Report of the HEPAP Subpanel on the Assessment of Advanced Accelerator Research and Development

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Executive Summary

The EPP2010 report from the National Research Council highlighted the importance of accelerators and accelerator R&D as a critical element of a world-competitive US particle physics program. Recognizing this importance, the DOE Office of High Energy Physics (OHEP) and the NSF Directorate of Mathematical and Physical Sciences charged the HEPAP Subpanel on Advanced Accelerator R&D to undertake a comprehensive assessment of all aspects of the OHEP and NSF accelerator R&D programs, addressing issues of relevance to national goals, stewardship, scope, quality, relevance, resources, management and training.

The remarkable discoveries over more than 50 years of particle physics were made possible because of progress and innovation in accelerator science and technology. Today, accelerators are also critical to other programs in the Office of Science and the national scientific enterprise, and they can significantly impact the economy, health, and security. The future of accelerator-based science and applications will be limited unless new ideas and new accelerator directions are developed. Likewise, the demands for trained accelerator professionals far exceed what can be provided by today's limited educational opportunities. The subpanel finds that there is an urgent need to strengthen accelerator science, technology and education in the US in order to address long-term needs of particle physics, other sciences and the nation.

Within the DOE OHEP the breadth of accelerator R&D programs is generally appropriate to meeting national goals--to enable those aspects of accelerator science and technology that have a strong potential to advance the capabilities of particle physics research. This report contains specific recommendations to sharpen the focus and strengthen these programs.

For decades, OHEP has had a historical stewardship of accelerator science and technology, which has resulted in substantial benefits to science and the nation. The subpanel endorses the importance of this stewardship responsibility and recommends that the mission statement of OHEP should be modified to include the following: *"The Office of High Energy Physics (OHEP) provides program planning, oversight and funding for research in fundamental accelerator science and technology.*

The NSF Particle Physics Program provides significant support for accelerator science and R&D at two user facilities (Cornell and Michigan State University) and several universities. The proposed new Accelerator Physics and Physics Instrumentation (APPI) program will provide additional funding for grant-based accelerator science and be a major step towards recognition of the importance of accelerator science. *The subpanel recommends that APPI should be established and funded.*

The education and the training of the next generation of accelerator scientists and engineers is a serious concern. The limited number of educational opportunities at universities is insufficient to meet anticipated future needs. The DOE and NSF have had the foresight to encourage and support university accelerator programs and should seek to expand these programs where possible. For this to happen, accelerator science and technology must be more broadly recognized as an important scientific discipline starting at the university level. A graduate fellowship program would help attract the best students and improve the visibility and stature of the field. *The subpanel recommends that an Accelerator Science Graduate Fellowship program in the DOE and NSF should be given high priority.*

The subpanel identified a number of critical enabling technologies for accelerator R&D on existing, planned or envisioned facilities. It appears that the key issues are being addressed and the overall quality of the R&D is very high. The program is generally well balanced given the level of available support. To sustain this level of quality, the right conditions must be provided including relatively stable funding, modernization of infrastructure when necessary, and a continuous inflow of well-trained new researchers. Early industrial involvement in design and optimization for large-scale mass production is critical and should be supported.

A primary focus of the subpanel is the longer-term accelerator R&D programs supported by OHEP and NSF. The mission of the DOE Office of Science requires a program of long-term R&D consisting of exploratory research aimed at developing new and innovative concepts in accelerator physics and technology, at new materials to advance these technologies, and at the fundamental physics, mathematics and understanding through simulations essential to the advancement of accelerator science. The NSF also supports accelerator research through its Particle Physics Program.

These programs support a balanced portfolio of both curiosity-driven and strategic research in cutting edge aspects of accelerator science and technology. The subpanel finds that these unique programs provide very high scientific value. For the long-term R&D to be successful it must be supported with high priority even in times of budget stress. *The subpanel recommends that this accelerator science support be protected at both the agencies and the laboratories to maintain stable levels of funding.*

The subpanel also recommends that the percentage of the OHEP budget assigned for long-term accelerator science should be 5% in FY07, and increased gradually and smoothly to 6% over the next ten year period.

