

# **SAND REPORT**

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## **Pulsed Power Peer Review Committee Report**

### **Pulsed Power Peer Review Committee**

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

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**Pulsed Power Peer Review Committee Report**

**Pulsed Power Peer Review Committee  
Sandia National Laboratories  
P.O. Box 5800  
Albuquerque, NM 87185-1190**

**I. 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 FY2002, a 15-member external review committee chaired by Dr. Alvin Trivelpiece (the Trivelpiece Committee) was convened by Sandia National Laboratories (SNL) on May 7 – 9, 2002 to review Sandia National Laboratories' Pulsed Power Programs as a component of the Performance Appraisal Process negotiated with the National Nuclear Security Administration of the Department of Energy (NNSA/DOE). 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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## II. 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 GPRA requirement in FY2002, a 15-member external review committee chaired by Dr. Alvin Trivelpiece (the Trivelpiece Committee) was convened by Sandia National Laboratories (SNL) on May 7 – 9, 2002 to review Sandia National Laboratories' Pulsed Power Programs as a component of the Performance Appraisal Process negotiated with the National Nuclear Security Administration of the Department of Energy (NNSA/DOE). 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, 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 findings.

This is not the first such external review of SNL's Pulsed Power Programs. The attached table lists previous reviews, both those requested and sponsored by SNL and those requested and sponsored by NNSA/DOE, since the late 1970's.

Originally, the Trivelpiece Committee included 16 members. Dr. Susan Seestrom of LANL was unable to participate due to illness and Dr. Jack Shlachter of LANL substituted for her on the 8<sup>th</sup> and 9<sup>th</sup> of May. Another Committee member from Sandia management, Dr. Joe Polito, was unable to participate due to pressing business matters, thus reducing the membership of the Committee to 15. In addition to the formal agenda in Appendix II, on May 8, Dr. Chris Keane of DOE's Defense Programs (DP) made some informal remarks to the Committee in an Executive Session, to explain the role of pulsed power, the importance of the five-year agreement between NNSA/DOE and the Office of Management and Budget (OMB), and the programmatic stability that this agreement can provide.

Planning for this review began in early 2002 and included meetings on logistics, committee membership, and committee charter. The following members of SNL Org. 1600 participated in the planning: Jeff Quintenz, Jim Asay, Doug Bloomquist, Lisa Mattox, Keith Matzen, Dillon McDaniel, Craig Olson, and Mary Ann Sweeney. The Committee was supplied with the following reference documents: Pulsed Power Peer Review Committee Report, Dec. 2000 (the report of the Garwin Committee Review, conducted in May, 2000), the two page memo "Pulsed Power Review Theme," Pulsed Power Implementation Plan Executive Summary (4/19/02 draft), Vision and Strategic Objectives for Pulsed Power, booklets of the unclassified vugraphs presented, and four recent publications - "Zero-dimensional energetics scaling models for z-pinch-driven Hohlraums," M.E. Cuneo et al., *Laser and Particle Beams* (2001); "Double z-pinch Hohlraums drive with excellent temperature balance for symmetric ICF capsule implosions,"

M. E. Cuneo, et al., accepted for publication in Phys. Rev. Lett.; "Radiation science using Z-pinch X rays," J. E. Bailey et al., Physics of Plasmas (May 2002); "Equation of state measurements in liquid deuterium to 70 GPa," M. D. Knudson et al., Phys. Rev. Lett. (Nov. 2001).

## External Review of Sandia's Pulsed Power Sciences Programs

<b>Name or Purpose</b>	<b>Chairman/Participants</b>	<b>Date(s)</b>	<b>Requester/Sponsor</b>
Technical Rev. Particle Beam Fusion Prog.	Al Trivelpiece	Nov. 1978	SNL
Ad Hoc Experts Group on Fusion (Foster Review of ICF Programs)	John Foster	1979 (Oct. 17 report)	DOE
Technical Rev. Particle Beam Fusion Prog.	Al Trivelpiece	Jan. 15-17, 1980	SNL
Davidson Review of Pulsed Power ICF	Ron Davidson	Oct. 1983	SNL
Davidson Review of Pulsed Power ICF	Ron Davidson	Jan. 21-23, 1985	SNL
NAS Review of ICF Programs	unknown	1985	DOE
NAS Review of ICF Programs	Will Happer	1986 (Mar. rept)	DOE
Davidson Review of Pulsed Power ICF	Ron Davidson	July 1987	SNL
Assessment of status of light ion program as part of overall review of ion, KrF, & solid state laser programs	Alex Glass, Gerry Yonas, Charlie Martin, Ron Davidson, Ian Smith	Oct. 27, 1988	DOE
Davidson Review of Pulsed Power ICF	Ron Davidson	Sep. 26-28, 1988	SNL
GAO audit of ICF Programs	Victor Rezendes	1990	House Armed Serv.
NAS Review of ICF Programs and LMF proposal	Steve Koonin	Nov. 3, 1989 and Aug. 29, 1990	DOE
Fusion Policy Advisory Committee	Guy Stever	Sept. 1990	DOE
Review of light ion beam fusion prog.	Dave Hammer	Dec. 16-17, 1991	SNL
ICFAC Review National ICF Program	Venky Narayanamurti	Dec. 16-18, 1992	DOE
ICFAC Review of light ion program	Venky Narayanamurti	Mar. 8-10, 1993	DOE
ICFAC Review of Progress on NIF (target diagnostics, chamber, and power conditioning)	Venky Narayanamurti	May 1994	DOE
Jason Review of ICF role in stockpile stewardship	Sidney Drell	June 1994 (Oct. 26 report)	DOE
ICFAC Review of Progress on Nova contract and SNL light ion program	Venky Narayanamurti	June 5-8, 1995	DOE
Jason Review of ICF role in stockpile stewardship	Sidney Drell	Jan. 17, 1996 (Feb. 20 report)	DOE
Welch Review of pulsed power program for Stockpile Stewardship Program	Jasper Welch	Feb. 21-23, 1996	SNL
Welch Review to assess quality and relevance of z-pinch program to SSP	Jasper Welch	Mar. 24-25, 1997	SNL
Workshop on application of pulsed power to SSP	Steve Koonin, Marshall Rosenbluth, Art Kerman	April 9, 1998	DOE request; SNL and LANL sponsors
Classified workshop on fast and slow pulsed power for SSP	Robin Staffin; weapon scientists	May 12-14, 1998	DP-1 request; SNL and LANL sponsors
HEDP Advisory Comm. on Z shot plans	individual recommendations	Aug. 1998	DOE request
Review of conceptual design, cost, schedule, performance of Z-Beamlet	Bill Simmons	Nov. 1998	DP-18 request; SNL sponsor
Pulsed Power S&T Peer Review	Richard Garwin	May 17-19, 2000	SNL
Hostile Environment Simulation Rev	Bill Martin	May 23-24, 2000	ASCI sponsor
Hostile Environment Simulation Rev	Bill Martin	Dec. 7-8, 2000	ASCI sponsor
Mission Need Review for ZR	individual recommendations	June 25-26, 2001	DOE request
Non-Nuclear Environment Simulation Rev	Tinsley Oden, Bill Martin	June 13-14, 2001	ASCI sponsor
Non-Nuclear Environment Simulation Rev	Tinsley Oden, Bill Martin	Jan. 14-15, 2002	ASCI sponsor
ZR Pulsed Power and Project Management Readiness Peer Review	individual recommendations	Mar. 13-14, 2002	DOE request
Non-Nuclear Environment Simulation Rev	Tinsley Oden, Bill Martin	May 6-7, 2002	ASCI sponsor
Pulsed Power S & T Peer Review	Al Trivelpiece	May 7-9, 2002	SNL
Radiation Effects Sciences External Rev	Douglas Eardley	May 20-22, 2002	SNL



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Albuquerque, New Mexico 87185-0101  
Livermore, California 94551-0969

*date:* August 20, 2002

*to:* Pulsed Power Program Peer Review Participants and Authors

*C. Paul Robinson*

*from:* C. Paul Robinson, MS-0101

*subject:* Thank You

It was Sandia National Laboratories' distinct pleasure to host the Pulsed Power Program Peer Review during the period May 7-9, 2002. This peer review process is of paramount importance to the management and conduct of the Pulsed Power Program, and it also supports the NNSA/SNL Performance and Appraisal Process negotiated between Sandia and NNSA.

I would like to thank all of the distinguished peer review panel members for an outstanding job done with total objectivity and professionalism. My thanks also go to the many professionals from Sandia who helped make this peer review a success, including the multiple sources and efforts in preparing for, and conducting, this review. Sandia is privileged to have all of your participation in a truly significant event.

*Exceptional Service in the National Interest*

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**Pulsed Power Program  
Review**

**May 7 – 9, 2002**

**Executive Summary**

### III. PULSED POWER PROGRAM REVIEW – EXECUTIVE SUMMARY

Each year Sandia National Laboratories (SNL) undertakes a Performance Objective Self-Assessment as part of the NNSA/DOE/Sandia Performance Appraisal Process. Sandia management chose its Pulsed Power Program (the Program) for review and assessment in FY02. The Pulsed Power Review Committee (the Committee), an external group chaired by Dr. Alvin Trivelpiece, met on May 7 – 9, 2002 to conduct this review and assessment. This document summarizes the key points of the Committee’s findings.

This Committee found that the recommendations made by the previous Committee (the Garwin Review) in FY00 have generally been implemented in a satisfactory manner. The Committee is impressed with the remarkable progress that has been made since the last review in the science and technology that forms the core of the Pulsed Power Program. This progress has been made by careful and creative uses of the funds and talent available. The Committee remains concerned that SNL’s Pulsed Power Program is still not receiving high enough funding priority to meet national needs regarding the Stockpile Stewardship Program (SSP) and related issues. The Committee believes that pulsed power is a key element in various aspects of the SSP. This includes the various equation-of-state (EOS) measurements that can be made on materials of interest, and concern using the new techniques available with existing and planned pulsed power drivers.

