Sandia National Laboratories

Pulsed Power Program

External Review Panel Final Report

April 23 – 25, 2006

I. Executive Summary

Background:

Since the last review in 2004, some changes have been instituted in the processes associated with certain programmatic reviews. In that regard, Sandia's Science Advisory Board (SSAB) has been established to manage the overall review process and to prepare the various reports that are to be provided to senior management. The SSAB comprises a collection of scientists and engineers with experience relevant to Sandia's research programs. The chair of a given external review panel will also be a member of the SSAB and will report to it on the results of the annual programmatic peer review.

To assure a proper degree of independence in programmatic peer reviews, Sandia has asked the University of Texas to help manage and organize certain aspects of the review process. This is the first review conducted under this new arrangement. Review committees are to provide both the intensive advice to program managers to aid them in their efforts to guide the technical aspects of the program. They are also expected to report any evidence that would suggest that the programs are not being conducted in a professional manner with respect to progress toward expected goals, that effective cost controls are not in place, or if proper attention is not being given to health, safety, and environmental requirements.

Pulsed power is an important and increasingly useful tool for stockpile stewardship. Since the last external review two years ago there has been significant progress in pulsed power ICF, science campaigns (Dynamic Material Properties, Primary Assessment Technology, and Secondary Assessment Technology), and engineering campaigns (Nuclear Survivability and Electromagnetics). In addition there are extensive collaborations within Sandia, with Livermore National Laboratory, with Los Alamos National Laboratory, and with universities and industry. The Z-facility refurbishment and the upgrade of the Z-Beamlet facility are scheduled for completion in FY07. Even though the requests for use of the pulsed power capabilities at Sandia continue to grow, and the demand exceeds present resources, funding for utilization of many facilities could be significantly reduced for FY07 based upon '07 budget actions to date. This would be a serious problem and certainly would influence what can be accomplished. In light of the decision to conduct these reviews annually, and to shorten the time devoted to each review, the elements of the ICF activities were not reviewed this year, but will be the focus of next years review.

Closeout:

At the closeout, brief summaries of some of the principal observations, advice and recommendations of the panel were presented to members of management and the technical staff from the perspective of outlining what impressions were gained. The closeout also gave those who made the presentations an opportunity to correct any misunderstandings that the panel might have had. In addition to thanking all those who worked to make the presentations, the final remark by the Panel was, "There is a surplus of good news, but it isn't always obvious how to capitalize on this good news."

The three-tiered structure of the charge to the panel was used as the organizing principle for the closeout briefing by the panel following the presentations and it is also used in the main section of the report.

A. For General Performance and Results Act (1993) and for input to Sandia's annual Performance Evaluation Process, provide an assessment of:

- **Relevance to national needs and agency mission:**
  Pulsed Power Sciences (PPS) has some unique capabilities that are being applied to National Security needs, especially the Stockpile Stewardship Program of the NNSA. The Panel finds that there have been extraordinary scientific and technical achievements that advance National Security interests.

- **Quality of science, technology, and engineering:**
  The PPS research activities that we reviewed are now solidly at the "World Class" level of quality.

- **Program performance management and planning:**
  Although we concentrated our brief review time on science and technology issues, it is our view that the program management is generally excellent. However, we believe that allocation of Z/ZR shots would benefit from a more formal planning process that is transparent, and we urge Sandia management to find ways to relieve the administrative burden on the scientific staff as much as possible.

B. For Sandia's Science Advisory Board and for input to Rick Stulen, Sandia Vice President for Science, Technology and Research Foundations, provide an assessment of:

- **National and international trends that may affect the program:**
  This is difficult to answer definitively. From the Panel's perspective it seems likely that there will be continuing budget stress due to international commitments related to national security. This means that funding for the Stockpile Stewardship Programs is going to remain constrained. As a consequence, it is going to be imperative to stress the value of the program elements such as materials measurements and the uniqueness of radiation source capabilities. It will be equally important to make clear that the perception of duplication with

other Inertial Confinement Fusion programs is not accurate, and that high yield is an important goal.

- **Opportunities that should be explored:**
  This question led the panel to suggest that the Pulsed Power Sciences program look for opportunities to collaborate with programs in the Department's Office of Science and to explore ways by which "shot rate" could be increased, thereby decreasing the cost per shot.

- **Culture and environment of the organization (e.g., innovation, creativity, collaboration, etc.):**
  Based on lunch meetings with several members of the technical staff, without the presence of management, the panel observed that the existing culture and environment fosters a strong spirit of innovation and creativity. The motivated and dedicated individuals in the Pulsed Power Sciences Center that we met strongly believe in the value of what they are doing. Even so, there were the usual concerns that "nonproductive work is alive and well at Sandia." Such activities should be reduced as much as possible for members of the technical staff.