To strengthen the management of medium and long-term accelerator R&D in OHEP, *the subpanel recommends that these programs be subject to a yearly review by a broad-based committee of accelerator scientists, including members who are cognizant of the possible longer-term accelerator needs of the other Office of Science and NSF programs. This committee should be appointed with overlapping terms to assure continuity.*

Accelerator science is a field of science with a strong international flavor, and evolution towards an eventual global strategy is natural and inevitable. A global strategy would consider the complementary capabilities available and seek to optimize the use of resources in the best interests of science and the participating nations. Such a strategy would, of necessity, require a broadly accepted view of what R&D should be considered in a worldwide context and what is best left to regional entities.

The subpanel believes that OHEP should develop a strategic framework for its portfolio of mid-term and long-term accelerator R&D. This framework should be consistent with the overall strategic direction of particle physics and the anticipated needs of the Office of Science, in the context of international efforts. *The subpanel recommends that OHEP develop a strategic plan* *for medium-term AARD based on the upcoming P5 Roadmap for HEP. This plan should be reviewed by the committee described above and updated on a yearly basis.*

For long-term accelerator R&D, a set of principles should be developed to guide the management of that program. The breadth of long-term accelerator R&D should reflect the stewardship responsibility of OHEP for accelerator science and technology. Contributions from the universities, the laboratories and industry should be encouraged. High priority should be given to R&D that holds the promise of producing new inventions, techniques, approaches or technologies to extend the reach of accelerator-based physics and to research of the highest quality that addresses fundamental aspects of accelerator science. Activities that contribute to the education and training of students and postdocs and collaborative activities should be strongly encouraged.

A major challenge for the accelerator science community is to identify and develop new concepts for future energy frontier accelerators that will be able to provide the exploration tools needed for HEP within a feasible cost to society. The future of accelerator-based HEP will be limited unless new ideas and new accelerator directions are developed to address the demands of beam energy and luminosity and consequently the management of beam power, energy recovery, accelerator power, size, and cost.

To conclude, the subpanel emphasizes the critical importance of accelerator science and technology to particle physics, other sciences and to the nation. The US is fortunate to have a strong, world-class accelerator program. Maintaining and extending the health and vitality of this resource into the future is a challenge that must be met by the scientific community, the funding agencies, the universities, national laboratories and industry if the contributions of this field are to continue at the present high level.

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1. Introduction

The HEPAP AARD Subpanel has conducted an assessment of the Advanced Accelerator Research and Development (AARD) within the DOE Office of High Energy Physics (OHEP) and the NSF Elementary Particle Physics (EPP) Program.

We conclude that accelerator science and technology has a significant role in the OHEP and EPP program. It also benefits other programs in the DOE Office of Science and the broader scientific enterprise, and has the potential for significant impact in the health, economy and security of the nation. We feel it is essential to assure the health and vitality of research in accelerator science and technology both because of its many contributions and because of its intrinsic scientific importance.

Our report addresses the stewardship responsibility of the DOE OHEP for fundamental accelerator science and technology, and the training and education of the next generation of accelerator scientists and engineers. We analyze the full range of short, medium and longer-term R&D and offer recommendations. We consider the management of AARD in the NSF and DOE OHEP, including the grant-based AARD program and the accelerator part of the OHEP SBIR program, and we propose a framework for a strategic plan for the OHEP accelerator R&D program.

The charge to the subpanel by Dr. Robin Staffin, head of the DOE Office of Science OHEP and Dr. Michael Turner, Assistant Director of the National Science Foundation appears in Appendix 1 and the membership of the subpanel in Appendix 2. The members represent a cross section of accelerator users and accelerator scientists. They were selected to provide a broad perspective of the uses and capabilities of particle accelerators in particle physics research, including the potential of longer-term R&D to enable significant new breakthroughs.

The subpanel was asked to regard accelerator R&D as loosely partitioned into three categories: short term research, required for planned or approved new facilities or upgrades of operating facilities; medium term research, to bring new concepts to practice so that they can be considered for the design of a new facility; and longer term, exploratory research aimed at developing new concepts for acceleration, new magnet and rf technologies, new materials and scientific understanding of core material, and advanced simulation techniques. The training of accelerator physicists, engineers, and technologists is regarded by the funding agencies and the subpanel as an important goal of this effort. Accelerator R&D in all three partitions is carried out in universities, several Federally funded national laboratories, two Federally operated laboratories, and industry and has a total annual budget of about $121.5M in FY05, including R&D in support of operating and future major accelerator facilities such as the Tevatron, PEP-II, ILC ($22.6M) and LHC ($3.3M).

