Report of the
Basic Energy Sciences Advisory Committee
Panel on Novel Coherent Light Sources

January 1999

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Basic Energy Sciences Advisory Committee

Panel on Novel Coherent Light Sources

From a workshop
held at the
Gaithersburg Hilton
Gaithersburg, Maryland

January 18-22, 1999

Stephen R. Leone (Chair)
JILA and NIST
University of Colorado
Boulder, CO 80309

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UNIVERSITY OF OREGON

March 3, 1999

Dr. Martha Krebs
Director, Office of Energy Research
Department of Energy
Washington, DC 20585

Dear Dr. Krebs,

As a result of recommendations of the Birgeneau Report on D.O.E. Synchrotron Light Sources and Science (November 1997), you charged the Basic Energy Sciences Advisory Committee (BESAC) with advising BES on the development and application of such sources in the future. To that end, Prof. Stephen Leone, a member of BESAC, assembled a panel of scientists to address issues related to the charge and to write a report summarizing their conclusions and recommendations. The Panel was comprised of scientists from diverse backgrounds, with representation from several communities with particular emphasis on the potential user community. Participants on this Panel included experts familiar with second and third generation synchrotron light sources, currently operating FELs and laboratory based laser systems. Input was solicited from user communities as well as staff of the current synchrotron light sources, FEL laboratories and laser development centers. The Panel met in January 1999 in Gaithersburg Maryland. The Workshop was highly productive, providing a forum for those in attendance to address some of the most important issues with regards to the scientific merit and technical feasibility of future novel coherent light sources.

As you know, the report of this Panel was submitted to BESAC at its meeting on February 24-25, 1999. After much thoughtful discussion, BESAC members unanimously accepted the "Novel Coherent Light Sources" report. I therefore am forwarding to you a copy of this report. I believe that you will find it to be a very impressive document, reflecting the depth of discussion and consideration that went into analyzing both the science that would be enabled by such novel sources, as well as the technological developments that need to be pursued. The report summarizes the findings and recommendations of the Panel, both for the development of future light sources that might become user facilities, as well as for development of smaller scale laser-based sources for innovative scientific experimentation and integration with large scale facilities. The report also provides recommendations for a series of steps to be undertaken as progress is made towards a light source of the future aimed at novel, hard X-ray

DEPARTMENT OF CHEMISTRY
College of Arts and Sciences 1253 University of Oregon Eugene OR 97403-1253 TELEPHONE - (541) 346-4601
FAX - (541) 346-4643 INTERNET - chemistry~oregon.uoregon.edu TELEX - (541) 597-0354
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science.

The BESAC members are very grateful for the dedicated effort of this Panel and particularly to Steve Leone as Chair of the Panel, and Eric Rohlfing from BES who assisted in an advisory capacity in organizing the Workshop. BESAC also wishes to recognize the helpful input and discussions of the liaisons from the National Laboratories who were involved in development of this report.

Sincerely,

Geraldine Richmond

Geraldine Richmond
Chair, BESAC
Professor of Chemistry
Knight Professor of Liberal Arts
& Sciences

cc. Pat Dehmer, Director, Basic Energy Sciences
Prof. Stephen R. Leone, Chair, JILA and NIST, University of Colorado

Report of Panel

on

Novel Coherent Light Sources

Panel:

Stephen R. Leone, Chair, JILA and NIST, University of Colorado
Paul Alivisatos, Chemistry, University of California, Berkeley
Nora Berrah, Physics, Western Michigan University
Philip Bucksbaum, Physics, University of Michigan
William Colson, Physics, Naval Postgraduate School
Richard Haight, Physics, IBM Watson Research Center
John Hepburn, Chemistry, University of Waterloo
Raymond Jeanloz, Geology, University of California, Berkeley
Stephen Laderman, Materials Science, Hewlett-Packard Laboratories
Donald Levy, Chemistry, University of Chicago
Simon Mochrie, Physics, Massachusetts Institute of Technology
Keith Moffat, Biochemistry and Molecular Biology, University of Chicago
Yves Petroff, European Synchrotron Radiation Facility
Geraldine Richmond, Chair of BESAC, Chemistry, University of Oregon
Jochen Schneider, Physics, HASYLAB at DESY, Hamburg
Yuen-Ron Shen, Physics, University of California, Berkeley

DOE Advisory Role:

Eric A. Rohlfing, on assignment from Sandia National Laboratories to BES

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1.0 Executive Summary

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Accelerator-based synchrotron light sources play a pivotal role in the U.S. scientific community, and the Department of Energy is the premier steward of these facilities (Report of the BESAC Panel on DOE Synchrotron Radiation Sources and Science, 1997). The Panel recommendations in Section 7.0 are made in the context that limited government funding will permit only a very few large-scale proposals to be supported in the future, even though many possible proposals are highly meritorious. The Panel found that the most exciting potential advance in the area of innovative science is most likely in the hard X-ray region, in the range of 8-20 keV, and even higher. This is especially the case if a light source can be built with a high degree of coherence, temporal brevity, and high pulsed energy. Key categories of new experiments involve time dynamics coupled with structural information, as well as holographic imaging and multiple photon processes at very short wavelengths. However, the Panel unanimously recommends that the case for the science still must be improved, through an early and close interaction between X-ray source developers and prospective users.

The development of a hard X-ray source user facility is likely to be based on a self-amplified spontaneous emission principle in a linac-driven free electron laser, or a linac-driven, seeded amplified stimulated emission free electron laser. Dramatic improvements have been made in the necessary electron beam parameters, sufficient to warrant cautious optimism that such a device can be built with additional research and development of numerous crucial aspects. Parameters such as electron beam emittance and transport, interaction of the electron beam with radiation, beam compression, laser gain, saturation, and wavelength and their scalings must all be investigated in carefully orchestrated experiments.

The Panel recognized that there will be a symbiotic relationship between future accelerator-based sources and high-powered ultrafast lasers, which are necessary for photocathode drivers, seeding, and possibly electron beam slicing, as well as time-dynamics of the science to be performed, where a pulsed laser will most probably be used to initiate processes that are probed by coherent X-rays. Developments in pulsed table-top lasers have made remarkable progress, achieving shorter wavelengths, higher powers, and shorter pulse durations, on the verge of producing readily available attosecond soft-x-ray pulses. The state-of-the-art light source facility of the future will include a complete marriage of accelerator principles and laser art, which has not previously been recognized widely.

There are many key factors to begin making progress towards a light source of the future aimed at novel, hard X-ray science. These include (a) an early and strong coupling between substantial numbers of scientific users, laser experts, and source developers, (b) development of a compelling and rigorous scientific case, possibly facilitated by chief scientists, that can only be achieved if such a source becomes available, (c) a tightly focused and fiscally responsible programmed series of steps to determine the feasibility and design of a 1.5 Angstrom coherent light source, with continuation contingent upon successful demonstrations of the necessary physics and the case for the science, (d) independent and vigorous support for the development of laboratory laser sources in unique time and wavelength ranges, (e) better utilization of 3rd generation sources and table-top lasers as proving grounds for innovative science and experiments planned for light sources of the future, and (f) support for the development of new forms of X-ray detectors and optics.

2.0 Procedure of the Panel

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A Panel on Novel Coherent Light Sources, consisting of a group of scientific experts and light source builders and practitioners from industry, universities and government laboratories, was formed to advise Basic Energy Sciences (BES) of the Department of Energy (DOE) on the scientific benefits and recommendations for development of accelerator-based fourth generation light sources and laser-based light sources. The Panel recommendations were considered within the context that limited government funding will permit only a few excellent, large scale proposals to be funded in the future, even with the possibility of good financial circumstances.

