LUX - Linac-based Ultrafast X-ray Source

Technical Review, April 28-29, 2003

Final Report

Eric Colby (SLAC), Jean Delayen (JLab), Helen Edwards (DESY-FNAL), Paul Emma (SLAC), Roger Falcone(UCB), Rod Keller (LBNL), Kwang-Je Kim (ANL), Geoffrey Krafft (JLab), Sam Krinsky (BNL), and Todd Smith (Stanford U)

Berkeley Lab, July 31, 2003

Table of Content

Executive Summary

General Comments

The committee was very impressed by the volume and quality of material produced by a very small group on a minute budget, and we commend all presenters for their efforts in preparation for this review. The work performed to date is impressive. The overall concept of the proposed facility appears to be sound. We strongly encourage LBNL to continue supporting this project.

The LUX machine is based upon a very novel and innovative accelerator design; the excellent analysis of accelerator physics issues performed thus far provides a basis to evaluate the feasibility. Collaboration with, and involvement of, other laboratories has been productive, and it is crucial that the staff expand on it. The choice of a superconducting technology is clearly the right one.

In details, however, there are still significant gaps in the understanding and description of the planned facility:

- The design team needs to integrate the design and define a consistent set of major performance parameters. The major design parameters don't look particularly aggressive. In view of recent experiences in the field of accelerators, it might be possible to either simplify the design (reduce cost) or aim at somewhat increased performance, e. g., higher flux.

- Demonstration of the key LUX ideas of electron compression, kicker technology, synchronization of x-rays and lasers, and optical compression by x-ray optics should be a high priority for the project to gain confidence that the major specifications can be met.

- No built-in upgrade path is apparent
  - towards the already envisaged attosecond range
  - towards larger numbers of photons-per-pulse
  - towards higher photon energies

- Diagnostics and instrumentation needs should be identified and planned for, to support tuning and feedback strategies.

- System tolerances have to be established in a consistent way and related to general choices for subsystems.

Areas That Predominantly Need More Attention

- Optimization of the accelerator layout

- Full end-to-end simulations with consistent sets of components and operation parameters

- Sensitivity study of the design parameters

- Consistent set of tolerances

- Generating a beam with the required, small, vertical emittance and maintaining this beam quality in view of many emittance-diluting effects

- Lattice details
  - Linac quadrupole focusing on first pass

- The R&D program for the RF gun needs to be better defined
  - Expand the collaborations with Fermilab and DESY to leverage available resources

- Specifically look into pulsed heating and surface-erosion effects with the electron gun

- Build and test a half-cell model of the cathode to specifically assess the rf performance

- Bunch compression
  - Examine a gradual compression scheme over several arcs

- Demonstration of key concepts of x-ray pulse compression

- Timing stability and synchronization
  - Detailed concept
  - Ability to synchronize or diagnose the relative timing of laser and x-rays on a pulse-to-pulse basis will be crucial for running experiments.

- Multibunch effects

Not Addressed So Far

- Reliability / availability budget
  - The budget allocations to specific subsystems will influence their technology choice

- Shielding and other personnel and equipment protection issues
  - Strategy to deal with failure modes

- Field quality requirements for the superconducting undulators necessary to obtain higher harmonics

- Accommodating the anticipated user needs for rapid tunability and rapid-scan spectroscopy

- Longitudinal resistive-wall wake in arcs with respect to emittance growth and transverse resistive-wall wake between cavity and hard x-ray undulators for crabbed beam

- Time-dependent x-ray tracing

- User needs, for what are envisioned as laser-based sources operating both as integrals parts of, and in concert with, the x-ray sources, involve a range of wavelengths, pulse lengths, and powers. The user needs envisioned for LUX should be determined.

In summary, the plans for future work appear to be reasonable overall, but the expected limitations in resources will significantly slow down the progress towards a fully consistent design and getting ready for CD-0.

Comments on detailed issues are given below, grouped by accelerator-specific topics. Recommendations made by individual reviewers are imbedded among these comments.