The Committee offers the following specific recommendations that it believes will help continue or accelerate the outstanding progress made by the SNL’s Pulsed Power Program:

- We recommend that the Program implement an appropriate “shot-allocation” priority algorithm that most efficiently supports the national security mission needs of the NNSA among the several SSP Campaigns. Moreover, the Committee recommends that contingency shots be set aside to enable Z/ZR to be used for new opportunities and to respond to evolving programmatic mission needs. A competitive selection process — coordinated through the Pulsed Power Council — should be established to allocate shots.
- We recommend that the Pulsed Power Council take a more active role in determining overarching priorities for the major Pulsed Power Sciences Center resources on Z/ZR and, perhaps, Saturn. The possibility of LANL and LLNL membership on the Council should be considered.
- We recommend that pulsed power user groups for Z and ZR be established. Their purpose should be to help set priorities within available resources, including review proposals for contingency tests and university-based research. This recommendation was also made by the Garwin Committee but was not implemented in the mode and manner expected.
- We recommend that the Program work with Sandia management and NNSA/DOE to bring the funding of ZR into the baseline program and to fund a full shift of Z operation in the baseline program.

- We recommend that the Program continue to cultivate innovation and independent thinking.
- We recommend that the Program maintain its technical program to the maximum extent possible throughout the implementation of the ZR project.
- We recommend that caution be exercised in the growth of the number of activities pursued. The Committee is concerned that the quality of the work may suffer if new projects are undertaken without adequate increases in personnel.
- This Committee reaffirms the Garwin Committee's endorsement of high yield as a long-term goal for the Sandia's Pulsed Power Program. We recommend that a "road-map" to the high-yield goal should be developed, even if it is just an internal discussion document, and even if it has alternate paths, so that the required technology developments on the path(s) to high yield will be clear to all, both inside and outside of Sandia.
- We recommend that the Program maintain and grow the intellectual vitality of the work force and the development of advanced capabilities using Inertial Confinement Fusion/High Yield (ICF/HY) as a strong motivator for attracting young people, both experimentalists and in target design activities.
- We recommend that the Program pursue ICF/HY to provide quantitative design and cost information to prepare for an NNSA decision in the FY2008 era on a machine and program capable of ICF/HY.
- We recommend that the Program pursue a sustained long-term investment strategy to support the experimental efforts on the ZR-accelerator to provide fundamental dynamic materials properties. These efforts should be focused on off-Hugoniot isentropic compression experiments (ICE) and the use of high-velocity flyer-plate impactors for shock compression experiments. These experimental advances in measuring dynamic materials properties are at the very forefront of the field of high-pressure research and shock physics. The ZR-accelerator affords unique capabilities to contribute to this area of significant importance to the stockpile stewardship program.
- We recommend that the relative priorities of the double-ended and dynamic hohlraums be re-evaluated to ensure that adequate resources are devoted to obtain maximum benefit from the impressive results showing the creation of a thin, uniform shock wave produced in dynamic hohlraum experiments.
- We recommend that the Program sustain an investment strategy to support radiation flow experiments on the Z-accelerator. These experiments are critical to the successful execution of the national NNSA stockpile stewardship mission. Moreover, the Z-accelerator provides unique and complementary capabilities with respect to other facilities in support of the national High Energy Density Science Program.

- We recommend that SNL build on the “grass roots” support for Special Nuclear Materials (SNM) capability by initiating a concerted effort with the other weapons laboratories to develop a strong advocacy in national priority discussions. It is further recommended that the Program allocate resources with respect to this effort to develop appropriate diagnostic enhancements, to conduct source characterization experiments, and to apply their unique modeling tools.
- We recommend that the Program further explore with the appropriate elements at LLNL and LANL the feasibility of sustaining a jointly supported experimental program on the Z-accelerator to perform dynamic high-pressure experiments on SNM.
- We recommend that SNL carefully examine the possibility of being able to handle SNM on its facilities. Money should be invested for hardware only when there are compelling demands and the safety of such operation is assured.
- We recommend that the Program identify, develop and exploit areas in which it is uniquely capable and in which it will continue to have unique capability after the National Ignition Facility (NIF) is operational. We recommend that the Program’s management work with the DOE/NNSA and their counterparts at LLNL, LANL, LLE, etc., to create mechanism and a program plan, prior to completion of NIF, to ensure full integration and coordination of NIF, ZR, and Omega. We believe that ZR’s capability, when fully realized, has the potential of complementing NIF’s capability and that the NIF/ZR synergy will greatly benefit the Stockpile Stewardship Program. We recommend the development of such synergy should be encouraged.
- We recommend that the Program study low-to-moderate hohlraum temperature "foot " physics in collaboration with other national laboratories, as was discussed at the last review and recommended by the Garwin Committee.
- We recommend that any significant expansion of the capability or mission of Z-Beamlet, such as a Petawatt option, should be undertaken only after strong programmatic relevance is established. Uses of Z-Beamlet, even if converted into a petawatt laser, should be keyed into pulsed power’s unique capabilities, such as the ones that involve dense z-pinch plasmas.
- We recommend that the initial work being done on petawatt laser (PW) research and development concepts performed at SNL take advantage of petawatt laser work in the wider scientific community. This will ensure optimum progress, and will help determine the unique capabilities that will be available with the Z-Refurbishment (ZR)/Petawatt laser (PW) facility.
- We recommend that the Program maintain its significant level of contributions to radiation effects sciences as they support both NNSA and DoD certification efforts.

- We recommend that SNL seek Department of Defense (DoD) support for its efforts to develop higher energy K-line radiation sources for cavity System Generated Electromagnetic Pulse (SGEMP) radiation effects testing of DoD systems.
- We recommend that the Program further explore opportunities to contribute to the development of compact, flexible radiographic sources in conjunction with the sub-critical experiments at the Nevada Test Site (NTS).
- We recommend that the Program work with Defense Threat Reduction Agency (DTRA) to determine what can be done to sustain a healthy level of support for the industrial and academic sectors of pulsed power technology in the US. It is imperative that this capability be maintained at a healthy level and that a critical mass of talent in this field remains available. Further, we recommend that the Program's management, together with DTRA, determine what is the right level and mode of involvement with the pulsed power industry, and to help ensure that national interests are well served.
- We recommend that the Program further explore the implementation of a broad-based academic user program in support of fundamental science on the various Sandia pulsed power facilities. Funds should be sought from NNSA/DOE to implement such a program.

Submitted August 26, 2002,

Alvin W. Trivelpiece, Chairman  
 David E. Bell  
 Anthony Michael Dunne  
 Richard L. Garwin  
 Charles M. Gilman  
 Yogendra M. Gupta  
 David A. Hammer  
 Mary Y. P. Hockaday

Otto L. Landen  
 Christian Mailhiot  
 Robert L. McCrory  
 Barrett H. Ripin  
 Jack S. Shlachter  
 Marshall M. Sluyter  
 Philip W. Spence

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**Pulsed Power Peer Review  
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**Alvin W. Trivelpiece, Chairman**

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**Marshall M. Sluyter**

**Philip W. Spence**

**July 2002**

# PULSED POWER PROGRAM REVIEW

## I. Introduction

Each year Sandia National Laboratories (SNL) undertakes the Performance Objective Self-Assessment as part of the NNSA/DOE/Sandia Performance Appraisal Process, which spans Management, Programmatic, Administration, and Operations performance. Pulsed power is one of the five research foundations in SNL's science base, and is a key element of the National Nuclear Security Administration (NNSA) Stockpile Stewardship Program (SSP). Sandia management has chosen this important program for review. Similar reviews were held previously, chaired by Dr. Richard Garwin in FY00<sup>1</sup> and Dr. Jasper Welch in FY96<sup>2</sup> and FY97.<sup>3</sup>

This external review committee, chaired by Dr. Alvin Trivelpiece, was chartered by SNL's management to meet with and be briefed by SNL Pulsed Power Program staff members on May 7-9, 2002. The review focused on the applications of pulsed power to DOE/NNSA's Stockpile Stewardship Program campaigns, including:

- The study of high energy density physics for Inertial Confinement Fusion (Campaign 10)
- The development of high energy density environments for equation of state, radiation flow, radiation hydrodynamics, and code validation (Campaigns 2, 4, and 11)
- Development of improved radiographic capabilities for primary certification (Campaign 1)
- Development of sources for nuclear weapons effects and abnormal environments certification testing (Campaign 6 and 7)

The DOE/NNSA SSP elements include Campaigns, Required Tech Base and Facilities (RTBF), and Directed Stockpile Work (DSW). This report frequently refers to these elements, which are defined below:

- Campaign 1: Primary Certification
- Campaign 2: Dynamic Material Properties
- Campaign 4: Secondary Certification and Nuclear Systems Margins
- Campaign 6: Weapons System Engineering Certification
- Campaign 7: Nuclear Survivability
- Campaign 10: High Energy Density Physics
- Campaign 11: Advanced Simulation and Computing

Preliminary recommendations of the Committee were summarized orally at the conclusion of the meeting and are presented herein in complete form. Appendix I is a list of committee members that identifies each member's participation on panels that were formed to address the specific elements of the charge presented to the Committee. Appendix II lists the presentations that were made by Sandia staff members to the Committee.

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<sup>1</sup> R. Garwin, et al., "*Pulsed Power Peer Review Committee Report*" Sandia National Laboratories Report SAND2000-2515 (December 2000).

<sup>2</sup> 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).

<sup>3</sup> J. Welch, et al., "*Meeting Report – Committee on Pulsed Power-Based Stockpile Stewardship*," Science Applications International Corp, NM (16 May, 1997).

## II. General Comments

The members of the Committee were impressed with what they learned regarding the scientific and technical progress that has occurred since the last review. It would be difficult to find any areas where dramatic level improvements could be recommended. There is every reason to believe that this progress will continue, and that the plans to achieve the Pulsed Power Program goals are sound and reasonable.

The Committee is concerned that insufficient financial resources are being provided to pulsed-power-based research to meet national needs regarding stockpile stewardship and related issues. This includes both DOE/NNSA and DTRA.

The Pulsed Power Program's scientific and technical achievements certainly warrant increased support. Along with this, SNL's ICF program should be included as an integral element contributing to the overall DOE/NNSA ICF goals and objectives.

Regarding shots on the Z facility, a very strong effort has been made to work effectively with all of the other laboratories and in engaging the university community. Considerable effort has been made to ensure that Z functions as a good user facility.