C. For the Pulsed Power Sciences Center, please address the following issues:

- **Assess the strengths of pulsed power science for National High Energy Density Science/Stockpile Stewardship Program (HEDS/SSP) applications:**
  The people, their creativity and innovation, are one of the key strengths of the program. There is no evidence of any impediment resulting from the "not invented here syndrome," but rather a willingness to consider all ideas and to collaborate with scientists from other laboratories and academia.
  The dynamic materials work is excellent, as is the development of new and improved diagnostic capability, especially that associated with the Beamlet laser. Weapon radiation effects capabilities are unique, and remain an essential part of certification. The 3D electromagnetic codes, and radiography capabilities are essential tools.

- **Assess the importance of the unique and complementary uses that the refurbished Z facility can provide for the National HEDS/SSP community both before and after NIF is fully operational:**
  Over the next four years, with ZR and Omega as the only large-scale high energy density platforms, there will be many unique contributions that can be made. In addition to the broad range of HEDS/SSP applications that can be addressed, research on ZR will be able to make important contributions in preparation for experiments on NIF. Beryllium melt and fill-tube hydrodynamics work are two examples of research areas in which ZR will be able to make important contributions to the National Ignition Campaign.

  After NIF is operational, ZR will continue to have unique dynamic materials studies capabilities, and will continue to provide energy rich environments for

stockpile stewardship tasks, as well as radiation effects testing capabilities that are still needed for weapons certification.

- **Comment on the risks to the health and vitality of the National HEDS/SSP based on the present funding profile for Sandia's ICF and high yield program for FY2007 through FY2012:**

  Forecasts of funding for ZR operations suggest that it will be totally inadequate to meet programmatic needs. However, the "one-landlord concept" should be reinforced.

- **Comment on the utilization of Z at 200 (full single shift), 300, and 400 (full utilization) shots per year to meet the needs of the National HEDS/SSP:**

  Even at full [single shift] funding, the demand from the Campaigns will exceed the capacity that might be expected of ZR to be able to provide. In the national interest it would be irresponsible to reduce the shot limit below 200, and Sandia management should vehemently oppose any such reduction. A $20 M reduction (which is anticipated to support only 50 ZR shots per year) is a disaster for the SSP program. It would destroy innovation in addition to greatly impeding progress. High yield is a legitimate long-term goal and would also be adversely affected by such a reduction. With temporary funding reductions, saving people is more important than saving hardware.

- **Assess the importance of investing in pulsed power technology development to the future of the National HEDS/SSP and comment on the research plan:**

  Pulsed power technology is a suite of core, inter-related theoretical, experimental, and engineering skills and capabilities that are used to address a wide variety of applications, including the design and optimization of high-current accelerators, compact radiographic sources, and pulsers for dynamic material properties research. Corporate investment in the skill sets required for pulsed power technology development should be encouraged to protect this unique national capability. Pulsed power science at SNL has unique facilities and provides essential stewardship capabilities.

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

The same organizing principle is used in this section as for the Closeout. The questions as presented to the Panel are reproduced and the observations by its members are collected under the appropriate heading for that question. These observations are in addition to and expand on the brief summary made at the Closeout.

A. For General Performance and Results Act (1993) and for input to Sandia's annual Performance Evaluation Process, provide an assessment of:

- **Relevance to national needs and agency mission:**
  The extraordinary accomplishments of the Sandia Pulsed Power Sciences (PPS) Center make it an important contributor to the NNSA's Stockpile Stewardship mission through several research areas, including inertial confinement fusion, weapon physics, development of pulsed radiography and weapon effects simulation capability and the development of high yield capability should NNSA decide to pursue it if and when the NIF achieves ignition. Several of the capabilities provided by PPS to the stockpile stewardship program and other national security missions are unique to the Sandia program.

- **Quality of science, technology, and engineering:**
  The research in the programs reviewed is "world class" and state of the art. The Technology and Engineering in Pulsed Power Sciences (PPS) at Sandia has been outstanding for decades, but in the last ten years, the science is catching up and now merits equal accolades. It is amazingly good in several areas, such as dynamic materials studies and x-ray diagnostics in a harsh environment.

