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Pulsed Power Peer Review Committee Report

Pulsed Power Peer Review Committee
Dr. Richard Garwin, Chairman

Prepared by
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Abstract

In 1993, the Government Performance and Results Act (GPRA, PL 103-62) was enacted. GPRA, which applies to all federal programs, has three components: strategic plans, annual performance plans, and metrics to show how well annual plans are being followed. As part of meeting the GRPA requirement in FY2000, a 14-member external peer review panel (the Garwin Committee) was convened on May 17-19, 2000 to review Sandia National Laboratories' Pulsed Power Programs as a component of the Performance Appraisal Process negotiated with the Department of Energy (DOE). The scope of the review included activities in inertial confinement fusion (ICF), weapon physics, development of radiation sources for weapons effects simulation, x-ray radiography, basic research in high energy density physics (HEDP), and pulsed power technology research and development. In his charge to the committee, Jeffrey Quintenz, Director of Pulsed Power Sciences (1600) asked that the review be based on four criteria: 1) quality of science, technology, and engineering, 2) programmatic performance, management, and planning, 3) relevance to national needs and agency missions, and 4) performance in the operation and construction of major research facilities. In addition, specific programmatic questions were posed by the director and by the DOE/Defense Programs (DP). The accompanying report, produced as a SAND document, is the report of the committee's findings.

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Foreword

In 1993, the Government Performance and Results Act (GPRA, PL 103-62) was enacted. GPRA, which applies to all federal programs, has three components: strategic plans, annual performance plans, and metrics to show how well annual plans are being followed. As part of meeting the GRPA requirement in FY2000, a 14-member external peer review panel (the Garwin Committee) was convened on May 17-19, 2000 to review Sandia National Laboratories' Pulsed Power Programs as a component of the Performance Appraisal Process negotiated with the Department of Energy (DOE). The scope of the review included activities in inertial confinement fusion (ICF), weapon physics, development of radiation sources for weapons effects simulation, x-ray radiography, basic research in high energy density physics (HEDP), and pulsed power technology research and development. In his charge to the committee, Jeffrey Quintenz, Director of Pulsed Power Sciences (1600) asked that the review be based on four criteria: 1) quality of science, technology, and engineering, 2) programmatic performance, management, and planning, 3) relevance to national needs and agency missions, and 4) performance in the operation and construction of major research facilities. In addition, specific programmatic questions were posed by the director and by the DOE/Defense Programs (DP). The accompanying report, produced as a SAND document, is the report of the committee's findings.

This is not the first such external review of our Pulsed Power Programs. The table lists previous reviews, both those self requested and sponsored by Sandia and those requested and sponsored by DOE, since the late 1970s.

The original composition of the Garwin Committee was 17 members. Because of the Cerro Grande fire, the three from Los Alamos National Laboratory (Stephen Younger, James A. "Jas" Mercer-Smith, and Stirling Colgate) were not able to attend. In addition to the formal agenda in Appendix II, on May 17, Chris Keane of DP made some opening remarks to explain the context of pulsed power with respect to DP and the Stockpile Stewardship Program (SSP); Allan Hauer informally summarized LANL's use of Z in place of Bob Chrien and Fritz Swenson, who could not attend; and Mike Dunne of the Atomic Weapons Establishment (AWE) explained the role of Z in providing weapon physics data. On May 18 Al Romig, Vice President of 1000, and Paul Robinson, Sandia's President, explained the role of pulsed power at Sandia as a whole, and Ray Leeper briefly summarized the progress in diagnostics since the 1997 Welch Review. May 19 was devoted to committee deliberations and an outbriefing to Sandia management.

Planning for the review began in December 1999 and included monthly planning and semi-monthly logistics meetings. The following Sandians in 1600 participated in the planning: Jeff Quintenz, Jim Asay, Doug Bloomquist, Marti Martin, Keith Matzen, Dillon McDaniel, and Mary Ann Sweeney. In addition, Jerry Hanks, Elizabeth Gonzales, and Mary Payne from Org. 12141 (Integrated Management & Assessment) participated in the meetings. The Committee was supplied with the following: the Pulsed Power Sciences strategic plan (Pulsed Power Path Forward: A Strategy for Leadership), the two-page memo "Pulsed Power Review Theme," booklets of the vugraphs presented, and a summary of the recommendations of the two most recent peer review committees (The Welch Committees), which met February 21-23, 1996 and March 24-25, 1997.