Reviewers and Their Assigned Areas of Special Attention

Roger Falcone(UC Berkeley)	Lasers and beamlines
Geoffrey Krafft (JLab)	Accelerator physics and instrumentation
Paul Emma (SLAC)	Accelerator physics
Eric Colby (SLAC)	Rf photocathode gun
Jean Delayen (JLab)	Superconducting rf
Kwang-Je Kim (ANL)	Synchrotron radiation production
Helen Edwards (DESY-FNAL)	Rf systems, flat-beam production, magnets, and vacuum
Sam Krinsky (BNL)	Beam dynamics
Todd Smith (Stanford U)	Superconducting rf systems
Rod Keller (LBNL)	Chair

Charge to Review Committee

- Review the work to date, as presented during the meeting and in the feasibility study report
- Identify areas requiring additional attention
- Identify topics of importance that have not yet been addressed
- Comment on soundness of plans for future work

Introduction

On April 28 and 29, a technical review of the Linac-based Ultrafast X-ray Source (LUX) design was held at Berkeley Lab. This review was held to exclusively address technical design issues and was not intended to cover user-related questions (an introductory presentation on science options notwithstanding) or the position of this proposed facility in the general context of other existing and proposed US light source facilities. However, the review committee would like to direct the machine team's attention to the fact that the linkage between technical issues such as considered in this review and the scientific case for a proposed facility has become a very important aspect in interactions with the DOE Office of Basic Energy Sciences.

A list of reviewers with assigned areas of special attention as well as the charge to the review committee are given above, and a list of all presentation titles is given in the Appendix. One of the principal authors of these presentations was not present at the review, and that presentation was given by J. Corlett, instead.

After the first day of presentations and discussions, the committee generated a list of questions, and these questions were answered by J. Corlett on the second day, ahead of the originally scheduled presentations.

The time left to the committee to discuss findings and recommendations during the review was disproportionally short, and in a few instances follow-up comments were integrated into this report that may not have been adequately incorporated into the close-out presentation given by the committee chair at the end of the review. For the same reason, the committee did not formally decide on a list of recommendations, but comments made by the reviewers on detailed issues are given below, grouped by accelerator-specific topics, and individual recommendations are imbedded among these comments

Detailed Comments

General Issues

Impressive progress has been made since the 2001 Femtosource Review and a large amount of work has been completed. Examples are the theory and simulation of the flat beam generation with rf guns that have advanced significantly, and the very encouraging, initial flat beam experiments at FNPL. Extensive engineering work leading to a practical design for this very challenging gun has been done. The progress in both areas is particularly noteworthy given the limited resources that have been available to be directed at these issues.

However, a lot more remains to be done before a complete and self-consistent story is achieved. In addition, there seems to be a mismatch between what still needs to be done before being ready for CD0 and the actually expected level of effort that can be dedicated to the project preparation work.

Collaboration with and involvement of other laboratories will be crucial for keeping the project's momentum going.

A first cut at a top-level performance-parameter set might be useful in bringing more coherence and consistency between the various subsystems. The major design parameters don't look particularly aggressive. In view of recent experiences in the field of accelerators, it might be possible to either simplify the design (reduce cost) or aim at somewhat increased performance, e. g., higher flux.

For such a facility availability is a major performance parameter. This is true for several time scales. An availability budget will have to be developed and assigned to various subsystems. Availability requirements for each subsystem could be a major factor in making the technology choice for each subsystem, and such choices could force a departure from the current nominal design.

With substantial effort being invested (and substantial risk undertaken) on the accelerator side of the facility a commensurate level of effort (and risk) should be undertaken with the x-ray optics systems (such as the exploration of other, perhaps yet untested, means to further compress the x-ray pulses. Is it possible to spectrally broaden the x-ray pulse in a nonlinear medium, permitting further compression with gratings?).

Accelerator Physics

The LUX machine is based on a very novel design with many innovative features. At this time, the baseline design has been developed to the point where feasibility can be evaluated and optimization can begin. The analysis carried out thus far is impressive and a great deal has been learned about this unique accelerator system. The lattice design seems sound and the analysis of the effects of CSR and wake fields is off to a good start. It is important to continue identifying and addressing the key design issues and to integrate the results.

The design is based upon a new x-ray compression scheme to attain short-duration pulses. This approach requires producing a correlated vertical angle-chirp on the electron bunch. It is important to clearly specify the tolerances that must be imposed on the accelerator system to achieve this correlation and produce the desired pulse duration. Tolerances must also be given to assure that the variations in pulse duration and arrival time are kept within acceptable limits. Cases where feedback will be required should be identified, and consideration should be given to the beam diagnostics that will be necessary for system debugging and control.

