# Research in Superconducting RF at Cornell University's Laboratory of Elementary Particle Physics

## 1 Introduction

This document describes research in superconducting RF systems, to be performed by Cornell University's Laboratory of Elementary Particle Physics (LEPP), partially in support of the International Linear Collider (ILC), for the period of October 1, 2005 to September 30, 2006. During this time period it is anticipated that the baseline design for the ILC will be derived under the auspices of the GDE and a reference design report and cost estimate will be started.

Work at LEPP for this period will primarily involve generic basic research in SRF, and work targeted at high gradient SRF cavities. The work is partially funded through the Department of Energy's Advanced Accelerator R&D program, and partially by the National Science Foundation.

## 2 Statements of Work

This section contains the work packages to be carried out at LEPP during the period of time indicated above. These are given in the form of the proposals submitted to the DoE and NSF for this work.

## 2.1 WBS 3.9.9: Research in Superconducting RF Systems

## 4.2 Research in Superconducting Radiofrequency Systems Personnel

**and Institution(s) requesting funding**
H. Padamsee, M. Tigner, R. Geng, V. Shemelin, M. Liepe, Laboratory of Elementary Particle Physics, Cornell University

**Project Leader**
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(607) 255-5727

**Project Overview**

Rapid advances in superconducting cavity performance have made RF superconductivity an important technology for a variety of accelerators, fulfilling the needs for high energy physics, nuclear physics, radioactive beams for nuclear astrophysics, intense proton accelerators for neutron spallation sources, muon acceleration for future neutrino factories and muon colliders, storage ring light sources, free electron lasers, fourth generation x-ray free electron lasers, and energy recovery linacs. Improved understanding of gradient-limiting mechanisms, together with technology advances, are responsible for the steady increases in performance [1]. Gradients of 25 MV/m at Q values of $10^{10}$ are now regularly achieved in one-meter long superconducting structures suitable for TESLA (TeV Energy Superconducting Linear Accelerator). To reach such gradients, high-purity, high thermal-conductivity niobium is used to prevent thermal breakdown of superconductivity, while high pressure rinsing and clean room assembly techniques are used to reduce field emission and voltage breakdown. LEPP research has played a major role in pushing cavity performance to these levels [2].

The goal of our future R&D program will be to push gradients towards the theoretical limit (50 MV/m), which is another factor of two higher than achieved levels. Advances in understanding gradient and quality factor (Q) limitations, together with progress in gradients will benefit the goals of large scale accelerators, such as TESLA and its upgrades to higher energies and luminosities. We also plan to explore improved cavity designs that lower surface fields thereby raising the maximum possible accelerating gradient. Preliminary explorations suggest designs that offer a 20% improvement, raising the theoretical accelerating field limit for superconducting structures to 60 MV/m.

We are also developing new techniques for cavity fabrication and treatment to lower production costs for large scale accelerators. If such procedures are successful with smaller cavities, we aim to combine the less expensive fabrication and processing techniques with the improved designed and build multi-cell structures. Here we will need the help of industry.

The sophisticated techniques associated with fabricating, treating and testing superconducting niobium cavities now resides primarily in European industries. Having a US industry learn these high tech procedures would greatly improve the choices for US contributions to the future accelerators base on SRF. During the third year of the proposal we will transfer the high level of technology associated with fabrication, surface preparation and cryogenic testing of superconducting structures to one or more US firms while fabricating, treating and testing full scale structures with improved design and methods.

Much of the work described in the first two years will be carried out by graduate students doing doctoral work. Funds are requested for equipment, materials, supplies and surface analysis work. Support for graduate students is paid for by our regular NSF contract.

**Basic studies of the sources of high field Q-slope and quench field in Nb cavities**
Two mechanism operate to reduce the Q of a superconducting cavity at accelerating fields above 20 MV/m. One is field emitted electrons from particulate contaminants in the high electric field regions of the cavity. This phenomenon is quite well understood and methods to control emission are in hand. High pressure water rinsing (at 100 bar) eliminates field emission by eliminating micron and sub-micron particles. The high power available for the beam can also be used to burn up any residual emitters that accidentally enter structures during the final stages of assembly. The other important field limitation is a phenomenon called the "high field Q-slope" [3]. In very clean cavities that show little or no field emission, there persists a steady decline in Q0 above 20 MV/m, followed by a quench between 20 and 30 MV/m. Absence of x-rays corroborates absence of field emission. Temperature maps reveal that power dissipation occurs over high magnetic field regions of the cavity. Yet the losses are not uniform. Collaborative work at several laboratories shows that electropolishing, instead of the standard chemical etching procedure, substantially reduces the Q-slope and increases the quench field. Another cavity treatment (baking at 100$^o$C for 48 hours) further improves the high field Q-slope of electropolished cavities, and raises the quench field substantially. Baking also has a slight beneficial effect on the Q-slope of chemically etched cavities, but no significant effect on the quench field. As a result of these new procedures accelerating fields of 35-40 MV/m are now realized in TESLA 9-cell structures.

An understanding of the Q-slope mechanism will point the way to treatments that can lead to even higher performance. There has been some recent theoretical progress as well as new models proposed for explaining why electropolishing and baking help to reduce the Q-slope. One mechanism is magnetic field enhancement at grain boundaries[4]. Surfaces prepared by buffered chemical etching tend to develop grain boundary steps and sharp grain boundary edges due to differential etch rates for different grains. Electropolishing eliminates steps due to higher etch rates at sharp features. A model for the benefits of baking involves the redistribution of oxygen in the rf layer[5].

Much experimental and simulation work remains to validate these explanations or to eliminate them. We plan to use our state-of-the-art thermometry system to identify hot regions responsible for the Qslope, and premature quenches [6]. These studies will be carried on single cell cavities with surfaces prepared by a variety of methods, such as chemical etching, electropolishing, baking, and anodizing (electrolytic oxidation). After identifying lossy regions we will dissect the cavity and study the spots with surface sensitive techniques such as Auger, SIMS (secondary ion mass spectrometry), and XPS (x-ray photoelectron spectroscopy). Auger and SIMS will give surface sensitive elemental information, while XPS will help sort out differences in surface oxides. Use of other surface techniques may be warranted.

