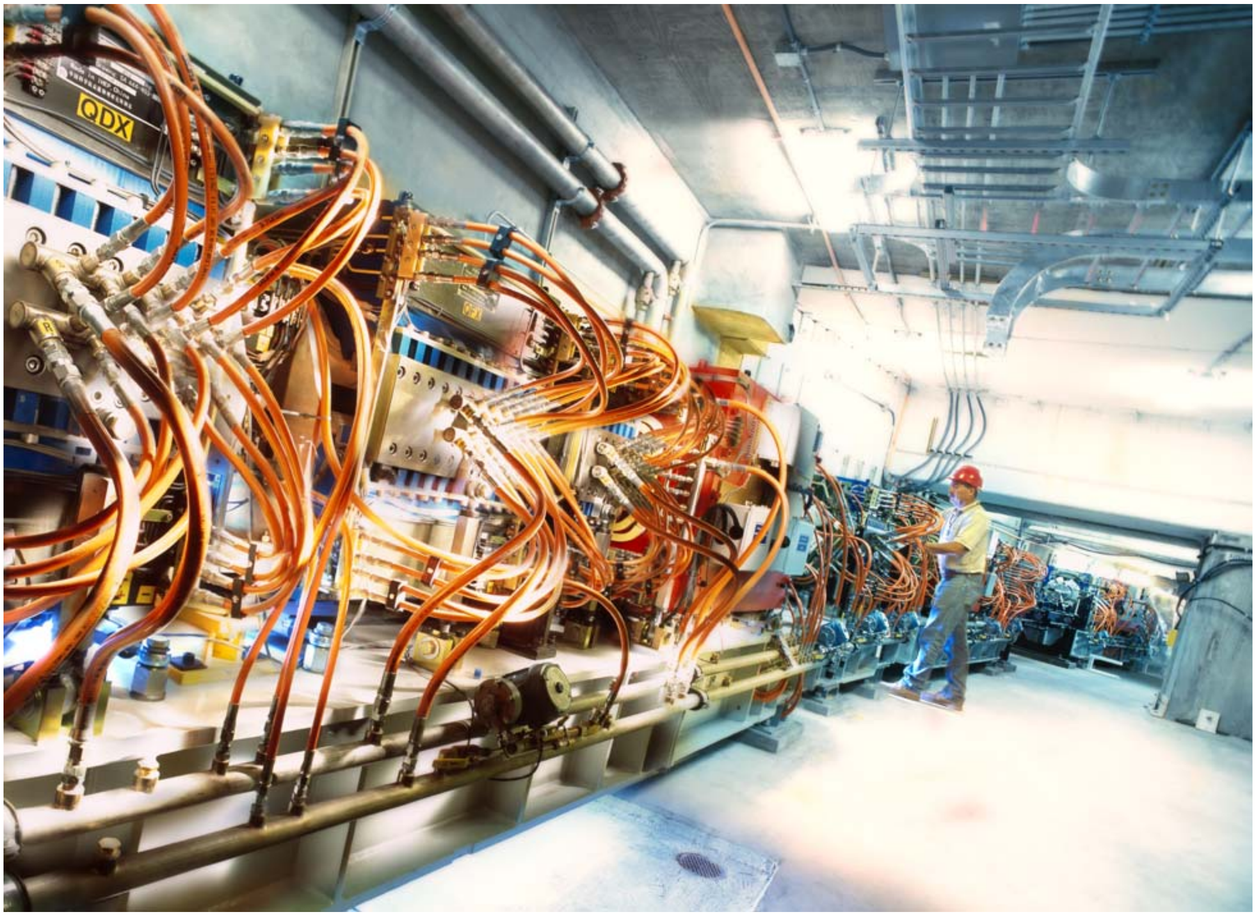
# The SPEAR 3 Upgrade Project
## Close-out Report




## April 2004

# The SPEAR 3 Project

## 1. The Beginning – Project Plan and Approval

The Stanford Positron Electron Asymmetric Ring (SPEAR) has provided the source of radiation for experiments at the Stanford Synchrotron Radiation Laboratory (SSRL) for many years. While SPEAR was originally designed as a high-energy physics colliding beam facility, it has been an important and effective source for synchrotron radiation experiments for all of its 30-year history. An upgrade of the operational energy, from 2.4 to 3.0 GeV in 1974, gave rise to the name SPEAR 2. Since 1990, SPEAR 2 has been totally dedicated to synchrotron radiation experiments, operated under the stewardship of the DOE Office of Basic Energy Sciences. It has been continually improved to raise reliability and performance, enabling higher user throughput and scientific impact.

While prior studies had been made to reduce the SPEAR emittance in the 1970s and the 1980s, the addition of a third injection kicker enabled a practical alteration of the lattice magnet settings in 1991 that reduced the emittance from 500 nm-rad to 130 nm-rad. Even lower emittance lattices, which require new magnets and vacuum chamber, have been considered and proposed.

In January of 1997, a study group was formed to begin the design of SPEAR 3. With input and consultation from SSRL users, the SSRL scientific staff, the SSRL faculty and the SSRL advisory committees, a design for SPEAR 3 evolved. In May 1997, an SSRL user's workshop examined the benefits of SPEAR 3 in terms of enhanced photon flux density and brightness and new scientific opportunities. The workshop concluded, "The important new opportunities for Science and Technology afforded by SPEAR 3, which are detailed in this report, provide compelling reasons to proceed in the most rapid way possible with the SPEAR 3 upgrade. This will be a cost effective means to preserve and enhance the significant public and private investment at SSRL and will provide world-class science and technological capabilities that will become increasingly important into the next century. Such capabilities will also be of increasing importance to the research and technological infrastructure of the western United States, which is served in the x-ray region by SSRL. The SPEAR 3 project receives the strongest possible endorsement from this workshop."

The goals for SPEAR 3 were as follows:

- 18 nm-radian (or lower) beam emittance, a decrease from 160 nm-rad
- 500 mA stored beam current, a factor or five increase
- 3 GeV "at energy" injection, an increase from the current 2.3 GeV
- Maintain long beam lifetimes (>15 h @ 500 mA)
- Improve machine reliability and beam stability

In order to achieve these goals, a new arrangement of the lattice magnets was developed such that the circumference of the ring did not change so that all components could be housed in the existing accelerator tunnel and support buildings. This served to minimize overall project costs. Most of the existing vacuum chamber components and all bending and focusing magnets would be replaced. The positions of the existing wigglers and undulators did not change, and there were only minor angular changes to the bending magnet beam lines. These modifications would take place within the existing SPEAR enclosure with minor modifications to the utilities.

Achievement of the upgrade goals would result in an increase of the focused photon flux density from insertion device beam lines by typically an order of magnitude. Due to higher critical energy, the photon flux density from bending magnet beam lines would increase by typically two orders of magnitude. As a result, SPEAR 3 would provide major performance enhancements to all of the existing experimental stations thereby greatly benefiting the SSRL user community. The increased brightness would extend experimental capability in a variety of research areas.

During 1997, the DOE Basic Energy Science Advisory Committee (BESAC) convened a subcommittee (Birgeneau/Shen) to investigate the current status of DOE synchrotron radiation facilities and their future potential. The committee report recommended SPEAR 3 as one of only two major synchrotron radiation facility upgrades. Subsequent endorsement for the importance of this recommendation for upgrades has come from the FASEB 1999 Consensus Funding Report and DOE BERAC structural biology advisory subcommittee report (November 1998). The SPEAR 3 upgrade also directly addressed needs raised in the NIH NCRR Strategic Plan Update (1998-2003), The Report on Molecular Environmental Science and Synchrotron Facilities (1997) and the BioSync Report (1997).

In concert with the above activities, the SPEAR 3 project received its first external review on November 3-5, 1997. This review, called by SLAC Director Dr. Burton Richter, was conducted by a panel of outside experts chaired by Dr. Sam Krinsky from BNL. The goal of the review was to evaluate the preliminary conceptual design report and identify areas of weakness and in need of further study. The review found the overall concept sound, but noted areas that included project management, schedule and the installation plan as needing particular attention.

Presentations were also made to the SSRL Users Group to inform them of the plans for converting SPEAR 2 to SPEAR 3. In general, the users highly approved of the upgrade and enhancement of SPEAR 2 capabilities; however, they strongly suggested that the transition period be as short as possible to minimize interruption of research programs. A very preliminary study provided the goal of a <u>6-month installation period</u>.

Work progressed vigorously on the design detail in early 1998 and resulted in the first DOE Lehman review in July 1998. At this review, the Conceptual Design Report was presented together with the Mission Need Statement, the Environmental Assessment, and the Management Plan. The Work Breakdown Structure was established and detailed project cost data sheets were provided to back-up the estimated costs. An Organizational Plan was also presented. The three-year schedule was based on the proposed funding profile. The Cost Estimate presented at this review is shown on the following page.

## SPEAR 3 Cost Estimate
## (July 1998)

| | | |
|---|---|---|
| 1 | SPEAR 3 Project | M$ |
| 1.1 | Magnet and Supports | 6.7 |
| 1.2 | Vacuum System | 9.1 |
| 1.3 | Power Supply System | 3.5 |
| 1.4 | RF System | 0.6 |
| 1.5 | Instrumentation, Control and Protection Systems | 2.6 |
| 1.6 | Injector | 0.2 |
| 1.7 | Beam line Front Ends | 1.0 |
| 1.8 | Facilities | 1.3 |
| 1.9 | Installation and Alignment | 4.0 |
| 1.A | Project Physics, Management and Administration | 2.7 |
| | **Total Direct in FY'98M$** | 31.6 |
| | Indirect Costs | 4.7 |
| | Contingency | 9.6 |
| | Escalation | 3.3 |
| | **TOTAL ESTIMATED COSTS (TEC)** | **49.2** |

The success of the July 98 Lehman Review provided increased enthusiasm to proceed with an expanded R&D program for FY99. The overall preliminary design advanced significantly over this year, enabled by R&D funding provided by DOE Basic Energy Sciences. The design team expanded with many experienced engineers from SLAC. Design details evolved and for some systems differed substantially from concepts presented in the 1998 Conceptual Design Report, particularly for the RF and vacuum systems. The increased project funding to 53.1M$ made it possible, among other things to install a new RF system capable of supporting 500mA operation (the previous cost estimates of 49.2M$ was geared to 200mA operation).

PEP-II engineering expertise also led to an improved vacuum chamber design. Instead of the formed stainless steel design envisioned earlier, the chamber would be machined from copper. The water-cooled copper chamber would be passively safe for dipole radiation beyond 500mA, and protected from mis-steered insertion device radiation for beam currents above 20mA by an orbit interlock.

Other design changes included replacing the existing concrete magnet support girders with new steel girders, providing a new cable plant outside the ring shielding, and improving the tunnel shielding and thermal insulation properties via new concrete roof and walls that completely enclose the east and west straight sections. As recommended by the 1998 DOE Lehman Review, the new magnet girders would be preassembled and aligned with magnets and vacuum chambers prior to installation in the tunnel to help ensure the achievement of a six-month installation schedule.

Significant progress was made on the magnet designs, which took place in collaboration with the Institute of High Energy Physics in Beijing. The precedence for this effort was set during the PEP-II project where IHEP participated in the design and production of the Low Energy Ring magnets. An Inter-laboratory Collaborative Agreement (ICA) was signed by SLAC and IHEP directors in March 1999, and IHEP engineers arrived at SSRL in June to participate in the designs for dipole, quadrupole, and sextupole magnets.

The good news of project approval arrived on May 25, 1999. This approval was certainly aided by the historic efforts of Martha Krebbs (DOE) and Harold Varmus (NIH) in providing joint funding support from two government agencies for an accelerator project. The following notification from Pat Dehmer (BES) to Keith Hodgson (SSRL) was received.