- **Program performance management and planning:**
  Without the excellent leadership of the program since the last review, it is unlikely that the reported progress would have been possible. The review panel two years ago commented with concern on the low percentage of LDRD funding in the program's portfolio. In this regard, the Pulsed Power program has done an excellent job of cultivating and increasing its LDRD funding from only about 1% to nearly 6% of the funding in program 1600 ($1.4 M to $7M). This is significant not because of the funding level itself, which is quite modest on the scale of the program's $117M /yr budget, but because it indicates a strong vitality within the program and a high level of creativity. The management of 1600, as well as the Vice President for Science and Technology, should be highly commended for their very active cultivation of LDRD within the program. However, we believe that allocation of Z/ZR shots would benefit from a more formal planning process that is transparent and also assures that this particular program resource is effectively utilized. We also urge Sandia management to find ways to relieve the administrative burden on the scientific staff as much as possible.

B. For Sandia's Science Advisory Board and for input to Rick Stulen, Sandia Vice President for Science, Technology and Research Foundations, provide an assessment of:

- **National and international trends that may affect the program:**

  For the next several years it will be impossible to divorce Federal programs in any area from political changes that are not far off. It appears likely that two issues will continue to receive considerable attention, the Federal budget deficit and the hostilities in Iraq, regardless of political outcome later this year or in 2008. It can be expected that budget reductions will be needed to address these issues. A reduction in current hostilities will almost certainly result in reduced DoD budgets, which usually affects research budgets first; however budget cuts are never universal. Another international development that will be of substantial importance will be the expected shortage of oil supplies. This will lead to examination of all potential energy sources, and may lead to increases for research into advanced energy production.

  The national stockpile stewardship program is embarking on a process of transformation, both of the stockpile and the nuclear weapons complex. Key to this is consolidating redundant capabilities and establishing a suite of unique capabilities that will be shared resources to the laboratory community. Pulse power technology and the Z machine represent just such a unique capability.

  Further budget cuts resulting from the U.S. budget deficit and the cost of the war in Iraq are possible at any time. Furthermore, there is a concern that, in spite of all of Sandia PPS's successes, the NNSA will shift money from the Sandia program to the NIF National Ignition Campaign (NIC) if there is a concern at NNSA that the NIC needs it for timely achievement of ignition. Sandia management should be prepared to vigorously defend against this possibility.

  High yield is not yet an NNSA mission. It would be an enormous benefit to PPS if a mission need for high yield were established.

- **Opportunities that should be explored:**

  Anticipated tight budgets for the next several years make it imperative that the most reliable, least expensive alternatives for each component of U.S. nuclear weapons (under SNL's purview) be sought. Detailed analyses should be done to determine when a new component is ready and if and when it should replace an old one. This must include design, testing, static and dynamic stress, survivability and maintenance. All plausible scenarios must be examined. It is clear from the presentations given that the pulsed power facilities at SNL (extant and planned) are extremely well suited to these tasks. In fact, in most cases, they appear to be uniquely suited. Those with authority over the programs within the DOE and elsewhere need to be reminded of this capability. Further opportunities exist to examine and test more of the weapon components under relevant extreme conditions using pulsed power machines.

  As part of this transformation process, NNSA has stated that large facilities will be operated as national user facilities. Sandia has the opportunity to help define what this means and to establish the model for the user facility process by being

proactive in this regard at both Z and Z Beamlet. However, these facilities are not like the "user facilities" of the Department of Energy's "Science" laboratories. 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. 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 who might become involved in the program.

As oil prices rise and remain stable at relatively high levels, energy sources other than fossil fuels become economically feasible. There are potential pulsed power applications in clean coal burning, and tar sands oil extraction and refining as well as to ICF. Other possible contributions of pulsed power (broadly defined) to energy production also exist.

While the connections between capsule fusion in the laboratory and thermonuclear weapons is rather direct, the use of laboratory scale fusion as an energy source is still some distance in the future. The possibility of producing high fusion yield in the laboratory, while valuable for weapon simulation and certainly an exciting scientific goal, has not been able to secure adequate funding for the coming years. SNL should not give up making the case for high yield based on the lower cost, both construction and operating, of pulsed power. Political realities cannot be expected to help in this case, however. Only Sandia can credibly make the case, although they should try to enlist collaborators.

Even with the anticipated reductions in military spending it is important to recognize that the military services have identified a critical need to modernize the engagement hardware before the next conflict. The Army, for example, has embarked on the early stages of a "Future Combat System" with a significant anticipated budget. SNL pulsed power representatives should remain in contact with relevant military representatives and help develop the specific systems and testing platforms that will be necessary for the programs. Well-characterized pulsed power driven EM environments are already being used as test platforms. This appears to be a growth area.