The Panel met in a workshop format January 18-22, 1999 in Gaithersburg, Maryland, to address the charge of the Basic Energy Sciences Advisory Committee (BESAC). Panel members Jeanloz and Alivisatos were unable to attend the workshop. The BESAC charge letter and final workshop agenda are presented in Appendices 1 and 3, respectively, of this report. The workshop first involved extensive presentations by a range of scientists who provided their expertise regarding both the scientific and technological case for future development of novel coherent light sources. Major presentations were made by representatives from seven DOE laboratories, the Advanced Photon Source/Argonne National Laboratory (APS/ANL), the Advanced Light Source/Lawrence Berkeley National Laboratory (ALS/LBNL), the Free Electron Laser/Thomas Jefferson National Accelerator Facility (FEL/TJNAF), Lawrence Livermore National Laboratory (LLNL), Los Alamos National Laboratory (LANL), the National Synchrotron Light Source/Brookhaven National Laboratory (NSLS/BNL), and the Stanford Synchrotron Radiation Laboratories/Stanford Linear Accelerator Center (SSRL/SLAC). In addition, six invited experts presented their research on table-top laser light sources and their views on scientific opportunities. The Panel examined extensive documentation and previous reports, as enumerated in the charge letter, in considering the recommendations. Following the presentations, the Panel met extensively with the appointed DOE Laboratory Liaisons from each of the national laboratories and in closed sessions to consider the recommendations. This report summarizes the findings and recommendations of the Panel, both for the development of future light sources that might become user facilities, as well as for development of smaller scale laser-based sources for innovative scientific experimentation and integration with large scale facilities.

The Panel uses the term 4th generation light source to mean any sources that involve advances in coherence and power, but at a variety of wavelengths. The term Linac Coherent Light Source (LCLS) is used to indicate the proposed X-ray Free Electron Laser test facility at the Stanford Synchrotron Radiation Laboratories, based on the Stanford Linear Accelerator. The term X-ray free electron laser (X-FEL) is used to indicate any X-ray laser device based on accelerator methods. The term Advanced X-Ray Source (AXS) is used to indicate a possible future large-scale hard X-ray user facility with multiple undulator devices and superconducting linac technology.

3.0 The Case for a Hard X-Ray Free Electron Laser

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3.1 What New Science?

Over the past three decades, accelerator-based synchrotron radiation has played an increasingly important role in our understanding of the microscopic and macroscopic properties of matter. Synchrotron radiation provides, in many cases, unique capabilities that surpass conventional laboratory sources in intensity, brightness, and photon energies, extending from the far infrared to the X-ray region. In the United States, second (2nd) generation user facilities, such as the Stanford Synchrotron Radiation Laboratories (SSRL) and the National Synchrotron Light Source (NSLS) at Brookhaven National Laboratory, followed more recently by the third (3rd) generation facilities of the Advanced Light Source (ALS) at Lawrence Berkeley National Laboratory and the Advanced Photon Source (APS) at Argonne National Laboratory, have enabled a remarkable range of new scientific endeavors that continue to advance the scientific knowledge base and state-of-the-art in experimentation. Fourth (4th) generation sources, which would involve a higher degree of coherence, and potentially higher power, brilliance, and ultrashort pulses, possibly at very short wavelengths, such as the hard X-ray region, would offer a further major advance in scientific capabilities. Such sources, probably based on free electron laser (FEL) concepts, provide a very appealing basis for the future development of light-source user facilities, for which there is an extensive user community. The panel considered information about 4th generation sources in three spectral regions, the infrared (IR), deep ultraviolet (DUV), and X-ray.

The panel unanimously felt that the most exciting potential area for truly innovative science can be made in the hard X-ray region, 8-20 keV, and even higher. As discussed in separate sections below, explorations of 4th generation light source capabilities in the infrared and deep ultraviolet regions may play an important role in the development of light source technology and prototypical experiments, but these longer wavelength 4th generation sources are less likely to make the dramatic advances in science offered by a potential user facility based on an advanced X-ray source (AXS). A free electron laser source in the X-ray spectral region (X-FEL) has the potential to provide extremely high electromagnetic fields for very short pulse durations, with time-averaged brilliance many orders of magnitude greater than existing synchrotron sources. The coherent, diffraction limited beam provided by such a source has the potential to open new areas of science that are likely to be well beyond what can be anticipated by current scientific knowledge and predictions. Some of the advances will be built upon methods that are presently being developed at 3rd generation sources, while others will require the new capabilities provided by 4th generation sources, for example, to achieve measurements on smaller length scales and shorter time scales.

While the Panel found many exciting areas of science that might be enabled by this new type of source, the Panel also recognized that much of the discussion of the proposed science was brief and lacked key details. It will require a more concerted effort to think critically and quantitatively about the feasibility of these potential new areas of science. Detailed comparisons of light characteristics available from among 3rd and 4th generation sources and lasers, for each particular experiment, will need to be made. Caution must be exercised so as not to become enamored with large light output parameters that do not necessarily enable important new experiments. To warrant the detailed research and development and preliminary experiments in X-ray science that may eventually lead to the construction of a full-fledged user facility based on a 4th generation light source (AXS), the panel feels that a considerably more detailed scientific case remains to be made and must be made, prior to making large-scale funding and construction decisions for the proposed test facility (the Linac Coherent Light Source, or LCLS). Successful operation of the LCLS and conduct of initial experiments there would, in turn, provide the foundation for a subsequent decision about whether to construct an AXS.

The development of a sound and effective scientific case will require identification and exploration of several key classes of experiments, in all aspects from the linac through the undulator to the optics, the sample, and the detector. Promising classes briefly outlined to the Panel include dynamic experiments that exploit the ultra-short pulses; structural imaging via holographic and other methods that exploit the spatial coherence; and multi-photon or multi-wave experiments. Wherever possible, quantitative estimates of the signal, of the sources of background, and of the robustness of the sample in the face of (for example) powerful pump laser pulses and brief, high brilliance X-ray pulses should be presented. Of necessity, these estimates will be derived in large part from ongoing experiments at 3rd generation sources or in laser laboratories. The panel felt that new experiments at these sources could be specifically planned to better understand the scientific case for the LCLS, and ultimately for the AXS.

Many of the important scientific opportunities at the LCLS and the AXS will depend on the pulsed structure of the X-ray beam, making use of an X-ray pulse to probe structure down to atomic length scales as a function of time following a laser pulse. Such time-resolved measurements of melting and re-crystallization and photo-induced structural changes are of great interest. Other cases, such as X-ray photon correlation spectroscopy (XPCS), transient grating experiments, and Mossbauer filter experiments, require both spatial coherence, as well as control over the pulse structure and time duration of the X-ray beam, in order to investigate density fluctuations in fluids and vibrations in solids. With the proposed characteristics of the light output at the LCLS test facility, it will be possible to monitor the evolution of speckle patterns created by successive X-ray bunches, separated by anywhere from 3 to 300 ns, and thereby carry out XPCS measurements of equilibrium dynamics on these time scales. These experiments can potentially impact important problems in statistical physics, including: order in alloys and liquid crystals, charge density waves, quasicrystals, low-dimensional systems, amorphous systems, diffusion of defects, and dynamic critical phenomena.

Pump/probe techniques implemented at a 4th generation X-ray source promise unprecedented insight into the dynamic structural response of many forms of condensed matter (polymer blends, protein crystals, liquid crystals), on time scales covering many orders of magnitude from 100 fs to ms or longer, and on length scales from microns to sub-Angstroms. Imaging techniques, including X-ray holography, also depend on the spatial coherence of the beam, and a 4th generation source can be expected to lead to greatly improved spatial resolution, possibly down to nanometer length scales. In this case, too, the pulsed character of the source may allow "snap-shots" of dynamic structures. Other suggested hard X-ray experiments include XPCS measurements to study single particle motions, time-resolved extended X-ray absorption fine structure (EXAFS), and the investigation of Hawking-Unruh radiation. However, the Panel cautions that all these experiments assume that potential problems of sample stability in the presence of powerful light pulses are overcome, including the X-ray pulses themselves and UV-visible-IR laser pulses, if these are used as a reaction pump.