It is imperative that the U.S. maintains a viable pulsed power program. There are many areas where the accumulated knowledge associated with pulsed power and its applications is valuable to national security beyond those associated with DOE/NNSA programs.

The Committee believes that the Pulsed Power Sciences Center has achieved an adequate balance between near term goals and long-term objectives. There is a healthy tension between utilizing existing capabilities to undertake scientific and technical problems of interest and extending the machine capabilities.

This Committee wishes to include a portion of the General Comments made by the Garwin Committee, which remain relevant. To wit, "The DOE SSP and the ICF Program Offices should support a robust, balanced, pulsed-power program 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 charged to provide evaluation and feedback in three key areas as input to the self-assessment process:

### A. **Quality: Evaluate the Quality of Technical Activities in Science, Technology and Engineering**

The quality of science, technology, and engineering was very high, across the board, in the activities underway at the Pulsed Power Sciences Center (the Center). Furthermore, its staff members demonstrated scientific and technical excitement, were well aware of programmatic needs, wanted to undertake new and important activities, and took pride in their efforts and accomplishments. The Center leadership deserves commendation for emphasizing scientific and technical excellence, and for the good morale that we observed during our review.

Center personnel have brought to bear their state-of-the-art pulsed power facilities and expertise to successfully address a multitude of diversified and multi-disciplinary scientific issues. This strength is best exemplified in the material dynamics work where the combination of pulsed power capabilities and materials related activities have been combined leading to new scientific accomplishments. SNL's clear ability to attract and team with LLNL and LANL in these scientific activities speaks highly of the Center's capabilities in this arena. At the same time, the materials dynamics and weapons science needs for Z-machine time have posed interesting challenges for finding shot time for developing improved pulsed power capabilities. Balancing these needs to achieve good science in the near term and establish good capabilities in the long term will be important.

From everything the Committee could observe, the Center's future is bright with regards to the quality of its scientific and technical activities. Specific activities are reviewed next.

### ***A.1 ICF - Campaign 10***

Since the last review, there has been impressive experimental progress in understanding and demonstrating the potential of pulsed-power-driven hohlraums, both vacuum and dynamic, for staging ICF capsule implosions. In the case of the dynamic hohlraums, the better than expected results merit further experimental pursuit and more vigorous design scaling to high yield. In the case of the vacuum hohlraums, which are less risky from a symmetry perspective but require greater power and energy to scale to high yield, the Program has done a good job of demonstrating reproducibility through an impressive high signal-to-noise symmetry scan using the Z-Beamlet laser as a radiography source.

We support the near-term plans of action proposed by the Program for continuing both vacuum and dynamic hohlraum research campaigns. The results are encouraging enough that the ICF roadmaps presented for each should be turned into national ICF program plan milestones as is done for other Program campaigns and by other labs. Besides these integrated physics implosion experiments, the Program should do more to use the unique long pulse, large area Z hohlraums to study the low-to-moderate hohlraum temperature "foot " physics, in collaboration with other labs as was discussed at the last review. Finally, in the area of Fast Igniter, Z and Z-Beamlet upgrades are well suited to provide the testbed high-energy-density compressed matter and short high intensity pulses for relevant studies. The Z researchers in this area are encouraged to seek collaborations within the laser-plasma interactions community at universities and at other national labs to assist in computational design and in planning future experiments and associated required instrumentation.

The potential of combining a petawatt laser (PW) with a compression facility such as Z is the subject of much discussion in the weapon physics and academic communities. We recommend that the initial work being performed by the Program be combined with that of the wider community to ensure optimum progress, and to help determine what unique capabilities the Z-PW facility will offer.

Given the impressive results showing the creation of a thin, uniform shock wave produced in dynamic hohlraum experiments despite significant magnetohydrodynamic instabilities in the driving plasma, the Committee recommends that the relative priorities of the double-ended and dynamic hohlraums be re-evaluated to ensure that adequate resources are devoted to obtain maximum benefit from this intriguing advance.

The future pulsed power driver and pulse mixing architecture requirements of the vacuum hohlraum (VH) (to achieve synchronous drive of the two ends) appear more difficult than that required for the dynamic hohlraum (DH) approach and there would be significant benefits to the practicality of achieving the long-term ignition goal if the DH method can be successfully developed. It would be useful to develop ignition-level VH and DH systems conceptual designs to get a better idea of the difficulties.

#### ***A.2 Secondary Certification - Campaign 4***

Z has established itself as a leading facility for Campaign-4 relevant studies, with the ability to generate a versatile high-temperature ‘vacuum hohlraum’ in which multiple experiments can be driven by a common source. In addition, Z can generate a still-higher temperature ‘dynamic hohlraum,’ which can access unique areas of high energy density phase space required by some complex radiation flow experiments. Driven mainly by LANL, these experiments have resulted in substantial progress in the production of a suite of code validation data since the last review. Given the potential for Z to directly contribute a series of Campaign-4 Level-1 milestones at LANL, sufficient facility time needs to be devoted to these applications and associated source characterization.

We recommend that the Program build upon this success by allocating resources to an appropriate set of diagnostic enhancements, source characterization experiments, and application of their unique modeling tools. In particular, we encourage the ongoing development of a national strategy to establish priorities across the various facilities, and to ensure optimum use of their complementary capabilities.

A number of radiography enhancements are recommended, including achievement of high resolution ( $\sim 5 \mu\text{m}$ ), and pushing the x-ray energies to 9-10 keV as key near-term goals. In the intermediate term, developing a flexible diagnostic capability for weapons-physics experiments on both standard vacuum and dynamic hohlraum sources, and developing multi-pulse recording capabilities should be accorded high priorities.

Evaluation of the preheat phenomenon seen in many radiation flow experiments is a key area of concern, and should form a central element of a wider emphasis to fully characterize the

weapon physics radiation drivers (space-, angle-, time-, and energy – dependent drive information), preferably supplied in a user-friendly format to encourage new users to take advantage of the facility. The Program must supply such data, as the capability to predict likely driver performance does not reside in the user community.

Tied to this is our considered opinion that significant benefit would accrue from further application of the code “ALEGRA” to predicting (and optimizing) the radiation sources and their impact on user experiments. This would make use of the Program’s unique capabilities in this area and would constitute an important service to the wider community. A particular area for optimization of relevance to Campaign-4 is the production of varying pulse shapes (fast-rising pulses for radiation flow, or long lived drives for hydrodynamics).

The longer-term goal to develop a suitable neutron diagnostic suite should be maintained, as this forms a cornerstone of longer-term Campaign-4 (as well as Campaign-10) studies.

The potentially significant applications of the petawatt laser to Campaign-4 studies should be actively considered during the design phase of the operating regime and focusing geometry (i.e. package radiography and access to high energy density states coupled to the radiation-hydro environment produced by Z). This may require a focused study of the unique potential applications of PW by the wider weapons physics community (combining the needs of Campaigns 1, 2, 4, 7 and 10). The approach whereby PW development does not compromise Z-Beamlet coupling to ongoing Z operations is highly commended.

### ***A.3 Materials Dynamics - Campaign 2***

The quality of the scientific and technical activities associated with the material dynamics effort in the Pulsed Power Sciences Center is indeed impressive. The staff members associated with this work deserve commendation for both scientific innovations and attention to detail. This work supports several milestones in Campaign 2 of the Stockpile Stewardship Program. Although this effort is relatively new in the Pulsed Power Sciences Center, important advances have been, and continue to be, made. Comments regarding specific activities are summarized below.

The EOS work on liquid deuterium is outstanding. The experimental measurements and related analysis have made an excellent case for the results and conclusions reported for D<sub>2</sub>. The experimental rigor and careful attempts to determine whether there is self-consistency using different types of measurements deserves special recognition. It is clear that the Z-results differ significantly from the earlier laser driven shock compression measurements on the Nova facility. It is important that Sandia and LLNL scientists work to understand these different results.

Quasi-isentropic compression or ramp wave loading at high pressures is a unique capability that addresses a long standing scientific need for understanding the dynamic compression of condensed matter. Both scientifically and programmatically, the ability to generate off-Hugoniot data is important to the development of a thermodynamically complete EOS. The ability to tailor the input waveform for an arbitrary pressure temporal profile has many, exciting scientific

applications. The work to date clearly demonstrates the considerable potential of this development. The Committee strongly encourages continued development work in this direction and its use for various scientific applications.

The use of the Z-machine to launch flyer plates (approaching 30 km/s) is again an important development. The combination of computational and pulsed power capabilities, together with shock wave expertise in the Pulsed Power Sciences Center is directly responsible for this development. The Committee applauds this multi-disciplinary approach and effort, and encourages further developments to ensure that flyer response is well characterized at these very high velocities. This capability can serve as an excellent bridge between gas-gun experiments and laser-shock experiments both in terms of pressure amplitude and sample size.

The recommendation by the Garwin Committee in 2000 regarding studying the possible testing of SNM in the Z-facility has been implemented. The feasibility studies for experimental work with SNM are well thought out and are progressing well. As is well known, this is a difficult technical challenge and the containment work to date looks very promising.

Finally, the materials dynamics effort deserves particular recognition and commendation for their collaborative approach and collegial interactions with all parts of the DP complex.

The Committee recommends that either more staff members are needed or the scope of activities may have to be somewhat limited to ensure that the materials dynamics effort maintains its scientific excellence. Investment in SNM studies needs to ensure that there is agreement that such work is needed from the other DP Labs and the Atomic Weapons Establishment (AWE) in Aldermaston, UK. Continued engagement of the DP Labs at the program level as well as the worker level is essential to obtain buy-in for a program that will require considerable investment and must be demonstrably safe.

#### ***A.4 Radiation Effects - Campaign 7***

The program continues to make good use of both in-house and outside facilities (such as the DTRA Python and Double-Eagle machines) for radiation effects testing. The Program recognizes that extra R&D resources may be necessary to make up for decreased DTRA support of fast Z-pinch K-shell line radiation source development and to possibly develop a reflex triode bremsstrahlung source capability on Saturn should the DTRA Double Eagle/Python facilities become unavailable late in the decade.