Graduate students will carry these studies. Students will also prepare niobium samples by the same techniques and carry out parallel measurements with surface analytic instruments.

**Improved Geometries, Fabrication and Preparation** Another way to tackle the high field Q-slope is to modify the cavity design to reduce the ratio of the peak magnetic field to the accelerating field. Although field emission is present in some cases, it does not present a brick wall limit because techniques exist to control it. This means that the peak surface electric field is less important than the peak surface magnetic field.

Preliminary studies using cavity design codes show that introducing re-entrant shapes offers the possibility of lowering the surface magnetic field by at least 10%, if we allow the surface electric field to rise by 20%. Since the cell-to-cell coupling factor of the re-entrant geometry is also higher, it is possible to reduce the aperture to make further reduction in the surface magnetic field. We expect to continue such optimization studies during the first year to determine the best cell length, aperture and higher order mode propagation properties.

The re-entrant shape leads to some technological complications for cavity fabrication, surface preparation and cleaning, which we intend to address at the single cell level during the second year.

Today, 9-cell TESLA cavities which are purified with Titanium at 1350$^o$C and electropolished reach accelerating fields of 35 MV/m. High temperature treatment for purification of 9-cell structures calls for large and expensive UHV furnaces. Heat treatment is also a lengthy process, since the furnace cycle takes three days. Diffusion of titanium into the bulk demands removal of more than 100 $\mu$m of the surface, another time-consuming operation.

To reduce large scale production costs, we aim to explore heat treatment at the half-cell stage. Stacking cups interleaved with titanium foils can improve the packing fraction in a furnace by at least a factor of two, thereby reducing the investment in infrastructure and processing time. Preliminary tests show that optimization of the time/temperature cycle during heat treatment can also lower the diffusion length of the titanium from 100 $\mu$m to about 20 $\mu$m, yielding a substantial reduction in chemical processing time.

The present method of electropolishing involves a large and expensive facility that must rotate a cavity full of acids and carefully exhaust the hydrogen produced at the counter electrode. Hydrogen dissolved in the bulk niobium precipitates as normal conducting islands of niobium-hydride on cool down. If so contaminated, an electropolished cavity must be heated at 750$^o$C for several hours to drive out the dissolved gas. Half-cell electropolishing is simpler, more open and poses less danger of hydrogen contamination.

In order for these proposed economical methods to succeed it is necessary to devise an electron beam welding procedure that produces an excellent final weld which requires very little post etching. The final weld operation must not contaminate the cavity surface. Preliminary welding studies show that both these conditions can be met.

During the first and second years, we plan to make several single cell cavities with the improved (re-entrant) shapes and prove out novel half-cell purification, electropolishing and final welding procedures.

**Transferring superconducting rf technology to US industries** the Cornell SRF group will work closely with US industries to build several multi-cell niobium structures of the advanced geometry with the more economical production and preparation methods. This will be an essential step for industry to develop large scale industrial process. Cornell Research Associates, technicians and graduate students will collaborate with industrial personnel using Cornell facilities described below. As a result, industries will learn the special techniques involved in deep drawing, half-cell purification, half-cell electropolishing, electron beam welding, and final chemical etching. We plan to take the industries through the special procedures of high pressure rinsing and cold testing 9-cell cavities to TESLA gradients of 25 MV/m and above. By using Cornell infra-structure, industries would not have to make the large up-front investment in facilities. Manpower support for Cornell personnel will be paid for out of our regular NSF contract. We anticipate that industrial firms would expect Cornell to cover part of the costs of training time for industrial personnel as contracts.

**SRF Infrastructure.** Newman Laboratory at Cornell has extensive infrastructure for research and development in RF superconductivity as well as for production, preparation, and testing of superconducting cavities. These facilities have been used to build the prototype SRF cavities for CEBAF and TESLA, as well as all the cavities that power the present storage ring at Wilson Laboratory (CESR). Cavity production facilities include a 100 ton press for deep drawing niobium cavity cells, digital control milling machines for precise die machining, an electron beam welder large enough for TESLA scale cavities, and a large UHV furnace to purify cavity half cells at 1300 C. Cleaning facilities include open and closed cavity etching systems that can handle TESLA type cavities, high purity water rinsing systems, and high pressure (100 atmospheres) water rinsing. There is a new 1100 sq ft Class 100 clean room for cavity assembly and a smaller Class 100 area for preparing smaller test cavities. There are several portable clean room set ups for critical assembly. Test setups include three radiation shielded pits, two of which can accommodate 1300 MHz cavities. We have several cryostats, and cryostat inserts to test cavities from 200 MHz to 3000 MHz, several 200 Watt CW power sources and a 1.5 MW pulsed klystron for high pulsed power processing 1300 MHz cavities. High power testing capabilities exist for windows at 500 MHz and HOM loads at 2450 MHz. Research facilities include a rapid thermometry system for studying single cell 1500 MHz cavities, field emission apparatus, and dedicated scanning electron microscope with energy dispersive analysis for element identification installed in a class 1000 clean room. An Auger System with SIMS Analysis capabilities augments our surface analysis capabilities.

**Year One Project Activities and Deliverables**

Studies of the sources of high field Q-slope and quench field in Nb cavities: This work will span the entire three year proposal period. As gradients in superconducting cavities continue to rise toward the theoretical upper limit, we expect new loss mechanisms to arise that will need investigation.

Improved Geometries, Fabrication and Preparation: The first year's deliverables will be progress reports and papers to conferences and journals on studies to optimize the shape of cavities.

**Year Two Project Activities and Deliverables**

Studies of the sources of high field Q-slope and quench field in Nb cavities: This work will continue in the second year. The second year's deliverables will be progress reports and papers.

Improved Geometries, Fabrication and Preparation: The second year's deliverables will be single cell cavities with improved shapes and test results, as well as progress reports and papers.

**Year Three Project Activities and Deliverables**

Studies of the sources of high field Q-slope and quench field in Nb cavities: This work will continue in the third year. There will be a final report.