It is clear to the Panel that development of the most effective case for a 4th generation X-ray source will require a close interaction between the X-ray laser source developers and a set of prospective users. This is likely to mean more interaction than was needed prior to the design of the second and third generation light sources, because the FEL source will become a truly critical part of the experiment. Its parameters will control the experiments that can be done, and these parameters are not yet fixed. For example, it may be beneficial to scientific users to explore trading off brilliance for (say) pulse duration, shape, chirp or repetition rate; or to modify or suppress the spiky temporal distribution of intensity inherent in a pulse derived from an unseeded self-amplified spontaneous emission (SASE) process. Temporal coherence may be an important parameter in future experiments, as well as spatial coherence. In addition, precise timing of the light source pulses with laser light sources will be required and represents a significant challenge. Until now, it has been difficult to actively involve all potential user communities in the planning for an as-yet unrealized light source; but now that feasibility experiments at the proposed LCLS are becoming a realistic possibility, it is imperative to attract a wider user community and to develop in detail a careful selection of proposed science topics. Ultimately, biological scientists and materials scientists are likely to form prominent user classes. Although a majority of synchrotron-based biological and biochemical experiments can be, and will continue to be, satisfactorily conducted on existing 2nd and 3rd generation sources, the panel felt that a significant sub-class of biological experiments may be devised that absolutely requires a 4th generation X-ray source.

3.2 Fourth Generation Source Technology

Since the early ‘90’s there have been proposals to build an X-ray free electron laser using a part of the Stanford Linear Accelerator (at SLAC) to achieve the high-energy, high brightness electron beam necessary for such a project. The design of the proposed Linac Coherent Light Source machine is based on the SASE principle, which requires, in addition to the unique accelerator offered by SLAC, a 100 m long undulator. The SASE principle and many key experiments were pioneered and continue to be developed by researchers at UCLA. Unless SASE is driven to saturation, the intrinsic noise associated with the process may make the output difficult to use for scientific experiments, and thus the requirements of very high gain and a very long undulator are not just to achieve high power. The earliest proposals were for a soft X-ray machine operating in the water window. Since the difficulty and cost of building an FEL goes up rapidly as the wavelength decreases, and since the shortest wavelength FEL that has actually been built operates in the ultraviolet, this proposal was a considerable stretch of known technology, and it was widely regarded as infeasible in the earliest years.

In addition to the technical difficulties involved in building a soft X-ray FEL, surveys of the scientific community in the United States indicated that there was relatively little interest in soft X-rays, and that to be useful to a broad community and for the most exciting experiments, a hard X-ray machine would be necessary. Several proposals for shorter wavelength machines were made, the final proposal (and the current proposal) being for a 1.5 Angstrom SASE-based FEL. This wavelength is just short enough to become useful to a large fraction of the scientific community that the machine is intended to serve. Of course, the construction of a hard X-ray machine is even more difficult than a soft X-ray machine.

Some physical principles involved in the construction of a hard X-ray FEL are well-known, have been demonstrated at longer wavelengths, and scale in a known way as a function of wavelength. The technical problems remaining have to do with achieving the very high quality electron beam and preserving the quality of that beam through the accelerator and transport to the undulator. The X-ray FEL requires an extremely high-intensity, low-emittance beam which must be compressed and then transported and controlled over enormous distances and to excruciatingly tight tolerances. Initially, there was considerable doubt within the accelerator community as to whether the required electron beam could be achieved.

However, remarkable progress in electron beam and accelerator design, led in part by requirements of the high energy physics community, has brought us to the point where the successful construction of a 1.5 Angstrom FEL now seems likely. Advances in high-brightness photocathode technology and bunch compression techniques suggest that an electron beam of the necessary quality can be built using technology that is either in hand or only a slight improvement over that which has already been demonstrated. The project is still a challenging technical feat that will require that a number of design parameters, each of which may have been demonstrated individually, must all be achieved at the same time in the same machine.

The Panel endorses the proposal to continue research and development for another two years leading to a conceptual design for a 1.5 Angstrom FEL, the proposed LCLS. The intention would be to begin construction of the proposed LCLS once the conceptual design is complete, assuming three important contingencies are met, as recommended by the Panel: (a) that the feasibility of the design can be demonstrated through a program of measurements of electron beam parameters and the interaction of radiation at various wavelengths with the electron beam, (b) that the scientific need can unambiguously be described, and (c) that vigorous involvement and active participation by the scientific user community is evident at an early stage. The Panel believes that this program should be supported with a focused path of research and development, as described further in Section 5.0.

There are two machine technology caveats that should be noted. First, the physics of an FEL is such that failure to achieve any one of the several critical design parameters may have a drastic effect on the operation of a hard X-ray machine. Since the design requirements are much more stringent at shorter wavelengths, demonstration of operation at longer wavelengths is not a guarantee that a 1.5 Angstrom machine will work. The path to construction should begin with a detailed and justified list of required design parameters, and convincing evidence that these can be achieved should precede any commitment to construction of the LCLS machine.

Second, critical to deciding whether future investment in the LCLS machine is warranted, the requirements of the scientific community for hard X-rays for the most important experiments means that any modification of the design to longer wavelength would severely degrade the utility of the machine. Even 1.5 Angstrom is too long a wavelength for some of the more interesting applications, and eventual construction of a true 4th generation user facility (AXS) is likely to require even further advances in FEL technology to achieve shorter wavelengths. If 1.5 Angstrom cannot be achieved in the proposed LCLS project, it will be very much less useful for probing the new areas of science that might be opened up by a very high brightness hard X-ray FEL.

3.3 The Role of Infrared and Deep Ultraviolet Free Electron Lasers

In the field of free electron lasers, IR-FELs have played and still play an important role. Their successful operation has established a firm foundation for the further development of FELs towards shorter wavelengths. For scientific and technological applications, the IR-FEL provides a unique coherent light source in the mid-to-far IR, especially at wavelengths longer than 9 microns, where frequency mixing of lasers becomes inefficient. There are a large number of meaningful scientific and materials processing problems that can be investigated by an IR-FEL. Among them are surgical uses in medical science, multiphoton excitations in polyatomic molecules in chemical physics, nonlinear optical spectroscopy in condensed matter, surface vibrational spectroscopy in surface science, and dynamical studies of phonons, vibrations and other low-frequency elementary excitations of material systems. Currently, the medical community has heavily endorsed the IR-FEL facilities. Several interesting scientific presentations portrayed the scientific potential of IR-FELs; however, work still needs to be done to attract users from the basic scientific community.

While FELs in the mid-IR to UV region (9-0.1 microns) can also help the further development of FELs (the impressive progress of the Jefferson Laboratory is an example), their impact on science and technology is not expected to be as large because of the existence of conventional lasers in this region, except where experiments require high average power.

DUV-FELs (100–1 nm) can also provide checks of principles for the development of an X-ray FEL. DUV-FELs are in a wavelength range that the scientific community has not found as potentially exciting as the hard X-ray region. This judgement is, however, based on past experience in studies of matter using conventional techniques with laser light sources. If a source becomes available with far superior flux, peak intensity and coherence, it is not unthinkable that new spectroscopic techniques could be invented and exciting new scientific problems could be conceived. A DUV-FEL can also help explore the feasibility and significance of future experiments intended for an X-ray FEL. Examples might be nonlinear optical effects from core electron responses, imaging and holography for mesoscopic structures, and dynamics of systems on mesoscopic length scales. Existing devices, such as laser-based high harmonic generation, soft X-ray lasers, and high brightness Bremstrahlung sources can also be better-exploited to develop the science in this region of the spectrum.