*"This letter provides authorization, effective June 1, 1999, for the SSRL Division of SLAC to initiate the SPEAR 2 capital equipment upgrade project as reviewed and recommended as being ready for project start by the DOE Lehman Review Committee in their report deriving for the project review that was held July 28-30, 1998 (report transmitted on August 31, 1998 from D. Lehman to P. Dehmer). The scope of the project as reviewed by the Lehman Committee is modified as per discussions between DOE-BES and NIH to include upgraded RF with an associated increase in maximum stored current from 200 to 500mA with no further changes in cost or schedule. The TEC of the project, estimated by the Lehman Committee to be $49,927M over the years FY1999-FY2002, is hence revised upward to a TEC over the same period to $53.130M."*

## 2. The Project Start – Design and Fabrication

### 2.1 CY99 (July 99 – December 99)

The design, cost and schedule for SPEAR 3 technical systems were examined by technical and management experts during the second DOE semi-annual Lehman review held on September 14-15, 1999. The review committee found “that the project continues to stay on track with respect to technical progress is on or ahead of schedule, the costs are in line, and it continues to be well managed. The depth and breath of expertise at SLAC is clearly adequate to meet the technical and scheduling challenges. In addition, the commitment of management to completing the project on time and on schedule is very evident.”

Prior to the above review, the SPEAR 3 Project Execution Plan (PEP) was completed, and approved by the DOE. This plan established the underlying principles and organization of project execution, as well as details related to project approval, funding, and management structure. The SPEAR 3 Project Design Report was also provided to the second Lehman review committee. This report provided the details of the design plans for all major technical systems.

The formal project start also signaled the beginning of major procurements. These included steel and copper for the main magnets and major RF components.

In the magnet area, our Chinese collaborators from IHEP worked with the SPEAR 3 magnet group for approximately four months (July – October) to complete the detailed design for dipoles, quadruples, and sextupoles. The design drawing packages (over 200 drawings) were approved, and released to IHEP for fabrication.

The copper conductor procurement for these magnets was awarded by SLAC on October 12, 1999. This effort was completed in early December and the shipment of conductors for the dipoles and sextupoles arrived at IHEP in January. The procurement for steel laminations was awarded by IHEP in October 1999 with delivery scheduled for May 2000. Fabrication of prototype magnets began in January. In addition, a magnetic measurement plan was developed jointly with IHEP staff and magnetic measurements coils were completed for use at both SSRL and IHEP.

A successful design review for the arc girder vacuum chambers was held on November 23, 1999. The dipole power supply system design and specifications were largely completed with a final review and RFP in the first week in January. A successful review for the bipolar supply units was held November 9, 1999.

In the RF area, the RFP for the four PEP-II style RF cavities was on the street at the beginning of October. Bids were received in December and the award occurred in early January. Bids for the Klystrons were received December 24, 1999.

The main efforts in the Instrumentation and Control System area involved refining design concepts, cost estimates, and schedules for the computer control, beam diagnostics, timing, and protection systems. The designs of some sub-systems were underway.

The facilities plan called for fabrication of new concrete enclosures for both the east and west straight sections in the FY 2000 fall shutdown. The engineering design was near completion for this work.

A further measure under study was to replace the existing asphalt tunnel floor with a new reinforced concrete slab that would support magnet girders. Apart from providing a more stable foundation this plan would minimize the complex roof block removal and re-installation and allow the smaller girders to be rolled into their tunnel positions without the requirement for heavy-duty cranes in very confined areas. RFQ's with the time duration and costs for tunnel excavation and new concrete floor installation occurred mid-January. A special review committee met in November 1999 and recommended that we consider this course of action.

Related to installation activities, a SPEAR 3 Davis-Bacon review committee convened March 1999 and provided a final report November 10, 1999. This report specified all Davis-Bacon covered work for SPEAR 3 installation and was approved by DOE on January 6, 2000.

While schedules for each WBS level 2 systems were prepared in the previous quarter, appropriate milestones were now incorporated. Monthly cost tracking compares the plan with actual costs to determine cost and schedule variances for each WBS 2 system. The detailed schedules were incorporated into "Primavera" and the project baseline into "Cobra." These programs were utilized for tracking the PEP-II project. While not required (initially) for SPEAR 3, it was believed that this system would be a valuable tool for tracking performance.

### 2.2 CY 2000

In the first quarter of the year all detailed drawings were finalized for the dipole, quadrupole and sextupole magnets. The core and coils for the prototype dipole magnet were fabricated at IHEP. The dipole prototype was on schedule as well as the quadrupole, and sextupole. The machined plates for girder vacuum chambers were ordered and production of six chambers scheduled to begin in July.

The order for the RF cavities was awarded in the second quarter with delivery scheduled for early FY02. Two 650 KW klystrons were planned but this was changed to one 1.2 MW klystron due to extremely high bid prices. The PEP-II type 1.2 MW klystron order was awarded after determining that the system was more economical, even with a new klystron power source. Maintenance efforts and spares could be shared with PEP-II.

The project management control system was first tested in February and improvements were incorporated over the next few months to track project performance.

Project stretch-out New DOE orders now required quarterly reports with Washington in addition to bi-weekly reports with local DOE Staff and the semi-annual Lehman reviews. The first such meeting with BES Washington was conducted on March 28, 2000. At this meeting, SPEAR 3 Management was informed that DOE (BES) could not provide funds on the schedule required to accomplish the SPEAR 3 project that had been presented and discussed in earlier reviews with DOE. The SPEAR 3 staff had to quickly re-plan the overall project schedule.

New project baseline On June 12-14, 2000, a DOE Lehman review committee conducted the third Technical and Management review of the SPEAR 3 project. The review report noted, “The management structure and dedicated staff are in place to effectively execute the project and ….the project team has made very good progress on the development of designs for the technical components and conventional facilities.”

At this review, the SPEAR 3 Team pointed out that the funding profile presented to the project at the DOE quarterly review (3/28/00) would delay the project up to two years. This resulted in a revised funding plan provided to the project on June 21, 2000. The impact of this plan was reviewed in terms of schedule impact, manpower requirements, and associated obligations and costs for the project. The revised project plans associated with the revised funding plan were presented at the August 7, 2000 DOE quarterly review. The overall impact was a one-year delay of project completion to the end of FY 03 with a 5M$ increase in project costs. This became the new official project plan. The detailed schedule with associated milestones was revised to match the new plan and the PMCS system was updated.

The revised SPEAR 3 cost estimated at WBS level 2 is provided below where the new total cost of 58M$ is indicated. The new DOE/NIH funding profile is presented in the second table together with the revised obligation and cost profiles. The Organization chart at this time is also provided.

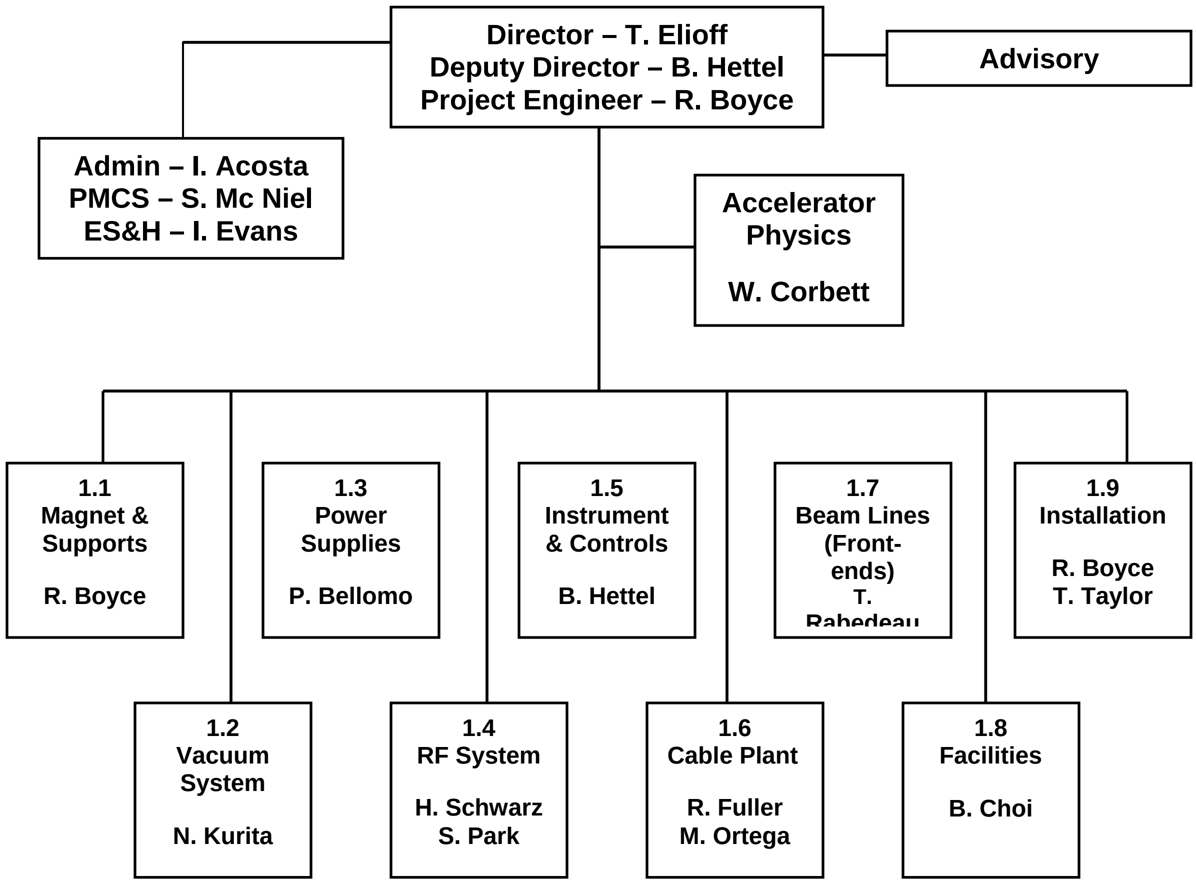
## SPEAR 3 Revised Cost Estimate
**(August 7, 2000)**

| | | |
|---|---|---|
| **1** | **SPEAR 3 Project** | |
| 1.1 | Magnets | 8.3 |
| 1.2 | Vacuum System | 10.3 |
| 1.3 | Power Supply System | 3.1 |
| 1.4 | RF System | 3.9 |
| 1.5 | Instrumentation, Control and Protection System | 3.5 |
| 1.6 | Cable Plant | 2.2 |
| 1.7 | Beam line Front Ends | 1.0 |
| 1.8 | Facilities | 2.5 |
| 1.9 | Installation and Alignment | 2.9 |
| 1.A | Projects Physics, Management and Administration | 3.8 |
| | **Total Direct in FY 99 M$** | **41.5** |
| | Indirect Costs | 5.8 |
| | Contingency | 8.0 |
| | Escalation | 2.7 |
| | **TOTAL ESTIMATED COSTS (TEC)** | **58.0** |

## SPEAR 3 Revised Funding Plan (M$)
(July 26, 2000)

| Fiscal Year | Appropriations | Obligations | Costs |
|---|---|---|---|
| 1999 (NIH) | 14.0 | 2.1 | 1.6 |
| 2000 (NIH) | 14.0 | 10.3 | 8.8 |
| 2001 (NIH/DOE) | 11.0 | 19.6 | 18.7 |
| 2002 (DOE) | 9.0 | 16.0 | 18.6 |
| 2003 (DOE) | 10.0 | 10.0 | 10.3 |
| **Totals** | **58.0** | **58.0** | **58.0** |

## SPEAR 3 Project Organization
**(August 2000)**




By the end of this year, all major magnets (dipole, quadrupole, and sextupole) were in production at IHEP (Figure 1). Magnetic measurements at both SLAC and IHEP confirmed the required field quality. Also, the design of the magnet support system on the Arc girders was completed.