Improved Geometries, Fabrication and Preparation: Through the technology transfer program to US industry, we will fabricate multi-cell niobium structures and test these structures at 2K. There will be a final progress report.

**Budget justification and three-year budget, in then-year K$**

Institution: Cornell University

| Item | Year 1 | Year 2 | Year 3 | Total |
|---|---|---|---|---|
| Equipment | 10 | 45 | 34 | 89 |
| Materials and Supplies | 6.3 | 25.1 | 32.1 | 63.5 |
| Other direct costs: Surface Analysis Contracts | 0 | 10 | 10 | 20 |
| Other direct costs: Industrial Personnel | 0 | 25 | 25 | 50 |
| Total direct costs | 16.3 | 105.1 | 101.1 | 222.5 |
| Indirect costs | 3.7 | 34.9 | 38.9 | 77.5 |
| Total direct and indirect costs | 20 | 140 | 140 | 300 |

Equipment: Computers and electronics for thermometry data acquisition, RF for cavity testing, vacuum, chemical equipment, fixtures.
Materials & Supplies: helium, nitrogen, niobium, acids.
Surface Analysis: Hourly rate to Evans East for SIMS, XPS, AFM
Industrial personnel for technology transfer program in second and third year

## References

[1] For a review of rf superconductivity see: H. Padamsee, J. Knobloch and T. Hays, RF Superconductivity for Accelerators, Wiley, New York, 1998.

[2] H. Padamsee, "The Nature of Field Emission from Microparticles and the Ensuing Voltage Breakdown", in High Energy Density Microwaves, AIP Conference Proceedings 474, R. Phillips, ed., p. 212 (1998); G. Werner et al., "Investigation of Voltage Breakdown Caused by Microparticles", Proc. 2001 Particle Accelerator Conf., Chicago, paper MPPH127 (2001).

[3] For a review see: H. Padamsee, "The Science and Technology of Superconducting Cavities for Accelerators", Superconductor Science and Technology **14,** R28 (2001).

[4] J. Knobloch, "High Field Q-Slope in Superconducting Cavities Due to Magnetic Field Enhancement, J. Knobloch, Proceedings of the 9th Workshop on RF Superconductivity, Los Alamos National Lab, p. 77 (1999)

[5] H. Safa, "High Field Behavior of Superconducting Cavities, Proceedings of the 10th Workshop on RF Superconductivity, KEK, p. 279 (2001)

[6] J. Knobloch et al., "Design of a High Speed, High Resolution Thermometry System for 1.5 GHz Superconducting Radio Frequency Cavities", Rev. Sci. Instrum. **65,** p. 3521 (1994).

*DOE F 4620.1*
*(04-93)*
*All Other Editions Are Obsolete*

**U.S. Department of Energy**

# Budget Page

(See reverse for Instructions)

OMB Control No.
1910-1400
OMB Burden Disclosure
Statement on Reverse

| | |
|---|---|
| ORGANIZATION<br>Cornell University | **Budget Page No:** 1 |
| PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR<br>Hasan Padamsee | Requested Duration: 12 (Months) |

| A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates<br>(List each separately with title; A.6. show number in brackets) | DOE Funded Person-mos. | | | Funds Requested | Funds Granted |
|---|---|---|---|---|---|
| | CAL | ACAD | SUMR | by Applplicant | by DOE |
| 1. Hasan Padamsee - Sr. Research Associate | 0.00 | 0.00 | 0.00 | | |
| 2. | | | | | |
| 3. | | | | | |
| 4. | | | | | |
| 5. | | | | | |
| 6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE) | | | | | |
| 7. ( 1 ) TOTAL SENIOR PERSONNEL (1-6) | | | | 0.00 | 0.00 |
| B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS) | | | | | |
| 1. ( ) POST DOCTORAL ASSOCIATES | | | | | |
| 2. ( ) OTHER PROFESSIONAL (TECHNICIAN, PROGRAMMER, ETC.) | | | | | |
| 3. ( ) GRADUATE STUDENTS | | | | | |
| 4. ( ) UNDERGRADUATE STUDENTS | | | | 0.00 | 0.00 |
| 5. ( ) SECRETARIAL - CLERICAL | | | | | |
| 6. ( ) OTHER | | | | | |
| TOTAL SALARIES AND WAGES (A+B) | | | | 0.00 | 0.00 |
| C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS) | | | | | |
| TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A+B+C) | | | | 0.00 | 0.00 |
| D. PERMANENT EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM.)<br>Computers - 5000<br>Electronics - 5000 | | | | | |
| TOTAL PERMANENT EQUIPMENT | | | | 10,000.00 | 0.00 |
| E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS) | | | | 0.00 | 0.00 |
| 2. FOREIGN | | | | 0.00 | |
| TOTAL TRAVEL | | | | 0.00 | 0.00 |
| F. TRAINEE/PARTICIPANT COSTS | | | | | |
| 1. STIPENDS (Itemize levels, types + totals on budget justification page) | | | | | |
| 2. TUITION & FEES | | | | | |
| 3. TRAINEE TRAVEL | | | | | |
| 4. OTHER (fully explain on justification page) | | | | | |
| TOTAL PARTICIPANTS ( ) TOTAL COST | | | | 0.00 | 0.00 |
| G. OTHER DIRECT COSTS | | | | | |
| 1. MATERIALS AND SUPPLIES | | | | 6,329.00 | |
| 2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION | | | | | |
| 3. CONSULTANT SERVICES | | | | | |
| 4. COMPUTER (ADPE) SERVICES | | | | | |
| 5. SUBCONTRACTS | | | | | |
| 6. OTHER | | | | | |
| TOTAL OTHER DIRECT COSTS | | | | 6,329.00 | 0.00 |
| H. TOTAL DIRECT COSTS (A THROUGH G) | | | | 16,329.00 | 0.00 |
| I. INDIRECT COSTS (SPECIFY RATE AND BASE)<br>MTDC - 6,329 @ 58% | | | | | |
| TOTAL INDIRECT COSTS | | | | 3,671.00 | |
| J. TOTAL DIRECT AND INDIRECT COSTS (H+I) | | | | 20,000.00 | 0.00 |
| K. AMOUNT OF ANY REQUIRED COST SHARING FROM NON-FEDERAL SOURCES | | | | | |
| L. TOTAL COST OF PROJECT (J+K) | | | | 20,000.00 | 0.00 |

*DOE F 4620.1*

*(04-93)*

*All Other Editions Are Obsolete*

**U.S. Department of Energy**

# Budget Page

(See reverse for Instructions)

OMB Control No.