FEL developments at wavelengths longer than 1.5 Angstroms may be beneficial to the understanding and development of a 4th generation hard X-ray facility, as will be noted further below. Representatives from FEL projects are excited about the opportunity to make such contributions. We certainly encourage continued dialog among the FEL community to leverage such advances. As the design goals and practicality of the 4th generation X-ray source mature, the value of these opportunities will become more clear.

3.4 Further Investigation of Third Generation Light Sources

The set of beam characteristics presented to the Panel as a goal for a full scale 4th generation X-ray user facility (AXS) exceed those of 3rd generation facilities when measured according to flux (10^2 improvement), average brilliance ($\geq 10^4$-10^6), peak brilliance ($\geq 10^{10}$), pulse duration ($\leq 10^{-3}$), and transverse coherence (full coherence in the case of the 4th generation source). These anticipated improvements conceptually rest on the potential success of the X-ray FEL within the LCLS plan. As befits the expectations, scope, and required investments for a generation change in synchrotron radiation capability, such improvements, if achieved, might enable breakthrough capabilities in a broad range of scientific endeavors currently limited by one or more of these characteristics. The Panel recommends that X-ray scientists presently conducting experiments at 3rd generation sources and in laser laboratories comprehensively identify and articulate the specific fields of endeavor now known to be limited by these factors. A good understanding of the strengths of the proposed facility overall and any specific design in particular requires an excellent understanding of the potential benefits of each area of anticipated improvement. Such benefits, of course, must also self-consistently account for any constraints of the new source, such as may arise, for example, due to particular aspects of the X-ray energy dependence of the electron beam characteristics or shortfalls in performance.

Describing the potential scientific benefits in the context of experience with leading edge experiments at 3rd generation synchrotron radiation facilities is critical. For example, such a detailed description is rapidly developing for the case of photon correlation spectroscopy (time resolved “speckle” pattern analysis) discussed above. At the same time, pursuit of such experiments will clarify the science that critically requires a new source and will prepare those endeavors to take maximum advantage of the new source.

The new scientific knowledge obtained with 3rd generation sources creates a clear context and leads to the most compelling new questions. This is true for both particular experimental endeavors that may migrate to the new source and explorations that create a base of knowledge and the motivation for the new experiments. Both situations exist in the field of atomic and molecular dynamical studies. For example, further use of 3rd generation sources for developing the science and principles that can lay the groundwork for research using 4th generation light sources might include: pump-probe experiments to study highly excited states; quantum control studies; dynamical studies of multi-photoionization and single-photon multiple ionization; and interactions and measurements of X-rays with novel states of matter, such as the collapse of a Bose-Einstein condensate into a solid entity. Similar cases may be made for condensed matter, biological systems, and other disciplines.

3.5 Development of Detectors

While it was not the Panel's role to consider the subject of detectors and optics, an important issue was raised in this regard that warrants discussion. Pursuit of leading-edge experiments at existing synchrotron sources creates advances in technical implementations of experiments that are essential for beneficial use of 4th generation sources. For example, key explorations of the dynamics of atomic scale processes in condensed matter and in biological macromolecules that would appear to be profitably advanced by a 4th generation X-ray source are limited in their 3rd generation source configuration by X-ray detector capabilities. Major advances in detectors and optics will be required before the full promise of a new generation source can be realized. Holography experiments proposed for 4th generation X-ray sources may require major detector advances that incorporate new inventions. Additional support for detector and optics development must be significant and made consistently in conjunction with experiments at 3rd generation sources. Existing sources are appropriate platforms for critical path developments and benchmarks that clarify specific and realistic implementation plans for emerging 4th generation X-ray experiments. In addition, there is a major need for light beam diagnostics, to measure the temporal and spatial coherence properties, autocorrelations, and chirp of such novel light pulses.

4.0 The Case for Laser Source Development

4.0 The Case for Laser Source Development

The Panel was also required to consider laser light sources and their role in future advances of science. This section and Section 6.0 consider these findings. The advanced technology needed for future X-ray FEL sources (LCLS and AXS) and for the experiments that take advantage of these sources goes far beyond incremental advances in electron beams and undulators. If the DOE is to achieve a successful program in this area, it is clear to the Panel that it must include direct support for research, development, and science experiments using advanced lasers as an integral part of the program. Laser science has a direct involvement in the overall 4th generation X-ray light source project in several ways. In the development of the X-FEL itself, lasers play an integral role in gun technology and possible seeding, and the final performance of the X-FEL will be linked directly to developments in laser technology. At the present time, there is strong and rapidly growing interest in time-resolved experiments at short wavelengths. Spectacular advances have been made over the past few years in this area, and strong support of these studies will push forward the methodologies for time-resolved X-ray experiments. Finally, if a decision is made to build a 4th generation light source user facility (AXS), there must be substantial laser research and technology support within this facility in order to carry out the scientific program.

4.1 Role of Laser Technology in FEL Development

Advanced laser technology has played, and will continue to play, a key role in FEL development. Some examples of this are:

- The capabilities of the FEL are determined by the performance of the electron gun, and continuing improvements will be necessary in this area. Improvements in short pulse duration, energy, and repetition rate of lasers will be an important part of gun development.

- To take full advantage of the temporal coherence possibilities of the X-FEL amplifier, it will be necessary to provide a short wavelength laser pulse for seeding the FEL amplifier. One source for controllable, fully coherent seed pulses (temporal and spatial) is high harmonic generation (HHG). This will enable attosecond X-ray pulses through chirped pulse amplification (CPA) and pulse compression. In addition, temporal coherence will improve both the resolution and time structure of the X-FEL light pulses and reduce intensity fluctuations compared to SASE.

- There is a great need to develop metrology for the X-FEL pulses, such as ultrafast, position sensitive streak cameras, and autocorrelation devices based on attosecond laser pulse/X-FEL pulse two photon absorption.

- Laser wakefield acceleration is a candidate for ultrashort light source pulses and possibly very short wavelengths.

4.2 Development of Time-Resolved Short Wavelength Experiments with Lasers

At present, there are several laser techniques that can be used to generate ultrafast pulses of short wavelength light. In the soft x-ray range, HHG has been developed into an excellent source of intense femtosecond pulses. At shorter wavelengths, laser generated plasmas, and a variety of pulse slicing techniques can be used to do time-resolved X-ray scattering experiments. Research in this area serves the roles of 1) advancing the laser technology that will be used in X-FEL development, 2) initiating time-resolved experiments that will advance the science and methodologies in this field, and 3) helping to develop a strong scientific program at a future 4th generation X-ray light source. While we do not expect that laser sources will compete with the X-FEL facilities for peak and average brilliance applications in the hard X-ray regime in the foreseeable future, the Panel recognizes the important and independent role for laser-based explorations in all regions of the spectrum.

- There are several plans to use lasers to slice or otherwise modulate the X-ray beams, through physical processes such as Bragg switching, or interactions between high power laser pulses and electron beams as well as laser plasma accelerators and injectors. These techniques provide a method to generate ultrafast X-ray pulses at a wide range of wavelengths.

- Transient grating experiments can be done now at soft X-ray wavelengths, enabling condensed matter experiments on length scales 100 times smaller than are currently possible with visible/uv lasers. These experiments take advantage of the spatial coherence and time resolution of the HHG sources.

- X-ray microscopy with ultrafast pulses minimizes the effects of X-ray induced damage on the image and opens the possibility for time-resolved imaging.

- Core-level spectroscopy on light elements can be performed, to probe transient structures through core-level shifts (charge transfer processes, dissociations, reactions in a cluster environment)

- Transiently shocked material can be studied first on ultrafast time and atomic length scales by pump-probe laser X-ray methods.

- The attosecond regime will most likely be first reached and explored by laser experiments in the vacuum ultraviolet.

- Time-resolved photoemission experiments are a useful way to study ultrafast dynamics, and these experiments are well matched to laser sources.