The charge requested that the subpanel address the following aspects related to AARD: national goals, stewardship, scope, quality, relevance, resources, management and training. The subpanel held three meetings to gather and evaluate information related to its charge. The first was held in the Washington DC area November 1-2, 2005 for the purpose of hearing from cognizant program managers from the DOE OHEP and the NSF EPP. The second meeting was held in Palo

Alto CA on December 21-22, 2005 to hear presentations from SLAC, LBNL and the west coast accelerator community. The third meeting was held at Fermilab on February 15-17, 2006 for input from Fermilab, ANL, BNL, Cornell and the rest of the US accelerator community. This meeting included a series of presentations on critical technologies for the current and next generation of cutting-edge accelerator facilities for particle physics, such as superconducting radio-frequency technology and superconducting accelerator magnet technology. A component of all three meetings was a “town meeting” organized by the American Physical Society Division of Physics of Beams. A final meeting was held on May 4, 2006 near Dulles Airport to work collectively on detailed aspects of this report. The agendas for the first three meetings of the subpanel can be found in Appendix 3.

2. The Role of Accelerator R&D in the DOE OHEP, NSF and its Benefit to the Nation

Role of the Accelerator R&D in OHEP

Accelerator R&D within OHEP is a diverse forward-looking program. Its goal is to enable state-of-the-art research and development in those aspects of accelerator science and technology that have a strong potential to advance the capabilities of particle physics research. Important additional considerations are the benefit to other programs in the DOE Office of Science and the national scientific enterprise, as well as the potential for significant impact in the economy, health, security and other sectors. The program has had a historical stewardship of accelerator science and technology for decades because of its broad impact on other sciences and overall benefit to the nation.

Specifically, OHEP supports accelerator R&D targeted at several time horizons. Near term R&D enables the design and construction of the new facilities needed to advance the field-- the particle accelerators and colliders required for frontier particle physics research. It also enhances the capabilities of existing accelerator facilities such as the Tevatron at Fermilab and the PEP-II B-factory at SLAC, where there have recently been highly successful efforts to significantly improve luminosity.

Medium term accelerator R&D focuses on bringing new concepts to practice to enable the design of new facilities with advanced capabilities. This includes R&D towards the International Linear Collider (ILC) and the anticipated luminosity upgrade of the LHC, which could be approved in the next few years, as well as further future facilities like CLIC or a neutrino factory and muon collider.

Longer term accelerator research is exploratory and aimed at developing new concepts. Topics studied include sophisticated simulation techniques, advanced magnet and acceleration technologies, ultra-intense beam sources, cutting edge diagnostic techniques, and new materials utilizing new core technologies. This longer-term, multi-disciplinary research is laying the foundation for advances in accelerator science and technology that will have an impact in the decades ahead. Examples of recent progress include the achievement of extremely high accelerating gradients utilizing plasma wakefields, the development of powerful computational techniques for modeling particle beams, the application of new materials and techniques to reach extremely high magnetic fields in superconducting magnets or high gradients in superconducting cavities, and the understanding of the complex dynamics of beams in extreme conditions.

A critical contribution of the OHEP AARD program has been the training of the next generation of accelerator scientists and engineers. The program has supported the research of over 200 graduate students. Many of these PhDs have assumed lead roles in accelerator physics and nearby disciplines, such as plasma physics, lasers, and light source science. This work force is absolutely essential if accelerator science is to continue to benefit the scientific community and the nation. These professionals work in academia, in the laboratories and in industry to advance the frontiers of accelerator science. The US Particle Accelerator School, supported jointly by the NSF and DOE plays an important role in training new accelerator scientists.

Accelerator science, as it has advanced through its support by OHEP and its predecessors, has a long history of transformative contributions to science and to the nation.