External Peer Reviews of Sandia's Pulsed Power Sciences Programs

Name or purpose	Chairman or participants	Date(s) conducted	Requester or sponsor
Technical Review of Particle Beam Fusion Program	Al Trivelpiece	Nov. 1978	SNL
AdHoc Experts Group on Fusion (Foster Review of ICF Programs)	John Foster	1979 (Oct. 17 report)	DOE
Technical Review of Particle Beam Fusion Program	Al Trivelpiece	Jan. 15-17, 1980	SNL
Davidson Review of Pulsed Power ICF	Ronald Davidson	Oct. 1983	SNL
Davidson Review of Pulsed Power ICF	Ronald Davidson	Jan. 21-23, 1985	SNL
NAS Review of ICF Programs	Unknown	1985	DOE
NAS Review of ICF Programs	Will Happer	1986 (Mar. report)	DOE
Davidson Review of Pulsed Power ICF	Ronald Davidson	July 1987	SNL
Assessment of status of light ion program as part of overall review of ion, KrF, and solid state laser programs	Alex Glass, Gerry Yonas, Charlie Martin, Ronald Davidson, Ian Smith	Oct. 27, 1988	DOE
Davidson Review of Pulsed Power ICF	Ronald Davidson	Sept. 26-28, 1988	SNL
GAO audit of ICF Programs	Victor Rezendes	1990	House Armed Services Comm.
NAS Review of ICF Programs & LMF proposal	Steve Koonin	Nov. 3, 1989 & Aug. 29, 1990	DOE
Fusion Policy Advisory Committee	Guy Stever	Sept. 1990	DOE
Review of light ion beam fusion program	Dave Hammer	Dec. 16-17, 1991 (Feb. 5 report)	SNL
ICFAC Review of National ICF Program	Venky Narayanamurti	Dec. 16-18, 1992	DOE
ICFAC Review of SNL light ion program	Venky Narayanamurti	Mar. 8-10, 1993	DOE
ICFAC Review of Progress on NIF (SNL involved in target diagnostics, target chamber, and power conditioning)	Venky Narayanamurti	May 1994	DOE
Jason Review of ICF role in stockpile stewardship	Sid Drell	June 1994 (Oct. 26 report)	DOE
ICFAC Review of Progress on Nova technical contract and SNL light ion program	Venky Narayanamurti	June 5-8, 1995	DOE
Jason Review of ICF role in stockpile stewardship	Sid Drell	Jan. 17, 1996 (Feb. 20 report)	DOE
Welch Review of pulsed power program in Stockpile Stewardship Program (SSP)	Jasper Welch	Feb. 21-23, 1996	SNL
Welch Review to assess quality and relevance of z-pinch program to SSP	Jasper Welch	March 24-25, 1997	SNL
Workshop on application of pulsed power to SSP	Steve Koonin, Marshall Rosenbluth, Arthur Kerman	April 9, 1998	DOE request; SNL/LANL sponsors
Classified workshop on fast & slow pulsed power for SSP	Robin Staffin (SNL/LANL/LLNL weapon scientists)	May 12-14, 1998	DP-1 request; SNL/LANL sponsors
HEDP Advisory Committee on Z shot plans	No formal chairman; participants gave individual recommendations	Aug. 1998	arranged by SNL at DOE request
Review of conceptual design and cost, schedule, and performance of Z/Beamlet	Bill Simmons	Nov. 1998	DP-18 request; SNL sponsored

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PULSED POWER PEER REVIEW
COMMITTEE REPORT

TABLE OF CONTENTS

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Pulsed Power Program
Peer Review

May 17-19, 2000

Executive Summary

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Pulsed Power Peer Review

Committee Report

Richard L. Garwin, Chairman
William Bookless
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July 2000

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PULSED POWER PROGRAM PEER REVIEW

I. Introduction

Each year Sandia National Laboratories undertakes a Performance Objective Self-Assessment as part of the DOE/Sandia Performance Appraisal Process, which spans Management, Programmatic, Administration, and Operations performance. Pulsed power is a key element of Sandia's Science and Technology programs and as such was chosen by Sandia management for assessment in FY00. Similar reviews of the pulsed power programs, chaired by Dr. Jasper Welch were held in FY96[1] and FY97.[2]

An external review committee, chaired by Dr. Richard Garwin, was chartered by Sandia to meet and hear briefings by Sandia and outside collaborators on May 17 and 18, 2000. The FY00 assessment concentrated on the applications of pulsed power to the Stockpile Stewardship Program (SSP):

- the development of high energy density environments for Inertial Confinement Fusion (ICF),
- application of z-pinch sources to weapon physics (with LLNL and LANL)
- development of compact radiographic capability in support of LANL sub-critical experiments,
- development of radiation sources for certification in hostile environments, and
- simulation of weapon effects in partnership with the DoD Defense Threat Reduction Agency (DTRA).