In the discussion of the science goals for LUX, it was stated that users will eventually want to reduce the pulse duration from 50 fsec down to 5 fsec and even 0.5 fsec. An important question is whether the LUX design is sufficiently flexible to allow for future upgrades to attain shorter pulses. In this regard one should compare the potential performance of LUX with that of SASE x-ray FELs. With the SASE FEL, the pulse intensity is sufficiently high that it is feasible to reduce the pulse duration by pulse slicing rather than pulse compression. With LUX, pulse compression is required in order to maintain intensity while shortening the pulse. The novel technique of using synchrotron radiation from an earlier recirculating arc to provide a signal for synchronization could in principle be implemented in a facility based upon a SASE FEL.

Accelerator Layout

A comprehensive point design has been presented. It would be helpful to have a good understanding of a much larger range in parameter space. Only preliminary studies of the effects of field errors and tolerances have been completed which verify that storage-ring magnets already designed will fit the LUX needs. More detailed tolerance studies should be undertaken. A benefit may be that less stringent requirements may be arrived at for some systems, or more usefully, the design shifted from “tough-to-achieve” to “easier-to-achieve” systems.

Two examples of yet not clearly answered questions are:

- What is the net effect if the nominal emittance cannot be achieved?

- What are the trade-offs, based on experimenters' input or other criteria, between maximum flux or charge versus shorter pulse length?

Most modeling has been done using 2.5-d codes. Is there a plan to go 3-d, or if not, a very good reason not to? At some point this jump will have to be made anyway.

Examine if three passes (with almost the same cost as four) are feasible because that lattice is simpler, more reliable, and has less CSR.

It might be useful to include insertable tune-up beam dumps after each pass, or at least after the injector loop.

Lattice

Investigate the benefits of implementing dispersion correction in each arc, especially for the vertical dispersion. One might be able to empirically minimize the projected emittance using orthogonal combinations of quadrupole settings.

Elaborate on the path-length adjustment scheme and derive a more detailed plan.

The flat-beam correction scheme with sextupoles needs to be looked at more closely at some point because of the coupling they can generate. Vertical alignment of the sextupoles may be a critical issue, especially with $\eta_x \neq 0$ and with a flat beam. Is there a way to reduce the number of sextupoles (now 66) or eliminate them entirely?

Establish the required vertical alignment tolerance of the linearizing 3.9-GHz accelerating structure in view of its smaller iris and stronger transverse wake field. Has the value of β_y been minimized here to relax this tolerance?

Beam Dynamics

Optimize the linearizer concept.

Since the main goal of this project is to produce ultra-short x-ray pulses, a ray tracing program tracking the full 6-d phase-space evolution is most urgently necessary.

It is not clear what exact field model was used to derive the longitudinal focusing action of the cavities. The longitudinal distribution in a bunch used to calculate wake fields appears highly idealized.

The chirped energy spread (0.5% rms) in the compressor, added recently to control the CSR driven emittance growth with sextupoles, was probably not included when the tracking studies were performed with misaligned components. If this is the case, this larger energy spread may change these results significantly.

Are there any significant second-order path-length effects associated with the transverse deflectors which may limit the pulse length at increased voltage?

How much x-y correlation in the beam (coupling) is allowed before the x-ray compression would suffer?

Establish the required power-supply regulation tolerances for the non-achromatic bend-magnet groups.

Examine what beam feedback systems are needed (e.g., trajectory, energy in each arc, T-cavity phase, …).

Regarding collective effects, most of the presented material dealt with single bunch, single pass effects. A 10 kHz, 2 psec, beam will have a rich Fourier spectrum up to high frequencies. Are multi-bunch effects really a non-issue?

Emittance-related Issues

The transverse normalized emittance goal of 4 (mm-mrad)^2 for a round beam and 8-9 (mm-mrad)^2 for a flat beam are certainly not overly ambitious, in comparison to the 1 (mm-mrad)^2 goal for the LCLS project. This relaxed emittance goal is believed to be compatible with accommodating the high heat load expected with 10 kHz c.w. operation. The 4-d, absolute, emittance at 3 GeV will be around 25×10^{-20} (m-rad)^2 which is comparable to the emittances in typical third-generation light sources (4×10^{-9} m-rad horizontal and 4×10^{-11} m-rad vertical).

Still, producing and maintaining the small vertical emittance remains a critical issue. The vertical emittance directly impacts the obtainable x-ray pulse length, and hence a critical parameter for the scientific program. No vertical emittance-growth budget was presented, and no detailed study of the mechanisms for emittance growth was undertaken.

Sources of and tolerances on vertical emittance dilution effects must be carefully simulated and understood.