4.3 Lasers at a Fourth Generation User Facility (AXS)

One of the often-cited advantages of proposed X-FEL sources is the short pulse, which opens up the possibility of dynamical structure studies. The short time characteristics of the X-ray beam are not particularly useful by themselves, but could be very important if synchronized with some dynamical process under study. This means that a program to create laser sources to initiate dynamics is a critical part of 4th generation X-ray light source development. A state-of-the-art laser facility, associated with the 4th generation lab, will be necessary. This laser facility will need to be staffed with laser research scientists and will provide both the hardware and expertise in order to conduct frontier dynamics research.

Indeed, dynamical initiation lasers must have temporal characteristics that are at least as good as the FEL itself. We get some sense of the magnitude of this challenge from the third generation sources. At present these produce pulses that are about 20-100 ps in duration. At several facilities there are now ultrafast lasers that are synchronized to these sources, with timing that is only precise to about 1 ps. This will not be adequate for next generation 100 fs FELs. Furthermore, if temporal dynamics studies really become useful in molecular and condensed matter physics, then there will certainly be a push to bring the timing down to the 10 fs range, in order to study motions of the lightest atoms in molecules and solids. Synchronization on this level is a significant and unmet challenge. Injection seeding or other laser-based X-ray generation schemes may become necessary in order to realize this level of dynamics studies. The DOE should support this kind of research and development, and it will be most efficient if this can be done in the coordination with general source development of 4th generation machines. Nevertheless, the Panel recognizes the potential reward for laser development as being so great, that this option should be pursued, even independently if necessary. Since lasers will be an integral part of any time-resolved experiments, at any contemplated facility there must be adequate support for laser infrastructure.

5.0 Recommended Steps Toward Development of a Fourth Generation Hard X-Ray Source

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Presently each of the laboratories is exploring some aspect of FEL development or laser interaction with electron beams, with goals towards eventual source development. This work is being carried out with laboratory discretionary support. There is a major collaboration already under way, involving many of the labs, to push forward the 1.5 Angstrom SASE-FEL project. The projects presented by all the various laboratories are important for the development of new accelerator-based and laser-based light sources. However, as noted above, the Panel recommends that the one project that will have the most important effect on the user community is the 1.5 Angstrom FEL and should be the first priority. Several critical issues for the success of a 1.5 Angstrom SASE-based FEL (proposed LCLS) must be examined over the next several years of development. A few key laboratories should be designated to perform these crucial tests and measurements to fulfill these goals. A programmed series of steps involving measurements of electron beam parameters and the interaction of the electron beam with radiation is essential.

5.1 Critical Issues

- The brightness of the electron gun source is crucial to the subsequent amplification of X-ray laser light from spontaneous emission. The electron beam emittance, established at the electron gun with a laser-driven photocathode, needs be less than ~1.0 π mm mrad in order for the LCLS to operate as planned. If the emittance at the gun is found to be much larger than the design value, there can be a dramatic decrease in performance, reducing the output power and coherence by many orders of magnitude. A slice emittance of ~1.2 π mm mrad has been achieved. If better emittance can be reliably established, and delivered to the entrance of the undulator, this could reduce the undulator length required to reach saturation of the amplified X-ray laser beam and thereby reduce system cost and complexity.

- In the transport of the high quality, low emittance electron beam, through the accelerator, the bunch compression sections, and the undulator, it is crucial to maintain the low emittance and energy spread. The bunch compression systems can potentially degrade the electron beam emittance while compressing the bunch length by a factor of ~30. The degraded emittance would then affect the proposed LCLS performance just as would a low quality electron gun.

- Processes such as coherent synchrotron radiation (CSR) feedback on the electron beam (the effect of CSR on beam emittance) during the probe compression process may impose emittance growth. The CSR feedback has been long predicted, but in fact, never observed to degrade an electron beam. Theoretical studies and computer simulations indicate that CSR feedback is not a problem in the LCLS. But, the understanding of CSR feedback is not a mature subject, so that it could become a critical issue. Understanding the CSR problem may require measurements of the electron beam characteristics with radiation interactions.

- Another critical issue is the beam positioning along the undulator. The 112 m long undulator must maintain the ~50 micrometer diameter electron and x-ray beams and their overlap over the entire length.

- The detectors for experiments and beam diagnostics, as well as X-ray beam optics for the output of the proposed LCLS SASE FEL are crucial to the successful use of the coherent X-rays. Detector development appears to be insufficient even on the third generation synchrotron sources. It is recommended that detector development and X-ray optics for experiments and X-ray beam diagnostics, including temporal and spatial coherence and chirp, be incorporated into the plans so that adequate X-ray detectors, beam diagnostics, and optics are not a limitation when the LCLS beam becomes available.

5.2 Considerations of Laboratory Expertise

It is clear that SLAC must take a prominent role in the development of the LCLS, since it is based on the SLAC linac and the existing expertise there. However, several laboratories are already working effectively together to make this a successful collaborative venture.

ANL is presently in charge of the undulator, including the vacuum chamber and the incorporated photon and electron beam diagnostics. Their Low Energy Undulator Test Line (LEUTL) activity is considered as an integrated systems test for the LCLS undulator. The number of undulator segments needed to make the test convincing has to be considered. Plans to make the LEUTL FEL available to users should be considered in the context of the laboratories' efforts to get the users involved in the X-FEL physics, but it is of lower priority than direct contributions to the LCLS development for the two years to come.

BNL has expertise with photocathodes and should be involved in the gun design for LCLS. The Accelerator Test Facility (ATF) and the DUV-FEL offer the possibility to study gun emittance control, bunch compression, and emittance growth. These facilities also permit the study of saturation in intermediate (visible) wavelength ranges (visible self-amplified spontaneous emission, VISA, experiment) as well as possible experiments using this light output, but these activities must be a lower priority compared to the gun development and electron beam dynamics studies.

LANL (together with UCLA, SSRL, and the RRC-Kurchatov Institute) has been a major player in proving SASE at the 12 micron level, which was crucial to the X-FEL development. They are prepared to do "Coherent Synchrotron Radiation" experiments, which could be important for bunch compressor research and development, and their work on a regenerative amplifier FEL (RAFEL) could provide additional desirable beam characteristics and shorter gain lengths for saturation. The latter research is not immediately crucial to the LCLS demonstration, but may be important for the future if the need for recirculation becomes clear.

TJNAF is also in the position to do CSR experiments and has the experience with superconducting cavities in the U.S., which will be important for the long term perspectives of X-FEL user facilities but not for the immediate LCLS proposal. The Jefferson Laboratory also has expertise in synchronization of accelerator radio frequency systems, which can be valuable for synchronization with external laser sources.

LLNL and LBNL have important expertise in timing, overlapping, and interacting pulsed laser beams with electron beams for novel concepts of pulse slicing, which could produce important intermediate sources and X-ray diagnostics. In addition LLNL has considerable capability with solid state pulsed lasers, which will be necessary for the integrated laser/X-ray facility ultimately envisioned, and with calculating matter interactions with high flux X-rays, which will be valuable for damage response estimates.

5.3 Recommended Laboratory Roles and Support

The Panel recommends that SLAC, ANL, and BNL take the lead role in formulating the experimental steps needed to resolve the SASE FEL issues, as well as other concerns known to the community. They should involve other laboratories and universities when expertise warrants. The Panel recommends that provisional funding be provided for key projects and to begin investigations in earnest, but that these funds be discontinued if the scientific case is not made rigorously and convincingly in two years. Several million dollars per year, or even more, is likely to be needed for several years prior to a final decision on LCLS construction. Funding should only be provided specifically for focused work to demonstrate the feasibility of the required LCLS principles. The proposed timetable is extremely ambitious (immediate conceptual design for the LCLS, two years of electron beam research, followed by construction of the LCLS in FY02), and the Panel notes that support may need to be given for more than the two years proposed by the laboratories to arrive at a final decision about feasibility. DOE should examine the budgets with care for cost effectiveness, as well as the progress, and base continued support on adequate and timely advances for both the source and the scientific case.

