufficient damage threshold for a robust PW capability on Z-Beamlet do not exist. Gold grating technology can only be used for lower powers, and hence implies very large areas. The Panel anticipates that more robust grating technologies will be available in the future. This argues for building to need, and delaying a decision to upgrade to a more capable system when the need is demonstrated.

The Panel endorses the plan to transfer the Nova petawatt hardware and endorses that path to sooner-rather-than-later performance. A plan to accomplish this was not presented at this meeting, although the Panel hopes that this exists or is being prepared. The Panel suggests that it is in NNSA's interests to expedite the transfer of the Nova equipment to Sandia.

E. Dynamic Response of Materials

The Panel is impressed with the set of scientific results presented for the use of Pulsed Power in the dynamic characterization of materials. Given additional resources, more investment in this area is both appropriate and needed.

The Sandia group has made a major contribution by developing new techniques on Z for accurate equation of state studies: the Isentropic Compression Experiments (ICE) to provide continuous compression curves that were previously unavailable at megabar pressures; and magnetically launched flyer plates for shock Hugoniot experiments at velocities and pressures that significantly exceed those available with gas guns. As one Panel member put it, "They are sitting on a gold-mine" with these capabilities. The impact on Campaign 2 has already been significant. In particular, the work on the equation of state of deuterium underscores the critical need for multiple techniques to examine critical weapons physics issues. Another Panel member said, "…the deuterium EOS work is the 'Poster Child' of this program."

The ramp wave loading experiments are providing new and important insights into dynamic material response.

Continue the effort on possible collaboration with LANL and LLNL on SNM.

F. Electromagnetic Pulse Program

The Panel was given a presentation on the electro-magnetic pulse (EMP) activities in the Program. The work is interesting, of high quality, and obviously relevant to the stockpile mission. The management decision to fit this effort into Pulsed Power appears to be the correct choice.

G. Secondary Certification

The Z Machine is the most powerful tool in the world for studying radiation physics and secondary hydrodynamics. This makes it the premier HEDP facility for many Stockpile Stewardship experiments. The Campaign 4 collaboration represents an outstanding template for synergistic use of multiple laboratory facilities or platforms that needs to be encouraged. The hydrodynamic physics collaboration is to be commended in particular for successfully transferring a previously laser-based experimental platform to Z, and for applying improved x-ray radiography developed in-house. The radiation physics collaboration has struggled over the past two years to develop a dynamic hohlraum configuration sufficiently robust to support routine experiments and it places heavy demands on the backlighter diagnostic. Recent successes in deploying the dynamic hohlraum and backlighter in other technical areas and the planned addition of a high energy short pulse radiography facility bodes well for future experiments at Z and ZR in this important area of weapons physics. The case for accessing

new radiation physics domains when transitioning from Z to ZR could benefit from more detailed peer review.

IV. Format of Meeting

The format of the meeting - technical and programmatic talks interspersed with several opportunities for Executive Session - worked well. Even though the total length of the meeting seemed burdensome, the breadth of material to be covered, together with the importance of the topic, made it necessary to have this much time available. The meeting was almost always short of time for the presentations and the executive sessions, yet a more explicit review of the ICF and high-energy density system requirements during the early overview talks would have been beneficial for the Panel. Improvements could be made in ensuring adequate time for Panel questions and discussions with the presenters. At times, it seemed as if the presenters had made no allowances for this needed exchange, filling their entire timeslot with viewgraphs. A possible alternative arrangement would be to reduce the number of topics chosen for presentation. It seemed anomalous that an experimentally-driven program would not involve any tours of experiments. Such tours allow for poster sessions and facilitate more contact between the Panel and bench scientists.

V. Acknowledgements

The External Review Panel of the Pulsed Power Center of Sandia National Laboratories commends Jeff Quintenz, Director of the Center for his exceptional leadership and direction of the program. The Panel thanks Dr. J. Pace VanDevender, Sandia Vice President for Science, Technology and Engineering, for his contributions and discussion. We also appreciate and applaud the enthusiasm and careful preparation of the management and staff of the Pulsed Power Center. The presentations and interactions were uniformly professional and informative. The Panel recognizes the hard work that went into this meeting and appreciates the effort. The Panel thanks Lisa Mattox and Cari Gerlock for providing quality arrangements and meeting support.

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Appendix: Meeting Agenda

Monday, May 3, 2004

6:00 p.m. Evening Reception ……Managers/Panel
Hilton Garden Hotel, Enchantment Ballroom

7:30 p.m. Panel meets with chair

Tuesday, May 4, 2004

7:30 a.m. Bus leaves from hotel ……All
Hilton Garden Hotel

7:45 a.m. Badging ……..…All
Sandia Badge Office

8:00 a.m. Continental Breakfast ……All
TAIV, 962/1402

8:30 a.m. Welcome ……... Pace VanDevender

9:00 a.m. Overview of Pulsed Power Sciences……..…….Jeff Quintenz

10: 30 a.m. The HQ Perspective ……..Chris Keane

10:45 a.m. Break

11:00 a.m. Executive Session ……Panel

12:00 p.m. Lunch…… Panel/New Staff
962 Auditorium Lobby

1:00 p.m. High Energy Density Physics Overview…….Keith Matzen

2:00 p.m. Inertial Confinement Fusion…….Roger Vesey
Mike Cuneo

3:00 p.m. Break

3:15 p.m. Inertial Confinement Fusion (Cont.)…….Jim Bailey
Bob Campbell

4:15 p.m. Executive Session ……Panel

5:30 p.m. Depart to Hilton Garden Hotel …….All

6:30 p.m. Dinner – El Pinto ……..……Speakers/Panel

Wednesday, May 5, 2004

7:45 a.m.	Bus leaves from hotel ……..All	Hilton Garden Hotel
8:00 a.m.	Continental Breakfast ……..……All	TA IV, 962/1402
8:30 a.m.	Inertial Fusion Energy ……...Craig Olson	
10:00 a.m.	PW Laser Development and Collaborations ..……John Porter	
10:30 a.m.	Break	
10:45 a.m.	Executive Session ……Panel	
12:00 p.m.	Lunch	
1:00 a.m.	Radiography …….John Maenchen	
1:30 p.m.	Dynamic Materials……...…Chris Deeney	Marcus Knudson Clint Hall Paulo Rigg
3:00 p.m.	Break	
3:15 p.m.	Nuclear Survivability (X-rays and EM)…….……Mark Kiefer	Chris Deeney
4:15 p.m.	Executive Session ……..……..Panel	
5:30 p.m.	Depart for Hotel …….……..All	Hilton Garden Hotel
6:30 p.m.	Dinner …….……..…Panel/Deputies/DMTS	Landry's

Thursday, May 6, 2004

7:45 a.m.	Bus leaves hotel ……..……	All Hilton Garden Hotel
8:00 a.m.	Continental Breakfast ……..……	All TA IV, 962/1402
8:30 a.m.	Secondary Assessment Technologies……..…….	Rick Martineau Bernie Wilde
9:30 a.m.	Executive Session ...…….	Panel
11:15 a.m.	Out Brief …….…….	All
12:00 p.m.	Adjourn/Lunch Available ……	All

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