For the vacuum system, studies were made to evaluate the type of copper to be used for the standard girder chamber. A second set of plates were machined from ¼ hard “Revere” copper in October. These plates were easier to machine, easier to straighten, and the final box weld (Figure 2) had smaller deflections than ½ hard copper. A decision was made to utilize the Revere material for the longer BM1 and BM2 chambers. The shorter QFC units (Figure 3) would continue to be fabricated with the existing ½ hard material in order to expedite the schedule.


Figures 1

Upper photos show first completed Quadrupole & Sextupole units.

Lower photos show Dipole production and assembly of Dipole core laminations.

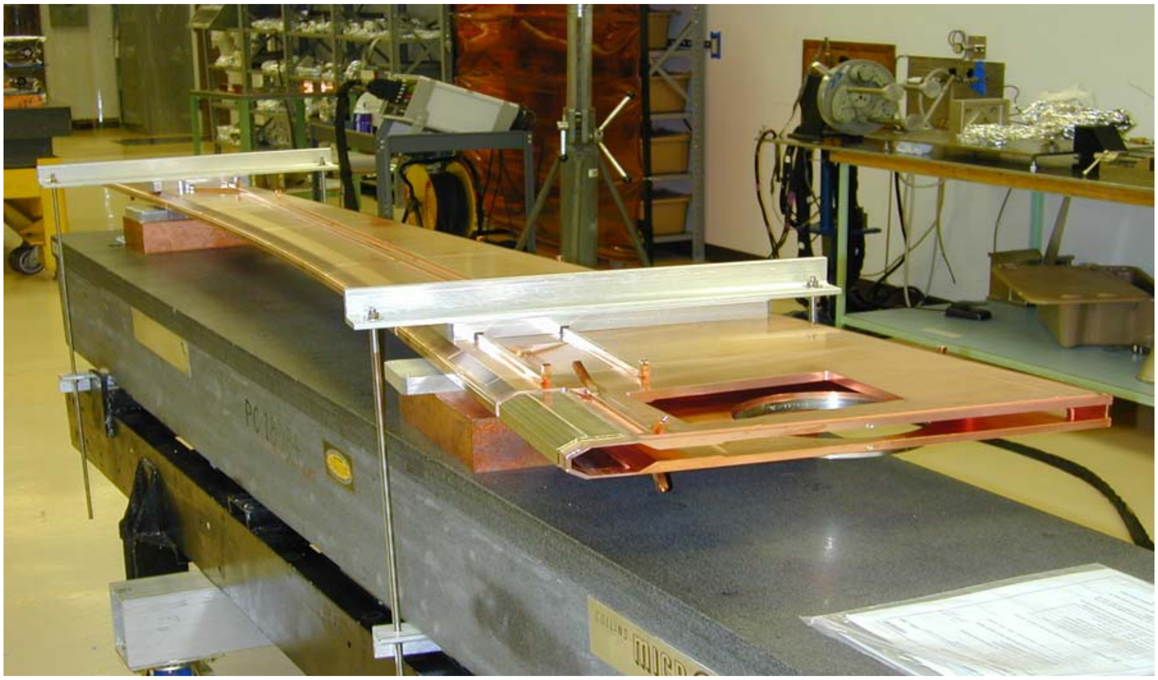


Figure 2 – BM1 chamber box

Figure 3 – Two QFC chambers nearing completion

Fabrication of the 4 PEP-II style RF cavities made good progress. A new electro-forming procedure for covering the water cooling channels was approved and the process was completed on the first two cavities (Figure 4). The acceptance test of the 1.2 MW klystron was scheduled for February 2001 at the factory. The layout design for the waveguide system was complete. The SLAC Earthquake Committee approved the design of support stands for the cavities and the circulator.

Figure 4 – RF Cavity Production

A design review was held September 20 in which the plan for computer control hardware and software development was presented and endorsed. Design work proceeded on the fast digital power supply controller, BPM timing/crate driver synchrotron light monitor system, signal generator for master oscillator, as well as orbit and vacuum interlock systems.

The annual scheduled downtime for SPEAR maintenance occurred during the third quarter. In both the East and West straight sections, SPEAR 3 work included the construction of new concrete foundations (Figure 5) in the pit areas (required for SPEAR 3 magnet supports), new shielding walls (Figure 6), and new entry mazes. The work was completed on schedule while costs were ~70% above baseline mainly because there was only one bidder for the contract in a busy construction period for this area. The new shielding walls incorporated all of the cable tray penetrations for the SPEAR 3 cable plant as well as wall supports for future trays. Work continued on plans and design of outside cable tray supports.

Figure 5 – Construction of new West straight section foundation and new shielding walls. SPEAR 2 magnets (under plastic cover) remain in place.

Figure 6 – Completed west straight section outer wall with future beam line port

Design of the cable tray system was the dominant activity in the Cable Plant area. The conceptual designs, and many of the details, were defined. Unresolved issues center on upgrading the East-West elevated cable trays and integration of cable tray installation into scheduled yearly maintenance periods. Additionally, management of the Cable Plant has shifted to the SLAC Controls Department, with a concomitant increase in the level and expertise of staffing. Also, the drafting, documentation, and QC sections of the Controls Department were formally assigned a SPEAR 3 cable plant role.

The accelerator physics program continued software development and began on-line software testing. Efforts included refined specifications for location and operational parameters for diagnostic components, modifications of the matching cell lattice configuration to reduce engineering costs, and studies of photon beam mis-steering through the matching cell sections. Preliminary studies for low-beta optics in the long straight were made.

Work continued on the near term radiation physics objectives that had an effect on this years' shutdown, as well as long term goals to comprehensively assess all shielding and design parameters, thus assuring that respective regulations and internal limits are met. Ongoing work included defining what additional shielding may be required for the new "C" shaped dipole magnets and minimum thickness of roof shielding for areas around the ring.

### 2.3 CY 2001

DOE conducted reviews of the project on February 9, 2001 and July 14, 2001. Revision 1 of the Project Execution Plan was approved by DOE. This revision reflected the project changes of August 2000 that included the baseline cost increases due to the extended schedule with project completion in February 2004.

The July Review agenda covered Accelerator Physics, Magnets, Vacuum RF System, Instrumentation and Controls, Installation Plans, EH&S and Cost Schedule. The Review Committee Summary report concluded, "SPEAR 3 project is within costs, on schedule (CD-4 is 2/22/04) and meets the Technical scope objective." The committee expressed strong interest in the final installation plans scheduled for FY 2003. They requested a complete and refined schedule at their next review and recommended that an independent technical and ES&H review of the installation plan be conducted.

By September, the overall project neared the 50% completion mark in terms of accomplishments, costs and overall progress. The major part of the conventional construction (mostly shielding modifications) had been accomplished on schedule during the CY2000 and CY2001 regular shutdown periods with final completion scheduled for the CY 2002 regular shutdown.

The first shipment of production magnets (9 Dipoles and 12 Quadrupoles) left IHEP at the beginning of March and arrived at SLAC April 4. By December the production of all major magnets (dipoles, quadrupoles and sextupole) was completed on schedule resulting from a highly successful collaboration with our colleagues at the Institute of High Energy Physics (IHEP) in Beijing. The production of corrector magnets was in progress. The production of support rafts for the magnets continued. Apart from electrical connections, two QFC rafts were assembled with magnets and vacuum chambers.

For the Vacuum System, six sets of QFC machined halves were received in February in preparation for e-beam welding. Tooling was designed and fabricated to straighten the plates for BM1 and BM2 chambers. The vacuum fabrication facilities were prepared. All parts required to complete a BM2 chamber were completed together with associated e-beam welder tooling. The e-beam welding progressed; however, welding problems developed at high stress points in the chambers, which resulted in leaks. A detailed analysis indicated that deeper welds and thinner plates for the copper chamber would help the problem. In addition, other information indicated that the copper undergoes structural changes at bake-out temperatures of 200° C. Future bake-outs of longer periods at ~150° were then utilized. Deeper e-beam welds and outside gussets were used to eliminate small leaks in the first units. Full QFC raft production was delayed to late January. The main box structure for the more complex BM1 chamber was successfully welded. Progress was made also on the design of the matching cell chambers near the two straight sections.

In the RF area, the 1.2 MW klystron (Figure 7) was successfully tested and arrived at SLAC on April 9; however, in PEP-II tests this tube as well as several other tubes delivered to PEP-II failed. The manufacturer did not appear capable of repairs and appropriate actions were taken. While some failed tubes were being repaired locally at CPI and at SLAC, a decision was made that SLAC would manufacture four tubes in the next two years. The SLAC tubes are more robust and should have longer lifetimes. Note that PEP-II requires in excess of eight tubes, while SPEAR 3 requires only one.

Figure 7 – The new 1.2 MW Klystron arrival

Other significant problems arose in the RF area. The first two of four RF cavities being fabricated for SPEAR 3 developed leaks in the cooling channels. These channels are machined in the outer surface and filled with wax. Approximately 9 mm of electro-plated copper coats the outer surface to seal the channels after which the wax was removed by flowing heated water through the channels. The process was successful in the production of 26 cavities for the PEP-II project. PEP-II (which has ordered 6 additional cavities under the same current contract) and SPEAR 3 worked with the manufacturer to understand the problem.

All power supplies for corrector magnets were received and tested in February. Following a no-bid response, it was decided the main dipole supply would be built in-house following the PEP-II design. The dipole magnet power supply transformer was delivered in early June. A PEP-II chopper module supply was tested in August. The module performed well and the decision was made to proceed with fabrication of six modules for the dipole power units. A design package was reviewed for six other larger freestanding supplies that power four quadrupole and two sextupole strings. The chopper modules for the dipole units were being assembled with their controllers and the specifications for the associated bulk supply in progress. The six large supplies for quadrupoles and sextupoles strings were released for fabrication. The same company was selected to design and manufacture the 82 intermediate supplies. Another manufacturer was contracted to design and build the 150 units of the bipolar power supply for the corrector magnets.

During this year work continued on all Instrumentation and Control systems. Effort was devoted to further specifying Computer Control System software tasks and developing the first EPICS IOC application. Detailed design of the fast corrector controllers continued. The BPM processing plan was finalized and the processor procurement was initiated. The RF/Timing Signal Generator system was ordered. Components for the Vacuum Protection System were specified, a new design review for the Orbit Interlock System was arranged and the Temperature Monitoring system was specified.

An important accomplishment during the annual fall shutdown period was the fabrication and installation of new cable trays and associated supports that carry power, control, and monitoring cables from building 118 across the ring to each straight section area (Figure 8). New supports were required to meet earthquake standards. New cable trays were also installed through building 118 to meet the needs of the new power supply systems.

Figure 8 – New cable trays in construction

Efforts continued during the year to identify all cable requirements for power, monitoring, and controls. While a major part of the West straight sections shielding was completed in CY00 shutdown, final connections to the existing shielding together with the addition of new roof blocks over the entire straight section (required for 500 mA) took place in the regular CY 01 shutdown. This made possible the completion of the new RF system enclosure with installation of the new klystron, associated components, and the waveguide system from the klystron to the top of the west straight section shielding. As previously noted, in order to achieve a final installation scheduled of near 6 months duration, these modifications, had to be done in the "normal" shutdowns prior to FY03. Design plans were underway this year to complete the east and west shielding in 2002 as well as the klystron building near the west straight section.

The Accelerator Physics Group made good progress toward specifying corrector and kicker magnet performance, performing tracking studies, and developing software for orbit control. Efforts included specifying locations and operational parameters of diagnostic components, and studying mis-steering through matching cell lattice sections. Work also included girder vibration modeling, beam dump specifications for radiation protection, and studies of electron beam losses to implement radiation protection. Other important work included field coupling in the corrector magnets, testing of the slow orbit correction system, studies of the new beam line 4 and 7 wigglers and preparations for the on-line control application software. Progress was also achieved in collaboration with the Radiation Physics Group on injection safety and Synchrotron Light Monitor Safety. Efforts also started in the development of the turn-on and pre-operational plans.