Several years of tightly focused experiments with this seed funding will be needed to address the principles outlined above. The proposal for construction of the LCLS, to be submitted only after the successful conclusion of that exploratory work, needs to contain a detailed cost estimate and timeline for the further research and development work. The personnel and hardware investments required to solve the individual critical issues will need to be discussed together with the respective timelines. The collaborations between all the various DOE laboratories should be strictly focused on the LCLS proposal and outlined in detail.

With regard to better justification of the scientific case, it is suggested that a list of the scientists involved in the individual projects and the role of one or more chief scientists to facilitate the scientific case be developed. These scientists would be intimately involved in the proposal for construction of the LCLS as well. The Panel recommends that there must be a very close collaboration between the users and the machine development team, to obtain a tool useful for the user community. In addition, there should be workshops to allow the community to follow and contribute to the development of potential experiments and output criteria. It is emphasized that input from the users' workshops be used to influence the design options of the LCLS at an early stage of development. However, the construction team must be careful not to deviate from the main goal of obtaining coherent lasing output in a limited time at the 1.5 Angstrom wavelength.

If outstanding progress is made in all phases of the source development and case for science after completion of the LCLS, the possibility of an advanced X-ray source (AXS) user facility may become a definite reality. Such a facility will require further innovative technology, such as perhaps a superconducting linac and numerous undulators, to service multiple users in the future, as well as expert integration of pulsed laser technology and state-of-the-art advanced detectors and beam diagnostics.

6.0 Recommended Model for Laser Development Support

6.0 Recommended Model for Laser Development Support

In Section 4.0 the case was made for support of laser development in parallel with X-FEL development. It was noted that lasers are an integral part of the design of an X-FEL, for the e-gun, for injection, and for timing issues related to the science experiments. In addition, lasers are an important alternative light source in their own right, which may be uniquely suited to some kinds of experiments, particularly in the XUV region and for dynamics studies. Even if X-FEL development should encounter unforeseen problems, laser-based developments may provide important alternative sources. In this section we recommend the establishment of a parallel program of support for laser-based sources and science.

To date there exist a number of impressive and potentially exciting methods for generating fluxes of short pulsed radiation in the deep UV, vacuum UV and extreme UV (XUV) using ultrafast high peak power lasers. These methods include femtosecond high harmonic generation, femtosecond and nanosecond laser generated plasmas, picosecond-laser-produced and nanosecond capillary discharge XUV lasers and laser based electron accelerators. As light sources, fluxes generated by these methods may be useful in a limited range of experiments and show promise for considerable improvement. From this perspective alone such sources require consideration.

Additionally, short pulsed lasers occupy a central role in the development of a 1.5 Angstrom FEL and other short wavelength sources since they will serve in a number of capacities. These include roles as a seed pulse for amplification in an FEL, a pump source in pump/probe dynamics experiments and polarized excitation sources for the photocathode gun for electron injection at the front end of an FEL. Research and development on short pulsed lasers also provides an agile test bed for exploring issues that will impact the development of FELs such as detector development, metrology, and evaluation of experimental paradigms.

With the exception of the large solid state laser effort at LLNL, new laser development (as contrasted to engineering) has traditionally not been done in very large user facilities, but rather in smaller groups of 1-10 scientists and engineers typically at universities with a common research and development goal. This will probably continue to be a very important component of future laser development. The DOE should encourage proposals from university groups for the development of laser sources and experiments that directly connect to scientific goals of materials research, chemistry, biophysics, and the other myriad activities in X-ray research. Naturally some individuals at DOE laboratories may also fulfill the desired spirit of this recommendation. The interaction between such groups and the X-ray machine groups will grow naturally out of ideas to utilize better the machines for science. The main criterion for support must be the quality of science that can be done using laser-based research, but there should be a significant component of source development. The development of sources goes hand-in-hand with the science problems they are designed to address. Peer review is the most efficient and effective way to determine which projects will best support the goal of rapid science progress in areas of interest to BES.

In many cases the laser work and the electron machine work are intimately tied. Important examples that the Panel heard about were efforts on Thompson scattering, laser bunching of electron beams, and plasma acceleration using high power lasers. In addition, lasers are an intimate part of the electron gun technology and may be required for seeding applications of accelerator devices. In these cases, the laser source development requires special expertise outside the e-beam machine community, but which exists in university and National Laboratory groups. While the Panel strongly endorses individual peer-reviewed research proposals, there is also justifiable merit to establishing one, or more, in-house laser research groups to provide bases of DOE laboratory expertise and engineering which would be available to both the user and machine community.

An important part of this support model is that it should also involve groups doing experiments that do not necessarily require electron accelerator light sources, but do impact the same science. Time-resolved Bragg scattering is an important example here. The specific work that reported about picosecond diffraction studies of laser-induced strain in crystals could not presently be done with this time resolution at 3rd generation synchrotrons, and it investigates a particular science problem that may be of interest at a 4th generation X-ray machine.

A lot of the work in chemical physics that could be done at XUV light sources can now be done using table-top laser-based systems, such as those employing high harmonic generation. Support for this science can have a high pay back for the dollars invested, since these sources are relatively inexpensive and are on a very rapid track of improvement in source quality and cost. Funding small independent university groups to pursue laser based research substantially improves the prospects that a wide variety of exciting scientific experiments and viable source approaches will be investigated. Time-resolved dissociation dynamics involving core level photoelectron spectroscopy is one example that the Panel heard about. Dissemination of results to the community at large through publications, conferences, and direct communication is the most effective way to enlarge this research.

One characteristic of the new generation light sources that is not yet well appreciated by much of the community is temporal coherence. This point was stressed in the discussion about some uses for X-ray coherence. The Panel also heard about ideas for holography on atomic length scales. Indeed, much more work should be done to develop applications for this novel attribute of the FELs. Here the laser community can provide some important input on how to use spatial and temporal coherence to enhance measurements, spectroscopy or control dynamics.

Through these kinds of advancements we can expect a number of important indirect benefits, in addition to the direct accomplishment of science progress. First, the improvement of laser sources will directly spur improved methods for using the electron based light sources, through better timing, pump-probe techniques, and the like. Second, if laser programs are funded by the same BES organization that has been so long committed to synchrotrons, we can expect a greater merging of the community of scientists in these areas. This merging is perhaps the greatest long term benefit, since it will quickly break down the traditional cultural divide that has been one of the impediments to rapid progress in the science.

A total support level of several millions dollars per year for the university based groups would have a significant impact on laser-based light source development and science. Additional support would be necessary for the DOE laboratory-based support groups in laser-based science. With this level of funding one can foresee continued dramatic improvements in flux, wavelength coverage, and temporal characteristics of photons generated directly from laser-matter interactions.

7.0 Panel Recommendations

7.0 Panel Recommendations

(1) Given currently available knowledge and limited funding resources, the hard X-ray region (8-20 keV or higher) is identified as the most exciting potential area for innovative science. DOE should pursue the development of coherent light source technology in the hard X-ray region as a priority. This technology will most likely take the form of a linac-based free electron laser device using self-amplified stimulated emission or some form of seeded stimulated emission. The developers of such a source should seek to attain both temporal and spatial coherence, as well as precise timing with ultrashort pulsed lasers, which will be required for laser pump/X-ray probe experiments.

(2) The scientific case for coherent hard X-ray sources is in the formative stages and appears extremely promising, but must be improved to a attain a more compelling and rigorous set of experiments that can be achieved only if such a new coherent light source becomes available. In this regard, the scientific case should be developed by seeking an early and strong coupling of scientific users, laser experts, and source developers, possibly facilitated by chief scientists, so that the light source properties can be defined as an integral part of the science requirements. Major issues of sample degradation by high energy X-ray pulses and laser pulses, if used as pumps, must be addressed at an early stage.