The complete recommendations of the committee are presented in this report. Appendix I is a list of committee members that identifies each member's participation on panels which were formed to address DOE performance appraisal evaluation criteria. Appendix II lists the presentations that were made by Sandia and its collaborators in pulsed-power research to the committee.

II. General Comments

The committee believes that a program with the potential of the Z machine (Z), which has achieved the remarkable progress documented in this peer review should be nurtured. The benefits of doing this will support the Nation's Stockpile Stewardship (SSP), Inertial Confinement Fusion (ICF) and High Energy Density Physics (HEDP) programs. Further progress is now limited more by funding constraints than by scientific or technological

[1] J. Welch, *et al., "Sandia National Laboratory External Advisory Committee on Pulsed Power-Based Stockpile Stewardship,"* Science Applications International Corp, Albuquerque, NM (2 April, 1996).

[2] J. Welch, *et al., "Meeting Report – Committee on Pulsed Power-Based Stockpile Stewardship,"* Science Applications International Corp, Albuquerque, NM (16 May, 1997).

obstacles. We are concerned that pulsed power ranks low in DOE's funding priorities, and believe that an increase in the priority of the Pulsed Power Program at Sandia is justified by the program's scientific achievements and relevance to the SSP, ICF and basic science. The DOE SSP and ICF Program Offices should support a robust, balanced, pulsed-power program at Sandia. Along with increased fiscal support, a set of clear goals and objectives that are supported by DOE/DP and Sandia executive management should be set for the Pulsed Power Center. To support this process, a DOE-DP external HEDP overview committee should be chartered to include all of the HEDP (ICF/WS) programs at the various laboratories in the stewardship context so as to optimize the effectiveness of overall ICF and weapon science experiments.

III. Committee Responses to Self-Assessment Evaluation Criteria

The committee was asked to address four evaluation criteria as input to the self-assessment process:

A. Quality of Science, Technology and Engineering - Assess the quality of science, technology and engineering so far achieved and definitely planned for Z and other pulsed power facilities.

The three years since the last review of the Sandia Pulsed Power Sciences Program have witnessed the transition from a pulsed power program with aspirations to do inertial confinement fusion (ICF) research to an outstanding high energy density physics (HEDP) program based upon pulsed power. Improving the diagnostic capability, expanding the involvement of other laboratory scientists and understanding the physics of wire array z-pinches as intense sources of x-rays are necessary for productive operation of Z. These efforts are well underway, advancing at a rate limited by financial resources. The productivity and the quality of the scientific output are now very high and the participation of scientists from LANL, LLNL and AWE in experiments on Z is an indication of the value of that facility for stockpile stewardship, ICF, weapon physics and nuclear weapon effects. The greatly improved and impressive new ASCI computational capabilities form an essential part of the Sandia program.

A major recommendation of the 1997 Welch Committee was to assure the maintenance of the pulsed power engineering program at Sandia as the best in the world. This is still an important goal in order to effectively build upon the successes of recent years. The planned upgrades to Z that collectively would yield the Z-Mod machine seem prudent to us and should be implemented as soon as it is possible to do so without undue interruption of the ongoing physics program. It is important to continue the pulsed power engineering research program at an adequate level, in order to ensure the science base and engineering skill level needed for these machine upgrades and for building a next generation facility if and when needed.

The Z machine is much more potent, flexible, and versatile than was envisaged a few years ago. DOE and Sandia should consider some reallocation of resources to allow at least a full single-shift operation and progress on the Z-Mod upgrade. We hope the customers, LANL, LLNL, and DTRA, will also be willing to increase their financial contributions.

The number of shots allowable under present budgets is not adequate to pursue all the important objectives we list below.

In order to exploit the success of the Z program, it needs to proceed in diverse areas. We first recommend four areas to fully exploit the capabilities of the present Z machine.

- Continuing to enhance the capabilities of Z, by better understanding and optimization of wire arrays, flux compression applications, characterization of advanced hohlraums, improved diagnostics and computations, should remain a key focus of the Z program.
- Physics studies - equation of state (EOS), radiation transport, and opacity measurements. This work can provide important high energy density physics (HEDP) information of use to SSP, supplementing data from NOVA and Omega lasers and benchmarking ASCI code predictions.
- Physics studies on Z in the lower temperature regions of the NIF foot pulse, along with equation of state (EOS), radiation transport, and opacity measurements all support the NIF by helping to benchmark ASCI codes. The proposed high-yield physics program involving hohlraum studies and capsule implosions also constitutes effective NIF support.
- Radiation effects testing on Z and Saturn – it would be useful if DTRA and Sandia, in coordination with STRATCOM and OSD, could provide a set of hardness criteria for future threat scenarios appropriate to the 21st Century, to enable a judgment as to the urgency of upgraded X-ray production capabilities, and the necessity for the use of Z rather than less advanced machines at this time.