Sources of vertical emittance must be understood, and the following choices confronted:

(1) Laser photon energy: does reducing the photon energy closer to the work function improve the thermal emittance?
(2) Laser profile uniformity: how much transverse and longitudinal intensity variation is allowable?
(3) Photocathode emission uniformity: how much quantum efficiency variation is tolerable?
(4) Photocathode surface roughness, detailed surface chemistry, etc.

The flat beam generation with a large-to-small emittance ratio of 40-50 should be feasible since a ratio of similar magnitude has already been achieved at the A0 facility at FNAL, although at slightly larger emittances. Building on these experiences, and with tighter control on cylindrical symmetry, an emittance ratio of 100 or higher should be feasible in the future.

Recommendations

1) Continue and expand the collaboration with Fermilab to perform measurements on flat beam production. This effort will require detailed, high-fidelity simulations of the experiments, and further enhancement of the diagnostics (e.g. to get higher resolution emittance measurements). It is well worth adding 1.0 FTE to the present effort to permit a thorough exploration of the technical issues impacting the production of small vertical emittance flat beams with rf guns.

2) Work closely with the laser engineers to understand what types of transverse and longitudinal profile non-uniformities will likely be present in the laser pulse, and do simulations to understand what limits must be placed on the amplitudes of these non-uniformities to obtain the required emittances. This effort should be part of a larger effort (on the order of two additional postdocs above existing effort levels) to produce a high-fidelity end-to-end simulation of the entire

LUX machine that links the various computer simulation codes to simulate the entire process from photo-emission to the final, compressed x-ray pulse.

No data was presented on emittance growth over a single pass or through the entire machine (through the usual synchrotron H-function integral); both the gun and final emittance specification are listed at 0.4 μm. Similarly, the energy-spread increase due to quantized radiation emission, or the requirements it places on the lattice design, were not discussed. Because of the relatively small bend radius to be achieved and the unfavorable scaling with bend radius, future iterations should include this information. These topics should be part of the final design documentation.

Except for some tracking with orbit corrections, there was no mention of emittance measurement and correction. Roll errors of quadrupoles, displacements of quadrupoles and sextupoles, transverse wake fields, and field-quality errors, especially in the bends, will generate correlated emittance growth, which is correctable if appropriate correctors and emittance measurement stations are included. The addition of small 'tweaker' quadrupoles (2 skew and 2 normal) in each arc will allow empirical emittance correction. Rough estimates suggest that some of the quadrupoles at $\eta_x \approx 1$ m and a 0.5% chirped energy spread will have roll tolerances of ~100 μrad. At this difficult level, vertical dispersion correction will be needed (2 weak skew quads – see experience at KEK-ATF).

According to the simulations completed to present, Coherent Synchrotron Radiation (CSR) driven emittance, which is predominantly produced in the injection bend and merge section, seems to be manageable. However, there was general unease expressed with the status of code benchmarking and the lack of experimental support for the various calculations that were done. Experimental characterization of the produced CSR is needed. Perhaps, collaboration with LCLS on this issue would be beneficial.

Specify locations for emittance measurements and the measurement technique itself. Investigate if local beam optics are optimized to enhance the emittance measurement precision.

Bunch Compression

Examine if more gradual compression (as compared to two steps) in the arcs would be beneficial because the bunch length can be kept longer until the energy and radius of curvature have increased in the later arc-sections (less affected by CSR).

Investigate if the second-order compression term (T_{566}) could be utilized against the RF curvature to cancel the 2nd-order compression aberration. This is generally possible in systems where $T_{566}/R_{56} > 0$ (i.e., in an arc, but not in a chicane), but might not be practical here.

We encourage an early hardware test of the x-ray pulse compression mechanism. The efforts should be focused on how to measure the pulse length

The compression from 20 psec towards 2 psec is designed as a $\pi/2$ phase space rotation to reduce the effects caused by timing jitter, but the final level of 2 psec range is then critically dependent on the 20-keV energy spread from the injector. If this energy spread is significantly larger, can an under-compressed configuration still meet the jitter requirements?

The longitudinal resistive-wall wake field may be important, in addition to the longitudinal wake field generated in the cavities.

The transverse deflector phase-tolerance of 0.01 deg. seems unusually tight.

Stability

Clarify what the rf phase and amplitude tolerances are throughout the machine and what effects determine these limits. With $R_{56} \approx 1.6$ m, a small energy jitter of 1×10^{-4} in the injector linac will produce a 500-fsec timing jitter. Would this be a problem?