Radiography is a recognized outstanding competence of Pulsed Power Sciences at SNL. This competence has been demonstrated very effectively as part of the SSP program with the Cygnus machine at NTS. Certainly this should continue and expand, whether or not an expanded program evolves to develop a RRW. Within the modernization programs of the DoD there will also be a substantial need for radiography. SNL should investigate, with the new management team at NTS, the possibility of building a major radiography facility there for a DoD service sponsor.

As a general point, any and all opportunities to develop mutually beneficial research projects and programs with LANL and LLNL should be pursued. This will generate the need for additional shots on Z from scientists and engineers whose programs require the results to make progress in certain areas of NNSA's missions.

As another general point, before any future bigger machine will be approved for high yield, Sandia will have to be able to base projections from ZR to the high yield machine on a credible set of experimental results together with a solid framework of theory and computer simulations. Thus, "Precision ZR," meaning a machine that reliably and reproducibly delivers the conditions required for experiments, and a diagnostic set that reliably provides data with the necessary precision, should be Sandia's goal for ZR.

- **Culture and environment of the organization (e.g., innovation, creativity, collaboration, etc.):**

  The culture and working environment of SNL's pulsed power directorate are outstanding. This is directly attributable to the concerned and enlightened management. From discussions with the staff it was clear that they feel empowered to accomplish what they, and everyone on their particular team, agrees needs to be done. Safety is a good example. Each staff member felt responsible for his own safety and the safety of those around him. Safety was not viewed as the responsibility of a separate organization.

  There is general respect for each other whether an individual is a senior manager or a young technician. Ideas and technical opinions of everyone are considered. This has led and continues to lead to greater innovation and creativity as evidenced by the exceptional publication record. Relationships with collaborators from LANL, LLNL, AWE and universities are outstanding because of the competence and civility of the SNL pulse power staff and management.

  The fact that most of the programs within PPS are functioning well in spite of their budget constraints is, in our opinion, indicative of effective management.

C. For the Pulsed Power Sciences Center, please address the following issues:

- **Assess the strengths of pulsed power science for National High Energy Density Science/Stockpile Stewardship Program applications:**

  Pulsed Power Sciences Center fields the best pulsed power capability in the world. Sandia is now effectively the steward for pulsed power in the United States. Pulsed Power can do now (and will always be able to do) things that cannot be done any other way, or are much more difficult or expensive to do any other way, for the Stockpile Stewardship program. By "now" it is meant that this is in competition with OMEGA and other present day high energy density laboratory facilities, and the parenthetical remark is intended to mean even after the NIF and OMEGA EP are in operation. The strength of pulsed power technologies can be divided into two categories:

Demonstrated capability:
Pulsed power technologies, and the Z machine in particular, have several unique strengths for HEDS/SSP applications.

The materials work being conducted on Z is an example of a Pulsed Power Sciences program that is recognized as outstanding by the scientific community outside of Sandia, and a model for what is possible in this area. It is among the strongest science efforts supporting the stockpile presently being pursued on Z. The materials group has made important contributions to equation of state studies via isentropic compression (ICE), materials dynamics phenomena including the study of phase transitions and resolidification, and compression of mesoscopic and energetic materials. This work is "world-class" materials science. It is providing valuable data for the Stockpile Stewardship program and will continue to do so well into the future. This capability is complementary to the capabilities that will be available when the NIF is completed, and will continue to be valuable even after NIF is fully operational.

The materials group has augmented the ICE capabilities on Z by investing in a smaller pulsed power machine for low-pressure ICE research. This was an astute move on the part of this group given the very limited availability of shots on Z/ZR and the likelihood of increased competition for shots on ZR in the future. ZR will push the attainable pressure on an isentrope to over 8 Mbar and access on the shock Hugoniot to 20 Mbar. This presents exciting scientific opportunities that should be fostered by Sandia. Z/ZR and the new pulser are the facilities of choice for ICE experiments as the magnetic drive readily provides shockless conditions.

The materials compression capabilities on Z have been improved dramatically in recent years with ICE experiments regularly achieving a-few-percent accuracy. This is impressive; however, achievement of 1% accuracy, which may be needed for some EOS measurements, is challenging because of the stringent timing accuracy required (< 100 ps). Continued work in improving timing accuracy should be aggressively pursued by this group. The work on solidification in tin is impressive as are the data on strength of aluminum at pressure up to 1.5 Mbar.
The group should also be commended for aggressively developing, in collaboration with LANL and LLNL, a plan for study of SNM on Z. This is clearly a forefront capability that provides high quality quantitative data for a wide range of material conditions important to the Stockpile Stewardship Program and to basic material science.

