Chapter 12 -- Project Plans and Management

This chapter discusses the schedule, cost, and organization of the QPS project.

12.1. Project Schedule

12.1.1. Schedule Considerations

The QPS physics and engineering design efforts leading up to this review have produced the physics basis for the QPS CE-level experiment as a part of the compact stellarator proof-of-principle program. QPS is both complementary to, and supportive of, the principal experiment in the compact stellarator PoP program, NCSX. The reference plasma and coil configuration are adequate for the QPS mission, but further improvements have been identified that can be made in both; these are discussed in Chapters 3 and 4. Refinement of the plasma and coil configuration will be pursued during the remainder of 2001 to improve the physics capabilities and reduce the cost of the coils. Chapter 9 describes a preconceptual design that should be adequate for the QPS mission, but improvements are needed in the modular coils, the force support structure, the central stack with the TF coil center legs and Ohmic current solenoid, and fabrication techniques for the modular coils, as discussed in that chapter. The major emphasis in the engineering studies will be increasing the confidence in the design and reducing the cost of building QPS. These physics and engineering design optimizations are tasks that are done after a pre-conceptual design study for a Physics Validation Review. These tasks are needed to prepare for a Conceptual Design, Cost, and Schedule Review, planned for April 2002.

A proposed schedule for the QPS project is shown in Figure 12.1. The actual pace of the project will depend on the DOE budget preparation schedule and the QPS funding profile. The earliest

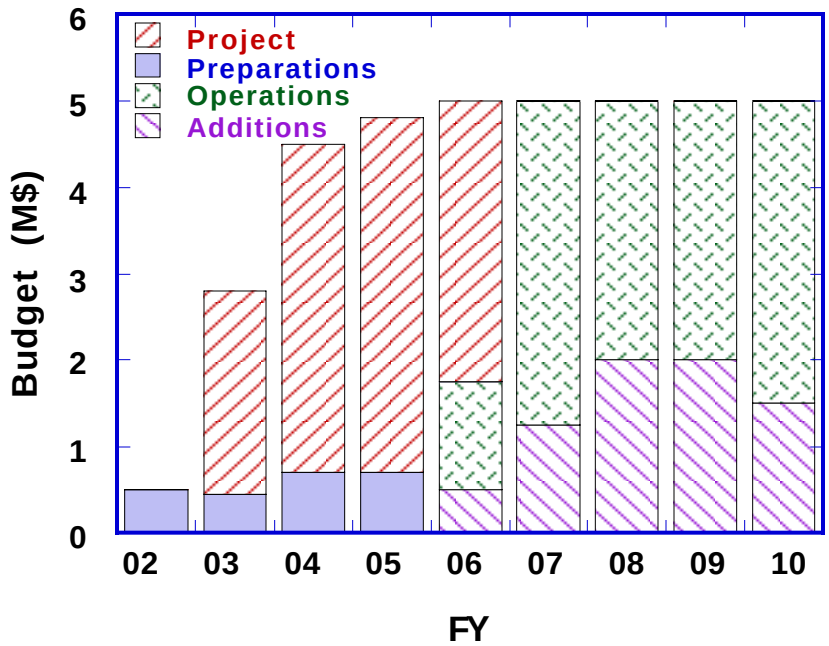

Figure 12.1. Projected QPS budget profile.

time that actual fabrication of QPS could begin is October 2003. This date is determined by the Project Validation Review in May 2002 for inclusion of QPS construction in the FY-2004 budget, which follows the April 2002 Conceptual Design, Cost, and Schedule Review. Approval to construct QPS would depend on a successful outcome of these reviews. Title I, Title II, R&D, and development of prototype modular coils and validation of fabrication techniques would occur in FY-2003, but award of construction contracts must await the beginning of FY-2004. The pace of construction and commissioning of QPS depends on the annual budget for the QPS program, which is requested at the high end of the range defined by FESAC for a CE-level program. Key dates for QPS prior to start of fabrication are shown in Table 12.1.