The 0.01-deg (7 fsec) phase-stability requirement for the transverse deflector seems severe. Can this be relaxed by sensing phase errors using a vertical Beam Position Monitor after the deflector and binning the pump-probe data to accommodate the timing error? Maybe bunch arrival-time errors can be distinguished from rf phase errors by also using a BPM beyond the 2nd deflector (at +**I** separation). Timing errors will produce a Δy on the first BPM (between deflectors) but no Δy on the second BPM, while a phase error on the 1st deflector will appear as Δy on both BPMs.

Injector Systems

The flat-beam dynamics and their control need more understanding through continued analytical approaches, simulations, and measurements. In particular, understanding the limitations of minimum emittance that can be expected from the thermal transverse momentum, and just how close actual systems can come to this limit needs to be measured.

The adjustments performed in order to compensate for space charge and to minimize correlation terms need to be further understood and tested in experimental measurements and observations. Work toward further experimental verification of low emittance and adjustment of optics parameters should continue with high priority at Fermilab (FNPL). The LBNL / FNPL collaboration is very important to both parties.

The gun and injector system as designed should also be simulated and the expected round beam conditions be determined as this would give an alternate operating mode for the x-ray generation.

RF Gun

It is a complication having to deal with two different guns. It might be advisable, at least at the beginning, to operate the facility with a single round-beam gun. Crabb-kicking and x-ray compression for a pulse length about 100 fs may still be possible with 2 mm-mrad round beams, by rearranging optics (to reduce the angular divergence at the undulator location) and by increasing the kick strengths.

The mechanical gun design is very demanding with respect to thermal effects, and testing of a prototype at elevated power levels is certainly warranted. Minimization of peak heating at localized rf surfaces (e.g. couplers) needs careful design as has already been initiated for the body.

Pulsed heating and surface erosion will be critical issues for this very high repetition rate gun. Careful design work to minimize pulsed heating-temperature rise will be essential. Work has been done on cavity wall current densities, but must still be performed for the input couplers.

The cathode choke-spring or resonant-trap design will similarly be critical; a reliable means of making a high power rf contact will need to be designed and tested. Examination of the high-power cathode choke-spring designs of the TTF guns and the Boeing 433-MHz APLE gun should be instructive.

A test model of the cathode half cell should be built and tested at the required power level, possibly also at FNPL to achieve cost savings overall, and preferably with high repetition rate to study aging effects, and the basic functionality of cathode and coupler designs. In view of many possible effects to study, it is recommend this test be primarily dedicated to the rf performance, obviating the need for a laser, special cathode, or specialized beam diagnostics.

Information on the LUX gun will be obtained from recent FNAL work. However, the present LUX design for the gun is not the same. Early experimental verification of the performance of the new gun design should be sought as soon as possible

Setting up the new gun, if there is sensitive dependence of its performance on the various parameters that must be tuned, may be difficult. This is especially true if the diagnostics complement during early tests are not able to “distinguish” various parameter settings. All the more, this effort should be started early.

Recommendations

(1) Continue the thermo-mechanical engineering work, paying particular attention to the pulsed-heating temperature rise around the coupler irises.
(2) Limit the scope of the proposed rf gun test to addressing the issues of pulsed heating and surface erosion. A full-scale model of the entire gun is important, but should wait until financial resources improve.

Research on a dc/rf gun hybrid is indeed interesting and may ultimately lead to an upgrade scenario for the injector, but only in the long term. Work in the short term should focus on the rf photocathode design.

Specific Question

What must be demonstrated with a gun test stand prior to CD0?

Response in order of diminishing importance

1) Production of the required vertical emittance, not necessarily at the full 10 kHz rep rate; 10 Hz is sufficient. In the process of performing this demonstration, the simulation model must be shown to produce reliable and accurate predictions of the measured performance.

2) Operation at 10 kHz of at least a half cell with the same geometry as the proposed gun cathode cell, complete with the same coupler, and rf choke joint around the cathode (the cathode need not be CsTe, it can be bare molybdenum, thus eliminating the need for a cathode preparation chamber). If the geometries, surface fields, and pulsed heating temperature-rises of the 3-cell accelerator cells are very similar to the half cell then a demonstration of a full-power full cell is not critical. The full-power half cell must demonstrate:
   a) Reliable gradient holdoff (64 MV / m at the cathode)
   b) Sufficient rf cavity life span to meet MTTF requirements
   c) Adequate vacuum pressure with the rf on (10^{-9} Torr range or better) to expect reasonable cathode lifetime

3) Demonstration of the proposed laser techniques for meeting the radial and temporal profile requirements set by the tolerance studies outlined above, perhaps at reduced repetition rate.