Efforts were underway to plan and establish the details of the major installation in FY2003. The work involves the complete removal of SPEAR 2, building a new reinforced concrete floor for the tunnel, and the installation of SPEAR 3. Details of the effort were being assembled and scheduled for all technical and associated support systems.

ES&H studies continued to comprehensively address all design and shielding requirements. During this period, the new west straight section area shielding was complete and ES&H issues were reviewed, monitored, and properly addressed by the subcontractor. Efforts included Personnel Protection System issues and requirements by the SLAC earthquake safety and electrical safety committees.

### 2.4 CY2002

FY2002 was the third full year of design and fabrication for SPEAR 3. The project was reviewed by the DOE in February, July and December of this year. The executive summary of the July review noted: “The Review Committee found that adequate progress was being made to meet baseline objectives. The SPEAR 3 installation plan can succeed, but is tight in both schedule and costs, and needs to be optimized. The pre-operations/commissioning plan is well defined for this stage of the project. Also, the ES&H aspects of the project are being adequately addressed. The total project cost estimate of $58 million and project completion milestone date of February 2004 appeared reasonable without much margin for error.”

Regarding the installation plan, progress continued with further optimization of the necessary manpower resources, the SPEAR 2 removal process, and SPEAR 3 installation. Contractors were consulted regarding the scope of rigging and transporting techniques for components. Engineering consultants were utilized to evaluate methods and procedures that could be used to establish the new tunnel floor. WBS-2 System heads were involved to insure that all components were included and properly sequenced in the installation process.

The December DOE Review summarized the project status as follows: “The project has made good progress. The magnet and power supplies systems have completed most technical equipment fabrication. The vacuum system has resolved issues with chamber production and the completion scheduled will meet installation requirements. The RF cavities are in production after electroforming issues were resolved with the vendor. Delivery milestones for the four cavities have been revised. Accelerator Physics and Control system have developed resource-loaded schedules to complete critical activities to support SPEAR 3 startup. The installation plan continues to be optimized. ES&H

plans were prepared for the Accelerator Readiness Review and installation activities. The Final Safety Analysis Document will be ready for review early next year."

In the magnet program, a significant milestone was achieved late April with the final shipment of 20 corrector magnets from the Institute of High Energy Physics (IHEP) in Beijing. This marked the end of a very successful collaboration between SSRL and IHEP. A total of 294 Dipoles, Quadrupoles, Sextupoles and Correctors were fabricated on scheduled. All units met or exceeded the SPEAR 3 magnetic field requirements. Four IHEP staff members arrived at SSRL in April and participated in the installation and alignment of the magnets on their support rafts. All 46 support rafts for the 14 standard cells of the lattice were on hand; the order for the remaining 8 rafts for the matching cells was placed in June.

For the vacuum system, 54 major vacuum chambers had to be integrated and aligned within the appropriate magnet rafts as shown in Figure 9. At the end of this year, 35 units were fabricated and a major fraction of these inserted within the magnet rafts. The goal called for completion of all 54 rafts before April 1. 2003. This reflected several months delay from the original schedule. Other vacuum system components that were in final design procurement or fabrication included matching girder chambers, drift (straight section) chambers, RF chambers, bellows, DCCT, beam stoppers, injection and septum chambers, and isolation valves.

Figure 9 – Completed BM1 raft

By October of this year, all 200 power supply units (of 13 different types), were released for fabrication and in various stages of assembly. All were scheduled to be on-site and bench tested by December. Plans were underway for the removal of all existing SPEAR 2 supplies, renovation of the existing power supply building with new re-enforced concrete floor, and a new AC distribution system. These activities together with installation of the new power supplies were planned to take place during the major installation period in CY'03.

The manufacturer selected for the RF cavities used the beginning of this year to evaluate the causes of unsuccessful plating of the cavities (which seals the water cooling channels) for both SPEAR 3 and PEP-II. Assuming a new plan would be developed following the successful method used for the initial 26 PEP-II cavities, production would resume. This problem resulted in a one-year delay in delivery. Klystrons for both SPEAR 3 and PEP-II were being repaired locally while production of additional units was underway at SLAC. The Klystron power supply for SPEAR 3 was delivered in March. Other RF system components (including waveguide) together with RF Cavity accessories (coupling box, high order mode loads, tuners, etc) were complete in September.

In the Instrumentation and Controls area, computer control system hardware and software plans were approved in a final design review. The prototype VME interface to the digital control daughter cards for the corrector power supplies was completed and detailed development of related software began. Commercial BPM units were received and the design and fabrication of ancillary components were in progress. Detailed specifications of the DCCT, injection monitors, tune monitor and synchrotron light monitor continued. The injector RF signal generator and timing controller were under construction. Detailed design of the Orbit Interlock, Beam Current Interlock, and other protection systems continued as well as work on the I&C interconnection diagrams and equipment rack profiles. The I&C long haul cable plant specifications were completed for Cable Plant plans.

The overall goal for the Cable Plant systems (power, control, and monitoring) was to complete as much as possible external to the shielding before the major shutdown in FY2003. By September, the cable external tray system was 90% complete. The tray systems for the East and West straight sections areas and for the power supply building were 100% complete. The design for the internal shielding tray system was 80% complete. The Electrical Safety, Seismic Safety, and ES&H committees approved the planned installations. All cable was ordered for the external installation, which took place between August 02 and March 03. This installation was successfully completed.

As in the case of the cable plant above, the goal for Conventional Facilities was to accomplish most tasks prior to the major system installation. Note that east and west straight sections with associated pits, shielding walls and entry mazes were accomplished in the normal FY2000 shutdown. West straight section transition area walls and all new west area roof blocks were accomplished in FY2001. This year the Klystron building enclosure was completed in June. The contract for completing the east transition area walls and roof blocks started July 12. This contract completed all planned shielding modifications and included a new AC distribution system for tunnel power and tunnel lights as well as the required smoke detector system. This final phase was completed October 2, 2002.

During this year, the Accelerator Physics Group also focused on tasks with direct bearing on installation and commissioning. These tasks included analysis of magnet measurements for dipole magnets, final diagnostic engineering designs, specifications for the M0 mirror in the synchrotron light monitor, software development for application programs and radiation safety. A group leader was appointed to lead the commissioning effort, which follows the installation period. The July Lehman review found the preliminary commissioning plans adequate for this stage of the project and that accelerator physics issues important to the commissioning effort were being addressed.

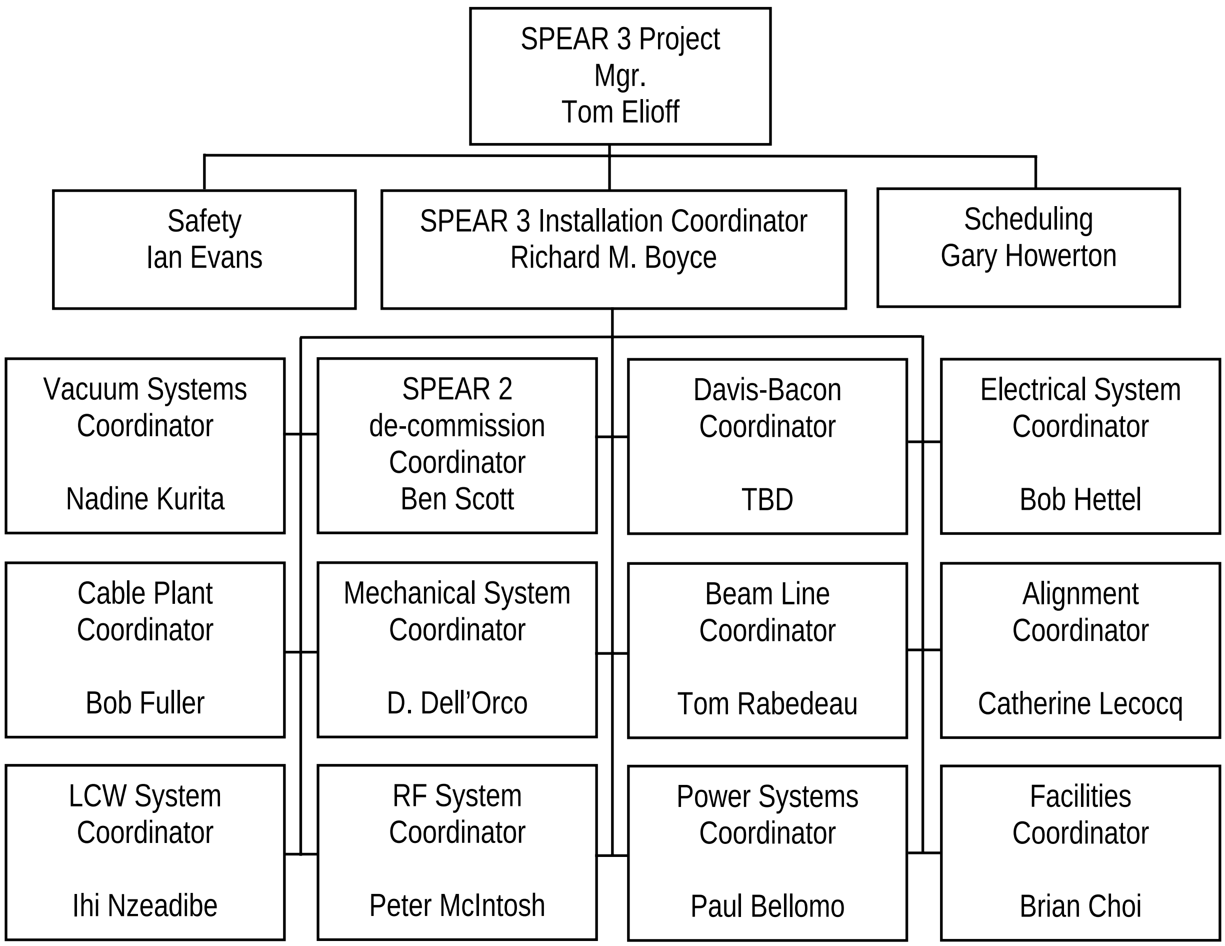
While efforts noted above for cable plant and shielding continued this year to minimize efforts during the final FY03 shutdown, further details were developed for the shutdown period. The FY03 plan was transferred from Microsoft Project to Primavera in order to provide greater flexibility in the optimization of multishift operations together with greater than 5-day workweeks. Efforts focused on the identification and inclusion of all tasks.

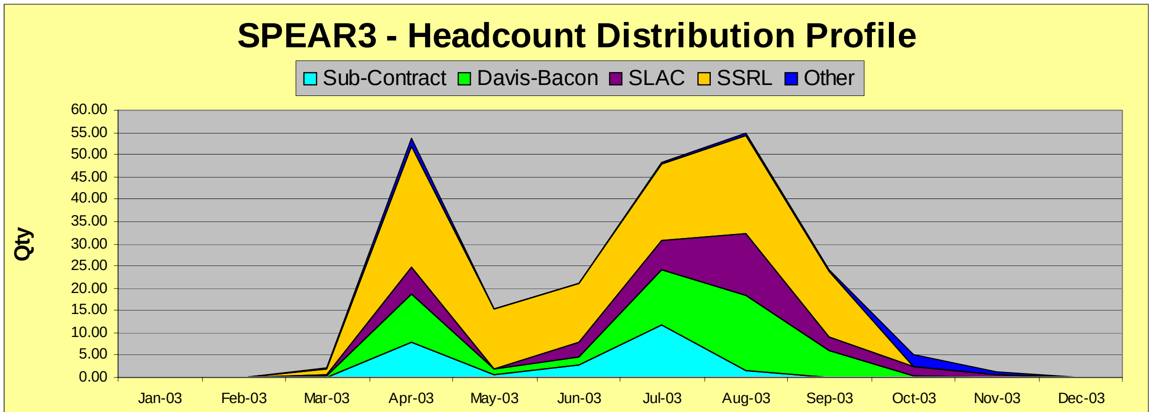
A preliminary installation plan was presented to the July DOE Lehman review. This included a revised organization chart (see below) to better fit the installation needs with a detailed manpower estimate and the associated costs. The cost estimate is shown in figure 10 in terms of projected subcontracts and laboratory labor resources. The first peak (April) reflects the intensive effort to remove SPEAR 2 while the second peak (July) indicates the resources needed to install SPEAR3. The valley indicates the planned effort for excavation of the ring and power supply building floors followed by the construction of new heavy duty concrete floors.