Maximum advantage will be taken of the parallel physics and engineering design efforts and the results from the R&D tasks in the larger NCSX project as it prepares for its Conceptual Design, Cost, and Schedule Review in April 2002 and Project Validation Review in May 2002. The DOE budget preparation schedule dictates that QPS hold to the same schedule. The fact that the same joint team is doing both and examining similar issues will maximize the team's efficiency and minimize the effort needed to prepare for the QPS reviews.

12.1.2. Completing the Design and R&D.

For the remainder of FY 2001, the focus of the physics activities will be on any follow-up calculations that are needed as a result of the April PVR and preconceptual design studies in preparation for conceptual design studies in FY 2002. The primary physics activity

Table 12.1. Required Tasks and Dates before Construction of QPS

Task/Milestone	Date
Conduct Physics Validation Review of QPS	04/01
FY-2003 Project Validation Review of QPS	05/01
Update the QPS Reference Configuration	09/01
Complete conceptual design and cost estimate for QPS Conceptual Design Review	04/02
Complete documentation needed for the FY-2004 Project Validation Reviews of QPS	05/02
Complete design for prototype QPS coils	08/02
Update conceptual design for QPS	09/02
Start Title I design for QPS	10/02
Complete procurement of prototype QPS coils	07/03

will be refinement of the modular coil designs for QPS and exploration of the configuration flexibility inherent in the QPS modular coils, TF coils, vertical field coils, and ohmic current solenoid. Methods to simplify the 3-D surface on which the modular coils are wound will be explored in order to reduce the complexity of this winding surface. A new parameterization for the winding surface will be explored and a multi-filament model for the modular coils will be incorporated into COILOPT. The coil geometry will be optimized and development of the basic design concepts will proceed. Specific engineering tasks will include:

Coil modeling. 3-D Pro-Engineer CAD models will be constructed of the coil set and structure. These models will be used to verify geometric feasibility and for discussions with shops and potential vendors.

Field, force, and structural analysis. Scoping calculations will be performed to assess the fields and forces as well as preliminary analyses of the structural response of the revised coil assembly.

Cost and schedule. The cost will be re-assessed for the revised coil configuration, and the size and performance will be adjusted as needed.

In FY 2002, conceptual physics and engineering design activities will be completed and advanced conceptual design and R&D will accelerate. The primary physics activity will be refinement of the modular coil design, which will be finalized for the optimized QPS configuration. Confinement analysis will be largely completed for QPS configurations of interest. DKES will be used to calculate energy-integrated transport coefficients over the full plasma volume of QPS, and these coefficients (coupled with Monte Carlo ion loss calculations) will be used to predict the self-consistent ambipolar electric field. Improved realism of ICRF heating in experiments and alpha-particle confinement in reactors will be incorporated in the confinement calculations. Exploration of the interesting new family of high-beta, QPS/tokamak hybrid devices will continue and their suitability as reactors will be evaluated. The 1-D TOROPT reactor optimization and assessment code will be used to scope out issues for further analysis with the ARIES group in preparation for a larger study of compact stellarators as reactors. This systems code incorporates 1-D stellarator transport including self-consistent electric fields with the ARIES materials assumptions and costing algorithms. Advantage will be taken of development of increasingly realistic tools for the modeling of three-dimensional systems along with improvements to the Oak Ridge Stellarator Optimization Code and the COILOPT and genetic algorithm coil optimization codes. These developments will be applied to assessments of equilibrium, stability, transport, and RF heating to support the design and operation of QPS.