The following three areas involve pulsed power engineering and envisage more powerful or differently configured machines.

- Pulsed Power - Sandia pulsed power capabilities are an important national asset. A minimal program to conserve this asset with a very valuable end product would be the incremental, cost-effective upgrade of Z to Z-Mod. The recommended best next step is Z-Mod at a 28 - 30 MA target level.

- High Yield - For the longer term the high-yield “vision” provides a useful direction for future developments. Although some level of design work is appropriate, it is premature to settle on a single option such as X-1. Efforts relative to high yield should be appropriately balanced against fully exploiting the present Z capabilities. A more aggressive collaboration with French and Russian pulsed power programs that are developing alternative technologies is encouraged.

- Radiography - the Inductive Voltage Adder (IVA) x-ray radiography source to be fielded at NTS is a demonstration of the utility and flexibility of pulsed power technology for SSP.

B. Programmatic Performance, Management and Planning - Evaluate the programmatic performance, management and planning thus far exhibited in the Z program.

Programmatic Performance

The Pulsed Power Program has fully implemented the 1997 Welch Committee's recommendation of acquiring and installing an extensive suite of high quality diagnostics equipment on Z, and has also come a long way towards developing a very good understanding of the Z-pinch physics using wire arrays. The program should be commended for these accomplishments.

- Although now done on an informal basis, to increase the programmatic impact of Z, we recommend that a formal user's group be constituted and actively maintained through regular and intensive participation of the user community and other stakeholders. The function of this group would be to advise Sandia management on how to optimize the utilization of Z for ICF, weapon physics, and radiation effects, consistent with the DOE/DP and DoD/DTRA needs and resources.

Management Performance

We were gratified to note the strong support of the Pulsed Power Program in the recent congressional testimony of Sandia president, Dr. C. Paul Robinson. Consistent with this executive management support, an additional $5M invested by DOE-DP and/or Sandia to expand Z operations to their full single-shift pulse capability would be of enormous benefit to Sandia, to the DOE Stockpile Stewardship Program, and the DoD.

We note and applaud the move for a strong, continued effort to cement and enhance the Sandia Pulsed Power Program's relationship with the Defense Threat Reduction Agency (DTRA) in radiation effects. Within Sandia, there is both an organizational and a programmatic separation between the Pulsed Power Sciences and Applied Physics Centers. Saturn, Hermes III and Sphinx, which are organizationally in the Applied Physics Center, have key roles in radiation sciences, weapon effects and code development, and rely on science and technology developed in the Pulsed Power Sciences Center. There is a need for cold x-ray source development that could be addressed on Z with increased funding for radiation source development. In the current FY'01 plan, due to shortfalls in funding, only 140 shots are scheduled on Z, with 10 allocated for radiation sciences/weapon effects testing. With increased funding, adding 50 shots to cover the FY'01 request supporting radiation effects is well within the number of shots that could be done under single shift operation.

- While it was clear that at the working levels there is effective collaboration between the Centers, we nevertheless raise the question of whether putting Saturn/Hermes III/Sphinx and Z under the same organizational unit might not be beneficial. We urge Sandia's executive management to explore the feasibility of such integration, or absent that, programmatic alignment with the establishment of a program oversight

committee or program matrix manager to assure optimum utilization of Sandia's pulsed power assets.

Planning

Although the long-range goal of achieving high-yield capsule fusion is worthy of future consideration, this goal is still too far in the future and fraught with problems, and should be pressed with prudence and caution rather than as a committed goal. For the next several years, the overarching principle should be to balance and prioritize present Stockpile Stewardship Program utilization and exploration of new physics possibilities on Z, versus efforts to establish new, much larger facilities. In short, now is the time for harvesting the magnificent opportunities for doing physics on Z. We endorse a strategy that begins immediately with obtaining sufficient funding, either internally or externally, to increase the number of experimental shots on Z from the current FY 2001 plan of 140 to full single-shift operation of about 220. Further, we believe that the proposed modernization of Z, to Z-Mod, should be pursued to improve the reliability of the Z machine, as well as to obtain an increase in current capability from the present 20 MA to 28 - 30 MA.

The research carried out in France and Russia has the potential for development of new technologies that have the promise of increased efficiencies and lower costs. We believe that collaboration with France and Russia provides great opportunities for leveraging Sandia's research activities.

- The Pulsed Power Program should develop a strategic investment plan for funding activities with the Russian scientific institutions to maximize the leverage afforded by the difference in the salary structures in the two countries. Likewise, planning should address enhancement of the collaboration with France as well as with the British, the DoD, the US pulsed-power industry, and universities.