While this plan fit within the goals of 6-months duration, further work remained to optimize the plan within available resources and contract limitations. The plan was largely optimized by the end of this year. This was necessary in view of the schedule for contract bids and awards that were planned in the first quarter of CY03 in order to meet the April 1 installation start. Appropriate ES&H plans and procedures were also being finalized.

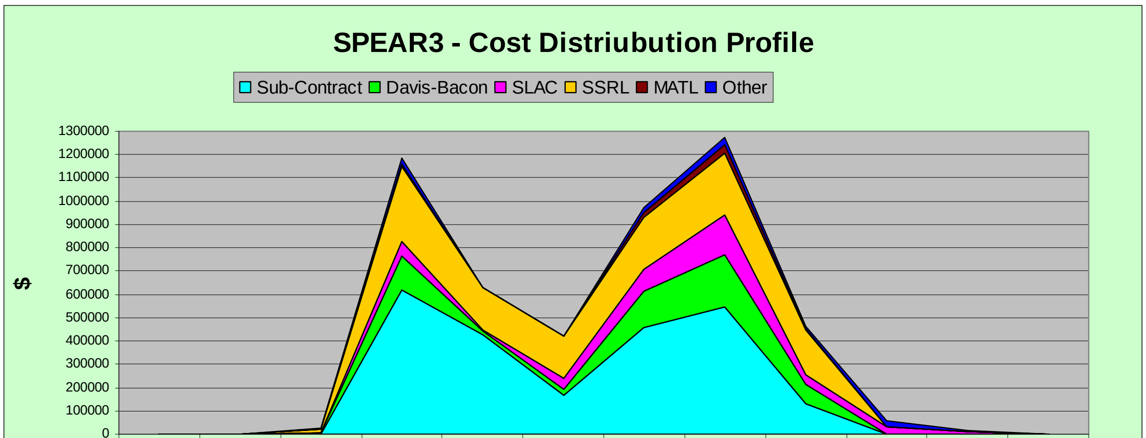
# Organization Plan for SPEAR 3 Installation

*(7/16/02)*






| | Jan-03 | Feb-03 | Mar-03 | Apr-03 | May-03 | Jun-03 | Jul-03 | Aug-03 | Sep-03 | Oct-03 | Nov-03 | Dec-03 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Other | 0.00 | 0.00 | 0.10 | 1.67 | 0.03 | 0.00 | 0.39 | 0.46 | 0.17 | 2.71 | 0.73 | 0.00 |
| SSRL | 0.00 | 0.00 | 1.37 | 27.02 | 13.44 | 13.44 | 17.18 | 22.19 | 14.77 | 0.00 | 0.00 | 0.00 |
| SLAC | 0.00 | 0.00 | 0.26 | 6.26 | 0.18 | 3.42 | 6.69 | 13.88 | 3.22 | 2.17 | 0.58 | 0.00 |
| Davis-Bacon | 0.00 | 0.00 | 0.26 | 10.83 | 1.24 | 1.76 | 12.32 | 16.90 | 5.90 | 0.19 | 0.00 | 0.00 |
| Sub-Contract | 0.00 | 0.00 | 0.00 | 7.77 | 0.46 | 2.64 | 11.70 | 1.37 | 0.00 | 0.00 | 0.00 | 0.00 |




| | Jan-03 | Feb-03 | Mar-03 | Apr-03 | May-03 | Jun-03 | Jul-03 | Aug-03 | Sep-03 | Oct-03 | Nov-03 | Dec-03 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Other | 0 | 0 | 2675 | 25825 | 900 | 0 | 20950 | 34413 | 10237 | 21700 | 5800 | 0 |
| MATL | 0 | 0 | 1675 | 14025 | 900 | 0 | 20950 | 31763 | 8887 | 0 | 0 | 0 |
| SSRL | 0 | 0 | 15940 | 319480 | 181440 | 181440 | 221080 | 268940 | 192500 | 0 | 0 | 0 |
| SLAC | 0 | 0 | 2680 | 62980 | 1800 | 51250 | 96425 | 169625 | 40800 | 30380 | 8120 | 0 |
| Davis-Bacon | 0 | 0 | 3088 | 143644 | 16416 | 23872 | 153784 | 226420 | 80138 | 2584 | 0 | 0 |
| Sub-Contract | 0 | 0 | 0 | 620551 | 427949 | 166396 | 459408 | 543553 | 132143 | 0 | 0 | 0 |

Figure 10 – Installation Plan

## 2.5 CY03 (January through March)

This was the last quarter prior to the start of installation. It should be noted that the project team worked very hard to reduce the length of the installation periods such that the off time for SPEAR users would be minimized. The overall plan called for completion of all SPEAR 3 components (ready to install) prior to installation start (March 31, 03). This goal was important to manpower, costs and resource needs. While not fully achieved, it was important to maintaining the overall installation schedule.

In general most of the technical systems were completed this quarter; however, completion of some components, particularly in the Vacuum, RF and I&C areas extended into the shutdown period. This delay did not significantly affect the installation program, which was initiated on schedule starting on March 31, 2003.

All of the support rafts for the main ring magnets were completed with the exception of three that were awaiting the completion of vacuum chambers (Figure 11). The raft supports for the 4 matching cells were aligned and grouted in building 750 using the same technique that will be used in the SPEAR tunnel. The LCW headers for the standard cell girders were received and modified by the manufacturer to meet geometrical tolerances. The magnets for the injection beam transport system were completed and measured. The septum magnet for injection was fabricated and measurements completed in April.

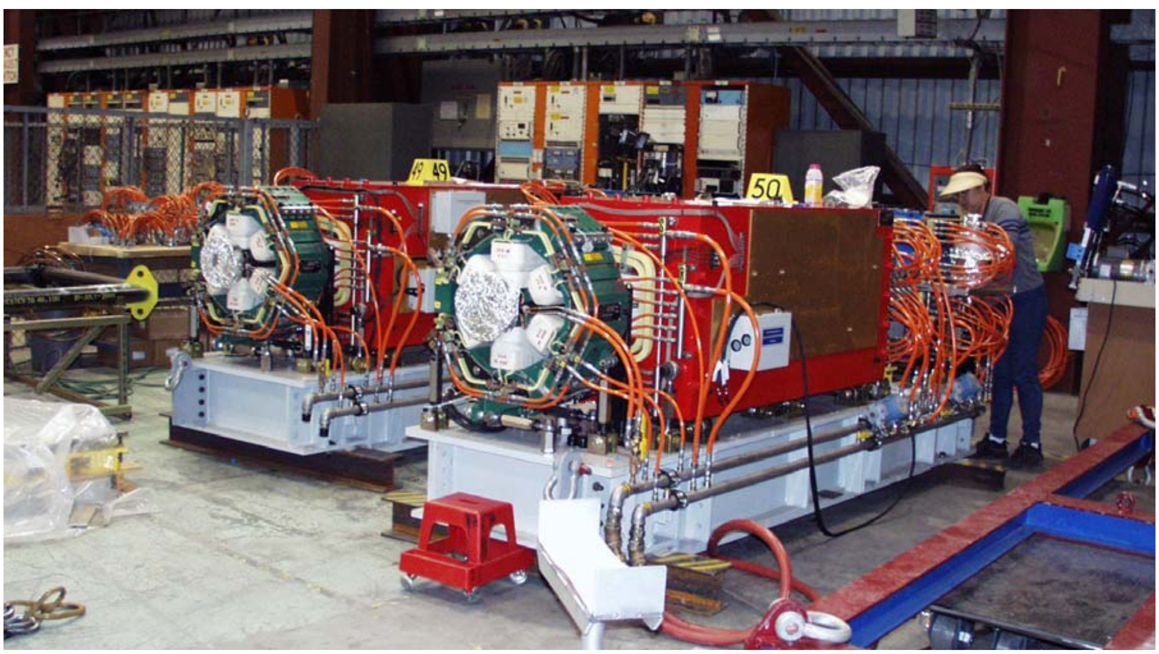



Figure 11 – Stored Magnet Rafts

All assembly welding and vacuum processing of arc section vacuum chambers was completed with a bake-out of the last 3 chambers in April. Assembly within magnets was completed in June. Other vacuum work that continued beyond April 1 included final manufacturing and assembly of bellows, straight section components, RF transition sections, and PPS stoppers.

All magnet power supplies were fabricated or near completion. Those power supplies on-site were bench tested. The finishing touches on power supply rack assembly and wiring were being made as Intermediate Power Supplies arrived from IE Power. The delivery of the remaining Dipole Bulk Power Supply and the deliveries for the remaining Intermediate Power Supplies were on track to support SPEAR 3 installation. A contract was placed for removal of existing supplies in a first phase followed by building refurbishment and new equipment installation in a second phase. The subcontracted placement was fully congruent with the April 1, 2003 installation start.

One of several klystrons manufactured or repaired by SLAC was scheduled to be delivered in May. The High Voltage Power Supply for the SPEAR 3 klystron was moved into its final location, which was a challenge because of the 46,500 lbs of the device. The RF Cavities being fabricated in Germany experienced more delays; however, the new plating process, similar to that used for PEP-II cavities, was successful and two of the four cavities finished the forming process. The first assembled unit was tested in April. The revised schedule had sufficient time to assemble and test the cavities before installation in August 2003. The low-level RF system prototype modules were completed. Work on RF software changes for SPEAR 3 made good progress.

Work on the computer control system continued with the configuration of the power supply control software, progress with the BPM data acquisition system, and the implementation of other remote control applications. Digital control components for the corrector power supplies were in production and acceptance testing was underway. Testing of commercial BPM processing units continued. The design of the computer-interfaced controller was initiated. Work on I&C interconnection diagrams continued, and detailed cable specifications were in progress.

Phase 1 of the cable plant installations was completed March 24, 2003. This included power, signal, and monitoring cables that could be installed outside of the tunnel and within the power supply building. Preparations for Phase 2 were near completion. Phase 2 includes final connections within the tunnel, power supply building and the control room. A contract for this work was out to bid.

The SPEAR 3 accelerator physics group focused efforts on the 3 GeV booster tests, Day-1 lattice specifications, construction of the synchrotron light monitor and further development of application programs. Detailed plans for the overall beam commissioning effort continued.

In the ES&H area, the SPEAR 3 Safety Assessment Document was completed in March. Preparations continued for the Accelerator Readiness Review (ARR) planned for July. The ARR addresses the following areas:

- Identification of equipment and systems having safety importance- Hardware Readiness.
- Identification of procedures necessary for the safe operation- Procedure Readiness.
- Identification of personnel necessary for safe operation and the definition of minimum training requirements- Training Readiness.

As noted above, the SPEAR 3 installation program was initiated on schedule March 31, 2003 following the final operations and shut down of the SPEAR 2 storage ring. In this quarter progress continued toward establishing the final schedule of the many details for terminating and removing SPEAR 2, improving and modifying the facilities, and installing the new SPEAR 3 ring. Also, most of the major contracts associated with the Installation program were developed, sent out to bid and awarded. A summary status of the contracts is provided below. The total of the awards was within the project cost estimated.