(3) There is a symbiotic relationship between future accelerator-based sources and high-powered ultrafast lasers. Future light sources will involve a complete marriage of accelerator principles and lasers. Lasers are also likely to be the avenue where the shortest pulses are attained and many new scientific experiments are developed first. The Panel recommends that DOE should support laser light source development independently and vigorously. This is best done by support of peer-reviewed proposals based on science that requires a significant component of laser source development. It is also desirable to support one or more DOE laboratory centers for laser development that can be coordinated with overall light source facility development plans.

(4) Provisional support should be provided for a highly focused and fiscally responsible set of investigations to determine the feasibility and design of a 1.5 Angstrom coherent light source, contingent on (a) continued successful demonstrations of electron beam parameters and their properties upon interactions with radiation, (b) strong and active involvement of a significant body of scientific users who demonstrate the need and desire to utilize such a source, and (c) the successful development of multiple, compelling examples of scientific cases within two years. Three laboratories, SLAC, ANL, and BNL, should assume the lead role of formulating the necessary experimental steps, and involving other laboratories and universities when expertise warrants.

(5) The final design and possible construction of a 1.5 Angstrom free electron laser test facility should only be considered after the successful completion of recommendation (4).

(6) Support should be provided for the development of X-ray detectors and optics, concomitant with better utilization of existing synchrotron facilities and lasers to carry out tests of potential new experiments that may be enhanced by a coherent hard X-ray source.

Appendix 1

Panel Charge Letter (BESAC Chair to Stephen Leone)

UNIVERSITY OF OREGON

September 1, 1998

Prof. Stephen Leone
JILA
CB 440
University of Colorado
Boulder, CO 80309

Dear Steve:

The report of the Basic Energy Sciences Advisory Committee (BESAC) Panel on D.O.E. Synchrotron Radiation Sources and Science (the Birgeneau Report, dated November, 1997) placed as one of their highest priorities exploratory research on the fourth generation of light sources. More explicitly, the report recommended that another panel, comprised of potential users and builders of fourth generation light sources, be convened to advise Basic Energy Sciences on the development and application of such sources, keeping in mind the limited funding available. To this end, BESAC has now been charged by Dr. Martha Krebs to implement this recommendation of the Birgeneau report. I am delighted that you have agreed to take on the task of convening and chairing this panel.

The Birgeneau panel limited consideration of a fourth generation light source to a free electron laser (FEL) operating in the X-ray region. This definition follows from the historical development of the particle-beam technology associated with synchrotron light sources. However, we want your panel to think more broadly with respect to the definition of novel light sources to include all possible ways in which increased brightness, intensity, coherence, temporal resolution and wavelength coverage can be achieved. In particular, we would like your panel to address two primary questions:

(1) What new science will be enabled by novel coherent light sources? Besides the obvious increases in brightness there are fundamental differences in peak intensity and coherence properties between the second and third generation synchrotron sources and the envisioned new light sources. How can the high intensities, coherence, and temporal properties of novel sources be utilized to provide new probes of matter using photons? In what fields will the new light sources have the most significant impact?

(2) Given the present state of science and technology, what might be a reasonable research and development plan for novel coherent light sources in the next five years?

DEPARTMENT OF CHEMISTRY
College of Arts and Sciences 1253 University of Oregon Eugene OR 97403-1253 TELEPHONE - (541) 346-4601
FAX - (541) 346-4643 INTERNET - chemistry~oregon.uoregon.edu TELEX - (541) 597-0354
An equal opportunity, affirmative action instituion committed to cultural diversity

> How would such sources be configured (individual laboratories, modest user centers, large-scale facilities, etc.) and how might they serve the potential user community?

Your panel should be composed of scientists from diverse backgrounds, balanced among several communities but with particular emphasis on the potential user community. Included among these are experts familiar with second the potential user and third generation synchrotron light sources, currently operating FELs, and laboratory based laser systems. The panel should solicit input from individual principal investigators and from the management and staff of the current synchrotron light sources, FEL laboratories, and laser development centers through a focused workshop devoted to the topic of novel coherent light sources. In addition, the panel should be aware of and utilize the results of previous studies and workshops devoted to FELs and fourth-generation light sources. These include the 1994 NAS report on "Free Electron Lasers and Other Advanced Sources of Light, Scientific Research Opportunities," the 1994 "Workshop on Scientific Applications of Coherent X-Rays" (SLAC report 437), the 1996 "Workshop on Fourth Generation Light Sources" (ESRF, Grenoble, France), and the 1997 "Workshop on Scientific Opportunities for Fourth-Generation Light Sources" (APS, Argonne National Laboratory).

Both BESAC and the Birgeneau panel feel strongly that the D.O.E. synchrotron light sources have provided and will continue to provide unique capabilities for our ability to interrogate matter with photons. We look forward to your report on the direction of research and development for the next generation of light sources and on how these novel coherent sources may impact scientific research.

Sincerely,

Geraldine Richmond

Geraldine Richmond
Professor of Chemistry
Chair, Basic Energy
Sciences Advisory
Committee

cc.
Dr. Patricia Dehmer, Associate Director of Energy Research, DOE
Dr. Martha Krebs, Director of Energy Research, DOE

Appendix 2

Novel Coherent Light Source
Panel Roster

BESAC Panel on Novel, Coherent Light Sources

Dr. Paul Alivasatos
Department of Chemistry
University of California
Berkeley, CA 94720-4767
510-643-7371
Fax: 510-642-6911
Alivis@uclink4.berkeley.edu

Dr. Nora Berrah
Department of Physics
Western Michigan University
Kalamazoo, MI 49008-5151
616-387-4955
Fax: 616-387-4939
berrah@wmich.edu
Sabbatical address:
Advanced Light Source
Lawrence Berkeley National Laboratory
Building 4-212
1 Cyclotron Rd.
Berkeley, CA 94720
510-495-2439
Fax: is 510-486-7588
Nberrah@lbl.gov

Dr. Philip H. Bucksbaum
Department of Physics
University of Michigan
Ann Arbor, MI 48109-1120
734-764-4348
Fax: 734-764-5153
phb@umich.edu

Dr. William B. Colson
Department of Physics
833 Dyer Rd.
Naval Postgraduate School
Monterey, CA 93943
408-656-2765
Fax: 408-656-2834
colson@physics.nps.navy.mil

Dr. Richard Haight
29-207
IBM T. J. Watson Research Center
P.O. Box 218
Yorktown Heights, NY 10598
914-945-3805
Fax: 914-945-2141
Rhaight@watson.ibm.com

Dr. John W. Hepburn
Department of Chemistry
University of Waterloo
Waterloo, ON
N2L 3G1 Canada
519-888-4065
Fax: 519-746-0435
hepburn@watsci.uwaterloo.ca

Dr. Raymond Jeanloz
Department of Geology and Geophysics
University of California
Berkeley, CA 94720-4767
510-642-3993
Fax: 510-643-9980
jeanloz@uclink.berkeley.edu

Dr. Stephen Laderman
Hewlett-Packard Labs
3500 Deer Creek Rd.
Palo Alto, CA 94304
415-857-3202
Fax: 415-857-5308
laderman@hpl.hp.com

Dr. Stephen R. Leone, Chair
JILA
Campus Box 440
University of Colorado
Boulder, CO 80309
303-492-5128
Fax: 303-492-5504
srl@jila.colorado.edu

Dr. Donald H. Levy
Department of Chemistry
University of Chicago
5640 S. Ellis Ave.
Chicago, IL 60636
773-702-7196
Fax: 773-702-5863
levy@dilly.uchicago.edu