We endorse Sandia's proposal to establish a standing external pulsed-power technology advisory committee. However, for such a committee to be effective and worth the effort for all concerned, Sandia must regularly task it, keep it fully and accurately informed, and give genuine consideration to its recommendations.

- The Pulsed Power Program should develop priority plans, consistent with the recommendations of this report, and ensure their internal dissemination and discussion.

C. Relevance to National Needs and DOE Mission Other Than Stockpile Stewardship

Charge: Evaluate the relevance of pulsed-power work to national needs and the DOE mission, other than stockpile stewardship

Pulsed power science is important at the national level, and Sandia's pulsed power program is highly relevant to national needs. The Sandia pulsed power program is excellent, and benefits not only DOE but DoD and its industrial contractors. In particular, advances such as those made in Sandia's pulsed power program are critical to

DTRA's mission. The Z-pinch has been an effective tool for DoD's simulation of nuclear weapons effects, and we endorse its continued development for better simulation of warm and cold x-rays, which is imperative for this aspect of national defense, as defined by current radiation hardness requirements. The availability of other types of sources (gamma simulators, megavolt bremsstrahlung, electron beams) in the various Sandia facilities is also very beneficial. Sandia is expected to have an important role in the carefully planned development of higher power facilities of all types mentioned plus ion beams, and these facilities will be important for verifying the effects of threats listed in DTRA's "Red Book", the basis for nuclear hardening of US military systems. Sandia can also make important contributions to the development and verification of physical models of weapons effects, which is an important adjunct to the use of big simulators. Increased community coordination is needed to make full use of Sandia's capabilities.

- Between Sandia and DoD/DTRA, there is no formal weapon effects coordination working group. We recommend more coordination with DTRA and within SNL. Establishment of a coordination council between SNL and DTRA would strengthen and integrate the weapon effects community. There are opportunities for more teaming in this area that should be pursued.
- Given the present nuclear hardness requirements for the W76-1 warhead, more shots are needed (up to a total of 60 per year) for cold x-ray source development and radiation hardening certification. An effective and affordable nuclear weapons program will benefit from a review by DoD and DOE of the nuclear hardness requirement, and especially from design changes outside the primary and canned secondary assembly that might permit meeting a given hardness requirement with a less capable radiation source.
- Development of new machines should be part of a long-range strategy that develops new enabling technologies, balanced against meeting short-term needs, thereby allowing a powerful synergism that will sustain this vital national capability for many years to come.
- Continued engagement of industry and academia is strongly recommended to identify other possible applications and national needs, and thereby help maintain a center of national pulsed power expertise at Sandia and attract new scientists and engineers to do research in this dynamic field.

D. Science and Engineering Value of Pulsed Power Facilities for Stockpile Stewardship

Charge: Assess the science and engineering value of pulsed-power facilities for stockpile stewardship, for the existing Z machine, a fully utilized Z, a Z-Mod at 28 or 32 MA, ZX (60 MA), and X-1 (2x60 MA).

The Sandia high energy density Z-pinch pulsed power program has immediate relevance to the Stockpile Stewardship Program. Since 1997, the NOVA laser has been dismantled and completion of NIF has been seriously delayed. Consequently, the Z facility has now acquired greatly increased significance for accomplishing certain near-

term campaign goals of the Stockpile Stewardship Program. Sandia's plate is very full, and both the Sandia executive and Center management will have to set priorities that balance two strong and competing forces: constrained budgets, and the need to pursue many scientific and technical objectives.

- *Weapons Science Applications* - A high priority should be given to exploring and determining the feasibility of using the Z facility for experiments on Special Nuclear Material (SNM). Although this application raises ES&H issues and will require some sort of containment scheme, the time is ripe to initiate cost/risk/benefit design studies of possible usage scenarios. The ability to do such experiments will make the Z facility an excellent complement to other important DP experimental thrusts (JASPER, Sub-crits) for SNM studies. Committee members from LANL, LLNL, and AWE, stated that the Z facility will be, and should be, the principal radiative drive capability for the next 5-6 years for weapons-science applications. The pressures and time scales attainable with Z make it a unique capability for the SSP mission. A Tri-Lab consortium should provide guidance (and resources) to optimally use Z for weapons science applications.

- *Use of Z for EOS and Materials Applications* - The innovative Z experiments on isentropic compression make a compelling case for using the Z facilities for EOS and Materials Physics research that will contribute to both fundamental science and programmatic applications. Because the Z capabilities can bridge the gap between gas guns and laser drive facilities, it can play a central role in this triad of AGEX capabilities that are needed to ensure that the large investments made in ASCI are properly utilized for the SSP. Good partnerships established with LLNL, LANL, and AWE, and collaborations with a number of key universities should be continued.