Superconducting Systems and Cryogenics

The choice of superconducting technology for the linear accelerator is clearly the right one, and the assumptions made for the superconducting systems are not particularly aggressive. On the other hand, it is not obvious that these choices are optimal from an economic point of view, e.g., the nominal cavity gradient.

Variable couplers are helpful but there is only a limited amount of experience with high-power variable couplers. Are they really necessary?

The assumed level of detuning that the rf control system will need to accommodate will be a direct cost driver for the power rf systems. Conservatism is expensive, but too much aggressiveness could have a major impact on beam quality. Careful consideration will need to be given in developing the final specifications.

For TESLA, microphonics are a non-issue; and the TESLA cryomodule design is probably not optimal for minimizing microphonics. Again, this is an optimization issue.

High gradient, high Q superconducting systems are an active area of research (ERLs, CEBAF upgrade, RIA,…). Close contact with these activities would be beneficial.

Consideration should be given to designing the refrigeration system with a standby capability.

The superconducting structure's sensitivity to noise needs to be dealt with in more detail. LUX is very lightly beam loaded, and so the amount of RF power needed is largely controlled by the frequency stability of the structure. This will, of course, influence the overall system cost, and the LUX group is clearly aware of this. The TESLA structure was not designed with frequency stability in the face of pressure fluctuations as a primary criterion. The original superconducting structures at HEPL were built with strengthening bars that resulted in very good frequency stability. The point is, there are ways of making structures that are more stable. The usual engineering tradeoffs should be investigated.

In his presentation, Michael Green discussed the heat flow issue with respect to the "standard" TESLA helium vessel, and he suggested various ways of dealing with it. As it happens, the HEPL linac is now in the process of having the 30 year old structures replaced with TESLA structures purchased from Accel, incorporating several modifications very similar to those Michael mentioned-and for exactly the same reason. One modification that we didn’t see presented was to move the position of the vertical standpipes so that they are over a gap between cavities, rather than directly over the maximum radius point of the cavities as in TESLA's early design.

Another interesting piece of information was acquired only recently at HEPL. Their new cryomodule consists of two TESLA structures in one vacuum vessel, cooled and filled from the bottom; the horizontal pipe on the top is used only for gas return to the refrigerator. It was expected that the operating point for the helium level would be more or less half filling the gas pipe. But it turned out that with this system, both cavities show a very substantial frequency noise when helium is in the gas pipe. When the level drops so that the liquid / gas interface is in the standpipes or below, the noise basically goes away. As yet this behavior is not really understood, but it might be connected to the fact that when the liquid level is in the gas pipe, the two cavities can communicate with each other through the helium; when the level is lower the structures are pretty much decoupled. Electrical heaters in the helium vessel of each structure allow heat to be added to the system to see how it behaves as it is being required to transport various levels of power. Even adding as much as 80 Watts of heater power (the RF dissipated in the SRF structures was well under 1 W) had no noticeable effect on the noise behavior.

Many experiments could be performed at HEPL that could provide useful data for the LUX cryo system, and contacts between staff from both institutions have already been established. It shouldn’t need much urging to pursue a collaboration.

RF Systems

The rf systems comprise three subsystems: the gun system, the 1.3 GHz scrf, and the 3.9 GHz scrf. The Low-Level rf is based on the SNS system under development; this LLRF system will be state of the art.

Is 20 MV/m the optimal gradient without the Berkeley site requirement? At a minimum, the following question should be answered: What is the cost difference between 20 MV/m and a machine designed to minimize cost (capital plus cost associated with operating over the life of the facility) without any site-specific constraints.

The gun system will supply rf in 5 μsec pulses at 10 kHz repetition rate (5% d.f.). The peak power supplied to each of four gun cavities is 2.5 MW, and separate klystrons will be used for each cavity. One modulator (~1MW average power) will drive the four cavities. The present plan is to use a PFN/SCR switch arrangement followed by a low loss (Finemet) pulse transformer.

The modulator system needs a way to protect the klystrons from arcing energy which may be more complicated with the four klystrons being served by one modulator.