The Program has made good technical progress in development of higher energy K-shell line radiation sources for cavity SGEMP testing. Z, and especially ZR, will be unique facilities for generating higher yields of these harder x-rays. Because these radiation sources should also be of interest for DoD systems radiation effects testing, the Program should consider seeking DoD support for incremental enhancements to ZR both during and after the initial design and construction phase.

### *A.5 Miscellaneous Capabilities*

The Z facility has continued to make an effective transition from an R&D facility to a first-class user facility able to accommodate a variety of different customers and applications. The technical approach to ZR appears solid, incorporating planned, extensive, module-level development/demonstration tests in Z-20 (a 20 degree segment of ZR) to address switching, pulse forming, and power flow design issues. Integrated front-end-level tests on Z will address insulator stack and vacuum power flow issues. It is important to maintain priority for vacuum power flow R&D tests within the many demands for Z shots to support the design of a cost-effective ZR front-end.

In view of the relevance and unique potential capabilities of ZR for materials properties/EOS testing (Isentropic Compression Experiment -ICE and super-high velocity flyer plate impact) we recommend that more attention be given to generating a wider variety of output current pulse waveforms. The present coarse degree of “quantization” amongst short- and long-pulse modules driving each power flow “level” appears to limit the range of pulse shapes that could be generated.

The main benefit of the ZR facility, in addition to 40% more current, is likely to be improved reliability and precision, while its greatest beneficiaries are likely to be the EOS and radiation sources research - areas that scale strongly with increased energy. An increasing number of the planned Campaign 10 and Campaign 4 experiments will rely on the laser produced x-ray backlighting capability. Hence, it is important that the Program integrate the Z-Beamlet and PW capabilities with the Z and ZR machines, both from an operational (i.e. maintaining shot rate) and a user’s requirements perspective. In particular, issues that should be pursued include providing a multiframe radiography capability where warranted, developing gated imaging capability, and quantifying Z-Beamlet and Z-PW radiography needs for both Z-pinch science and High Energy Density Physics research.

Finally, since the Program will no longer be alone in being able to generate megajoule-levels of x rays when the NIF is full operational (~FY07), it is important that the Program collaborate with the other labs to better identify the complementary research areas and parameter space that each will study.

The introduction to SNL’s Pulsed Power Program of laser-based technology to address radiography and ICF requirements, and the possible extension of this to the petawatt laser is to be commended. The potential value of Z-Beamlet and PW to many areas of weapons physics is very high, and should be addressed via interaction with the wider community to optimize in-house target designs and ensure the unique applications of coupling to Z are fully realized.

The z-pinch Fast Ignitor concepts presented were at an early stage of development, but have clear long-term potential. We encourage this work, but urge collaborative effort with other groups in the DOE/NNSA complex to push Fast Ignitor research ahead as fast as possible.

The radiography team that is developing sources for the subcritical tests at the Nevada Test Site (NTS) seems in excellent shape. The team appears to be up-to-date with all current

developments in multi-MeV bremsstrahlung sources and has maintained close ties with both the technology and user communities, including research at AWE.

Impressive progress has been made in the application of ALEGRA and associated tools to the understanding of Z pinch dynamics, with benefits evident across the Campaign structure.

#### ***A.6 Quality Committee Recommendations***

We recommend that the relative priorities of the double-ended and dynamic hohlraums be re-evaluated to ensure that adequate resources are devoted to obtain maximum benefit from the impressive results showing the creation of a thin, uniform shock wave produced in dynamic hohlraum experiments.

We recommend that the Program study low-to-moderate hohlraum temperature "foot " physics, in collaboration with other labs as was discussed in the last review and recommended by the Garwin Committee.

We recommend that the Program: build on the "grass roots" support for SNM capability by initiating a concerted effort with the other weapons laboratories to develop a strong advocacy in national priority discussions. It is further recommended that the Program allocate resources with respect to this effort to develop appropriate diagnostic enhancements, to conduct source characterization experiments, and to apply their unique modeling tools.

We recommend that the Program seek DoD support for the efforts to develop higher energy K-shell line radiation sources for cavity SGEMP testing radiation effects on DoD systems.

We recommend that the initial work being on the Petawatt concept performed at SNL be continued in collaboration with scientists from the broader fast ignitor wider community to ensure optimum progress, and to help determine the unique capabilities of the PW facility.

We recommend that caution be exercised in the growth of the number of activities pursued. The Committee is concerned that the quality of the work may suffer if new projects are undertaken without adequate increases in personnel.

#### **B. Programmatic Performance and Planning: Evaluate the Programmatic Performance, Management and Planning, e.g. near term planning, meeting customer requirements, and providing for a robust future.**

Like our predecessor review committee chaired by Dr. Richard Garwin, this Committee believes that the Pulsed Power Sciences Center is a National Resource that should be nurtured by Sandia management, the DOE/NNSA, and other sponsors.

### ***B.1 Programmatic Performance***

The Committee was impressed with the quality of Sandia Pulsed Power Program from both the management and technical achievement perspectives. The Program's management has exercised sound judgment, execution of program objectives, and farsighted leadership.

There was little doubt two years ago that Sandia National Laboratory had the world's leading pulsed power program, but there was concern that the program might wane. Today the Sandia Pulsed Power Program appears to be revitalized and coming together in support of the refurbishment of the Z-machine, ZR, which is clearly an important programmatic goal for the next few years. The decision to modernize Z and increase its capability, reliability and, potentially, shot rate was sound. The refurbishment of the Z-machine is proceeding with measured deliberation and with appropriate attention to cost. We believe achievement of the stated 26 MA goal is a relatively low risk endeavor. The strategy of thorough component and reliability testing of modules prior to committal is both prudent and reassuring. The project appears to be on track for completion within the projected \$58M budget. We have concern that the cost envelope is vulnerable to potential delays outside of the Program's control, not unusual in these times of great funding uncertainties. The ZR project has benefited this year from a Congressional funding plus-up that enabled it to move forward. We view it as very risky to plan the future of ZR on the anticipation of further funding plus-ups and we urge both DOE/NNSA and Sandia management to work together to ensure that this additional vulnerability does not become a reality.

We are pleased to see that all levels of Sandia management support the completion of the refurbished Z-machine, ZR. This task is important for the continued health of the pulsed power program. Furthermore, the additional experimental capability that comes with the ~40% (or greater) increase in current is very important to the Stockpile Stewardship Program (SSP).

The decision to go forward with the installation of the re-assembled Beamlet for use as an x-ray backlighter source for Z and ZR posed significant risk because of the potential for draining resources from the rest of the program. Our Committee believes that this was a good decision. Good program management and technical support ensured that this extremely capable laser system was incorporated into the Sandia facility in a flexible and timely manner and without undue disruption of the main-line program. The Program now has an invaluable experimental asset, Z-Beamlet, to bring to bear upon weapon physics, ICF, and other experiments. We applaud the Program's management's foresight and skill in undertaking and successfully completing the laser installation project.

A characteristic of the program management in the Pulsed Power Sciences Center has been, and continues to be, its encouragement of innovation and independent thinking while keeping the bulk of the effort focused on "deliverables." The development of the capability to carry out Isentropic Compression Experiments on Z is but one of several examples of such innovation resulting in high payoff. The Committee appreciated the fact that speakers at our review did not appear to be constrained in expressing their personal views or in how they could answer questions.

## ***B.2 Management Performance***

We commend the program managers and research staff in the Pulsed Power Sciences Center for being supportive of other laboratories' needs during Z-machine experiments, as well as their efforts to work collaboratively with their counterparts at LLNL and LANL on joint projects of importance to SSP. It appears that Sandia management genuinely has the best interests of the overall DOE/NNSA program in mind when it assigns its resources, including campaigns on the Z machine.

Continuity of top management of the Pulsed Power Sciences Center should be a high priority, at least through the completion of ZR. The present management team is functioning well together and appears to have the confidence of the scientific and technical staff. In addition, they have established good working relationships with their counterparts outside of SNL in the ICF and Stockpile Stewardship programs.

We are concerned that it is risky to have the number of Z/ZR shots that can be fielded in a year held hostage to plus-ups. We note that the number of worthwhile experiments greatly exceeds the number of available shots in a given year. We believe it should be a priority to have a full single-shift of Z shots be included in base funding. At present, this is the Nation's unique resource for many issues being addressed by the SSP. When the NIF comes on line, the competition could be detrimental to the health of the SNL program unless the use of ZR is properly managed. Competition can be healthy, providing a check on critical science issues. A current example of this is the differing EOS findings for deuterium from Sandia and LLNL. In addition, the Program must demonstrate an important an important niche in the SSP program that only ZR can satisfy.

## ***B.3 Planning for the near and intermediate term***

Most of the recommendations of the Garwin Committee of two years ago were implemented. One exception is that a formal users group (or groups) has not yet been established for the purpose of helping to make decisions on Z/ZR-machine shot allocations. While we heard no overt complaints of unfairness from users, it is inevitable that complaints will eventually arise in such an oversubscribed and unique facility as Z/ZR. We are concerned that Sandia will not be in a good position to adjudicate disputes and may end up being forced to cede some of its own shot allocation to resolve problems. This would be a mistake, as it is important that Sandia have a vibrant scientific and development program of its own. We continue to think that users group(s) could be a useful mechanism to help make optimum use of the facility as well as stave off allocation disputes. Bearing in mind that the purpose of a users group is to help set priorities within limited resources, perhaps the following proposition could ease potential problems. First, continue the present practice of allocating a certain fraction of tests on Z to the labs to use as their internally set priorities determine. However, in addition to withholding 5% of the shot allocation for university-proposed experiments, we suggest holding in reserve another significant fraction of the tests, perhaps 15-20% that will be allocated by user groups as a result of peer-review of brief proposals. Programmatic importance and scientific merit should be the principal criteria for judging a proposed test or test series, but previous performance, likelihood of success, level of multi-laboratory collaboration, etc., could all be considered. The user groups could also help evaluate proposed university experiments on Z/ZR. With real resources to allocate, it should be possible to convince good people to participate.