- *High Energy Density Physics* - We recommend that the barrier between ICF and Weapons Science be removed, and the term "High Energy Density Physics" be used to denote these activities at the Pulsed Power Sciences Center. We encourage Sandia to hold workshops at LANL, LLNL, and AWE to inform scientists about Z capabilities and new developments, and to foster collaborations with appropriate groups at these laboratories. The Pulsed Power Sciences Center can, and should, rightly establish itself as a major element of HEDP for both civilian and defense applications.

- *Pulsed Power Development Laboratory* - The Committee strongly believes that, at an appropriate level, the Pulsed Power Development Laboratory (PPDL) is essential for maintaining the necessary expertise for future advancements. The PPDL provides an excellent opportunity for fruitful exchanges with the French and Russian efforts in switching and the alternative LTD technology. Interactions with the small number of U.S. pulsed-power contractors are important to ensure future advances and cost-effective developments.

- *Z Modernization* - The Committee was unanimous in its belief that Z-Mod is worth pursuing without compromising the use of Z for the stockpile stewardship program. More ambitious upgrades to Z (ZX, X-1) should be viewed as part of the longer-term vision. A cautious approach that builds on the experience of an upgrade to Z-Mod, and on the use of Z and Z-Mod for various HEDP applications over the next several years will likely lead to a more efficient and workable achievement of the longer-term vision.

- *Radiography* - In the past year, Sandia has made significant advances that have put IVA radiography diagnostics on the critical path for near term SSP sub-critical tests. The approach taken by Sandia/LANL/Bechetel-Nevada/PSI in exploiting the pulsed power technology base at Sandia to provide a flexible radiographic capability using IVA technology is excellent, and should provide a robust and expandable pulsed power driver for radiography.

IV. Responses to Programmatic Questions from the Pulsed Power Center Director

The committee was asked by the Pulsed Power Center Director to comment on four issues:

S1. How to address the eroding pulsed-power tech base and loss of expertise.

It is vital to maintain pulsed power capability for Sandia's HEDP programs to be viable. The aging and loss of the scientific staff is a major problem. The only way to maintain this capability is to actively engage in exciting programs both in pulsed power research and development and its application. Adding only one or two new outstanding staff each year to offset the loss of key people would maintain long-term program vitality. A modest but continuing investment in university pulsed power research programs would develop a source of this talent. The creation of the pulsed-power laboratory, foreign collaboration, and an aggressive program to define and implement modifications of Z at the 28–30 MA level will provide the near-term opportunity to reverse this loss, as would application of IVA technology to sub-critical radiography. In addition, Sandia should make more use of pulsed-power industry, as it has in recent radiography programs, which would both alleviate Sandia's staff problem and help maintain US capability as a whole at a time when applications for industry are decreasing.

S2. Z is oversubscribed (underfunded).

We strongly believe that Z is a resource that should be used to the single-shift limit of 220–240 shots per year. Since Sandia already has a mechanism and tradition of work for others (WFO), it should be made clear that shots beyond those provided in the budget are available at cost. For partners that do not normally provide funds, one might set up a "revolving fund" or similar mechanism for keeping track of credits, so that Z work financed by Sandia will incur a Sandia credit that could be worked off by additional Sandia access to partner's facilities and resources.

S3. How to balance the Sandia effort across the four program elements:

a) High-yield assessment

The committee believes that the *Path Forward*[3] statement: *"Our <u>focus</u> is on meeting the needs of the stockpile today. Our <u>vision</u> is to achieve high yield with pulsed power in the future,"* is an appropriate mission statement for a large part of the Pulsed Power Sciences Center. The long-range vision to achieve high yield addresses the "grand challenge" that will encourage the best efforts from the very talented staff already in the Center and its allied organizations at Sandia, and will also help to attract bright young people into the program. Synergistically, the research carried out in support of many weapon physics projects "automatically" contributes to building the database and level of understanding needed to achieve high yield in a future z-pinch facility. We believe that high yield should be maintained as a vision and that as preparations for Z-Mod go forward, a modest effort should be continued on high-yield capsule design, in collaboration with NIF. With NIF experiments delayed, the UGT moratorium, and the U.S. signature on the CTBT, the chief means over the next five years for establishing an experimental basis for the feasibility of achieving ignition and high-yield ICF will come from the pulsed power and HEDP programs at Sandia and the Omega laser at Rochester. Incorporating high yield, together with weapon science and Z-pinch research in a High-Energy Density Physics program, would be a useful and prudent step in the direction of achieving high-yield ICF. Before a DOE decision is made to pursue high yield as a national program, the feasibility, utility and affordability of a high-yield ICF facility must be addressed. The HEDP program on Z could make significant contributions to the question of feasibility. Characterization of pinch source and exploratory capsule implosions are an important part of this feasibility study. The Sandia ICF program, in conjunction with LLNL and LANL should continue with analyses of low-yield, break-even capsules, some of which might be accessible at the Z-mod level.