Pre-conceptual engineering design, analysis, and integration for the QPS device will be carried out for the April 2002 Conceptual Design, Cost, and Schedule Review. Requirements for each subsystem, including the modular coils, TF and VF coils, support structure, etc. will be finalized and used as a basis for conceptual design. Tasks in the major areas will include:

Modular coil design. The geometry of the finite cross section coils will be iterated to reach a balance between the physics requirements and a feasible mechanical design. The magnetic fields

and forces from all coils will be calculated. The coil winding pack design concept will be developed that optimizes the tradeoff between geometric, pulse-length, and cost requirements. The number of turns, current density, etc. will be selected. Fabrication options will continue to be evaluated with input from potential vendors. Selection of a cost-effective fabrication concept is critical to meeting the cost and schedule objectives, and this activity will receive significant attention throughout the design phase.

Support structure. A concept for the structural configuration of the modular coils will be developed, including the winding form and support interface locations.

Integration and assembly. A basic assembly concept will be developed and interfaces for pumping, cooling, electrical leads, plasma heating, and diagnostics will be identified.

R&D. An assessment of concept features will be made to identify R&D that may be needed. Every attempt will be made during the design process to avoid the need for R&D work, but at a minimum a prototypical modular coil will be required.

Cost and schedule. A complete, baseline cost estimate and project schedule for the conceptual design review will be prepared, along with conceptual-level Systems Design Description documents.

In FY 2003, activities will focus on engineering design and R&D. Physics activities will be limited to studies that are needed for the QPS design and long lead time preparation for operation. Advanced conceptual design and R&D that was begun after the April 2002 CDR will be completed as will Title I design of most components. Detailed design of many components for QPS will begin, and design of the modular coils and external vessel will be completed. Specifically, this will include:

Modular coils and coil structural forms. The detailed geometry and fabrication features for the coil set will be finalized based on the results of the R&D. Detailed analyses will be performed, including coupled thermal and structural analyses and analysis of coil fault conditions. The extra burden of fault conditions and the thermal performance of the coils are the primary issues that will effect the design and should be verified before the prototype coil design is completed. The geometry selected for the coil set will be used to produce detailed drawings and procurement specifications of the coil winding forms and conductor. If possible, the winding form geometry will be specified with 3-D CAD data to minimize the number and complexity of the drawings required.

TF and VF coils. Detailed design of the TF and VF coil sets would begin, including the integration of the TF coil center legs and Ohmic solenoid within the centerstack assembly.

Intercoil support structure, integration and assembly. Detailed design of the intercoil support structure will be completed. Particular attention will be paid to the assembly scheme and how to insure geometric accuracy of the modular coil placement.

External vacuum vessel All required modifications to the existing bell jar will be identified. Detailed drawings and specifications will be prepared for the centerstack assembly as well as all

necessary modifications to the existing bell jar, and potential vendors will be solicited to perform the work.

Analysis. Structural analysis of the coil winding and structure will be performed using detailed magnetic force and temperature distributions. The stress distribution in the coil insulation and the gross coil deflection will be the primary concerns. Fault conditions due to shorted coils will be assessed. Detailed transient thermal analysis of the coils will be performed and reconciled with the R&D tests. The temperature rise, subsequent temperature gradients, and cooldown time will be of primary interest. All remaining structural analysis, including integrated analysis of the TF and VF coil sets will be completed.

R&D. The primary issues are the modular coil winding, structure fabrication, thermal performance and vacuum performance. A complete modular coil winding form will be procured and prototype winding will begin. The vacuum properties of the coil winding form casting and methods for vacuum canning of the completed coil will be determined. These features are most critical to a cost effective design. The intent will be to involve at least one industrial supplier in the R&D work, and give that vendor or vendors the option to bid on fabrication of the entire coil set. Results of the FY 2002 and 2003 R&D, including fabrication and testing, will begin to be folded into the final design. All R&D will be completed early in FY 2003 to allow timely input into the detailed design of the modular coil set.