In particle physics, decades of advancing techniques for high energy accelerators and colliders have opened up new territory for discovery, giving physicists access to particles and phenomena at smaller and smaller size scales. From the 1950's when the anti-proton was discovered using the Bevatron at LBNL, through the 1960's when CP violation and the second flavor of neutrinos was discovered with the AGS at Brookhaven and the quark substructure of matter was discovered with the SLAC linear accelerator, into the 1970's when the revolutionary J/Psi was co-discovered at the AGS and at the SLAC SPEAR collider, and the third generation Tau lepton was discovered at SPEAR, the accelerator science supported by OHEP and its predecessors has continued to advance the energy frontier. The pace of discovery driven by accelerators has continued in recent decades with the discovery of the bottom and top quarks and third generation neutrino at the Fermilab Tevatron and the characterization of CP violation in the decay of B-mesons at the B-factory at SLAC. The promise of the next decades includes: the discovery of the Higgs particle that manifests the underlying physics which generates the masses of elementary particles; the observation of a whole new class of particles that reflect nature's underlying supersymmetry; and even the discovery of new dimensions.

Accelerators have enabled major discoveries in laboratories outside of the US. At DESY, the gluon was discovered at PETRA. At the CERN accelerator complex, neutral weak currents were discovered at the Proton Synchrotron (PS); the W and Z bosons, carriers of the weak force, were discovered at the Super Proton Synchrotron (SPS) proton-antiproton collider; and the properties of the Z boson were measured to great precision at the LEP electron-positron collider. Recognition of the role of accelerator science at the highest level of scientific discovery is exemplified by the award of the 1984 Nobel Prize in Physics jointly to Carlo Rubbia and Simon van der Meer for the discovery of the weak bosons. Rubbia and van der Meer made the key conceptual and technical contributions that enabled the SPS to be transformed into a proton-antiproton collider, making the discovery experiment possible. In Asia, at least two accelerator-based experiments have played leading roles in particle physics in the past decade - the B-factory at KEK and the K2K neutrino experiment.

For the rest of the scientific community, accelerator science and technology have led to capabilities that were undreamed of a few decades ago. A few examples that are particularly relevant to the DOE Office of Science include the development of synchrotron radiation and pulsed neutron sources that have become cutting edge tools in such fields as materials and surface science, chemical dynamics, protein crystallography, and molecular biology. X-ray free electron lasers that are now being developed will enable dynamic studies at the femtosecond time scale and angstrom length scale where the motion of individual molecules can be resolved. Such X-ray sources promise to revolutionize material sciences and structural biology, giving unprecedented information about biological systems. This information finds practical use in the development of new medicines (recent example: new anti-AIDS drug developed by Abbott Labs, using the APS at ANL). The accelerator-based Spallation Neutron Source now starting operation at Oak Ridge uniquely enables state-of-the-art material studies using neutrons. The flagship facilities for nuclear physics are the RHIC collider at Brookhaven which was has recently recreated a fluid of quarks and gluons similar to what filled the very early universe, and the Continuous Electron Beam Accelerator Facility at Thomas Jefferson Laboratory that is elucidating the underlying quark structure of nuclear matter. The DOE Fusion Energy Science program includes utilization of intense neutral beams to heat plasmas in magnetic confinement experiments and development of intense ion accelerators to drive inertial confinement fusion and for high energy density physics.

Accelerator Science and the NSF

The NSF supports accelerator science and accelerator R&D at two major accelerator-based user facilities, Cornell University and Michigan State University, as well as at a number of universities. Cornell and MSU conduct research in nuclear, particle and synchrotron radiation science. The support for these efforts has been significant on the scale of the NSF Particle Physics Program and there is hope that support for accelerator science will increase in the future, as grant-based support of accelerator science becomes a more recognized part of the portfolio.

Accelerator R&D at the NSF accelerator-based facilities is largely focused on their own programs but a modest portion involves research topics in basic accelerator science. This R&D includes: work on a variety of superconducting rf accelerating devices; materials and surface science relevant to high power rf devices; developments related to applications in medical accelerators; optics and beam theory; simulations of accelerator operation including beam-beam effects, IR edge radiation, and beam lifetime issues; and the design of low energy compact storage rings.

NSF-supported university groups have had increased involvement in accelerator research, much of this directed at rather specific goals for new facilities. NSF has not generally supported research by university groups into basic accelerator science for its own sake, but there is increasing recognition of its scientific and educational value. For example, for several years the Muon Collider and Neutrino Factory Collaboration has involved universities in accelerator R&D. The research includes work done by individual universities and collaborative work utilizing infrastructure at the traditional accelerator laboratories. NSF has also provided limited support for university physicists on R&D for the International Linear Collider under the UCLC (University Consortium for the Linear Collider).