Though the proposed PFN/SCR system seems a reasonably straightforward choice, pros and contras of using IGBT system vs. PFN/SCR could be evaluated as considerable engineering efforts for other projects have gone into these switches in recent years (NLC, TESLA, SNS, …) .

The overhead power-requirement associated with the finite rise and fall times of the modulator should be looked at.

There appear to exist two or three potential klystrons for the gun system, in particular a Toshiba tube that would need to be retuned from 1.25 GHz. The standard Thales 1.3 GHz (TH2104 ~4.5 MW at 1.5 msec pulses) should be looked at to see if it is suitable.

For the superconducting linac, independent control of the 42 to 50 cavities is planned. 9 kW klystrons would be required. At some point parallel control of a number of cavities from one klystron should be evaluated; this scheme may result in cost savings.

The loaded Q for the superconducting cavities will be determined by microphonics. A value of about 2×10^7 appears reasonable.

Sufficient power for the 3.9 GHz transverse-mode cavities should not be a problem, and the external Q value should be chosen as low as possible to ease the phase regulation.

The exacting requirements of the 3.9 GHz phase (0.01 degrees) appear very difficult to achieve, and R&D in this area is clearly warranted.

A hardware test of a phase-distribution system and its ultimate performance limits would be very useful prior to the compilation of a design document. It might be useful investigating the use of multiple, locked atomic clocks as phase information sources.

Magnets and Vacuum System

Magnets and the vacuum system have been looked at in a conceptual fashion only.

The layout at the beam-splitting and -combining sections at the ends of the linac are the most complicated ones and have received more detailed attention in order to assure that a physical layout is possible. In this region actual 3-dimensional magnetic fields including fringe fields have been calculated so that their effects on all beams, not only the beam that passes through that the magnet, can be evaluated.

As some of the splitter/combiner magnets have more than one beam passing through them and are coupled into dogleg pairs, it would be prudent to evaluate the tolerances on field regulation, and the effects of momentum errors.

Most of the magnets used throughout the arcs and the recirculating legs are based on existing ALS designs and as such should be more than sufficient in field quality for the recirculator. Here again, the field-regulation tolerances need to be investigated.

The vacuum system does not have stringent requirements, with an average pressure around a few 10^{-7} Torr. The impedance of the arc sections (with small gap for Coherent Synchrotron Radiation, CSR) must be balanced with the spacing of the pump-out ports, but this issue appears manageable. There might be some advantage in considering integrated pumping schemes such as coatings or NEG.

The superconducting linac section should be carefully isolated from the arcs by sections that provide differential pumping, and care should be taken that dust particles are eliminated as much as possible.

Wake-field shielding designs of ports and bellows have not yet been produced.

Lasers

Laser requirements for LUX have been defined at the basic level, to allow integration with other aspects of the project, such as sensitivity studies. Refined laser specifications are being postponed for now, with the expectation that capabilities of commercial and other advanced laser systems in the areas of high-average power and ultra-short pulses will have significantly evolved by the time that definitive choices will have to be made.

Other relevant advances at the frontier of laser technology, including RF-synchronization of laser pulses, phase-stabilized optical pulses, and coherent control techniques (for phase and amplitude control of optical pulses), are being developed internationally for a variety of applications. The LUX project should pay close attention to developments in these areas, and continue to grow local technical expertise, since they will crucially affect the capabilities of LUX.

The phase noise on lasers and intensity of low harmonics (for electron gun and HGHG injection) needs to be determined.

The reliability of state-of-the-art lasers is generally not considered at the level of typical accelerator-based user facilities; is this true, and if so, can this be improved? Reliability / availability of the laser systems is expected to be an important contributor to the facility availability overall. Information on the availability of various laser systems may guide design choices.

An LBNL program of high average power (100 W), ultra-short pulse laser development is underway in the context of a related project (the slicing source at BL 6 at the ALS), and experience there is expected to add to the ability to better define the possibilities for lasers at LUX.

Beam and Photon Diagnostics

Diagnostics overall are still sketchy, especially longitudinal diagnostics and operations-type diagnostics. Because of possible consequences for the lattice layout, a detailed plan for diagnostics should be integrated into the design, well before the design process goes into its final iterations.

Having no diagnostics in the linac sections because of space constraints is probably not going to create a problem.

Lasers may play an important role in diagnostics for the electrons. Electro-optic measurements, non-linear mixing of laser pulses with synchrotron light, etc., may play an important role in monitoring and control the accelerator parameters; needs for laser in such areas need to be determined.