Note that the users group in the previous paragraph is not the same as the Pulsed Power Council (PPC) that the Program already has in place, nor is it intended to replace the higher-level Pulsed Power Council. It appears to us that the PPC should take a more active role in determining overarching priorities for the major Pulsed Power Sciences Center resources on Z/ZR and, perhaps, Saturn. The Council should address questions such as prioritization and scheduling of shot series for weapon physics, ICF, source development, ICE, etc. If this suggestion is accepted, the possibility of membership on the Council by LLNL and LANL representatives should be considered.

The Pulsed Power Program is a national asset and, hence, we feel it is very important that the vitality of the pulsed power program remain healthy for the foreseeable future. In this regard, it is important to maintain a steady stream of hiring and training bright young scientists and engineers in all aspects of the field from source and pulsed power development for ZR and future machines, to ICF target design, high energy density science, etc.

#### ***B.4 Providing for a robust future***

This Committee reaffirms the Garwin Committee's endorsement of high yield as a long-term goal for the Pulsed Power Program. We believe that a high-yield capability is needed by this country's nuclear security program just as we believe that it is too early to focus on the specific technology that might be required to achieve that capability. Maintaining Pulsed Power's goal of high yield is also an essential factor that drives the Program's vitality and high rate of progress. That should be kept in mind both to keep motivating the scientific and technical staff and to keep everyone focused on the near-term developments needed to exploit the recent successes of the program. We believe that a "road-map" to the high-yield goal should be developed, even if it is just an internal discussion document, and even if it has alternate paths, so that the technology developments on the path(s) to high yield will be clear to all, both inside and outside of Sandia. All senior staff should contribute to developing this roadmap so that they feel ownership of the program to some extent. By its very nature such a road map would be a living document and would have to be updated on a regular basis, as new knowledge is gained.

As already noted, the SNL Pulsed Power Program is an important national resource for the country, and this is true for many purposes in addition to stockpile stewardship. We are concerned that the program might be especially vulnerable as the NIF starts up and (like every other program in DOE/NNSA) is short of money. To assure its long-term future at least as far as DOE/NNSA is concerned, the Program needs to demonstrate to the other laboratories, the DOE/NNSA, and the scientific community that it is indispensable. Areas in which pulsed power has a unique niche or complements the intended/expected areas of emphasis of the NIF should be exploited. Developing the capability to field experiments with special nuclear materials is one possibility. It seems likely that approvals for testing SNM in the NIF will be much more difficult to obtain than for the Z facility. However, we suggest that a confirmed customer needs to be established and essentially guaranteed before substantial financial resources are invested in fielding SNM capability on ZR.

One recommendation we make is that Sandia's pulsed Power Program, LLNL, LANL, UR and other major players in high-energy-density physics, work out a program plan to ensure full integration and coordination of NIF, ZR, and Omega prior to the completion of NIF.

The level of university support by the Program is commendable, as is the encouragement of innovative and independent thinking by staff members. One caution we wish to offer is to make sure that innovative uses of Z-Beamlet, even if it is converted into a petawatt laser, are keyed into pulsed power's unique capabilities, such as ones that involve dense z-pinch plasmas. The Program should avoid being in competition with other petawatt lasers that might be developed, either at other labs (especially the NIF) or at universities.

The Program has the responsibility to maintain a strong core competency in pulsed power and a related responsibility to consider maintenance of the US pulsed power capability as a whole. The pulse power industry is a vital part of this capability, and has made important contributions to SNL's programs. Therefore, the Program's management should act to assure that the Program keeps a "critical mass" of core competency in pulsed power and at the same time foster a balanced, synergistic relationship with the engineering capability of the US pulsed power industry. It is important to pursue the second goal by collaborating with DTRA to determine what are the right levels and right areas of industry involvement, so that the national interest is well served.

The process of self-evaluation, initiated by the Pulsed Power Program in 1999, has helped the program identify and define its objectives. It has produced several planning documents such as the Pulsed Power PATH FORWARD and, more recently, a draft of an Implementation Plan. Two years later, the Program appears well positioned to embark on the refurbishment of its Z facility, and a staff recruiting effort is under way, both items being on the wish list in 2000. It would then be appropriate to take this opportunity and revisit the operative planning document, re-examine it, and update it, if warranted.

### ***B.5 Programmatic Performance and Planning Committee Recommendations***

We recommend that the Pulsed Power Sciences Center work with higher-level SNL management and DOE/NNSA to bring the funding of ZR into the baseline program and to fund a full shift of ZR operation in the baseline program.

We recommend that the Pulsed Power Sciences Center continue to cultivate innovation and independent thinking.

We recommend that a user group or groups be established, the purpose of which should be to help set priorities within given resources. (This a reprise of a Garwin Committee recommendation.) It is also suggested that the Program continue the practice of allocating certain fractions of facility time to the laboratories to use as their internally set priorities determine, but reserve about 20-25% of all tests for allocation by the user groups as a result of peer-reviewed brief proposals. Users group(s) allocation recommendations might be sent to DOE/NNSA for approval to insulate against complaints of inequitable distribution of shots.

We recommend that SNL's Pulsed Power Program maintain its experimental program on the Z-machine to the maximum extent possible throughout the implementation of Z-refurbishment.

We recommend that the Pulsed Power Council should take a more active role in determining overarching priorities for the major Pulsed Power Sciences Center resources on Z/ZR and, perhaps, Saturn. The possibility of membership on the Council by LLNL and LANL representatives should be considered.

This Committee reaffirms the Garwin Committee's endorsement of high yield as a long-term goal for the SNL program. We recommend that a "road-map" to the high-yield goal should be developed, even if it is just an internal discussion document, and even if it has alternate paths, so that the technology developments on the path(s) to high yield will be clear to all, both inside and outside of SNL.

We recommend that the Pulsed Power Center identify, develop and exploit areas in which it is uniquely capable and will continue to have unique capability after NIF is operational. We recommend that the Program's management work with the DOE/NNSA and their counterparts at LLNL, LANL, LLE, etc., to create mechanism and a program plan, prior to completion of NIF, to ensure full integration and coordination of NIF, ZR, and Omega. A possible approach to such a mechanism would be through the governance of those facilities.

We recommend that SNL look carefully at the possibility of being able to handle Special Nuclear Materials on its facilities, but should invest money in hardware only when there is a compelling demand and the safety of such operation is assured.

We recommend that any significant expansion of the capability or mission of Z-Beamlet, such as a petawatt option, be undertaken only after a strong programmatic relevance has been established. Uses of Z-Beamlet, even if converted into a petawatt laser, should be keyed into pulsed power's unique capabilities, such as the ones that involve dense z-pinch plasmas.

We recommend that the Program take appropriate measures to ensure that pulsed power technology capability is maintained at a healthy level in the US and that a critical mass of talent is maintained. Further, we recommend that the Program management, in consultation with DTRA, determine what is the appropriate level and mode of involvement with the pulsed power industry required to ensure that the national interest is well served.

### **C. Relevance: Evaluate the Relevance to National Needs and Agency Missions**

Pulsed power science and technology are relevant to national needs and to DOE/NNSA missions, including basic science, energy production, and national security. The SNL Pulsed Power Program is outstanding and provides significant benefits to DOE/NNSA, DoD, and the industrial community. The Committee has evaluated the relevance of the SNL's Pulsed Power Program and organized this evaluation along the following program elements:

- Dynamic materials properties under extreme conditions

- Inertial confinement fusion and high yield
- High-energy-density science, radiation transport, and radiography
- Radiation effects science and hostile environment

In addition, the Committee has addressed several crosscutting issues associated with the university programs, development of next-generation capabilities and shot allocations on the various SNL pulsed power facilities.

### ***C.1 Dynamic materials properties:***

The development of experimentally validated scientific capabilities to predict the dynamic response of materials under extreme conditions of pressure, temperature, strain and strain rates is at the heart of the DOE/NNSA SSP. The utilization of the Z-accelerator as a flexible current source (and pressure-wave temporal profile) capable of generating extreme states of compression in materials — either quasi-isentropically to perform Isentropic Compression Experiments or under shock loading conditions through the launching of flyer plates at high-velocity — is a truly unique capability within the DOE/NNSA complex. This capability affords the investigation of the dynamic properties of materials under a wide range of conditions of pressure, temperature, strain and strain rates — on- and off- Hugoniot — that naturally complements those produced by gas-gun launchers and laser-driven impactor compression experiments. The numerous and high-visibility contributions of the SNL pulsed power science program to the field of dynamic high-pressure research continue to have a significant impact within the scientific community at large and to benefit the DOE/NNSA SSP through the development of predictive capabilities and physical data related to high-pressure properties of materials. This effort has direct relevance to several DOE/NNSA missions in fundamental science and national security and is of extremely high scientific quality. Consequently, the Committee strongly recommends that the dynamic materials properties program implemented on the SNL's pulsed power facilities be supported on a long-term basis.

A program is currently underway at SNL to explore the feasibility of performing dynamic materials properties experiments on Special Nuclear Materials (SNM), using proper containment techniques. This effort is making good progress. However, we reiterate that before additional resources are expended to explore the feasibility of such experiments, the review Committee recommends that SNL obtain strong commitment from the Lawrence Livermore National Laboratory (LLNL) and from the Los Alamos National Laboratory (LANL) for the support of a long-term, vigorous experimental program aimed at performing dynamic experiments on SNM at the SNL pulsed power facilities. Failure to do so will result in unnecessary expenditures of resources without clear scientific and/or programmatic benefits.

### ***Recommendations:***

We recommend that the Program pursue a sustained long-term investment strategy to support the experimental efforts on the Z-accelerator to provide fundamental dynamic materials properties. These efforts should be focused on off-Hugoniot isentropic compression experiments and high-velocity flyer plate impactors for shock compression experiments. These experimental advances in measuring dynamic materials properties are at the very forefront of the field of high-

pressure research and shock physics. The Z-accelerator affords unique capabilities to contribute to this area of significant importance to the stockpile stewardship program.

We recommend that the Program further explore with LLNL and LANL the feasibility to sustain a jointly supported experimental program on the Z-accelerator to perform dynamic high-pressure experiments on SNM.

### ***C.2 Inertial confinement fusion (ICF) and high yield:***

The typical high-yield design would provide 500 MJ energy release from DT gas. This might be achieved with spherical capsules using either a double-ended drive or dynamic hohlraum. It might also be achieved by the fast-ignitor concept using a petawatt laser to heat a tiny portion of DT fuel compressed to high density by a modest Z-pinch.