1910-1400

OMB Burden Disclosure

Statement on Reverse

ORGANIZATION Cornell University

**Budget Page No:** 2

PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR Hasan Padamsee

Requested Duration: 12 (Months)

| A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title; A.6. show number in brackets) | DOE Funded Person-mos. CAL | ACAD | SUMR | Funds Requested by Applpicant | Funds Granted by DOE |
|---|---|---|---|---|---|
| 1. Hasan Padamsee - Sr. Research Associate | 0.00 | 0.00 | 0.00 | | |
| 2. | | | | | |
| 3. | | | | | |
| 4. | | | | | |
| 5. | | | | | |
| 6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE) | | | | | |
| 7. ( 1 ) TOTAL SENIOR PERSONNEL (1-6) | | | | 0.00 | 0.00 |
| B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS) | | | | | |
| 1. ( ) POST DOCTORAL ASSOCIATES | | | | | |
| 2. ( ) OTHER PROFESSIONAL (TECHNICIAN, PROGRAMMER, ETC.) | | | | | |
| 3. ( ) GRADUATE STUDENTS | | | | | |
| 4. ( ) UNDERGRADUATE STUDENTS | | | | | |
| 5. ( ) SECRETARIAL - CLERICAL | | | | | |
| 6. ( ) OTHER | | | | | |
| TOTAL SALARIES AND WAGES (A+B) | | | | 0.00 | 0.00 |
| C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS) | | | | | |
| TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A+B+C) | | | | 0.00 | 0.00 |
| D. PERMANENT EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM.)<br>RF for cavity testing- 10000<br>Vacuum - 5000<br>Electronics - 10000<br>Chemical equip - 20000 | | | | | |
| TOTAL PERMANENT EQUIPMENT | | | | 45,000.00 | |
| E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS) | | | | 0.00 | |
| 2. FOREIGN | | | | 0.00 | |
| TOTAL TRAVEL | | | | 0.00 | 0.00 |
| F. TRAINEE/PARTICIPANT COSTS | | | | | |
| 1. STIPENDS (Itemize levels, types + totals on budget justification page) | | | | | |
| 2. TUITION & FEES | | | | | |
| 3. TRAINEE TRAVEL | | | | | |
| 4. OTHER (fully explain on justification page) | | | | | |
| TOTAL PARTICIPANTS ( ) TOTAL COST | | | | 0.00 | 0.00 |
| G. OTHER DIRECT COSTS | | | | | |
| 1. MATERIALS AND SUPPLIES | | | | 25,127.00 | |
| 2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION | | | | | |
| 3. CONSULTANT SERVICES | | | | 35,000.00 | |
| 4. COMPUTER (ADPE) SERVICES | | | | | |
| 5. SUBCONTRACTS | | | | | |
| 6. OTHER | | | | | |
| TOTAL OTHER DIRECT COSTS | | | | 60,127.00 | 0.00 |
| H. TOTAL DIRECT COSTS (A THROUGH G) | | | | 105,127.00 | 0.00 |
| I. INDIRECT COSTS (SPECIFY RATE AND BASE)<br>MTDC - 60127 @ 58% | | | | | |
| TOTAL INDIRECT COSTS | | | | 34,873.00 | |
| J. TOTAL DIRECT AND INDIRECT COSTS (H+I) | | | | 140,000.00 | 0.00 |
| K. AMOUNT OF ANY REQUIRED COST SHARING FROM NON-FEDERAL SOURCES | | | | | |
| L. TOTAL COST OF PROJECT (J+K) | | | | 140,000.00 | 0.00 |

*DOE F 4620.1*
*(04-93)*
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# Budget Page

(See reverse for Instructions)

OMB Control No.
1910-1400
OMB Burden Disclosure
Statement on Reverse

ORGANIZATION Cornell University

**Budget Page No:** 3

PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR Hasan Padamsee

Requested Duration: 12 (Months)

| A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title; A.6. show number in brackets) | DOE Funded Person-mos. CAL | ACAD | SUMR | Funds Requested by Applpicant | Funds Granted by DOE |
|---|---|---|---|---|---|
| 1. Hasan Padamsee - Sr. Research Associate | 0.00 | 0.00 | 0.00 | | |
| 2. | | | | | |
| 3. | | | | | |
| 4. | | | | | |
| 5. | | | | | |
| 6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE) | | | | | |
| 7. ( 1 ) TOTAL SENIOR PERSONNEL (1-6) | | | | 0.00 | 0.00 |
| B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS) | | | | | |
| 1. ( ) POST DOCTORAL ASSOCIATES | | | | | |
| 2. ( ) OTHER PROFESSIONAL (TECHNICIAN, PROGRAMMER, ETC.) | | | | | |
| 3. ( ) GRADUATE STUDENTS | | | | | |
| 4. ( ) UNDERGRADUATE STUDENTS | | | | | |
| 5. ( ) SECRETARIAL - CLERICAL | | | | | |
| 6. ( ) OTHER | | | | | |
| TOTAL SALARIES AND WAGES (A+B) | | | | 0.00 | 0.00 |
| C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS) | | | | | |
| TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A+B+C) | | | | 0.00 | 0.00 |
| D. PERMANENT EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM.)<br>Welding fixtures - 12000<br>Furnace fixtures - 12000<br>Assembly fixtures - 10000 | | | | | |
| TOTAL PERMANENT EQUIPMENT | | | | 34,000.00 | |
| E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS) | | | | 0.00 | |
| 2. FOREIGN | | | | 0.00 | |
| TOTAL TRAVEL | | | | 0.00 | 0.00 |
| F. TRAINEE/PARTICIPANT COSTS | | | | | |
| 1. STIPENDS (Itemize levels, types + totals on budget justification page) | | | | | |
| 2. TUITION & FEES | | | | | |
| 3. TRAINEE TRAVEL | | | | | |
| 4. OTHER (fully explain on justification page) | | | | | |
| TOTAL PARTICIPANTS ( ) TOTAL COST | | | | 0.00 | 0.00 |
| G. OTHER DIRECT COSTS | | | | | |
| 1. MATERIALS AND SUPPLIES | | | | 32,089.00 | |
| 2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION | | | | | |
| 3. CONSULTANT SERVICES | | | | 35,000.00 | |
| 4. COMPUTER (ADPE) SERVICES | | | | | |
| 5. SUBCONTRACTS | | | | | |
| 6. OTHER | | | | | |
| TOTAL OTHER DIRECT COSTS | | | | 67,089.00 | 0.00 |
| H. TOTAL DIRECT COSTS (A THROUGH G) | | | | 101,089.00 | 0.00 |
| I. INDIRECT COSTS (SPECIFY RATE AND BASE)<br>MTDC - 67089 @ 58% | | | | | |
| TOTAL INDIRECT COSTS | | | | 38,911.00 | |
| J. TOTAL DIRECT AND INDIRECT COSTS (H+I) | | | | 140,000.00 | 0.00 |
| K. AMOUNT OF ANY REQUIRED COST SHARING FROM NON-FEDERAL SOURCES | | | | | |
| L. TOTAL COST OF PROJECT (J+K) | | | | 140,000.00 | 0.00 |