Other applications of Z to high energy density science of importance to Stockpile Stewardship are also making good progress. The routine use of the Z-beamlet x-ray backlighter to help understand wire-array z-pinch physics is an excellent development. Every effort should be made to bring all research on Z/ZR up to the standard of the materials research. A "Precision Z" activity should be initiated to develop high precision, reproducible experimental platforms for each of the applications of Z. Once a more robust capability is in place the demand for experimental access from high energy density science and weapon science communities will surely grow.

A radiography capability is essential for stockpile stewardship. The pulsed power group at Sandia has a unique core competence in this area that must be maintained for enduring defense program needs. Collaborations with AWE should be a consideration before any reduction in effort in pulsed power technology and radiography capability becomes a serious possibility.

The use of Z for radiation effects testing is a particular strength of Pulsed Power Sciences. ZR will be the largest source of high-energy photons that can be delivered on a short time scale in a laboratory for stockpile stewardship applications even after ignition is achieved on the NIF.

The three-dimensional computational electromagnetics capability (and the computers to use it) is evidently a unique capability that is important to National Security

Innovation:
A number of inventions in the past decade have provided the foundations for the HED/SSP pulsed power program. The ICE capability has achieved the highest precision and reproducibility, but wire array x-ray sources and their applications, including the possibility of high yield ICF targets using vacuum hohlraums, have achieved a very credible scientific foundation. Innovations such as those discussed in the talk on liner implosions continue to expand the experimental opportunities provided by pulsed power (those with need to know should contact Keith Matzen for access to the classified appendix). With further efforts to enhance the precision of these x-ray sources, pulsed power can expect to have an expanding role in the SSP program to develop the precise data needed to validate physics models in the NNSA ASC weapon design codes.

The innovative staff is willing to collaborate, to listen and to learn from others and to benefit from advances made by others that can contribute to making Z-machine experiments a success. It is not possible to state with certainty what will not be invented or discovered within a financially starved program. What can be predicted with some certainty is that innovation will be lost and progress slowed substantially. The funding cuts that have been suggested as possible for the next year or more will deal a severe blow to innovation in the pulsed power program at SNL. This will have significant impact within the national programs.

- **Assess the importance of the unique and complementary uses that the refurbished Z facility can provide for the National HEDS/SSP community both before and after NIF is fully operational:**

  Some essential experimental measurements such as radiography and EMP vulnerability tests are better served by pulsed power sources than any other technology, particularly in terms of cost and size. Moreover the moderate cost and size of pulsed power machines can also lead, as has been demonstrated in the past few years, to more rapid innovation and knowledge growth in other science

areas, such as materials in extreme conditions, fusion, and even astrophysics. It is innovation that is most essential to broad national programs.

For at least four years, and possibly longer, Z/ZR will be the highest available energy laboratory x-ray source for any purpose.

Prior to the activation of NIF, Z/ZR provides high energy densities and long time scales that are not available at any other facility. Coupled with the excellent diagnostics suite, including Z Beamlet for radiography applications, a large variety of important SSP activities will be enabled. The ZR facility will be needed to keep innovative people engaged in the high energy density science required for Stockpile Stewardship ICF including fast ignition, materials properties under extreme conditions, etc., and it must be available for critical users with stockpile-related problems. ZR will be needed, together with OMEGA, to help prepare for experiments on the NIF (both directly relevant tests and diagnostic development). Currently, SNL's ICE capabilities are unique in the National HEDS/SSP program. Although similar types of experiments can be done with lasers, the space and time scale of the SNL experiments cannot be matched and the application to high-pressure dynamic material properties will be quite unique and world class.

There will always be a unique capability provided by ZR. Once NIF becomes operational, ZR will continue to serve several important purposes. The experimental capacity at NIF will certainly be inadequate to address all the needs of the SSP community. Additionally, the cost of experiments will demand that a high degree of preparatory or staging work be performed at other facilities to ensure success at NIF. For certain applications, such as isentropic compression of materials, the combination of time scales and pressure regimes accessible at ZR will remain unique even if ignition is achieved at the NIF.

Z's high-energy x-ray sources generated by wire arrays are also unique in the HEDS/SSP program. While this capability does provide reliable, reproducible radiation temperatures above 70-80 eV in vacuum hohlraums, the sources using dynamic hohlraums to produce higher radiation temperatures are less reproducible and harder to diagnose. As a result, experiments using these types of loads probably have less future in the SSP than experiments using lasers that can reach higher radiation temperatures. However, if some of the innovative ideas presented in the talk on liner implosions can be further developed, reliable hohlraums with temperatures near 200 eV or even higher may be feasible. If the precision required for quantitative benchmarking of NNSA ASC codes can be achieved, such targets will give SNL a capability with many SSP applications both before and after NIF is fully operational.