The ultimate vision is within the Program's mission space: 500 MJ corresponds to 0.12 tons; at 1 m, it provides the same energy fluence as 120 kt at 1 km. Thus it would be valuable to verify system-level Advanced Simulation and Computing calculations in the 2010 era.

Also within the Program's mission space is maintaining and growing the intellectual vitality of the work force and the development of advanced capabilities. ICF/HY is a strong motivator for young people, both on the machine and in the design realm.

Finally, inertial confinement fusion/high yield (ICF/HY) should be pursued to provide point designs and cost information for a decision in the FY2008 era on a machine and program capable of ICF/HY. At about this time, the National Ignition Facility (NIF) should be operating at full scale, and DOE/NNSA will be faced with decisions, whether NIF is fully successful or not. Pursuing the ICF/HY vision with ZR at SNL will provide one much-needed option for achieving ICF. The fast-ignitor approach might do this with a smaller machine, but is a much riskier approach, in view of potential problems with laser coupling and achievement of adequate density in implosion of a capsule that has a laser access port.

#### ***Recommendations:***

We recommend that SNL's Pulsed Power Program maintain and grow the intellectual vitality of the work force and the development of advanced capabilities using ICF/HY as a basis for attracting young people, experimentalists and in the ICF/HY target design activities.

We recommend that the Program pursue ICF/HY to provide quantitative and cost data for a potential DOE/NNSA decision in the FY2008 era on a machine and program capable of ICF/HY.

### ***C.3 High-energy-density science, radiation transport, and radiography:***

#### ***C.3.1 Radiation Flow***

Radiation flow efforts on the Z facility, conducted largely by Los Alamos National Laboratory, are a component of the secondary certification / margins campaign, Campaign 4. As such, this work is clearly not part of SNL's primary mission space. The work is, however, a core responsibility of the design laboratories and thus plays a major role in addressing national security needs. SNL's Pulsed Power Program contributes to this effort on several levels, and this contribution has been essential for the successes to date. In addition to having operational responsibilities for Z, Sandia characterizes and optimizes the radiation sources. The Program is also heavily involved in the development and operation of most of the diagnostics. The addition of the Z-Beamlet backlighter allows for a new dimension to the Campaign 4 experiments and will be used extensively for dynamic radiography. This augmentation to Z greatly enhances the capability of the facility in support of the secondary certification national mission. For the foreseeable future, Z will continue to provide the principal radiative drive environment to the design community. Radiation flow in complex geometry offers a unique validation role for next-generation ASCII codes, and the data provided by Z is an essential component in this process. In the absence of underground nuclear testing, access to relevant pressures and time scales is exceedingly difficult. Radiation flow work on Z is critical to the execution of the national SSP mission, and Z has complementarities with the other facilities in the national High Energy Density Science Program.

### ***C.3.2. Radiography Development***

In the previous review of Pulsed Power Sciences, the Committee indicated support for continued development of compact, 1-10 MeV intense electron-beam-based radiographic sources in conjunction with the Los Alamos sub-critical experiments at the Nevada Test Site (NTS). We applaud the successful collaborative efforts to date on defining and implementing source development. The requirements for the Armando experiment are well established and appear to be achievable with sufficient investment. While the schedule is aggressive, the path forward is well mapped. Radiographic needs for subsequent sub-critical experiments will require some extrapolation of the immersed-B diode concept, and research in this area appears warranted. Establishment of mission need for these experiments is outside the purview of this committee but should be reviewed critically by another body. Given an endorsement of that need, the enhancement of radiographic capability for use at the NTS is a justified component of the SNL's Pulsed Power Sciences program and should be pursued.

### ***Recommendations:***

We recommend that the Program sustain an investment strategy to support radiation flow experiments on the Z-accelerator. These experiments are critical to the successful execution of the DOE/NNSA stockpile stewardship mission. Moreover, the Z-accelerator provides unique and complementary capabilities with respect to other facilities in support of the national High Energy Density Science Program.

We recommend that the Program further explore opportunities to contribute to the development of compact, intense electron beam-based radiographic sources in conjunction with the sub-critical experiments at the Nevada Test Site (NTS).

#### ***C.4 Radiation effects science and hostile environments (DB)***

The Program's efforts in Radiation Effects Sciences are clearly relevant to the DOE/NNSA's Campaign 7 (Nuclear Survivability), where SNL has a major role. In addition, the work being accomplished on Saturn, Z, and Hermes III are very beneficial to DoD certification efforts. With the high photon energy and high fluence environment of Z (and even larger capability that ZR will provide), the Program has an impressive and unique capability for radiation effects testing for survivability validation.

The Program's efforts to bring a cavity System Generated Electromagnetic Pulse testing capability on-line at Z are important for weapon system qualification and model validation. Likewise, work at improving ICE, Z-pinch, Bremsstrahlung, and electron beam capabilities for thermomechanical shock and thermostructural response is critical for certification in hostile environments.

One concern that the Committee has is what the impact of a downturn in DTRA funding to radiation simulator research and development will have on the Pulsed Power Program's radiation effects sciences programs. Over the last several years, the Program and DTRA have worked closely together in the development of complementary capability for effects testing. With the potential slowdown on the DTRA side, it is important that the Program assess the impacts that might occur in the capability they require to perform their certification mission. What are the hidden costs that the Program will need to pick up? It is very important that the SNL Pulsed Power Program and DTRA maintain close coordination of activities to maximize benefits for both DOE/NNSA and DoD.

#### ***Recommendations:***

We recommend that SNL maintain its significant level of contributions to radiation effects sciences as they support both DOE/NNSA and DoD certification efforts.

#### ***C.5 Cross-Cutting Issues***

##### **Academic alliances:**

The effort expended by the SNL pulsed power sciences program to engage the academic community is highly laudable and should be encouraged on a long-term basis. The Committee recommends that such efforts be expanded in order to increase the exposure to the university community of the capabilities of pulsed power facilities as a fundamental science tool in dynamic high-pressure research and high-energy-density science. Moreover, strong coupling with the university community will ensure the training, attraction and retention within the DOE/NNSA complex of future leaders in pulsed power science and technology. The Committee recommends that the Program work with DOE/NNSA to establish an appropriate protocol enabling a specified fraction of the pulsed power capabilities to be allocated to university investigators and that mechanisms be implemented to support these academic investigators through a coordinated grants program — possibly within existing DOE/NNSA academic alliances programs.

##### **Development of next-generation pulsed power capabilities:**

The ability to develop next-generation experimental capabilities — including advanced diagnostics — on the SNL pulsed power facilities is critical in sustaining an intellectually vibrant and programmatically relevant program. Consequently, the Committee recommends that contingency shots be allocated for high-risk “technology development” efforts. The flexibility to accommodate such enabling technology shots within the SNL pulsed power sciences program is critical to ensure that DOE/NNSA retains access to the most comprehensive and up-to-date set of capabilities in the field of pulsed power.

*Shot allocations on pulsed power facilities:*

The SNL pulsed power facilities are severely oversubscribed. A Pulsed Power Council has been established by Sandia management to provide an appropriate balance between requests and allocations in order to optimize scientific and programmatic benefits. Currently, shot allocations supporting the various program elements (*i.e.* the NNSA/Defense Programs “campaigns”) appear to be, approximately, equally divided among dynamic materials properties (“Campaign 2”), radiation transport for secondary margins and certification (“Campaign 4”), radiation effects science and hostile (“Campaign 7”), and ICF / high-energy density physics (“Campaign 10”). Currently there is little direct correlation with shot requests among these program elements. The Committee recommends that contingency shots be set aside to enable flexibility to meet evolving programmatic mission needs and to test new ideas. A competitive selection process — coordinated through the Pulsed Power Council — should be established to provide optimal allocation.

***Recommendations:***

- We recommend that the Program further explore the implementation of a broad-based academic user program in support of fundamental science on the various pulsed-power facilities.
- We recommend that the Program implement an appropriate “shot-allocation” priority algorithm that most efficiently supports the national security mission needs of the DOE/NNSA among the several “campaigns”. Moreover, the Committee recommends that contingency shots be set aside to optimize dynamic alignment of the experimental pulsed power efforts to the evolving programmatic mission needs.

**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:

***Q1. How can we achieve better recognition of our facilities as a national asset?***

A paradox of success is sometimes the inability to fulfill the demands it creates. Many commercial operations fail out of a lack of understanding that the conditions that brought success are not permanent. Spending substantial capital to create the machinery of production to meet demand can leave a company without sufficient working capital to meet current expenses when the demand begins to diminish for unanticipated reasons. The result sometimes leads to failure and bankruptcy. Research institutions and the projects they manage are not immune from such cause and effect consequences. The circumstances and situations are quite different to be sure, but the outcome can be the same.

The necessary condition for success for the Pulsed Power Program at Sandia or for any facility constrained research and development is to continue to do good work. The results of experiments conducted and analytical supporting activities constitute a body of work that have made significant contributions to knowledge and understanding of altered states of matter. Those who already use the facilities and the knowledge they produce to advance their own projects and programs already know and appreciate them.

This is not a sufficient answer to the posed question. Since the demands for time to use the facilities are likely to remain unsatisfied, the question is from whom is it desired to have recognition?

A collection of satisfied users, both internal and external, constitute the best basis for expanding the understanding of the value of the facilities and what they can produce. This means providing them service that in some ways should model a commercial operation. The elements include ease of access to the facilities, timely completion of work proposed, access when promised, assistance in preparing and conduction experiments, etc. These details always seem mundane and irrelevant until there is an established collection of disgruntled users who are looking for another way to get their work done faster, better, cheaper.

If the Pulsed Power program continues to provide improving services to internal and external users, it is likely that the recognition of the value of the program will follow without special additional efforts. Open publications and presentations when circumstances permit, and the use of appropriate seminars and workshops among users in the Stockpile Stewardship world should result in sufficient recognition in the near term. In the longer term, keeping the users satisfied will be the major challenge.