## Budget Justification

Equipment: Computers and electronics for thermometry data acquisitio, RF for cavity testing, vacuum, chemical equipment, fixtures.
Materials & Supplies: helium, nitrogen, niobium, acids
Surface Analysis: Hourly rate to Evans East for SIMS, XPS, AFM
Industrial personnel for technology transfer program in second and third year

Indirect costs are calculated at Cornell’s 58% rate on modified total direct costs.

## 2.2 WBS 3.9.10: New cavity shapes and new materials

# SUMMARY OF PROPOSED WORK

**This supplemental R&D request is to fund a pilot program.**

## Background

**The GDE (the Global Design Effort) for the ILC has adopted a Baseline Configuration Design (BCD) to create the "Reference Design" [1] and a subsequent cost estimate. The Baseline is a "forward looking" configuration with reasonable confidence to achieve the required performance. The Baseline Document also has "Alternate Configurations" which promote R&D to improve performance and lower cost between now and the time that the ILC will ready for construction.**

**Among the recommended alternatives in the BCD document those likely to mature in a few years are: (a) two new cavity shapes, different from the baseline TESLA shape, and (b) better starting niobium material in the form of large grain (about 10 cm grain size) niobium and single grain niobium.**

**The alternative shapes and materials are promising for the following reasons.**

## New Cavity Shapes

**One alternate shape is called the "Low Loss (LL)" shape developed by a DESY/KEK/JLab collaboration [2] and the other is the "Re-entrant (RE)" shape developed by Cornell under NSF funding [3]. Both shapes provide a 10% reduction in the peak surface magnetic field for a fixed accelerating field. Since the magnetic field presents a fundamental limit to the highest possible gradient (via the critical rf magnetic field for the superconductor), the new shapes allow higher ultimate performance. Thus the baseline gradient may improve about 10% and correspondingly the linac length may be shorter by 10%. Since the superconducting linac is one of the most expensive components of the ILC, the cost impact can be significant.**

**Both new shapes also raise the peak surface electric field, making field emission control more challenging. Field emission currents increase the heat load and present a high radiation environment which can damage electronics in the accelerator tunnel. But field emission does not present a hard gradient limit, as does the critical magnetic field. Field emission can be kept under control by available cleaning methods as well as by high power rf conditioning.**

**The Low Loss shape has the disadvantage that it reduces the aperture from 70 mm to 60 mm to reach the lower peak magnetic field. This raises the wakefields and demands tighter alignment tolerances of cavities in the cryomodule. The re-entrant shape has the same 70 mm aperture as the baseline ILC shape, so that proven alignment tolerances will remain acceptable. (If the re-entrant shape also incorporates a 60 mm aperture, the peak magnetic field can be reduced by 15% relative to the baseline shape.)**

**The best gradient in a single cell 1.3 GHz cavity of the baseline shape is 42 MV/m, achieved by KEK, DESY and others [4]. This bodes well for the baseline choice of 35 MV/m for acceptance gradient of the full-scale 9-cell ILC structures at 1.3 GHz.**

# SUMMARY OF PROPOSED WORK

**In June 05, Cornell fabricated and tested the first single cell re-entrant cavity at 1.3 GHz to break the world record gradient by reaching an accelerating field of 47 MV/m [5]. In September 05, a Cornell/KEK collaboration established a new world record gradient of 52 MV/m in a single-cell cavity of re-entrant shape (70 mm aperture). This cavity was fabricated and purified at Cornell and subsequently treated and tested at KEK.**

**KEK and Jlab are aggressively pursuing the Low Loss shape. The best gradient so far in the LL shape is 47 MV/m established by the KEK group. Thus the higher performing re-entrant shape would be a unique opportunity for the NSF to make an impact on the ILC.**

## New Materials

**The idea of using large grain (about 10 cm grain size) and single grain niobium instead of the standard small grain (50 um grain size) originated at Jlab, and is now spreading rapidly through the SRF community[6]. Large grain sheets have the potential of providing significant material cost savings as well as better performance.**

**The large grain sheets are sliced directly from the high purity ingot so that the final sheet purity is better than standard material which has to go through many steps of forging, rolling and annealing. Each step presents the danger of embedding impurities, which will limit performance. If the slicing costs can be made low enough, the ingot slices would be less expensive than small grain material. The presence of grain boundaries is known to deteriorate the performance of superconducting cavities at high fields, so that cavities prepared from large grain material generally perform better [7].**