The NSF has begun a new program of accelerator and detector research and development. Named APPI (for Accelerator Physics and Physics Instrumentation), the program currently supports accelerator and detector R&D for the ILC, advanced acceleration techniques including plasma and laser technologies, advances in superconducting rf cavity development, and muon ionization cooling. A programmatic goal of the Physics Division is to reach an annual support level for APPI of approximately $10M/yr by the end of the decade.

An important goal of NSF support of accelerator research is educational impact. There is a significant national need for personnel trained in accelerator physics and related technologies, and it is important to attract more students into these areas. Currently most NSF-funded education and training in accelerator physics and technology takes place at the two university accelerator laboratories. This includes formal on-campus courses, degree-granting distance learning courses, distance learning technology courses without formal credit, and apprentice like programs where the students gain most of their experience working on and around the accelerators. In all of these programs, the US Particle Accelerator School, supported jointly by the NSF and DOE plays an important role. In total, the number of PhD students in accelerator physics produced through NSF support is about 6-7 per year, along with about 5 Masters students per year.

Most of the universities involved in accelerator science research do not offer comprehensive undergraduate or graduate training in the subject. The number of faculty positions in accelerator physics is also quite limited. The NSF is well positioned to encourage an increased level of research and training at the universities. The challenge will be to find the resources needed to support significant research at the universities, attract undergraduate and graduate students, and increase access to university-scale accelerator facilities for beam physics research.

Impact of Accelerator Science and Technology on the Nation

Accelerator science has a profound impact on society as a whole. There are well-established applications of accelerator science and technology in diagnostic and therapeutic medicine for research and for routine clinical treatments. A significant fraction of the radioisotopes used in treatment, diagnostics, and research are produced using accelerators. Beams of X-rays, neutrons, protons, and ions that are derived from particle accelerators are currently used in the treatment of cancer and other diseases, while accelerators are used in many biomedical research programs both to explore beam-related treatments and to develop other approaches to therapy. Each year numerous lives are saved due to the applications of accelerator science to health care. The development and improvement of superconductors for high field accelerator magnets has had a direct application in the large and competitive NMR medical diagnostic industry. Recently, electron beam-based sterilization of vulnerable components of the national food supply has added to the health benefits attributable to accelerator technology.

Accelerators and associated technologies have various important uses in industry for R&D, manufacturing, testing, and process control. Industrial researchers, in common with materials scientists in universities and national laboratories, use synchrotron radiation, neutron scattering, and other accelerator-based techniques as important tools in their R&D activities. In industry, the R&D is often undertaken to develop new products - for example, high-density magnetic storage media. In manufacturing, beams from accelerators are used to alter material composition (e.g., ion implantation); to improve important characteristics of a product (e.g., sterilization of medical equipment and the hardening of surfaces for greater wear resistance); as a basic part of the production process (e.g., ion implantation and X-ray lithography in silicon wafer production, or X-ray micromachining); to improve industrial processes (e.g., curing epoxies and plastics); and to provide information about manufacturing processes (e.g., wear studies of materials or characterization of impurities in semiconductors).

National security is also enhanced by the development of particle accelerators. Accelerator techniques, including X-ray and proton radiography hydrodynamic test facilities, can be used to test the reliability and aging of nuclear weapons without detonation. Accelerator-based systems have been developed to allow rapid screening of cargo containers to discover contraband nuclear materials.

Lastly, the World Wide Web was developed to allow rapid communication and exchange of information within the large scientific collaborations that were utilizing the accelerator complex at CERN. Even the Experimental Physics and Industrial Control System (EPICS) developed over the last decade and now used in tens of accelerators world-wide could be a possible spin-off of accelerator technology to industry.

What about the future? Will the pace of progress, discovery and contribution enabled by accelerator science and technology continue? There is very strong evidence that it will, and that the pace may indeed increase. We are in an era where new technologies and capabilities such as advanced computing, ultra-high field microwave cavities, advanced beam control electronics, high temperature superconductors, micro-machining and increased laser power are being utilized by accelerator scientists. As new technologies become available and are applied by accelerator scientists, the impact of accelerators on science, industry, national security, medicine and society as a whole will continue to grow. It is our hope and expectation that the value of accelerator science and technology to the nation will become increasingly recognized. A higher profile will lead to more training of accelerator scientists and engineers, and an increasingly synergistic interplay between the needs of particle physics, the wider scientific community and the rest of society.