b) Leveraging pulsed power advances in France and Russia

The Sandia facilities Z, Hermes-III, etc. illustrate that US pulsed power is presently well ahead of France and Russia. Sandia expressed concern that because these countries are spending more of their effort on developing new pulsed power concepts, US pulsed power leadership is threatened. We believe that it has been correct for Sandia to emphasize the use of existing US technology and the exploiting of its larger existing

[3] J. P. Quintenz, *et al.*, *"A Strategy for Pulsed Power Leadership,"* Sandia National Laboratories (May, 2000), unpublished.

facilities--the success of the modification that produced Z goes far to justify this. Moreover, Sandia's present technology may in fact be the best way to build ZX or X-1. Thus while new technology possibilities must always be considered, spending larger amounts of money than the French on new approaches is a losing proposition. Well-planned investments that take advantage of French and other foreign work is the right approach, partnering where appropriate. In the case of the French, Sandia might choose to complement their >0.5 microsecond vacuum-insulated LTD by developing ways to make it compatible with the time scale of Z-pinches; send Sandians to gain experience on the 10-MA LTD facility being built at CEG; or exercise an LTD module in the Pulsed Power Development Lab. In the case of the Russians, Sandia could supply additional funds to leverage the Russian developments in switching and power conditioning, which Russia is cost-effective in creating but not in a position to exploit. The Russian fluid-insulated LTD scheme, when developed, would require the same advances in vacuum interface/ power flow as would continued use of US technology. The pursuit of these power flow advances is a spearhead development activity for the US, and should be a high-priority for the Pulse Power Development Lab.

c) New applications of Z-pinch technology

As evidenced by the recent work in shock waves driven by magnetically accelerated flyer plates (and in isentropic compression experiments--ICE), there are valuable applications of the Z machine that do not involve Z-pinch. We urge the scientific staff and users to continue to explore opportunities to be surprised. Unexpected results effectively and creatively exploited in the area of equation-of-state experiments with the Z machine show promise to have major impact on the SSP program.

d) Supporting NIF

The pulsed power program can help substantially with NIF by benchmarking ASCI codes that deal with radiation transfer and ablation. Similarly, the same capsule design approaches that are to be used for NIF can be used by the NIF staff to design targets for Z, and diagnostics of incipient burn may be of help in the years before NIF operates. Some of this progress will be made by NIF projects at Z, and some will be made by scoping studies for high-yield capsules.

S4. What is the "best" next step for a pulsed power facility?

First is the improvement of efficiency and capacity for the operation of Z--more shots at less effort. At the same time, use this improved shot rate capacity to support definitive plans and implementation for a cost-effective Z-mod at the 28–30 MA level without taking more than 25% of the time for this transition.

V. Responses to Programmatic Questions from DOE/DP

Sandia's DOE/DP sponsor requested inputs in four programmatic areas related to Sandia's pulsed power programs. The committee is pleased to offer the following observations.

DP1. The utility of Z-pinches for weapon physics studies (no ignition).

Z (and a future Z-Mod) is a flexible resource for studying radiation flow in complex geometry, for validating ASCI codes for radiation flow, ablation, verifying opacity, equation of state, and the like. The recent results on equation of state and Hugoniot data are exciting, as is the potential for moving to higher pressures by "one-sided drive." Z can provide insight into the stability and unstable growth of interface disturbances, and should be particularly valuable if applied to SNM. A feasibility study addressing the technical and environmental issues involved in fielding small quantities of SNM on Z should be undertaken.

DP2. The utility of Z-pinches for NIF ignition studies.

The Z machine in its present configuration cannot directly replicate the expected hohlraum temperature of a full-scale NIF, but it can contribute to studies of radiation flow and uniformity, and to the validation of codes for the radiation-driven implosion of pellets designed with the same tools used for the laser-driven pellets in NIF. Given the availability of Z, it would be natural for the NIF team at LLNL to use their design tools to provide concepts for incipient ICF burn at Z, and for Livermore and Sandia to work together, if they desire, in order to provide diagnostics on such concepts. Furthermore, with the high-yield vision at Sandia, similar work should be undertaken by the Sandia team. Rather than forcing agreement on capsule design, such an approach would give the advantage of friendly competition, which can only aid NIF when it comes on line.