More detailed plans on X-ray pulse diagnostics, both transverse and longitudinal should be developed. Investigate if collaborations with SLAC or DESY are feasible.

Beam position and charge data should be accumulated in a bunch-by-bunch fashion and in a manner that separate beam passes can be distinguished at “linac” locations where there is a common orbit.

Interruptable pulse-by-pulse history buffers should be provided that allow quantifying line harmonics (at least over one 60 Hz cycle) for commissioning and troubleshooting purposes.

Provide verification of the required synchronization accuracy. 10 fsec are required (50 fsec for hard x-rays), equivalent to 0.005 (0.025) degrees, respectively.

Investigate if the back passes might provide opportunities for beam timing information.

Include instrumentation in the diagnostics plan that will allow performing operations diagnostics and procedures; e.g., transfer map verification and dispersion verification. Such requirements will be important in guiding some of the choices for diagnostics parameters.

Beamlines

There are a series of clever ideas suggested for beamline optics, e.g., dispersive optics for x-ray pulse compression and tuning schemes based on rotation of optics. The relative ease of tunability of the beamline photon energy need to be established.

Modeling of the temporal properties of the x-ray pulses needs to performed to determine the expected spectral cleanliness of the pulses. Formation of a pedestal under the desired peak has been a significant problem encountered with ultra-short x-ray pulse techniques; it can be caused by scattered photons and other effects. One mechanism for pedestal formation may be due to red-shifted, higher harmonic, photons which are produced at large angles and thus offset the "tagging."

Measurement of relative timing (pulse-to-pulse jitter measurement) of x-ray and laser pulses, during an event, versus the capability to precisely control that synchronization, need to be considered as alternative techniques.

There still seem to be some controversies regarding the level of spontaneous emission noise in high harmonic generation. The issue should be clarified comprehensibly including experimental observation at the BNL facility. Assessing the differences with (and similarities to) efforts of higher harmonic generation in atomic lasers may also be useful.

Appendix: Agenda and Presentation File Names

Agenda

April 28

08:30 *Breakfast, committee pre-meeting*

09:00 Bill Barletta - Welcome, charge to committee
09:10 Steve Leone - Science goals for LUX
09:40 John Corlett - Introduction, overview, achievements and goals

10:25 *Coffee break*

10:45 Sasha Zholents - Accelerator physics
11:30 Sasha Zholents - Lattice studies
11:50 Russell Wells - Magnets and vacuum systems

12:30 *Lunch*

13:30 Steve Lidia - Injector systems
14:15 John Staples - Rf gun design
14:35 Alex Ratti - Rf systems

14:55 *Refreshments break*

15:15 Sasha Zholents - Bunch compression and coherent synchrotron radiation
15:35 Bob Schoenlein - Laser systems

16:15 *Committee discussion*

April 29

08:30 *Breakfast*

09:00 Derun Li - Superconducting rf
09:40 Mike Green - Cryogenics systems

10:20 *Coffee break*

10:40 Stefano DeSantis (John Corlett) - Collective effects
11:25 Bill Fawley - Cascaded harmonic generation in FEL's
12:10 *Committee discussions*

12:30 *Lunch*

13:30 Phil Heimann - Beamline design

14:10 John Staples - Synchronization issues

14:55 *Refreshments break*

15:15 John Corlett - Recap and future plans

15:30 *Committee discussion*

16:30 Closeout session

17:00 *End*

Presentation File Names

The following presentation files have been collected on a CD in MS PowerPoint format:

2003 review agenda.ppt
Corlett - Overview.ppt
Corlett - Recap.ppt
DeSantis - Coll.Effects.ppt
Fawley - FEL.ppt
Green - Cryogenics.ppt
Heimann - Beamlines.ppt
Leone - Science Goals.ppt
Li - SCRF.ppt
Lidia - Injector.ppt
Ratti - RFsystems.ppt
Schoenlein - Lasers.ppt
Staples - RF gun.ppt
Staples - Synchronization.ppt
Wells - Mag.&Vac.ppt
Zholents - Acc.Phys.ppt
Zholents - CSR&Comp.ppt
Zholents - Lattice.ppt

Included in the CD is the full report: *"Feasibility study for a recirculating linac-based facility for femtosecond dynamics"* of December, 2002, in PDF format with the file name: LBNL-51766. Information contained in this report was part of the information on which the Review Committee was asked to give a technical judgment.