3. Education and Training of the Next Generation of Accelerator Scientists and Engineers

To address the charge on the training of future accelerator scientists and technologists, we sent letters to 10 national laboratories and 43 university research groups with accelerator R&D programs asking for responses to a specific set of questions. These laboratories and university groups are listed in Appendices 4.1. and 4.2. The questions and summaries of the responses obtained are provided in Appendices 4.3 and 4.4. Additional input was provided by presentations from William Barletta, the Director of the US Particle Accelerator School (USPAS), from Gerald Dugan, the chair of the Executive Committee of the American Physical Society Division of Physics of Beams (DPB), and from a selected number of University Research Groups.

There is overwhelming recognition, both at the national laboratories and by the university faculty active in the field, that there is significant unfilled demand for accelerator scientists and engineers. Frontier accelerator R&D efforts play a major role in providing the setting and impetus for the training of the next generation. Some of the highest priority thrusts in particle physics such as the proposed ILC will require many more well-trained and exceptionally creative accelerator scientists than may be available.

There are currently a limited number of universities providing the needed opportunities for training. Such university-based research is often complementary to that of the national laboratories, and almost always provides students with experience at the cutting edge in both theory and experiment. The DOE and NSF have been farsighted in encouraging and supporting these programs and should seek to increase the number of universities participating in such research.

The US Particle Accelerator School (USPAS) also contributes in an important way to the education and training of accelerator scientists and engineers and as a result is highly valued by those in the field. The school offers high quality courses twice each year, as well as hands-on experience to students, provided by outstanding accelerator scientists and engineers from across the country.

The national laboratories often work in close collaboration with university faculty and students, and so strongly contribute to training in accelerator science and technology. The laboratory facilities for experimental accelerator science play an essential role both in faculty research and in the training and research of future accelerator professionals.

A significant problem, which limits the availability of an accelerator science education at the universities, is that accelerator science and technology is not yet broadly recognized as an essential, vital, and exciting frontier research field. In most universities it is not considered as an academic subject worthy of faculty lines. Few incoming graduate students are aware of either its existence or its contributions, challenges, and promise. Until this is changed, the limited opportunities for education and training in the field will constrain the number of professionals educated and curtail the potential impact of accelerator science and technology. A graduate fellowship program would help attract the best students and improve the visibility and stature of the field.

In recent years, visa restrictions have made it increasingly difficult to recruit and retain foreign nationals in the field. This is particularly an issue for recent PhDs, postdoctoral candidates and junior researchers, who may be forced to return to their own country after being trained in the US. While this benefits programs elsewhere, the US fails to capitalize on its significant investment in the accelerator scientist.

Recommendations

To meet national scientific, industrial, and security needs, the importance of accelerator science and technology must be more broadly recognized, starting at the university level (professorships, graduate fellowships, undergraduate internships). Given the special role that education plays in the mission of the NSF, a strong commitment to training and research in accelerator science would significantly enhance the recognition of this field in the universities.

1. An Accelerator Science Graduate Fellowship program in the DOE and NSF should be given high priority.

2. Opportunities for education and training in accelerator science are limited. DOE and NSF should encourage expansion of these programs when opportunities arise.

3. Existing university experimental accelerator science facilities are a rare and precious resource for training and education. This capability needs to be maintained and new opportunities created when possible.

4. Increased collaboration between national laboratories and universities in accelerator science and technology should be encouraged. Examples include sabbatical support and joint appointments.

5. Opportunities for training at national laboratory experimental accelerator science facilities need to be maintained and enhanced.

6. Robust support of the US Particle Accelerator Schools is essential and should be continued, as well as close collaboration with other international schools.

7. Overseas opportunities for education and training of accelerator scientists and engineers should be encouraged through exchange programs and schools.