Z/ZR is also needed for nuclear weapons effects simulations over an important slice of the photon spectrum as long as testing radiation hardening remains a part of the weapon certification process. The Sandia capability in this regard is unique.

- **Comment on the risks to the health and vitality of the National HEDS/SSP based on the present funding profile for Sandia's ICF and high yield program for FY2007 through FY2012:**

  A $20 million cut in inertial confinement fusion would be very serious because of the drastic reduction in ZR shots. Based on the current funding profile for FY2007 and beyond, it appears very likely that ZR would deliver substantially fewer than 200 shots per year (maybe as few as 40), which would be clearly inadequate for the demands placed upon the facility. This would obviously limit the effectiveness of ZR in delivering its already demonstrated capability for exploring materials properties and serving other high priority SSP needs. In addition, the reduced budget and shot schedule would make it very unlikely that innovative ideas for new experimental capabilities would be developed. The NNSA HED/SSP program will almost surely oversubscribe the shot capabilities of NIF and OMEGA and would also obtain a substantial benefit from the data that could be obtained from ZR if it is adequately funded. The SSP program management at Sandia should not tolerate a reduction below 200 ZR shots

  There is the additional concern that the operations budget for ZR might be spread over a number of NNSA Defense Programs offices. Sandia should advocate for a single landlord for the facility (e.g., leaving the operations budget for the facility in the ICF and High Yield Campaign office) and ask that other DP offices pay for the incremental cost of fielding experiments (e.g., target fabrication, diagnostics, shot execution, development of special purpose experimental platforms). A process should then be put in place to allocate shots based upon programmatic priorities and technical quality. The current system of allocating shots among the user communities (ICF, C2, C4, C7) does not have an apparent mechanism for balancing priorities and was not transparent to the committee, and is therefore presumably equally opaque to the user community.

  It is not possible to state with certainty what will not be invented or discovered within a financially starved program. What can be predicted with some certainty is that innovation will be lost and progress slowed substantially. This could have significant impact within the national programs. Eventually, this could even cause substantially increased out year costs within the same programs.

  High yield is a legitimate long-term goal. It will be delayed indefinitely under the present funding profile, resulting in a loss of people and momentum from the national stockpile stewardship program. With this will go the pulsed power capability and radiography development because of staff reductions.

  Pulsed Power Sciences has a unique facility that has demonstrated its capabilities as a valuable x-ray source for stockpile stewardship at the level of the Z-machine. Credibility needs to be established for the extrapolation to a high yield facility (HYF) before decision makers outside of Sandia will take an HYF proposal seriously. This requires that ZR be operated as "precision ZR," just as Precision NOVA was essential to laser-driven ignition of D-T fuel capsules' gaining the credibility necessary to move forward with building the NIF. To do this requires

that ZR be highly predictable and its diagnostics be both credible and adequately accurate. This will simply be impossible on a significantly reduced budget.

Finally, Sandia must maintain core competency in Pulsed Power Technology. It is in the national interest and Sandia's interest as a cutting-edge applied science lab to make sure the pulsed power sciences, and especially ZR operations remain healthy. Sandia management should not allow layoffs, retirements and/or departures to gradually kill off this core competency.

- **Comment on the utilization of Z at 200 (full single shift), 300, and 400 (full utilization) shots per year to meet the needs of the National HEDS/SSP:**

  A budget that supports fewer than 200 shots from NNSA would be irresponsible. Only the highest priority proposals for machine use would be allocated shots, and those would be inadequately served. There will be no room for innovation or developing new capability. Sandia management should work with NNSA to make sure this doesn't happen.

  300 pulses would enable the Stockpile Stewardship Program to move forward more than minimally, including developing the wire-array z-pinch as a tool, and including testing some innovative concepts.

  400 shots would enable more innovative ("high risk") concepts to be investigated and would allow for some shots to be allocated to non-programmatic science.

  At any number of pulses per year, this valuable resource should be allocated to maximize its value to stockpile stewardship. Initially, an appropriately selected panel should judge the proposed experiments according to their potential value to the SSP. Effective use of the machine by a group for the benefit of the SSP should be rewarded with continued access to shots, and ineffective use should lead to a reduction in allocation.

  The ZR pulse allocation strategy implemented by Sandia should be transparent and should involve a national committee. The committee, which should include Sandia representatives, should set overall priorities to areas/campaigns/categories. The committee (or peer committees) should select experiments within categories from the proposals received from prospective users.