## SPEAR 3 Installation Contract Summary

| Contract | Awarded To | Date | K$ * |
|---|---|---|---|
| Remove S2 and Install S2 Rafts | Rigging International | Feb 25 | 441 |
| Concrete Foundations, Tunnel and Building 118 | W.P. Young | March 3 | 666 |
| Remove S2 and Install S3 Power Supplies | Farris Electric | March 5 | 376 |
| LCW System Mods | J.D. Collins | March 15 | 68 |
| Building 118 Seismic Requirements | D.W. Nicholson | May 17 | 32 |
| Building 118 Cable Tray Supports | D.W. Nicholson | June 3 | 99 |
| Drill and Install Tunnel Floor Anchor Bolts | Bayline Construction | June 2 | 44 |
| Install and Grout Magnet Raft Support Plates | Harris Construction | June 5 | 31 |
| Cable Installation Phase II | Palmer Electric | July 10 | 713 |
| HCW to Klystron | Western Allied | August 11 | 63 |

* Initial awards

## 3. The Installation Program

The SPEAR 3 Installation Program began on schedule March 31, 2003. The SPEAR 2 beam turn-off occurred at 6:00 am followed by a brief celebration during which Burton Richter and Keith Hodgson highlighted the history and the significant research from SPEAR 2 as well as a vision of the bright future anticipated with SPEAR 3.

While an early goal called for a 6-month installation period, detailed studies of the many activities and their interactions within the narrow confines of the existing tunnel indicated that a 7-month period was required. Even this was believed to be optimistic.

The Installation Program involved 3 phases: demolition of SPEAR 2, modification of the facilities to meet SPEAR 3 needs, and finally the actual installation of SPEAR 3 technical systems and components. Each phase was a complex procedure that was planned in great detail with overall completion projected by the end of October 2003. Phase one was completed on schedule near the end of April.

In phase one, the first two weeks included the regimented shutdown and component recovery process for electrical and vacuum systems together with radiation measurements within the tunnel followed by the removal of useful components of the ring. All magnet power supply units were removed from building 118. The removal process of various cable systems for power, controls, and monitoring was initiated. This overall effort was completed ahead of schedule thanks to the outstanding efforts of many SSRL and SLAC staff members.

During the third week, the cable cutting process inside the tunnel was completed. Appropriate shielding blocks were removed such that all of the Insertion Devices could be removed and stored. The fourth week initiated the removal of the eighteen main magnet girders. Most of these 30-foot long concrete supports with installed magnets and vacuum chambers were transported through the tunnel to a roof opening near the West straight section and removed by crane (Figure 12). The remaining work including cable removal inside the tunnel, removal of beam line front end components, and overall tunnel clean up was completed on May 5 allowing tunnel excavation (the beginning of phase two) to begin on schedule (see Figures 13 & 14). The overall timeline planned for the major installation activities is provided below.

**SPEAR 3 Installation Timeline**

- Begin April 2003
- SPEAR 2 remove: March 31 – May 8
- Building 118 renovation: March 31 – October 6
- Pour concrete floor: May 8 – June 20
- Install new monuments: June 20 – July 25
- Install mounting plates and holes: July 1 – August 11
- Install girder and straights, and shielding: August 11 – August 29
- Install cable plant: August 25 – October 15
- Install vacuum hardware and BL front ends: August 18 – October 16
- Leak check ring/beam lines-pumpdown: September 8 – October 22
- Final survey: October 22 – October 30
- Lock Ring-Installation complete: October 30, 2003

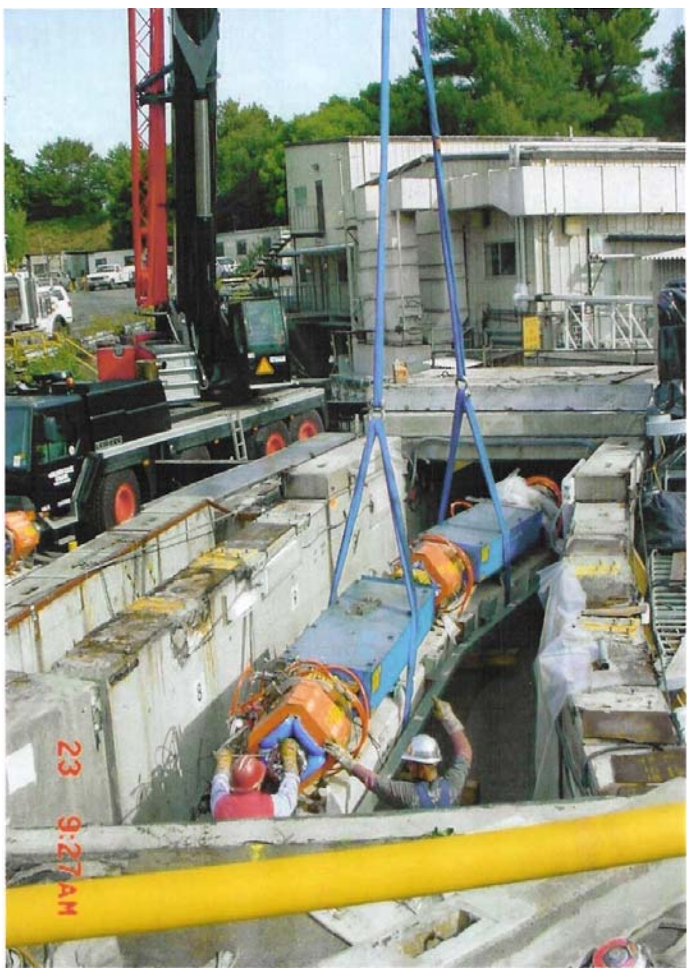



Figure 12 – Removal of SPEAR 2

Figure 13 - SPEAR tunnel near the end of April

Figure 14 - SPEAR 2 Bone-yard

After the successful removal of SPEAR 2 hardware in April, the contract for constructing new heavy-duty concrete floors for the ring tunnel and the power supply building began on May 3 slightly ahead of schedule. The floor for the power supply building was successfully completed in mid-May and the tunnel floor was completed in mid-June one week ahead of schedule. This allowed the task of establishing new survey and alignment monuments in the tunnel to also move ahead of schedule. In addition, the rather significant and unplanned seismic retrofit of the cable support structure in the power supply building was completed in May.

The contracts for the tunnel floor anchor bolts and the positioning and grouting of magnet raft support plates were awarded in early June. The core drilling for nearly 2000 anchor bolts began June 30. The last major contract for the installation of power and signal cables within the tunnel with connections to the power supply and control systems was out-to-bid in May. Award was made July 10.

Additional requirements for radiation shielding were provided by the SLAC Radiation Physics Group. Additional shielding was required for the injection area, the beam stopper, and for the exit walls of the photon-beams. Designs were reviewed and finalized by mid-July with installation in October 2003. This shielding allowed initial accelerator operations to 100 mA.

Another new requirement specified fences to restrict access to the tunnel roof. The fence was ordered and to be installed near the end of the installation period. Existing roof blocks were inspected by the SLAC Earthquake Committee and SPEAR 3 consultants provided further detailed evaluations. Four new blocks were ordered to replace those with stress cracks possibly due to additional loading by other blocks.

Design and production of remaining technical components for power supplies, beam line front ends, cable plant and RF systems were completed in June.

A major achievement for July was the preparation of the floor mounting plates for the magnet raft, beam line front ends and all straight section components. Starting June 30$^{th}$, some two thousand holes were drilled in the new tunnel floor for support studs. This was followed by final alignment and grouting of the floor support plates for all of the components. The work was accomplished by August 4, 2003 ahead of schedule.

July also marked the completion of the design and fabrication efforts for the magnet and support area. In summary, the following systems were complete, i.e. all components ready for installation.

- 1.1 Magnet and Supports
- 1.3 Power Supplies
- 1.4 RF Systems (except Klystron test)
- 1.6 Cable Plant
- 1.7 Beam Line Front Ends

Fabrication work continued for remaining components in the (1.2) Vacuum System and mainly for the High Conductivity Water (HCW) system completion in (1.8) Facilities. WBS 1.5, Instrumentation and Controls, because of its complexity, did not have a separate installation account and thus continued to include both design-fabrication and installation efforts.

All 4 RF cavities were now tested and ready for installation (Figures 15). SLAC was in the process of testing two new and two repaired 1.2 MW klystrons. One of these was planned for SPEAR 3 installation in October.

Figure 15 A – SP3 cavity #2 in final assembly

Figure 15 B - Four RF cavities installed

The only remaining major contract (Phase II) for cable installation was initiated. This involved final power and signal cable connections within the tunnel and the power supply building that could not be done prior to the current shutdown period. Note that most of the cable placement around the outside of the tunnel and to areas within the power supply building were accomplished in Phase 1 prior to the shutdown period.

A number of important milestones were achieved in August. On August 4$^{th}$, the floor grouting of the last four support plates for the magnet rafts was completed thereby allowing the start of the installation process for the main magnet/vacuum system raft assemblies. The 54 rafts (weighing more than 1,250,000 lbs total) were successfully rolled into the SPEAR tunnel and placed onto precision pins. This process was completed in 13 working days ending on August 27, thereby completing the SPEAR 3 magnetic lattice.

During August the injection system septum magnet and associated vacuum chamber were successfully assembled and electrical tests completed on the three-injection system kicker magnets. Installation of the all-new magnet power supply system (units previously tested) was completed and efforts continued with their electrical connection in Building 118. The RF klystron power supply, loads and associated waveguides were installed. All four RF cavities were received and checked out. Six insertion devices were installed and beam line front ends are in place except for BL10.

Work was scheduled for the final LCW connections to the magnet rafts, HCW piping to the RF system and electrical wiring in the tunnel. Areas that still required close attention for timely completion were remaining vacuum system components (straight sections and bellows), availability of the required 1.2 MW klystron for the RF system, testing of remaining instrumentation and control system components, and new shielding additions now required.

At the end of September, the final cable installation and hook-up to technical components was 90% complete. The magnet systems and power supply installations were complete and only awaiting the final cable hook-ups for power, LCW and monitoring. Beam line front ends were complete and awaiting final vacuum hook-up to the main ring. Remaining tasks involved the final bellows and straight sections installation for the vacuum system, the Klystron test (now delayed to October 15) with installation in early November, the HCW connection for the Klystron system, and the additional shielding now required in special locations.

The project held an Accelerator Readiness Review (ARR) on September 9-11, 2003. The review committee included members from DOE, LBNL, and SLAC. The ARR was conducted to verify that SPEAR 3 beam start-up could be accomplished safely and reliably. The review addressed:

- Beam Loss Scenarios
- Radiation Safety Requirements
- Shielding Requirements
- Personnel Protection System
- Beam Containment System
- Safety Analysis Document and Safety Envelope
- Operation Plans
- Non-Ionizing Radiation Safety Hazards
- Electrical Safety
- Seismic Safety
- Readiness of All Technical Systems
- Results from Reviews by SLAC Citizens Safety Committees:
    - Earthquake Safety
    - Electrical Safety
    - Fire Protection Safety
    - Safety Overview
    - Radiation Safety
    - Pressure Safety
    - Non-Ionizing Safety

The final report to DOE from the ARR committee had no findings, six concerns, seven opportunities for improvement, and five note worthy practices. The six concerns related to Fire Marshall approval of aisle space and emergency preparedness, documented protections for beam currents above 100 mA, hazard analysis for compressed gases for the LION system, consideration for gas bremsstrahling, a review of electrical hazards for the PPS system, and insurance that all safety procedures are complete. The concerns were addressed and reported to DOE. DOE provided official approval for start-up on November 13, 2003.