For a multipurpose lab such as Sandia, there is a continuing need for internal support as well as external recognition of the value of each of its activities. How to gain such support for one internal activity over another is never clear or obvious, but the old ways of earning it still apply. Seek internal funding support whenever the opportunity emerges. Seek to establish an external affinity group of users whose ability to make progress in their programs depends critically on the Pulsed Power facilities at SNL. Recognize that there may come a time when successful performance alone may not be sufficient to result in continued support, and plan for the changes that might occur.

***Q2. Pulsed Power provides complementary capability to Omega today and NIF in the future. How can we reduce/avoid destructive competition?***

The line between beneficial and destructive competition is not easy to define. No competition usually leads to lower performance. Too much competition usually leads to a reduced field of competitors as some drop out. In this situation, there are no rules of engagement that prohibit cooperation among the parties. Frank discussion among them would seem to be called for. There is never-ending hostile competition for funds for major research programs and projects. This competition is sometimes beneficial and leads to an ability to select the best from a collection of proposals to accomplish a particular objective. This competition can also be

destructive. If one group disparages the proposal of another rather than point out the good features of their own, and visa versa, they both unwittingly put information in the hands of those who would like to support some other project or program. This sometimes leads to the outcome where neither party receives any funding for their proposal. Such mutually destructive behavior reflects a misunderstanding certain aspects of the political process. The message is to provide reliable information on all programs: circling the wagons only to shoot inward is counterproductive. This is merely political common sense that is unfortunately not usually adhered to. The best way to ensure an efficient and vital National Program is for the laboratories to engage in continual discussion of programmatic priorities and long-range planning. Some degree of competition is healthy as a stimulus and as a check on findings.

***Q3. How can we overcome “mission creep” concerns felt by other labs?***

“Mission creep” is in the eye of the beholder. “Good fences make good neighbors,” Robert Frost from the *Mending Wall* is an admonition that applies in many situations. Here it would seem to imply that time spent before the fact in defining the ground rules under which the fence lines are drawn would be beneficial. Unfortunately, the parties involved are not entirely free agents in making such agreements. The Administration and the Congress have influence over the location of the fence lines, and they don’t always agree. Even so, it is better if the parties come to an agreement that they are comfortable with and can agree to than rather than to have imposed solutions that sometimes violate common sense. Approaching the problem with an “I win, you lose” mind set is not likely to be productive. It may not be possible to find a solution to the difficulties this problem presents, but it is worth seeking one. This means starting with those threatened to learn what troubles them, and then finding the areas in which some agreement is possible. For those remaining areas where the disagreements persist, it might be necessary to simply continue to disagree. This is not an easy problem to confront, but lack of engagement usually makes such problems worse. Some ‘mission creep’ is healthy – it allows extension of a program in fruitful areas, as mentioned before, some competition can be a healthy influence in the National Program. A danger of excessive mission creep is spreading its self too thin to do a good job at its core mission.

***Q4. How can we balance the need to maintain the vitality of Pulsed Power Science with the need to impact near term Stockpile Stewardship deliverables?***

Creative scientists and engineers in research and development programs are able to see things to do that are important and interesting. This sets up a natural conflict between the need to create and maintain the tools to produce the deliverables and a desire to pursue the inevitable new opportunities that the new tools make possible. This is a healthy problem. That doesn’t make it any easier to solve. Failure to produce deliverables results in unhappy sponsors and customers. Failure to make better tools does the same. The only practical answer to the question is to continue to make it clear to the sponsors that a reasonable degree of flexibility in expectations is in their interests in the long run. This means that it is necessary to have their trust. The sponsors have to be satisfied that the Pulsed Power program is doing a fair and responsible job of maintaining proper balance between meeting all of the near-term deliverables and providing long-term program viability. It appears that this is the case in the current Sandia program.

This issue goes beyond the direct question and calls attention to the fact that the overall support for Pulsed Power Science has diminished in the United States to the detriment of future possible challenges that will likely come in certain areas of national security. To the extent that it is possible, some degree of internal funding support would seem appropriate to augment any flexibility that sponsors or customers might allow. In addition, it would be helpful for those who believe that that this lack of priority afforded the pulsed power sciences field is going to be detrimental should call attention to this difficulty whenever and wherever they can.

#### **IV. APPENDIX I: COMMITTEE MEMBERSHIP**

Chairman: Dr. Alvin W. Trivelpiece, Consultant

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

Prof. Yogendra M. Gupta, Washington State University, Lead

Dr. Anthony Michael Dunne, Atomic Weapons Establishment (U.K.)

Dr. Mary Y.P. Hockaday, Los Alamos National Laboratory

Dr. Otto L. Landen, Lawrence Livermore National Laboratory

Dr. Philip W. Spence, Titan - Pulse Sciences Division

Panel 2: *Programmatic Performance, Management and Planning*

Dr. Barrett H. Ripin, United States Department of State, Lead

Mr. Charles M. Gilman, Science Applications International Corporation

Prof. David A. Hammer, Cornell University

Prof. Robert L. McCrory, University of Rochester

Dr. Marshall M. Sluyter, Consultant

Panel 3: *Relevance to National Needs and Agency Mission*

Dr. Christian Mailhot, Lawrence Livermore National Laboratory, Lead

Maj. David E. Bell, Defense Threat Reduction Agency

Dr. Richard L. Garwin, IBM Research Division

Dr. Jack S. Shlachter, Los Alamos National Laboratory

V. APPENDIX II: AGENDA

Pulsed Power Review Agenda  
Tuesday May 7

Time	Activity	Presenters
7:00	Bus leaves from hotel	
7:15 – 7:30	Badging (Badge Office)	
7:30 – 8:00	Continental Breakfast	
8:00 – 8:30	Welcome and Logistics <ul style="list-style-type: none"> <li>• Classification Level</li> <li>• JOWOG</li> <li>• Dinner Reservations</li> </ul>	
8:30 – 9:00	Executive Session <ul style="list-style-type: none"> <li>• Charter</li> <li>• Expectations</li> </ul>	
9:00 – 10:00	Overview <ul style="list-style-type: none"> <li>• Pulsed Power Overview</li> <li>• Garwin Recommendations Response</li> <li>• Key Issues</li> <li>• Agenda</li> </ul>	Jeff Quintenz
10:00 – 10:30	High Energy Density Program Overview	Keith Matzen
10:30 – 11:00	Break	
11:00 – 11:30	ALEGRA	Tom Mehlhorn
11:30 – 11:45	<i>Inertial Confinement Fusion Overview</i>	Keith Matzen
11:45 – 12:15	ICF (Campaign 10) <ul style="list-style-type: none"> <li>• Dynamic hohlraums</li> </ul>	Tom Mehlhorn
12:15 – 1:00	Executive Session-working lunch	
1:00 – 2:00	ICF (Campaign 10) <ul style="list-style-type: none"> <li>• Double-ended hohlraums</li> <li>• Z-Beamlet</li> </ul>	John Porter
2:00 – 2:30	Break	
2:30 – 3:00	Campaign 4 <ul style="list-style-type: none"> <li>• Overview</li> <li>• Requirements</li> <li>• Characterization &amp; Optimization</li> </ul>	Tom Mehlhorn
3:00 – 3:40	Campaign 4 <ul style="list-style-type: none"> <li>• Weapons physics issues</li> <li>• Experimental results on Z</li> </ul>	Bob Chrien
3:40 – 4:10	ICF (Campaign 10) <ul style="list-style-type: none"> <li>• Fast Ignition &amp; Beams</li> </ul>	Steve Slutz
4:10 – 4:30	PW Initiative <ul style="list-style-type: none"> <li>• PW Mission Need</li> <li>• PW Status &amp; Plans</li> </ul>	John Porter
4:30 – 5:30	Executive Session	

**Pulsed Power Review Agenda  
Wednesday May 8**

<b>Time</b>	<b>Activity</b>	<b>Presenter</b>
7:15	Bus leaves from hotel	
7:30 – 8:00	Continental breakfast & Welcome	
8:00 – 8:30	Campaign 2 Overview	<b>Jim Asay</b>
8:30 – 9:30	Campaign 2 Theoretical/Experimental Capabilities ICE & Flyer Plate EOS Results	<b>Marcus Knudson</b>
9:30 – 10:00	Campaign 2 • SNM	<b>Chris Deeney</b>
10:00 – 10:30	Break	
10:30 – 11:30	Campaign 7 • Radiation Effects Sciences • Z pinch physics & source development	<b>Mark Hedemann</b> <b>Chris Deeney</b>
11:30 – 12:00	Campaign 1 • Radiography program	<b>John Maenchen</b>
12:00 – 1:00	Executive Session-Working Lunch	
1:00 – 1:20	Summary of ZR Mission Need Review	<b>Keith Matzen</b>
1:20 – 1:40	ZR Project Planning & Management Overview	<b>Ed Weinbrecht</b>
1:40 – 2:30	ZR Technical Overview	<b>Dillon McDaniel</b>
2:30 – 4:00	Break and Tours • Posters of Fusion Energy and Work for Others • Z20, Z	
4:00 – 5:00	Executive Session	
5:00	Depart for Hotel/Dinner	<b>Committee &amp; Speakers</b>

**Pulsed Power Review Agenda  
Thursday May 9**

<b>Time</b>	<b>Activity</b>	<b>Presenter</b>
7:15	Bus leaves from hotel	
7:30 – 8:00	Continental breakfast	
8:00 – 9:00	Electromagnetics and Work for Others	<b>Larry Schneider</b>
9:00 – 9:30	Summary & Restatement of Issues	<b>Jeff Quintenz</b>
9:30 – 11:30	Executive Session	
11:30 – 12:00	Out Brief	
12:00	Lunch available	

Distribution:

Alvin W. Trivelpiece  
8 Rivers Run Way  
Oak Ridge, TN 37830-9004

Richard Garwin  
IBM Research Division  
Thomas J. Watson Research Center  
P.O. Box 218  
Yorktown Heights, NY 10598

Yogi M. Gupta  
Institute for Shock Physics  
Washington State University  
Pullman, WA 99164-2814

David A. Hammer  
Cornell University  
Laboratory of Plasma Science  
Room 369 Upson Hall  
Ithaca, NY 14853

Mike Dunne  
AWE  
Building E-3  
AWE Aldermasten  
Reading, RG7 4PR  
United Kingdom