DP3. The utility of Z-pinches for attaining high yield.

We believe that it is important for Sandia, DOE/ICF and DOE/DP to work together to align more closely their views, plans and goals about whether “high-yield” capsule fusion is an appropriate goal for the Pulsed Power Program, and urge all parties to approach the issue of pulsed power high-yield with maximum flexibility and openness. Many feasibility issues remain to be further explored, e.g., pinch source characterization, symmetry, reproducibility, possible intermittence and energetic particle production, efficiency of radiation transport from larger wire arrays etc., and as yet there has been no capsule implosion experience. Nonetheless, there appears to be a good possibility that the long range goal of achieving fusion high-yield is compatible with the projected capability of the Z-pinch approach in the future, and it should be adopted by the program as a “vision” with the concurrence of both the DOE ICF Program Office and DOE Defense Programs. For the near term, however, we feel that it is more appropriate to balance and prioritize the opportunities for increased utilization of the current Z facility and exploration of new physics issues on Z rather than undertaking to build major new facilities.

DP4. What areas of technology development should DP support?

DP should support the modifications in Z required to provide full operation, in order to realize the benefit from the existing investment. Beyond that, there is needed the

conversion of Z to Z-Mod, at the 28–30 MA level, in order to move exploration of equation of state to higher pressures, to increase the radiation temperature of Z-pinch driven hohlraums, and to exercise and benchmark modern pulsed power technology. In addition, DP should support cooperation of Sandia with the French and increase the very modest amount of investment in Russian activities. The inductive voltage adder (IVA) and the linear transformer drive (LTD) are promising approaches. DP should vigorously support work at Sandia on flux compression for pulse shortening and impedance matching. There is substantial benefit to be obtained by cleaning up some aspects of Z pinch that were passed over in the scramble to exploit the higher temperatures and larger radiation output. Improving the precision of wire placement should pay off in improved timing accuracy and repeatability, and this is desirable now in order to better plan for the future.

Appendix I: Committee Membership

Chairman: Dr. Richard Garwin, IBM Research Division

Panel 1: *Quality of Science, Technology and Engineering*

Prof. Marshall Rosenbluth, University of California at San Diego, Lead

Prof. David Hammer, Cornell University

Mr. Ian Smith, Titan Pulsed Sciences, Inc.

Panel 2: *Programmatic Performance, Management and Planning*

Dr. Marshall Sluyter, Consultant, Lead

Dr. William Bookless, Lawrence Livermore National Laboratory

Dr. Orval Jones, Consultant

Panel 3: *Relevance to National Needs and DOE Mission Other Than Stockpile Stewardship*

Dr. William Tedeschi, Sandia National Laboratories, Lead

Dr. Donald Linger, Defense Threat Reduction Agency

Dr. K. D. "Bud" Pyatt, Jr., Maxwell Technologies, Inc.

Panel 4: *Science and Engineering Value of Pulsed Power Facilities for Stockpile Stewardship*

Prof. Yogi Gupta, Washington State University, Lead

Mr. David Forster, Atomic Weapon Establishment (U.K.)

Dr. Alan Toepfer, Science Applications International Corporation

Dr. Richard Ward, Lawrence Livermore National Laboratory

Appendix II: Agenda

Wednesday May 17

Topic	Speaker
Welcome • Introductions	Jeff Quintenz
Introduction and overview • Charge to committee • Pulsed Power overview • Outline of review	Jeff Quintenz
Z-pinch tutorial	Rick Spielman Mike Desjarlais Darrell Peterson Rick Spielman
ICF Introduction and Need for High Yield	Keith Matzen
ICF	Keith Matzen Mike Cuneo Jim Hammer Joel Lash John Porter
Radiation Physics • Radiation transport • Case dynamics • Astrophysics	Bob Chrien Fritz Swenson
Summary	Keith Matzen

Thursday May 18

Activity	Speaker
EOS	Jim Asay
• Technique Development	Clint Hall
• Stockpile stewardship applications	David Reisman
• Cryogenics and D_2 EOS	Marcus Knudson
• Future SSP applications	Bob Cauble
RES & Weapon Effects	Jim Lee
DTRA Source Dev. & Lethality	Chris Deeney
Tour of Z and Z/Beamlet • Diagnostics • Wire array lab • Z/Beamlet facility	Doug Bloomquist Ray Leeper Rick Spielman John Porter
Radiography	John Maenchen
ASCI Codes Overview	Tom Mehlhorn
Pulsed Power Technology	Dillon McDaniel
Summary and Expectations	Jeff Quintenz

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