On October 10, 2003, a final DOE Review for the project was held. Its main purpose was to evaluate the status of project completion in order to achieve the Acquisition Executive approval decision for Critical Decision 4 (CD4). CD4 identifies project Completion and Approval for the start of operations. The conclusion of this committee was as follows:

“The committee commends the project team in the execution of the SPEAR 3 Upgrade project. There are no issues preventing the project from completing the installation phase and completing the project on cost and schedule. The committee identifies several action items required for completion prior to CD4 approval.”

One of the above action items directed to the project team was the verification of a list of remaining installations activities, which were discussed at the review. This list and its status as of October 20, 2003 is identified below as Attachment 2 (of the DOE Report).

Attachment 2

**SPEAR 3 Upgrade Project**

Remaining Items for Completion

(October 20, 2003)

| | | | | |
|---|---|---|---|---|
| | | **Completion Dates** (see note 3 below) | | |
| **Task** | | **Fab** | **Test** | **Install** |
| BTS: | | | | |
| | Special Components | 23-Oct | 24-Oct | 31-Oct |
| | Instrumentation | 28-Oct | 30-Oct | 31-Oct |
| Vacuum: | | | | |
| | 1S Diagnostic Components | 24-Oct | 31-Oct | 6-Nov |
| | 1S, 4S, 9S, & 14S Isolation Valves | complete | 27-Oct | 4-Nov |
| | 8S | 23-Oct | 27-Oct | 30-Oct |
| | 9S | 25-Oct | 27-Oct | 1-Nov |
| | 10S | complete | 25-Oct | 29-Oct |
| | BL 5, 9, & 10 Transition Sections | complete | 27-Oct | 29-Oct |
| | BL 11 Special Bellows | 27-Oct | 1-Nov | 3-Nov |
| | 17S | complete | complete | 23-Oct |
| | 18S West Pit (all components) | 30-Oct | 4-Nov | 6-Nov |
| | Straight Bellows (32 units total) | 100% | 27-Oct | 6-Nov |
| | Girder Bellows (38 units total) | 87% | 1-Nov | 6-Nov |
| RF: | | | | |
| | Klystron | complete | complete | 27-Oct |
| | LLRF | complete | 24-Oct | 30-Oct |
| Cable: | | | | |
| | Current Contract | complete | 27-Oct | 27-Oct |
| | Additions | | 5-Nov | 5-Nov |
| I&C: | | | | |
| | Remaining Systems (see note 1 below) | 1-Nov | 5-Nov | 6-Nov |
| Beam Line 6 ID | | | 30-Oct | 6-Nov |
| Straight Section LCW Connect | | complete | complete | 7-Nov |
| HCW System | | complete | complete | complete |
| Special Local Shielding Components (see note 2 below) | | 27-Oct | | 6-Nov |
| Survey and Alignment: | | | | |
| | Preliminary Mapping | | | 30-Oct |
| | Final Mapping (see note 2 below) | | | 15-Nov |

Note 1: While majority of components will be ready on site, the installation of some final units will be phased in as required during the pre-operations period.

Note 2: The installation of some special shielding units as well as the final survey mapping will occur at available times during the start-up and pre-operations and do not affect project completion date of November 7, 2003.

Note 3: Where more than one component is involved, the above dates signal the last item complete.

## 4. Project Completion

The tasks from the previous page requiring completion for CD4 approval (DOE Report Attachment 2) were completed approximately as planned. The last vacuum system component with associated LCW connections and the Beam Line 6 Insertion Device were installed November 12 thereby completing all installation. Vacuum pump-down was now underway for all four quadrants of the ring. The installation of special local shielding and final survey and alignment extended to November 15 thereby defining project completion. CD4 approval was given by DOE on November 24. This Level 1 milestone, established at the beginning of the project was achieved 3 months ahead of schedule and the final costs was $57,993.7K. The following illustrations provide:

- A view of the completed SPEAR 3 ring
- Summary of final costs
- Cost and funding profiles

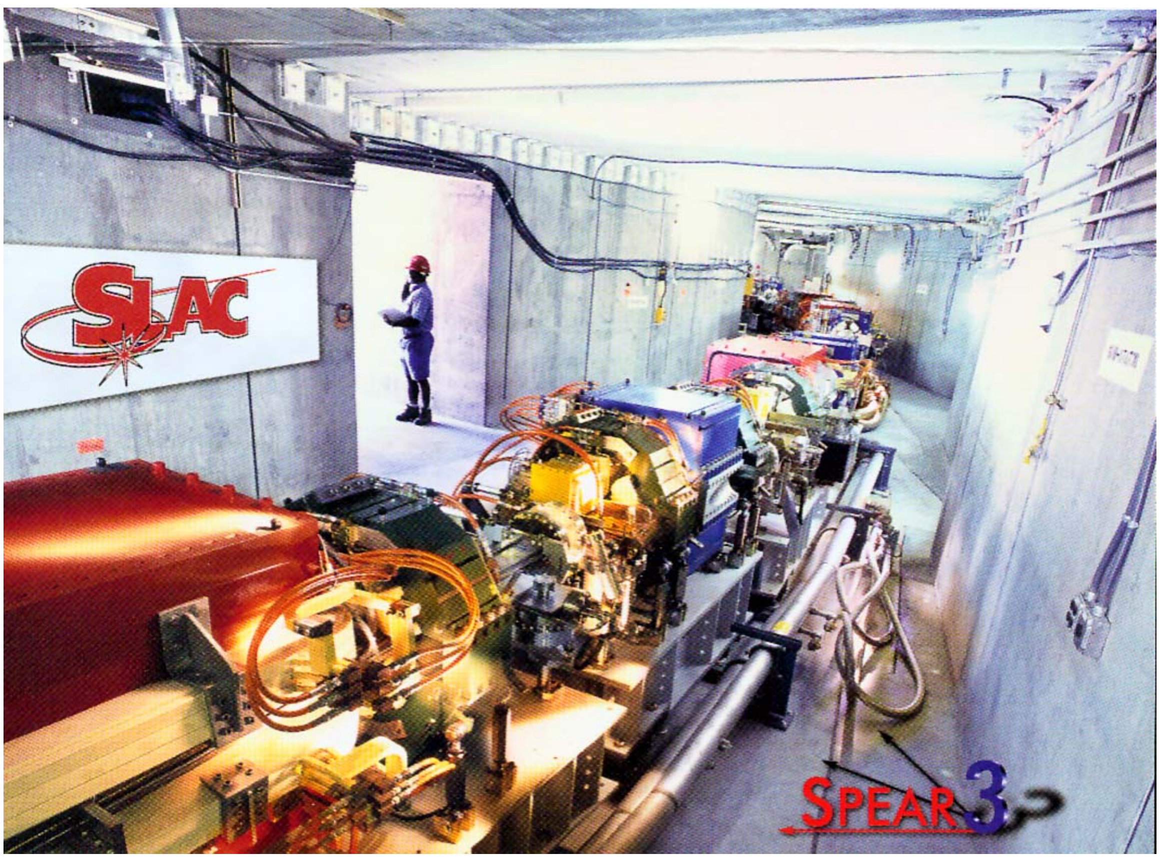
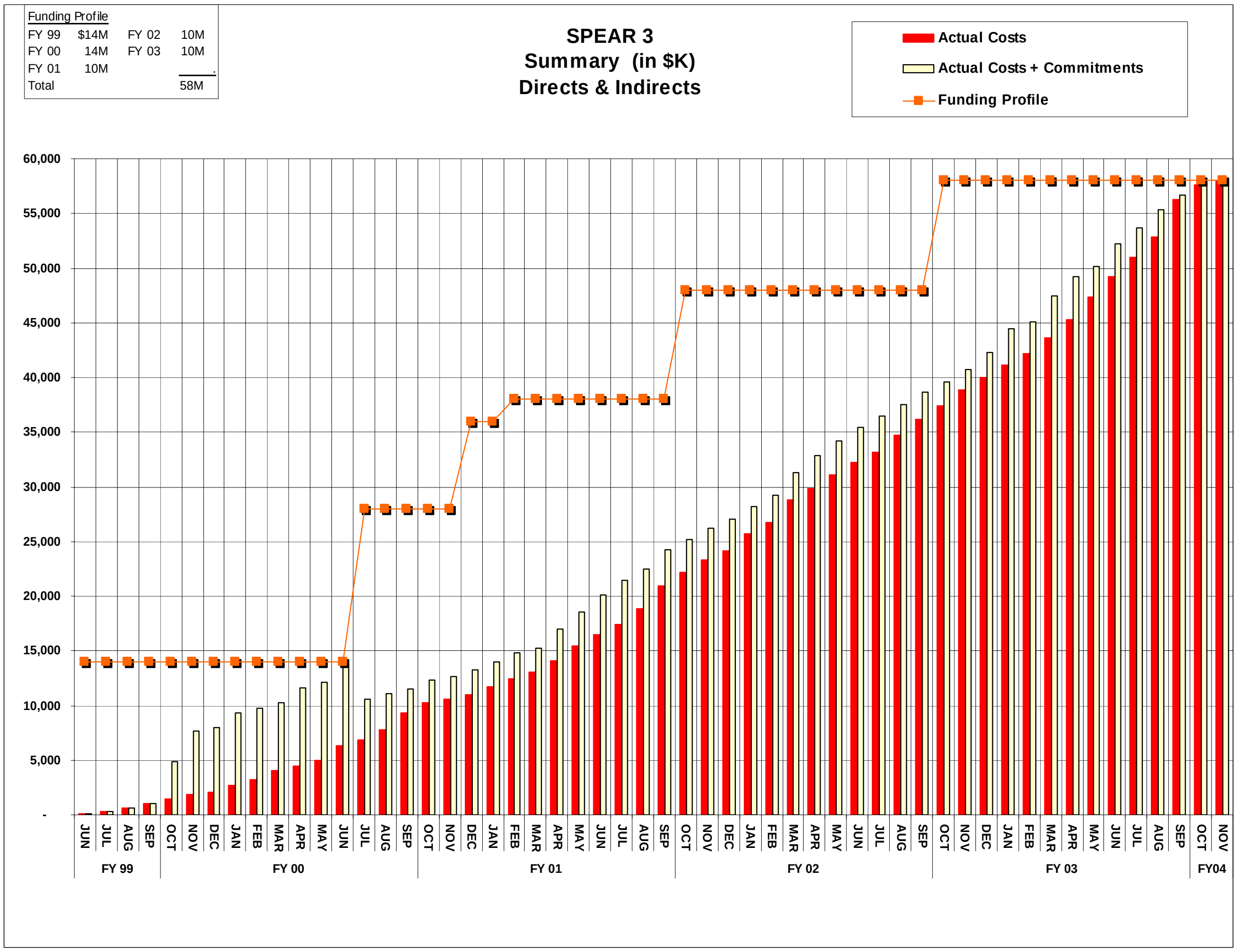



Figure 16 – Completed SPEAR 3 ring

## Summary of SPEAR 3 Final Costs

| | WBS | (Direct) K$ |
|---|---|---|
| 1.1 | Magnets and Supports | 8,420.5 |
| 1.2 | Vacuum System | 13,034.3 |
| 1.3 | Power Supply | 3,162.3 |
| 1.4 | RF System | 4,494.3 |
| 1.5 | Instrumentations Controls & Protection | 4,071.5 |
| 1.6 | Cable Plant | 2,102.0 |
| 1.7 | Beam Line Front Ends | 1,137.9 |
| 1.8 | Facilities | 3,805.8 |
| 1.9 | Installation & Alignment | 6,995.1 |
| 2.0 | Management and Accelerator Physics | 4,013.6 |
| | Directs Subtotal | 51,237.3 |
| | Indirect | 6,756.4 |
| | **Total** | **57,993.7** |

**Cost and Funding Profile**




## 5. Start-up and Commissioning

While the final components were being installed at the beginning of November, component and system tests as well as start-up procedures were underway. As early as July 2002, the commissioning team was completing planning details of the start-up and commissioning program with a projected beam turn-on date of December 10, 2004. On August 14, 2003, the Head of the Operations department selected the key staff members who would be responsible for turning on the various SPEAR 3 technical systems.