Dr. Simon Mochrie
Department of Physics
Massachusetts Institute of Technology
Cambridge, MA 02139
617-253-6588
Fax: 617-258-6883
simon@lindy.mit.edu

Dr. Keith Moffat
Department of Biochemistry and
Molecular Biology and Center for
Advanced Radiation Sources
University of Chicago
5620 S. Ellis Avenue
Chicago, IL 60637
773-702-9950
Fax: 773-702-5454
moffat@cars.uchicago.edu

Dr. Yves Petroff
European Synchrotron Radiation Facility
BP 220
38043 Grenoble Cedex
France
33 0 476.88.20.30
Fax: 33 0 476.88.24.18
petroff@esrf.fr

Dr. Geraldine L. Richmond
Department of Chemistry
University of Oregon
Eugene, OR 97403-1253
541-346-4635
Fax: 541-346-5859
richmond@oregon.uoregon.edu

Dr. Jochen R. Schneider
HASYLAB at DESY
Notkestr. 85
Hamburg, Germany 22603
49 40 8998 3815/2304
Fax: 49 40 8998 4475
schneider@desy.de

Dr. Yuen-Ron Shen
Department of Physics
University of California
Berkeley, CA 94720-7300
510-642-4856
Fax: 510-643-8497
shenyr@physics.berkeley.edu

Laboratory Liaisons:

ALS/LBNL
Dr. Brian M. Kincaid
Lawrence Berkeley National Laboratory
1 Cyclotron Road M/S 46A-1123
Berkeley, CA 94720
510-486-4810
Fax: 510-486-7066
bmkincaid@lbl.gov

APS/ANL
Dr. David E. Moncton
Associate Director, Argonne National Laboratory
Advanced Photon Source
OTD-APS401, A4110
9700 South Cass Ave.
Argonne, IL 60439
630-252-7950
Fax: 630-252-4599
dem@aps.anl.gov

LANL
Dr. Richard Sheffield
MS H805
Los Alamos National Laboratory
Los Alamos, NM 87545
505-667-1237
505-667-8207
rsheffield@lanl.gov

LLNL
Dr. E. Michael Campbell
Associate Director for Laser Programs
L-466
Lawrence Livermore National Laboratory
Livermore, CA 94551
925-422-5391
Fax: 925-422-5411
Campbell5@llnl.gov

NSLS/BNL
Dr. Sam Krinsky
Deputy Chairman, NSLS
National Synchrotron Light Source
Brookhaven National Laboratory
Upton, New York 11973-5000
516 344 4740
Krinsky@bnl.gov

SSRL/SLAC
Dr. Max Cornacchia
Assistant Director SSRL
Stanford Linear Accelerator Center
P.O. Box 4349, MS 69
Stanford, CA 94309-0210
650-926-3906
Fax: 650-926-4100
Cornacchia@SSRL.SLAC.Stanford.Edu

TJNAF
Dr. Fred Dylla
FEL Program Manager and Technology Transfer Manager
Jefferson Lab
12000 Jefferson Avenue
Newport News, VA 23606
757-269-7450
Fax: 757-269-6357
dylla@jlab.org

Appendix 3

Workshop Agenda

BESAC Panel on Novel, Coherent Light Sources
Stephen R. Leone, Chairman

Meeting Agenda - January 18 – 21, 1999
Gaithersburg Hilton, Gaithersburg, MD

Monday, January 18***********************************

7:30 pm – 9:00 pm Opening Session for Panel Members and Liaisons

************************************** Tuesday, January 19************************************

8:15 am – 10:00 am Open Session - Laboratory Presentations

8:15 am	Opening Remarks	Stephen Leone, Univ. of Colorado
8:30 am	Joint Presentation Session by Argonne National Laboratory, Stanford Linear Accelerator Center, Los Alamos National Laboratory	
	Toward a Fourth Generation X-Ray Source	David Moncton, ANL
	What Makes the X-Ray FEL <u>Unique</u> for Science	Sunil Sinha, ANL
	Structure Determination by Flash X-Ray Holography	Ian McNulty, ANL
	Functional Biology: A New Frontier in Biophysics	Philip Anfinrud, NIH

10:00 am – 10:30 am Break

10:30 am – 12:00 pm Open Session – Continue Joint Presentation Session

Physics and Performance of SASE-based FELs	Claudio Pellegrini, UCLA
Experimental Observations and Performance of SASE-based FELs	Dinh Nguyen, LANL
The LEUTL Program at APS	John Galayda, ANL
Overview of the LCLS Project and R&D Program	Max Cornacchia, SLAC
Summary and Concluding Discussions	Keith Hodgson, SLAC

12:00 pm – 1:30 pm Working Lunch – Panel Members and Liaisons

1:30 pm - 3:30 pm Open Session – Continue Laboratory Presentations

1:30 pm Science and Source Development at Brookhaven National Laboratory

The Road Map	John Marburger, BNL
A Path Toward an X-Ray FEL	Sam Krinsky, BNL
Challenges in High Field Physics	Lou DiMauro, BNL
The DUV-FEL and Beyond	Erik Johnson, BNL

2:30 pm Thomas Jefferson National Accelerator Facility

Intense IR/UV Light Provided by FELs	Fred Dylla, Jefferson Lab
Multicolor, Ultrafast AMO Physics	Bill Cooke, College of W&M
Chemical Dynamics of Highly Vibrationally Excited Molecules	Kevin Lehmann, Princeton Univ.
Materials Physics with Intense IR/UV	Len Feldman, Vanderbilt Univ.

3:30 pm – 4:00 pm Break

4:00 pm - 6:00 pm Open Session - Continue Laboratory Presentations

4:00 pm Lawrence Berkeley National Laboratory

Scientific Motivation for the Fourth Generation Light Source	Chuck Shank, LBNL
First Steps Toward Femtosecond X-Ray Sources	Brian Kincaid, LBNL

5:00 pm Lawrence Livermore National Laboratory

Laser-Based Next Generation Light Sources	Howard Powell, LLNL Todd Ditmire, LLNL
Los Alamos Laser Plasma Light Source	Al Arko, LANL

6:00 pm - 6:30 pm General Comments

7:00 pm - 8:30 pm Open Dinner for all Participants

9:00 pm - 10:30 pm **Tuesday Wrap-up Session – Panel Members and Liaisons**

** Wednesday, January 20**

8:30 am – 10:00 am **Open Session – Invited Presentations**

8:30 am	Ultrafast Coherent UV and X-ray Sources	Margaret Murnane, Univ. of Michigan
9:00 am	Discharge Pumped Table-Top Soft X-Ray Lasers	Jorge Rocca, Colorado State Univ.
9:30 am	Ultrafast, Laser-Based X-Ray Sources and Movies	Chris Barty, Univ. of California, San Diego

10:00 am – 10:30 am **Break**

10:30 am – 12:00 pm **Open Session - Continue Invited Presentations**

10:30 am	Non-Linear Optics Using Electromagnetically-Induced Transparency	Steve Harris, Stanford
11:00 am	Condensed Matter Spectroscopy with Coherent X-Rays: The Whole Brillouin Zone	Keith Nelson, MIT
11:30 am	Frontiers in Structural and Dynamic Biology	Graham Fleming, LBNL

12:00 pm – 1:30 pm **Working Lunch – Panel Members, Liaisons and Speakers**

1:30 pm – 2:30 pm **Scientific Brainstorming Session – Panel Members, Liaisons and Speakers**

2:30 pm – 3:30 pm **Feedback Session – Panel Members and Liaisons**

3:30 pm - 6:30 pm **Closed Session – Panel Members**

6:30 pm - 8:00 pm **Working Dinner – Panel Members and Liaisons**

8:30 pm – 10:00 pm Wednesday Wrap-up – Panel Members and Liaisons

*************************************** Thursday, January 21*************************************

8:00 am – 12:00 pm Closed Session – Panel Members