  Suggestions to stretch the budget, whatever it is:
  1. In order to be able to carry out more experiments on Z for the same or less money, making parts that will be destroyed anyway out of materials that will not destroy surrounding components (e.g., metal-coated plastic or even foam) may enable faster turnaround between tests.
  2. Especially for parts that are routinely destroyed or damaged beyond reuse without re-manufacturing, redesign them for easy removal, manufacture and installation (with or without implementing Suggestion 1).

- **Assess the importance of investing in pulsed power technology development to the future of the National HEDS/SSP and comment on the research plan:**

  Pulsed power will always be a cost effective and efficient method for delivery of large energies to high intensity loads. Investment choices between, for example, pulsed power improvements and diagnostic development should be determined by what adds precision and/or reliability and/or reproducibility and/or increased capability. Precision experiments on ZR, i.e., being able to deliver the design conditions on any given pulse (within reasonable margin) and knowing what the actual conditions were to the required accuracy in retrospect from the diagnostic suite, should be the goal for ZR operations. Outside of ZR, investments should be made in pulsed power to ensure the maintenance of a capability to design radiographic machines and to improve ICE driver reliability and flexibility.

III. Recommendations

Consider planning to become showcase model for "National User Facility" ala Vision of Complex 2030

Improved experimental precision is required to develop scaling laws and understand physical processes, and investment should be made accordingly on a broad set of platforms and diagnostics. This should enable higher value benchmarking of computer codes.

The "Precision ZR" activity implied by the previous recommendation should be visible and announced in public.

Choices of investments should be determined by the "Precision ZR" goals.

Embrace the broader mission space beyond ICF.

The process whereby the choices/shot allocation on Z/ZR should be transparent—i.e., the process should be such that people external to SNL can understand it. Even so, this is a mission-oriented program and the Office of Science models for "national user facilities such as Fermi National Laboratory" are not necessarily the best approach for ZR facility. This issue came up in the 2004 Review and no apparent progress has been made in resolving it.

Encourage corporate investment in Pulsed Power Technologies for Radiography, if push comes to shove, to protect this capability. The UK and US require this core capability

A more coherent and transparent process should be implemented for allocation of Z shots and setting shot priorities. The review committee suggests that some sort of small shot committee with representation from all three weapons labs be formed to allocate shots on ZR on a six-month basis. The process should not become unwieldy and so ossified that it precludes the exciting innovation that the committee found evident in the many parts of the program. But it should be more formal and more transparent than it is presently. This should be viewed as an opportunity to develop a model for the entire complex on the national use of its large-scale facilities (including NIF, Omega, DARHT etc.)

Pulsed Power Technologies provides Sandia with the world-class cutting edge science that Sandia needs for credibility in science. The Pulsed Power program should be nurtured as a high visibility window for Sandia to the broader scientific community. The program has an impact outside of Sandia well out of proportion to the size of the program within the entire Sandia research portfolio. Z has become the symbol of Sandia to the physics and engineering world.

This is a testament to the outstanding quality of the science that comes from this machine. This high visibility yields incalculable value in recruiting new young scientists and in establishing the scientific credibility of Sandia as a whole. The Committee strongly recommends that Sandia management continue to make the health of the Pulsed Power Program one of its top priorities. This will be even more crucial in the coming years as budget pressures in NNSA driven by the decaying infrastructure of the plants pushes on science efforts at all three labs.

IV. Format of Meeting

The new format of the meeting and its relationship to the newly instituted arrangement with the University of Texas as described in the "Background" section of this report, worked effectively. There were technical and programmatic talks interspersed with several opportunities for Executive Sessions. The balance of time between programmatic talks and Executive Sessions was better than for the 2004 Review. There was not the same necessity to cover every topic this time in light of the plan to have these reviews scheduled on an annual basis.

V. Acknowledgements

The External Review Panel of the Pulsed Power Sciences Center of Sandia National Laboratories commends Keith Matzen, Director of the Center for his exceptional leadership and direction of the program. The Panel thanks Dr. Rick Stulen, Sandia Vice President for Science, Technology and Research Foundations, for his effective support of this program. We also appreciate and applaud the enthusiasm and careful preparation of the management and staff of the Pulsed Power Sciences Center. The presentations and interactions were again uniformly professional and informative. The Panel recognizes the hard work that went into this meeting and appreciates the effort. In that regard, the Panel thanks Lisa Mattox and Cari Gerlock for providing quality arrangements and meeting support in addition to the support provided by the University of Texas team led by Dr. David Watson and his assistant, Dawne Settecerri.