12.1.3. Construction and Commissioning Phase

Construction activities will be begin in earnest in October 2003. It is expected that the modular coil central I-beam with the support members will be cast at a vendor and machined as necessary for the coil winding process, as determined in prototype development in FY 2003. It is anticipated that the coil winding will be done at a collaborating university. ~1-mm accuracy will be required in the winding process as determined in coil prototype development in FY 2003. After fabrication of the individual modular coils, the complete set will be assembled to the extent possible at the outside vendor's site, which helps to ensure the quality of the final product by placing more of the responsibility with the fabricator. However, due to the large weight of the completed assembly, only subassemblies of the machine can be handled for subsequent final assembly. The complete modular coil set would be pre-assembled, aligned and pre-fit around the centerstack, and all holes match reamed. The coil set will then be split apart into the two field periods for shipping and reassembly at the QPS site. The assembly procedure and preparations for commissioning are described in Chapter 9. The commissioning phase discussed in Chapter 11 requires connecting the cooling lines to a gas manifold around the base and performing a coolant leak check, connecting buswork to the coil leads and performing low-current electrical checks, leak-checking the vacuum vessel, installing machine diagnostics and I&C, performing pre-operational checkout and coil tests, installing two gyrotron systems, and installing the base set of machine and first-plasma diagnostics. First plasma is projected for the near the end of FY 2006.

12.2. Project Cost

QPS is being designed as the minimum-cost facility needed to carry out the QPS mission. Factors determining that need are discussed in Chapter 4. The main determinant on the size is the need to have non-intersecting (buildable) modular coils with a realistic current density. Existing components, power supplies, and plasma heating systems will be used to a maximum degree and only a minimum set of diagnostics is included in the project. Installation of the remaining plasma heating system and additional diagnostics will be covered in the operating budget.

The QPS project has been categorized by DOE as a Major Item of Equipment (MIE) activity and the project cost defined accordingly. The same costing procedure used for NCSX was adopted for QPS. The same Work Breakdown Structure (WBS) established for NCSX was used (with minor modifications) to define the scope of work and tabulate cost. The criteria for determining the scope of work in the Project Cost were the same as used for NCSX:

- the facility must be fully capable of supporting the initial experimental objectives;
- the facility must be fully capable of accommodating required upgrades.

Maximum advantage was taken of the extensive costing study for NCSX including the same costing algorithms and assumptions, and the same contingency was applied system by system. Advantage was taken of lower labor rates at a local university, similar to what was done in constructing HSX. Although the estimate is as complete as possible within the limits of our current understanding, there are large uncertainties in some of the systems as reflected in the contingencies for those systems, which ranged from 10% to 50%. In estimating the contingency, technical, schedule, and cost risk factors were considered for each WBS element as in the NCSX study. The technical risk factor was based on the current state and level of the design. The schedule risk factor was based on criticality to the overall schedule. The cost risk factor was based on the estimating methodology used. The overall contingency added up to ~26% of the total without contingency.

The cost estimate was based on a four-year period from the start of Preliminary Design (Title I) until first plasma. R&D activities prior to the start of Preliminary Design were also included in the cost estimate. A summary of the Project Cost by WBS element is provided in Table 12.2. The overall cost is $11.5 million (in FY-1999 $) including contingency. When inflated to the expected years of expenditure this cost becomes approximately $13.9 million.

In the conceptual design process, a bottoms up schedule will be developed. The cost will be re-estimated consistent with that schedule and any design changes that occur during the course of the conceptual design.

12.3. Project Organization

The QPS is proposed by Oak Ridge National Laboratory with Princeton Plasma Physics Laboratory as the principal collaborator. These two national laboratories are collaborating in the design, operation, and physics research for the QPS project. ORNL has the lead responsibility for

project execution and PPPL provides important support in key physics and engineering areas. The University of Texas at Austin has been a partner in the development of the QPS concept.