**Another potential cost benefit is the elimination of an advanced and expensive chemical treatment procedure, called electropolishing, This procedure is essential to achieve smooth surfaces on small grain Nb with a large density of grain boundaries [4]. Electropolishing has been adopted as the baseline treatment in the BCD. With large grain Nb it is possible to achieve a smooth surface using the standard chemical etching, again due to the few grain boundaries present[6]. The standard etching is much simpler and less expensive than electropolishing.**

**Large grain material is available from several Nb suppliers, but single grain material is scarce. One company has succeeded with one ingot which allowed 7 cm single grain sheets. These have been used by Jlab to make smaller (2.2 GHz) single-cell cavities which reach 45 MV/m [6]. DESY has gently rolled down thick single crystal material to make a single grain 1.3 GHz single-cell cavity[8].**

## First Steps -- The Pilot Program

**The ultimate goal of our ILC effort is to determine whether full-scale 9-cell, 1.3 GHz, re-entrant structures made from large grain (or single grain when available) and prepared by the standard chemical treatment process will significantly exceed the baseline level of performance so that the new shape, materials and procedures can replace the baseline. Toward this end, we propose to start with a pilot program to make several single cell cavities. Our supplementary proposal requests funding for the pilot program.**

# SUMMARY OF PROPOSED WORK

**This proposal will be unique to NSF/Cornell, since only Cornell is pursuing the re-entrant shape. In order for ILC to eventually adopt any of these alternative ideas, it will be essential to prove full-scale 9-cell structures, so that the results can be directly compared with 35 MV/m performance possible from standard structures, materials and treatments adopted by the ILC BCD.**

**Guided by the results from the pilot program, Cornell LEPP plans to incorporate a similar program based on full-scale 9-cell structures into a later comprehensive ILC R&D proposal from LEPP.**

**The steps we aim to follow in the pilot program are:**

*** Procure sufficient Nb of two types to fabricate six 1-cell cavities of the re-entrant shape. The two types of Nb are:**
**- large grain Nb with RRR = 300 - 400**
**- single grain Nb with sufficient thickness to roll blank discs for 1.3 GHz cavities**

*** Fabricate six one-cell cavities of the re-entrant shape with each variety of Nb using qualified industry to fabricate the cavities.**

*** Use the best methods for surface preparation and testing established at Cornell LEPP over many years**
**- post purification in our 1400 C furnace**
**- barrel polishing to smooth all mechanical imperfections including welds**
**- electropolishing/buffer chemical polishing (for performance comparison between large grain and single grain)**
**- heating at 800 C to remove H**
**- final electropolishing and standard chem. polishing**
**- high pressure rinsing**
**- pump drying with heating**
**- in-situ baking at 120 C**
**- standard rf cold testing**
**- high pulsed power processing to ameliorate any residual field emission if needed**

*** Prepare a 1.3 GHz thermometry diagnostic system (similar to our successful 1.5 GHz system) to study fundamental aspects of large grain and single grain cavity behavior and compare to the small grain cavity behavior.**

**We already have most of the needed facilities for cavity fabrication, chemical treatment, high pressure rinsing, high power processing, clean room, testing cavities.**

**The time scale for the pilot program is 1.5 years.**

## References

**[1] http://www.linearcollider.org/wiki/doku.php?id=bcd:bcd_home**

**[2] Design Of A Low Loss SRF Cavity for the ILC, J. Sekutowicz, K. Ko, L. Ge, L. Lee, Z. Li, C. Ng, G. Schussman, L. Xiao, I. Gonin, T. Khabibouline, N. Solyak ,Y. Morozumi, K. Saito, KEK, P. Kneisel, Proceedings of 2005 Particle Accelerator Conference, p. 3342 (2005).**

**[3] An Optimized Shape Cavity For Tesla: Concept And Fabrication, V. Shemelin, R. L. Geng, J. Kirchgessner, H. Padamsee, J. Sears , Proceedings of the 2003 Particle Accelerator Conference, p. 1314 (2003).**

**[4] Development Of Electropolishing Technology For Superconducting Cavities , K.Saito, Proceedings of the 2003 Particle Accelerator Conference, p. 462 (2003).**

**[5] World Record Accelerating Gradient Achieved in a Superconducting Niobium RF Cavity, R.L. Geng, H. Padamsee, A. Seaman, V. Shemelin. Proceedings of 2005 Particle Accelerator Conference, p. 653 (2005).**
**See also CERN Courier, June 2005, p. 32.**

**[6] Preliminary Results From Single Crystal And Very Large Crystal Niobium Cavities, P. Kneisel, G.R. Myneni, G. Ciovati, J. Sekutowicz, T. Carneiro. Proceedings of 2005 Particle Accelerator Conference, p. 3991 (2005).**

**[7] G. Ciovati, PhD. Thesis, Old Dominion University and Jefferson Lab.**

**[8] W. Singer et al, TTC meeting Frascati, Dec 05.**

# JUSTIFICATION FOR SUPPLEMENTAL FUNDING

**This supplemental R&D request is to fund a pilot program to explore two promising ideas that raise gradient performance and lower costs in superconducting niobium cavities for the ILC (International Linear Collider).**

# SUMMARY PROPOSAL BUDGET

**YEAR 1**

| | FOR NSF USE ONLY | | |
|---|---|---|---|
| ORGANIZATION | PROPOSAL NO. | DURATION (months) | |
| **Cornell University - Endowed** | | Proposed | Granted |
| PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR | AWARD NO. | | |
| **Maury Tigner** | | | |