System tests started in October while installation was still in progress. This was made possible by good coordination between system managers and the installation crews. Power supply tests were conducted nightly with work to complete the vacuum, LCW, and shielding during the day. By mid November SPEAR 3 was fully under vacuum, the LCW system was operational and certification of the PPS for the RF and Power Supplies was complete. Full power test and RF system processing took place during the week of December 1.

The first complete turn of an injected electron bunch around the SPEAR 3 ring was observed at ~2 am on December 11. There is some probability that the actual first turn occurred earlier, but went unobserved. By morning, 2 or 3 turns were seen, and by afternoon 10-15 turns were observed. This was a major milestone since it demonstrated that most of the major systems were working.

By December 15, the RF System was operational and SPEAR 3 started accumulating beam up to 2 mA. The operations staff then continued pursuing measurements of beam parameters and working to commission the diagnostics, perform beam-based alignment, and correct the orbit and linear optics. This phase of commissioning demonstrated a high degree of magnet and power supply accuracy and that the accelerator components were extremely well aligned. By December 28, routine fills to 20 mA were accomplished. In mid-January the commissioning team was able to verify the integrity of the orbit Interlocks for protecting narrow gap insertion device chambers from mis-steering of upstream dipole radiation and 50 mA was obtained. The stored current reached 100 mA on January 22, 2004 a major milestone in the commissioning program and the maximum current allowed for operation this year while beam line optical components are commissioned and further shielding is added for higher current operations.

Efforts continued in February to bring the machine to a state of routine, stable, and efficient operations. The turn-on procedures for beam lines began on schedule in March. Beam Line 9 was opened March 8 with first users March 15. Beam Line 10, 11, 6 and 5 were opened and ready for users near the end of March. Measurements of beam line parameters indicated that the SPEAR 3 optical performance goals were achieved.

## 6. Acknowledgements

As a result of the successful project completion a celebratory event was held on Thursday, January 29, 2004 to recognize the contributions that many people made towards the success of the project. The event included introductory remarks by SLAC Director Jonathan Dorfan, and presentations by Stanford President John Hennessy, Patricia Dehmer from the DOE, Amy Swain and John Norvell from the National Institutes of Health, Palo Alto Mayor Bern Beecham and SSRL Director Keith Hodgson. At the conclusion of the presentations these guests participated in an event that simulated injection into SPEAR 3 and delivering beam to users. A special movie featuring archival footage of the construction and interviews with staff members was created for the event. Staff and visitors also took advantage of the rare opportunity to take a guided tour of the new storage ring. “SPEAR 3 is a remarkable resource that will produce state-of-the art science in numerous fields,” says SSRL Director Keith Hodgson. “On this special occasion we recognize the people whose extraordinary teamwork made the project successful.”
It is noted that the SPEAR 3 project was listed as one of the Top 10 DOE Office of Science Achievements in 2003. The recognition reads as follows:

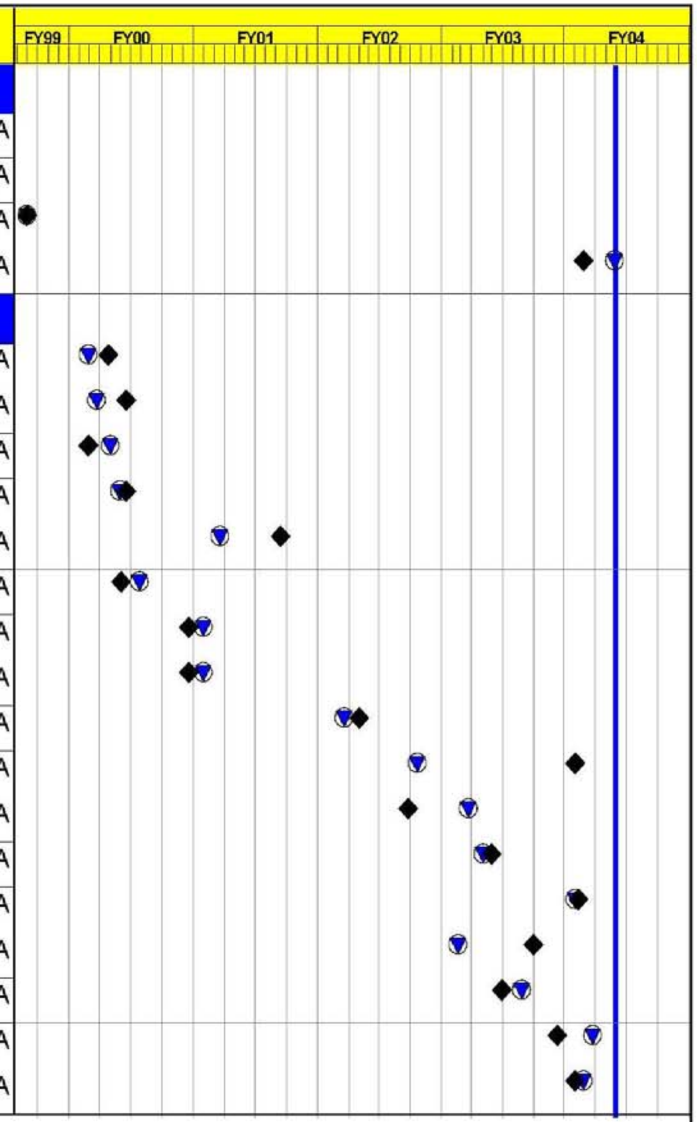
> *SPEAR 3 Completed Within its Budget and Ahead of Schedule:*
>
> *The Stanford Positron-Electron Asymmetric Ring (SPEAR 3) Upgrade is a Major Item of Equipment project funded by the National Institutes of Health and the Office of Basic Energy – each provided $29M. The project started in 1999 and was completed three months ahead of schedule, and within its $58M budget. The SPEAR 3 Upgrade project replaced the existing SPEAR 2 storage ring with a new lattice system that will increase the brightness of the source of synchrotron radiation 40 times for experiments at the Stanford Linear Accelerator Center. These extremely bright x-rays can be used to investigate various forms of matter ranging from objects of atomic and molecular size to man-made materials with unusual properties. The obtained information and knowledge is of great value to society, with impact in areas such as the environment, future technologies, health, and national security. The expeditious manner in which this project was carried out will result in an interruption of the user program at SSRL of only 12 months, also a significant achievement.*

The SPEAR 3 Project Management and technical group leaders echo the above praises to the many staff members from SSRL, SLAC, IHEP, and other institutions who were participants in the design, production, installation and commissioning phases. These contributors are listed in Appendix A2. Each person was an important member of the SPEAR 3 team who contributed to the successful evolution and completion of the SPEAR 3 storage ring. Thank You.

Finally the unprecedented joint support of the SPEAR 3 project by DOE and NIH is gratefully acknowledged.

## A1. Milestones

| Activity ID | Activity Description | Baseline Finish | Projected Finish |
|---|---|---|---|
| **MILESTONES LEVEL 1- Offc of Basic Energy Science** | | | |
| MS0010 | Approval of CD1 (Mission Need) | 05/28/98A | 05/28/98A |
| MS0020 | Approval of CD2 (Baseline Approval) | 09/30/98A | 09/30/98A |
| MS0030 | Approval of CD3 (Project Start) | 06/01/99A | 06/01/99A |
| MS0040 | Approval of CD4 (Start of Operations) | 02/27/04* | 11/24/03A |
| **MILESTONES LEVEL 2- DOE SPEAR 3 Proj. Office** | | | |
| MS0060 | RF Cavities Ordered | 11/30/99A | 01/25/00A |
| MS0070 | RF Klystrons Ordered | 12/22/99A | 03/20/00A |
| MS0080 | Main Magnet Designs Complete | 01/31/00A | 11/30/99A |
| MS0090 | Arc Vacuum System Design Complete | 02/29/00A | 03/17/00A |
| MS0100 | Safety Review - PSAD Approved | 12/22/00* | 06/15/01A |
| MS0110 | Start Vacuum System Production | 04/28/00A | 03/02/00A |
| MS0120 | Test Magnet Prototypes (Dipole) | 10/31/00* | 09/20/00A |
| MS0130 | Start Magnet Production (Dipole) | 10/31/00* | 09/20/00A |
| MS0140 | First Magnet Raft Assembled | 12/21/01* | 01/31/02A |
| MS0150 | Complete RF System Production | 07/26/02* | 11/01/03A |
| MS0160 | Complete Magnet Production | 12/20/02* | 06/28/02A |
| MS0170 | Final Safety Analysis Document Approved | 01/31/03* | 03/02/03A |
| MS0180 | Complete Vacuum System Production | 11/03/03* | 11/10/03A |
| MS0190 | Complete Raft Assembly | 11/22/02 | 06/30/03A |
| MS0200 | Start Major Installation | 05/29/03* | 03/31/03A |
| MS0210 | Accelerator Readiness Review Completed | 12/22/03 | 09/10/03A |
| MS0230 | Start SPEAR3 Turn On Procedure | 11/26/03 | 11/03/03A |

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|---|---|
| Start Date | 05/01/98 |
| Finish Date | 06/29/05 |
| Data Date | 03/01/04 |
| Run Date | 04/08/04 15:38 |



**SPEAR 3**
**DOE Milestone Schedule Levels 1 and 2**

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## A3. Lessons Learned (or relearned)

Some of the following lessons and comments are obvious; however, they are easy to lose track of during the race to achieve the technical goals of a complex project. Some of these items will, of course, vary depending on the specifics of a project; nevertheless, they are reiterated below.

Milestones at different levels should be defined as clear as possible together with their importance. In particular, transitions points from Construction to pre-ops or commissioning to operations should be carefully discussed and explained at all staff levels.

Systems Integration is important to milestone achievement. Critical or complex areas should be analyzed and addressed from the project start.

Installation Plans perhaps require the most intensive system integration. Depending on the project schedule, detailed analysis and planning may be required as early as possible. Aggressive SPEAR 3 milestone goals were set to have all technical equipment ready prior to the 7 months installation program. The installation plans and methods were reviewed early in the project timeline.

Safety is a number one priority and must be addressed at all levels. SPEAR 3 is fortunate that no significant accidents occurred. It is obvious that accidents can be very costly; however, changing rules and regulations are also costly. During SPEAR 3 the Earth Quake safety horizontal force design requirements were increased to 1.5 g for structural systems and shielding. This required additional foundations and more robust structural supports than originally planned. Structural fences atop shielding areas, not normally accessible, were also now required. Use of the existing power supply building required a new structure to support cables and was much more costly than building a completely new building. Extra contingency over and above the normal technical contingency should perhaps be added to cover such items.

Shielding should perhaps be over designed from the start to cover such items above or given a larger contingency that is closer that of technical systems rather than "conventional" construction.

High Vacuum Systems are generally very complex requiring more time and effort. The contingency should reflect this.

Communications (wishes and judgment factors)
---The offices of key staff members should be located together.
---Key staff (WBS 2 leaders) should be considered not only for their technical knowledge but also how they relate and communicate with others.
---e-mail is clearly an asset; however, it should be used appropriately so as not to waste the time of others.

---Brief daily meetings of the key staff should be considered. This was done in the installation phase and was clearly an advantage.

Experienced Staff from the B-factory project was an advantage to SPEAR 3 because they could be quickly integrated into the project. The use of B-factory technology also expedited the designs of SPEAR 3 systems.

Credit Card use was a clear schedule advantage particularly in the installation phase; however, the total of significant costs was difficult to track in a timely fashion as billing from many sources could arrive as much as 3 months later. In this circumstance, simple communication notes of the purchase cost, when made, could be sent to the budget officer for timely cost tracking.

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