Table 12.2. Cost Summary

Description	**FY 1999 $**
Fusion Core Systems	**$6220 k**
Vacuum Vessel	$381 k
TF Coils	$896 k
PF Coils	$482 k
Machine Support Structure	$762 k
Modular Coils	$3,699 k
Auxiliary Systems	**$519 k**
Diagnostic Systems	**$193 k**
Power Systems	**$123 k**
Central I&C & Data Acquisition Systems	**$255 k**
Site & Facilities	**$88 k**
Machine Assembly	**$823 k**
Project Oversight & Support	**$581 k**
Preparations for Operations	**$260 k**
Subtotal Without Contingency	**$9061 k**
Contingency (~26%)	**$2393**
TOTAL	**$11,454 k**

Management for the Project is within the ORNL organization, reporting to the Department of Energy through the Director of the ORNL Fusion Energy Division.

The physics concept development phase of the QPS project has been carried out by an integrated national team, led by ORNL, with participation from several universities (to date, the University of Texas at Austin, University of Montana, University of Tennessee, and the Universidad Carlos III de Madrid, Spain) in addition to PPPL. The QPS work has benefited from the work done for the NCSX project through the participation of the QPS team in the NCSX project. The physics and engineering tools developed at ORNL and elsewhere for the NCSX project were applied to the QPS work. The national team approach has facilitated cost-effective knowledge transfer and resource sharing within the DOE system of laboratories and been effective in broadening national participation in the program. Good communication is maintained cost-effectively through frequent teleconference meetings and web-based data sharing, with little need for travel. Input from the larger fusion community has been obtained from two QPS Project teleconference meetings in

addition to presentations at national and international conferences and seminars at different institutions.

In the next (conceptual design and fabrication) phases, stronger participation with a university and PPPL will be sought to broaden involvement and reduce costs. ORNL will continue to lead the team and necessarily be responsible for all procurement, fabrication, installation, testing, and commissioning in these phases. In the experimental operations phase of the QPS program, ORNL would further broaden participation with collaborating universities and other institutions. This model was used successfully in the ATF program and led to numerous student theses. It also fits well with ORNL's goal for broader participation of universities in ORNL research. It is anticipated that ORNL technicians will be needed for operations and facility modifications, but ~1/2 the participants in the physics program will be from PPPL, universities, and foreign institutions. Collaborators will be encouraged to bring specialized diagnostics for studies on QPS and a strong theory interaction will be fostered. Responsibility for physics areas will be shared among the participants in the QPS program. A national QPS Program Planning Committee will be created to reflect the breadth of the participation in the QPS program.

The QPS Project is strongly supported by the highest level of ORNL management and appears in the Laboratory's institutional plan. The QPS will serve as a focal point for the Confinement, Theory, and Plasma Technology programs in the ORNL Fusion Energy Division, to bring back the younger fusion researchers now mostly involved in other areas at ORNL, serve to attract new post docs and permanent staff, and re-establish our support of southeastern universities.

The ORNL team of senior physicists and engineers has extensive experience in stellarator design, construction, and operation, as well as in other fusion projects much larger than QPS. These same people have major physics and engineering design responsibilities on NCSX, which will add to the efficiency of their QPS work. The key personnel to date and their responsibilities are:

Program Direction

- Jim Lyon (Program Manager): overall project and program issues.
- Don Batchelor: Theory program coordination.
- Stan Milora (Fusion Division Director): ORNL management.

Physics

- Steve Hirshman (Physics Head): configuration optimization.
- Lee Berry and Dennis Strickler: modular coil design.
- Buff Miner and Prashant Valanju, U. Texas: modular coil design.
- Don Spong: confinement and transport.
- Andrew Ware, U. Montana: MHD equilibrium and stability.
- Don Monticello, Stewart Hudson, G.Y. Fu, PPPL: MHD equilibrium and stability.
- Raul Sanchez, Universidad Carlos III de Madrid, Spain: MHD equilibrium and stability.
- Peter Mioduszewski: vacuum quality, power and particle handling.
- Dave Rasmussen and Tim Bigelow: RF heating.

Engineering

- Brad Nelson (Engineering Head): overall engineering design and construction.
- David Williamson: modular coil design.
- Mike Cole: QPS systems.