| A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets) | NSF Funded Person-months | | | Funds Requested By proposer | Funds granted by NSF (if different) |
|---|---|---|---|---|---|
| | CAL | ACAD | SUMR | | |
| 1. **Maury Tigner - Professor** | 0.00 | 0.00 | 0.00 | $ 0 | $ |
| 2. **Hasan Padamsee - Senior Research Associate** | 0.00 | 0.00 | 0.00 | 0 | |
| 3. | | | | | |
| 4. | | | | | |
| 5. | | | | | |
| 6. ( 0 ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE) | 0.00 | 0.00 | 0.00 | 0 | |
| 7. ( 2 ) TOTAL SENIOR PERSONNEL (1 - 6) | 0.00 | 0.00 | 0.00 | 0 | |
| B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS) | | | | | |
| 1. ( 0 ) POST DOCTORAL ASSOCIATES | 0.00 | 0.00 | 0.00 | 0 | |
| 2. ( 2 ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.) | 24.00 | 0.00 | 0.00 | 100,000 | |
| 3. ( 0 ) GRADUATE STUDENTS | | | | 0 | |
| 4. ( 0 ) UNDERGRADUATE STUDENTS | | | | 0 | |
| 5. ( 0 ) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY) | | | | 0 | |
| 6. ( 0 ) OTHER | | | | 0 | |
| TOTAL SALARIES AND WAGES (A + B) | | | | 100,000 | |
| C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS) | | | | 33,000 | |
| TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C) | | | | 133,000 | |
| D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) | | | | | |
| **Barrel Polishing Equipment** | | | $ 7,000 | | |
| **Chemical Apparatus** | | | 3,500 | | |
| **Fabricatin (6 cavities)** | | | 30,000 | | |
| **Others (See Budget Comments Page...)** | | | 39,500 | | |
| TOTAL EQUIPMENT | | | | 80,000 | |
| E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS) | | | | 0 | |
| 2. FOREIGN | | | | 0 | |
| F. PARTICIPANT SUPPORT COSTS | | | | | |
| 1. STIPENDS $ 0 | | | | | |
| 2. TRAVEL 0 | | | | | |
| 3. SUBSISTENCE 0 | | | | | |
| 4. OTHER 0 | | | | | |
| TOTAL NUMBER OF PARTICIPANTS ( 0 ) TOTAL PARTICIPANT COSTS | | | | 0 | |
| G. OTHER DIRECT COSTS | | | | | |
| 1. MATERIALS AND SUPPLIES | | | | 18,500 | |
| 2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION | | | | 0 | |
| 3. CONSULTANT SERVICES | | | | 0 | |
| 4. COMPUTER SERVICES | | | | 0 | |
| 5. SUBAWARDS | | | | 0 | |
| 6. OTHER | | | | 0 | |
| TOTAL OTHER DIRECT COSTS | | | | 18,500 | |
| H. TOTAL DIRECT COSTS (A THROUGH G) | | | | 231,500 | |
| I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)<br>**MTDC - a (Rate: 58.0000, Base: 15417) (Cont. on Comments Page)** | | | | | |
| TOTAL INDIRECT COSTS (F&A) | | | | 10,761 | |
| J. TOTAL DIRECT AND INDIRECT COSTS (H + I) | | | | 242,261 | |
| K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.) | | | | 0 | |
| L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K) | | | | $ 242,261 | $ |

| | | | |
|---|---|---|---|
| M. COST SHARING PROPOSED LEVEL $ 0 | AGREED LEVEL IF DIFFERENT $ | | |
| PI/PD NAME | FOR NSF USE ONLY | | |
| **Maury Tigner** | INDIRECT COST RATE VERIFICATION | | |
| ORG. REP. NAME* | Date Checked | Date Of Rate Sheet | Initials - ORG |

***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

# SUMMARY PROPOSAL BUDGET COMMENTS - Year 1

** D- Equipment
Flanges, etc. (Amount: $ 3500)
Pure Niobium (Amount: $ 16000)
Thermometry System (Amount: $ 20000)
** I- Indirect Costs
MTDC - b (Rate: 59.0000, Base 3083)

# SUMMARY PROPOSAL BUDGET

**YEAR 2**

| | | | |
|---|---|---|---|
| ORGANIZATION<br>**Cornell University - Endowed** | **FOR NSF USE ONLY**<br>PROPOSAL NO. | DURATION (months)<br>Proposed | <br>Granted |
| PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR<br>**Maury Tigner** | AWARD NO. | | |

| A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets) | NSF Funded Person-months CAL | ACAD | SUMR | Funds Requested By proposer | Funds granted by NSF (if different) |
|---|---|---|---|---|---|
| 1. **Maury Tigner - Professor** | 0.00 | 0.00 | 0.00 | $ 0 | $ |
| 2. **Hasan Padamsee - Senior Research Associate** | 0.00 | 0.00 | 0.00 | 0 | |
| 3. | | | | | |
| 4. | | | | | |
| 5. | | | | | |
| 6. ( 0 ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE) | 0.00 | 0.00 | 0.00 | 0 | |
| 7. ( 2 ) TOTAL SENIOR PERSONNEL (1 - 6) | 0.00 | 0.00 | 0.00 | 0 | |
| B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS) | | | | | |
| 1. ( 0 ) POST DOCTORAL ASSOCIATES | 0.00 | 0.00 | 0.00 | 0 | |
| 2. ( 2 ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.) | 12.00 | 0.00 | 0.00 | 52,500 | |
| 3. ( 0 ) GRADUATE STUDENTS | | | | 0 | |
| 4. ( 0 ) UNDERGRADUATE STUDENTS | | | | 0 | |
| 5. ( 0 ) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY) | | | | 0 | |
| 6. ( 0 ) OTHER | | | | 0 | |
| TOTAL SALARIES AND WAGES (A + B) | | | | 52,500 | |
| C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS) | | | | 17,325 | |
| TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C) | | | | 69,825 | |
| D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) | | | | | |
| **Barrel Polishing Equipment** $ 3,000 | | | | | |
| **Chemical Apparatus** 1,500 | | | | | |
| **Fabrication ( cavities)** 10,000 | | | | | |
| **Others (See Budget Comments Page...)** 10,500 | | | | | |
| TOTAL EQUIPMENT | | | | 25,000 | |
| E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS) | | | | 0 | |
| 2. FOREIGN | | | | 0 | |
| F. PARTICIPANT SUPPORT COSTS | | | | | |
| 1. STIPENDS $ 0 | | | | | |
| 2. TRAVEL 0 | | | | | |
| 3. SUBSISTENCE 0 | | | | | |
| 4. OTHER 0 | | | | | |
| TOTAL NUMBER OF PARTICIPANTS ( 0 ) TOTAL PARTICIPANT COSTS | | | | 0 | |
| G. OTHER DIRECT COSTS | | | | | |
| 1. MATERIALS AND SUPPLIES | | | | 6,500 | |
| 2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION | | | | 0 | |
| 3. CONSULTANT SERVICES | | | | 0 | |
| 4. COMPUTER SERVICES | | | | 0 | |
| 5. SUBAWARDS | | | | 0 | |
| 6. OTHER | | | | 0 | |
| TOTAL OTHER DIRECT COSTS | | | | 6,500 | |
| H. TOTAL DIRECT COSTS (A THROUGH G) | | | | 101,325 | |
| I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)<br>**MTDC (Rate: 59.0000, Base: 6500)** | | | | | |
| TOTAL INDIRECT COSTS (F&A) | | | | 3,835 | |
| J. TOTAL DIRECT AND INDIRECT COSTS (H + I) | | | | 105,160 | |
| K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.) | | | | 0 | |
| L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K) | | | | $ 105,160 | $ |