VI. Panel Members

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Appendix: Meeting Agenda

Sunday, 23 April, 2006	
6:30 pm to 9:00 pm	Welcome Reception and Dinner – Wyndham Airport Hotel
Monday, 24 April, 2006	
6:45 am	**Pick-up @ Wyndham Hotel**
7:30 am to 8:00 am	Continental Breakfast
8:00 am to 8:30 am	Welcome and Opening Remarks **Rick Stulen** **Joan Woodard**
8:30 am to 8:45 am	NW Science & Technology Program **Tom Bickel**
8:45 am to 9:45 am	Pulsed Power Sciences Overview **Keith Matzen**
9:45 am to 10:00 am	Break
10:00 am to 11:15 am	Dynamic Materials Properties **Chris Deeney** **Marcus Knudson**
11:15 am to 12:00 am	Panel Discussion
12:00 pm to 1:15 pm	Lunch Informal discussions with staff
1:15 pm to 1:30 pm	NNSA Comments **Chris Keane (NA-16)**
1:30 pm to 2:00 pm	Electromagnetics and WFO **Larry Schneider**
2:00 pm to 2:30 pm	Pulsed Power Technology Development **John Maenchen**
2:30 pm to 2:50 pm	Break
2:50 pm to 3:20 pm	Secondary Assessment Technology **Randy Kanzleiter (LANL)**

3:20 pm to 3:50 pm	Radiography on Z **Dan Sinars**
3:50 pm to 4:30 pm	Liner Implosions **Jim Hammer (LLNL)**
4:30 pm to 5:30 pm	Panel Discussion
5:30 pm	Adjourn – Return to hotel
6:30 pm	**Depart hotel for dinner**
7:00 pm to 8:30 pm	Dinner – Sandia Casino
8:45 pm	Depart for hotel
Tuesday, 25 April, 2006	
7:00 am	**Pick-up @ Wyndham Hotel**
7:30 am to 8:00 am	Continental Breakfast
8:00 am to 8:40 am	Advanced Radiography for Primary Assessment **Bryan Oliver**
8:40 am to 9:00 am	Nuclear Survivability **Christine Coverdale**
9:00 am to 9:20 am	ZR and Z-PW **Ed Weinbrecht**
9:20 am to 9:40 am	Pulsed Power Sciences LDRD Program **Mark Kiefer**
9:40 am to 10:00 am	Break
10:00 am to 12:00 am	Panel Discussions
12:00 pm to 12:30 pm	Lunch
12:30 pm to 1:15 pm	**Panel Outbrief**
1:15 pm	**Optional tours (Z, ZBL, Z-20, RITS, Small Pulser, EM facilities…)**

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MS 0384 Art Ratzel, 1500
MS 0457 Steve Rottler, 2000
MS 0509 Carolyne Hart, 5300
MS 0511 Carol Adkins, 1020
MS 0511 Wendy Cieslak, 1010
MS 0513 Rick Stulen, 1000
MS 0839 Gerry Yonas, 7000
MS 0868 Kathleen McCaughey, 2700
MS 0887 Duane Dimos, 1800
MS 0938 Jeff Quintenz, 10800
MS 1152 Mark Kiefer, 1652
MS 1152 Michele Caldwell, 1653
MS 1159 Jim Bryson, 1344
MS 1159 Christine Coverdale, 1344
MS 1164 Bill Guyton, 5400
MS 1168 Chris Deeney, 1640
MS 1169 Jim Lee, 1300
MS 1178 Guy Donovan, 1676
MS 1178 Finis Long, 1637
MS 1178 Ed Weinbrecht, 1635
MS 1178 Doug Bloomquist, 1630
MS 1179 Mark Hedemann, 1340
MS 1181 Jim Asay, 1646
MS 1181 Marcus Knudson, 1646
MS 1181 Clint Hall, 1646
MS 1181 Larry Schneider, 1650
MS 1186 Tom Mehlhorn, 1674
MS 1190 Keith Matzen, 1600
MS 1191 John Porter, 1670
MS 1191 Mary Ann Sweeney, 1670
MS 1193 Bryan Oliver, 1645
MS 1193 Dan Sinars, 1673
MS 1193 John Maenchen, 1645
MS 1193 Briggs Atherton, 1672
MS 1193 Gordon Leifeste, 1675
MS 1196 Ray Leeper, 1677
MS 1221 Marion Scott, 5600
MS 1348 Mike Hazen, 4200
MS 1352 David Watson, 1000
MS 1391 David Thomson, 1649
MS 1391 Dan Bozman, 16491
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