Phil Spence  
Titan/PSD  
2700 Merced  
San Leandro, CA 94577

Marshall Sluyter  
707 Smallwood Rd.  
Rockville, MD 20850

Nino Landen, L-473  
University of California  
Lawrence Livermore National Laboratory  
P. O. Box 808  
Livermore, CA 94551-0808

Robert McCrory  
Laboratory for Laser Energetics  
University of Rochester  
250 East River Road  
Rochester, NY 14623

Susan J. Seestrom, D-434  
Los Alamos National Laboratory  
P. O. Box 1663  
Los Alamos, NM 87545

Christian Mailhot, L-090  
University of California  
Lawrence Livermore National Laboratory  
P. O. Box 808  
Livermore, CA 94551-0808

Barrett H. Ripin  
Research Applied  
7536 Sebago Road  
Bethesda, MD 20817

Mary Hockaday, P-918  
Los Alamos National Laboratory  
P. O. Box 1663  
Los Alamos, NM 87545

Charles Gilman  
SAIC  
2109 Air Park Rd., SE  
Albuquerque, NM 87106

Major David Bell  
DTRA  
6802 Telegraph Road  
Alexandria, VA 22310

Jack S. Shlachter  
Los Alamos National Laboratory  
P.O. Box 1663  
Los Alamos, NM 87545

Michael R. Anastasio, L-160  
University of California  
Lawrence Livermore National Laboratory  
P.O. Box 808  
Livermore, CA 94551-0808

Richard A. Ward, L-013  
University of California  
Lawrence Livermore National Laboratory  
P.O. Box 808  
Livermore, CA 94551-0808

Bill Bookless, L-160  
University of California  
Lawrence Livermore National Laboratory  
P.O. Box 808  
Livermore, CA 94551-0808

David Reisman, L-041  
University of California  
Lawrence Livermore National Laboratory  
P.O. Box 808  
Livermore, CA 94551-0808

Jim Hammer, L-018  
University of California  
Lawrence Livermore National Laboratory  
P.O. Box 808  
Livermore, CA 94551-0808

Bob Cauble, L-041  
University of California  
Lawrence Livermore National Laboratory  
P.O. Box 808  
Livermore, CA 94551-0808

Stirling Colgate, A105  
Los Alamos National Laboratory  
P.O. Box 1663  
Los Alamos, NM 87545

James A. Mercer-Smith  
Los Alamos National Laboratory  
P.O. Box 1663  
Los Alamos, NM 87545

Steve Younger  
DTRA  
8725 John J. Kingman Rd.  
MSC 6201  
Fort Belvoir, VA 22060-6201

Richard Krajcik, B218  
Los Alamos National Laboratory  
P.O. Box 1663  
Los Alamos, NM 87545

Allan Hauer, E527  
Los Alamos National Laboratory  
P.O. Box 1663  
Los Alamos, NM 87545

Bob Chrien, B220  
Los Alamos National Laboratory  
P.O. Box 1663  
Los Alamos, NM 87545

Fritz J. Swenson  
University of California  
Lawrence Livermore National Laboratory  
P.O. Box 808  
Livermore, CA 94551-0808

Darrell Peterson, B220  
Los Alamos National Laboratory  
P.O. Box 1663  
Los Alamos, NM 87545

Orval E. Jones  
12321 Eastridge Dr. N.E.  
Albuquerque, NM 87112-4604

David Forster  
AWE.  
Building H36  
Aldermaston, Reading, Berkshire  
RG7 4PR  
United Kingdom

K. D. Pyatt, Jr.  
Titan/PSD  
Systems Division  
4855 Ruffner St., Suite A  
San Diego, CA 92111-1531

Alan J. Toepfer  
SAIC  
2109 Air Park Road S.E.  
Albuquerque, NM 87106

Ian D. Smith  
Titan/PSD  
600 McCormick St.  
San Leandro, CA 94577

Marshall N. Rosenbluth  
UCSD, Dept. of Phys. BO19  
Mayer Hall, Rm. 3230  
La Jolla, CA 92093

Donald Linger  
DTRA  
6802 Telegraph Rd.  
Alexandria, VA 22310-3398

Dick Gullickson  
DTRA  
6802 Telegraph Rd.  
Alexandria, VA 22310-3398

Chris Keane, NA-113.1  
U.S. Department of Energy  
1000 Independence Avenue, SW  
Washington, DC 20585

Richard Thorpe, NA-113.3  
U.S. Department of Energy  
1000 Independence Avenue, SW  
Washington, DC 20585

Ralph F. Schneider, NA-113.1  
U.S. Department of Energy  
1000 Independence Avenue, SW  
Washington, DC 20585

Hans M. Mark  
Aerospace Engineering Department  
Campus Mail Code: C0600  
University of Texas  
Austin, TX 78712

Robert DeWitt  
Dept. of Physics  
Penn State University  
2428 2<sup>nd</sup> Avenue  
Altoona, PA 16602

Steve O. Dean  
Fusion Power Associates  
2 Professional Dr., Suite 248  
Gaithersburg, MD 20879

William F. Brinkman, Executive Director  
Physical Sciences Research Division  
Bell Labs  
Lucent Technologies  
600-700 Mountain Ave., 1C-224  
Murray Hill, NJ 07974-0636

Paul A. Fleury, Dean  
Faculty of Engineering  
Yale University  
New Haven, CT 06520

Venkatesh Narayanamurti, Dean  
Division of Engineering & Applied  
Sciences  
Pierce 217A  
Harvard University  
Cambridge, MA 02138

Albert R.C. Westwood  
13539 Cañada del Oso  
High Desert  
Albuquerque, NM 87111

M. Henry Hutchinson  
Director, Central Laser Facility  
Rutherford Appleton Laboratory  
Chilton, Didcot  
Oxfordshire OX11 0QX  
England

Paul Hommert  
AWEML, Bldg. C33.1A  
Aldermaston, Reading  
RG7 4PR, England

Arthur Johnson  
Corporate Vice President, Strategic  
Development  
Lockheed Martin Corporation  
6801 Rockledge Dr.  
Mail Stop 2-12  
Bethesda, MD 20817

Darrell W. Graddy  
Vice President, Energy & Environment  
Sector  
Lockheed Martin Corporation  
6801 Rockledge Dr.  
Mail Stop 220  
Bethesda, MD 20817

Arthur K. Kerman  
Physics Dept. 6-305  
MIT  
77 Massachusetts Ave.  
Cambridge, MA 02139-4307

Pete Lyons  
Office of Senator Pete Domenici  
328 Hart Senate Office Building  
Washington, DC 20510

Glen Dahlbacka  
MS 4-230  
Lawrence Berkeley Lab  
Berkeley, CA 94720

Nino Pereira  
Eco Pulse, Inc.  
P.O. Box 528  
Springfield, VA 22150

Dale M. Meade  
PPPL  
P.O. Box 451  
Princeton, NJ 08543

Robert J. Goldston, Director  
PPPL  
P.O. Box 451  
Princeton, NJ 08543

Miklos Porkolab, Director  
Plasma Science & Fusion Ctr.  
MIT  
167 Albany St. NW 16-288  
Cambridge, MA 02139

J. B. Greenly  
Laboratory of Plasma Studies  
Cornell University  
369 Upson Hall  
Ithaca, NY 14853

R. R. Peterson  
Fusion Technology Institute  
University of Wisconsin  
1500 Johnson Drive  
Madison, WI 53706

P. F. Ottinger  
Naval Research Laboratory  
Code 6770  
4555 Overlook Avenue SW  
Washington, DC 20375-5320

J. Davis  
Naval Research Laboratory  
Code 6720  
4555 Overlook Avenue SW  
Washington, DC 20375-5320

R. E. Reinovsky, F672  
Los Alamos National Laboratory  
P.O. Box 1663  
Los Alamos, NM 87544

J. S. DeGroot  
Dept. of Applied Science  
UC Davis  
Davis, CA 95616

G. W. Cooper  
Chemical & Nuclear Engineering Dept.  
University of New Mexico  
Albuquerque, NM 87131

R. M. Gilgenbach  
Dept. of Nuclear Engineering  
University of Michigan  
2355 Bonisteel Blvd.  
Ann Arbor, MI 48109

Randy Davis  
DTRA  
6802 Telegraph Road  
Alexandria, VA 22310

Roger White  
Titan/PSD  
4855 Ruffner St., Suite A  
San Diego, CA 92111-1531

D. Welch  
Mission Research Corporation  
1720 Randolph Rd. SE  
Albuquerque, NM 87106

M. Krishnan  
Alameda Applied Sciences  
2235 Polvorosa Avenue, Suite 230  
San Leandro, CA 94577

M. G. Haines  
Department of Physics  
Prince Consort Road  
Imperial College  
London SW7 2 BZ  
England

H. Bluhm  
FZKA  
Karlsruhe  
P.O. Box 3640  
Karlsruhe D-7513  
Fed. Rep. Germany

Yitzak Maron  
Weizmann Institute of Science  
Rehovot 76100  
Israel

Bruce Hammel, L-488  
University of California  
Lawrence Livermore National Laboratory  
P.O. Box 808  
Livermore, CA 94551-0808

Ken Schultz  
General Atomics  
P.O. Box 85608  
San Diego, CA 92186

Stephen Obenschain  
Naval Research Laboratory  
Code 6700  
4555 Overlook Avenue SW  
Washington, DC 20375-5320

Jill Dahlburg  
General Atomics  
P. O. Box 85608  
San Diego, CA 92186

R. J. Juzaitis  
Los Alamos National Laboratory  
P. O. Box 1663  
Los Alamos, NM 87545

Edward A. Heighway  
Los Alamos National Laboratory  
P. O. Box 1663  
Los Alamos, NM 87545

Larry Newkirk, NA-113.3  
U.S. Department of Energy  
1000 Independence Avenue, SW  
Washington, DC 20585

Jim Van Fleet, NA-113.2  
U.S. Department of Energy  
1000 Independence Avenue, SW  
Washington, DC 20585

DOE/OKSO Jeannette Norte  
DOE/OKSO Mike Zamorski  
DOE/OKSO Frank L. White  
MS 1186 Mike Desjarlais, 1674  
MS 1193 Mike Cuneo, 1673  
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