| | | | |
|---|---|---|---|
| M. COST SHARING PROPOSED LEVEL $ 0 | AGREED LEVEL IF DIFFERENT $ | | |
| PI/PD NAME<br>**Maury Tigner** | **FOR NSF USE ONLY**<br>INDIRECT COST RATE VERIFICATION | | |
| ORG. REP. NAME* | Date Checked | Date Of Rate Sheet | Initials - ORG |

***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

# SUMMARY PROPOSAL BUDGET COMMENTS - Year 2

** D- Equipment
Flanges, etc. (Amount: $ 1500)
Pure Niobuim (Amount: $ 9000)

# SUMMARY PROPOSAL BUDGET

Cumulative

| | | | |
|---|---|---|---|
| ORGANIZATION<br>**Cornell University - Endowed** | **FOR NSF USE ONLY**<br>PROPOSAL NO. | DURATION (months)<br>Proposed | <br>Granted |
| PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR<br>**Maury Tigner** | AWARD NO. | | |

| A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets) | NSF Funded Person-months<br>CAL | <br>ACAD | <br>SUMR | Funds Requested By proposer | Funds granted by NSF (if different) |
|---|---|---|---|---|---|
| 1. **Maury Tigner - Professor** | 0.00 | 0.00 | 0.00 | $ 0 | $ |
| 2. **Hasan Padamsee - Senior Research Associate** | 0.00 | 0.00 | 0.00 | 0 | |
| 3. | | | | | |
| 4. | | | | | |
| 5. | | | | | |
| 6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE) | 0.00 | 0.00 | 0.00 | 0 | |
| 7. ( 2 ) TOTAL SENIOR PERSONNEL (1 - 6) | 0.00 | 0.00 | 0.00 | 0 | |
| B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS) | | | | | |
| 1. ( 0 ) POST DOCTORAL ASSOCIATES | 0.00 | 0.00 | 0.00 | 0 | |
| 2. ( 4 ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.) | 36.00 | 0.00 | 0.00 | 152,500 | |
| 3. ( 0 ) GRADUATE STUDENTS | | | | 0 | |
| 4. ( 0 ) UNDERGRADUATE STUDENTS | | | | 0 | |
| 5. ( 0 ) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY) | | | | 0 | |
| 6. ( 0 ) OTHER | | | | 0 | |
| TOTAL SALARIES AND WAGES (A + B) | | | | 152,500 | |
| C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS) | | | | 50,325 | |
| TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C) | | | | 202,825 | |
| D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)<br>$ 105,000 | | | | | |
| TOTAL EQUIPMENT | | | | 105,000 | |
| E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS) | | | | 0 | |
| 2. FOREIGN | | | | 0 | |
| F. PARTICIPANT SUPPORT COSTS<br>1. STIPENDS $ 0<br>2. TRAVEL 0<br>3. SUBSISTENCE 0<br>4. OTHER 0 | | | | | |
| TOTAL NUMBER OF PARTICIPANTS ( 0 ) TOTAL PARTICIPANT COSTS | | | | 0 | |
| G. OTHER DIRECT COSTS | | | | | |
| 1. MATERIALS AND SUPPLIES | | | | 25,000 | |
| 2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION | | | | 0 | |
| 3. CONSULTANT SERVICES | | | | 0 | |
| 4. COMPUTER SERVICES | | | | 0 | |
| 5. SUBAWARDS | | | | 0 | |
| 6. OTHER | | | | 0 | |
| TOTAL OTHER DIRECT COSTS | | | | 25,000 | |
| H. TOTAL DIRECT COSTS (A THROUGH G) | | | | 332,825 | |
| I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) | | | | | |
| TOTAL INDIRECT COSTS (F&A) | | | | 14,596 | |
| J. TOTAL DIRECT AND INDIRECT COSTS (H + I) | | | | 347,421 | |
| K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.) | | | | 0 | |
| L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K) | | | | $ 347,421 | $ |

| | | | |
|---|---|---|---|
| M. COST SHARING PROPOSED LEVEL $ 0 | AGREED LEVEL IF DIFFERENT $ | | |
| PI/PD NAME<br>**Maury Tigner** | **FOR NSF USE ONLY**<br>INDIRECT COST RATE VERIFICATION | | |
| ORG. REP. NAME* | Date Checked | Date Of Rate Sheet | Initials - ORG |

C ***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

# Budget Justification Page

**The time scale for the pilot program is 1.5 years.**

**Direct Costs**

**The costs for the pilot program (1.5 years) are**

| | |
|---|---|
| **Pure Niobium ‘** | **25 K** |
| **Flanges etc** | **5 K** |
| **Fabrication for 6 cavities** | **40 K** |
| **Barrel Polishing equipment** | **10 K** |
| **Chemical apparatus** | **5 K** |
| **Helium for tests** | **20 K** |
| **Chemicals** | **5 K** |
| **Thermometry system** | **20 K** |

**Total purchases: 130 K**

**----------Plus Additional Manpower ------**

| | |
|---|---|
| **One RA** | **60/year** |
| **One tech ‘** | **40 K/year** |

**Fringe benefit rate is 33%**
**Indirect cost rate is 58% through June 07 and 59% thereafter. Here MTDC is direct cost minus capital equipment.**