4. Short and Medium Term AARD

There are several somewhat arbitrary and conflicting definitions of short and medium term advanced accelerator R&D. While generally following the definition provided in the charge, we have chosen to consider short-term R&D as that related to existing or approved facilities and medium term R&D as that related to possible new facilities. Medium term spans a wide range from projects which might be approved in the next few years like the LHC upgrade or ILC, to facilities that might be proposed years later, like CLIC or muon storage rings and colliders. Important R&D topics for short or medium term include accelerator theory, simulations, superconducting rf, high power rf sources, rf controls and feedback, high-gradient warm RF, cryogenics, electron/positron sources, beam diagnostics and instrumentation, lasers, superconducting magnets, energy recovery and energy efficiency, and muon cooling. In addition, we recognize the importance of long-term technology development and the technical infrastructure needed to support R&D.

Short term advanced accelerator R&D

Short term Advanced Accelerator R&D is defined in the charge as research required for planned or approved new facilities, excluding research on existing facilities unless the goal is to test a hypothesis or develop a technique for future facilities. Nevertheless, we have also included R&D aimed at increasing the luminosities of PEP-II at SLAC and the Tevatron at Fermilab in the category of short-term AARD because of the impact this will have on future machines. We also consider the LHC Commissioning portion of LARP (LHC Accelerator Research Program) as short term. Table 4.1 lists the facilities considered in short-term AARD.

Table 4.1: Facilities Included in Short -Term AARD Evaluation

Facility	Host Laboratory	Status	Funding Agency
PEP-II	SLAC	Operating	DOE HEP
Tevatron	FNAL	Operating	DOE HEP
LCLS	SLAC	Approved, CD-2	DOE BES
12 GeV Upgrade	JLab	Approved, CD-1	DOE NP
LARP Commissioning	FNAL for the US	Approved	DOE HEP

Medium-term advanced accelerator research and development

Medium term Advanced Accelerator R&D is defined in the charge as bringing new concepts to practice so that they can be considered for the design of a new facility. We considered R&D on enabling technologies for the ILC, the Proton Driver (aka Super Neutrino Beam), and the LHC Upgrade in this category, as well as R&D for the Energy Recovery Coherent X-ray Light Source to be funded by NSF at Cornell. The R&D on high-gradient rf for CLIC, and on muon cooling and targetry for muon accelerators, also falls into this category.

Table 5: Facilities Included in Medium-Term AARD Evaluation

Facility	Host Laboratory	Status	Funding Agency
RIA	Not decided	DOE 20 Year Plan	DOE NP
ILC	Not decided	DOE 20 Year Plan	DOE HEP, NSF
SNS 2-4 MW Upgrade	ORNL	DOE 20 Year Plan	DOE BES
SNS Second Target Station	ORNL	DOE 20 Year Plan	DOE BES
RHIC-II	BNL	DOE 20 Year Plan	DOE NP
NSLS Upgrade	BNL	DOE 20 Year Plan	DOE BES
Super Neutrino Beam	FNAL	DOE 20 Year Plan	DOE HEP
ALS Upgrade	LBNL	DOE 20 Year Plan	DOE BES
APS Upgrade	ANL	DOE 20 Year Plan	DOE BES
e-RHIC	BNL	DOE 20 Year Plan	DOE NP
LHC-Upgrade (LARP)	FNAL for the US	Planned	DOE HEP, NSF
Energy Recovery Linac	Cornell	Planned	NSF

Enabling Science & Technology

We have identified a number of major areas of science and technology where the associated R&D is either necessary or likely to be important for future particle physics accelerator facilities, as well as facilities for other sciences. R&D on each of these topics is being carried out in many laboratories, universities and industry, sometimes independently, more often in close collaboration. The R&D synergy between the non-HEP and HEP projects is cost-effective and benefits both HEP and the broader applications of accelerators.

Accelerator Theory

Historically, theory has been an area of research where creative people have made contributions of major significance with relatively little funding. Today, researchers at laboratories and universities have access to significant computational resources and this facilitates the creation of accelerator theory groups in diverse environments. Theory is also excellent for attracting and training students, because it allows major advances in understanding to come from the smaller centers. Clearly this is an area that should be supported and encouraged. Beam study time on existing accelerators and colliders, as well as accelerator test facilities that can be used to test theory and new ideas, are extremely valuable for progress in this type of AARD.

Computer Simulations

The availability of computer clusters has ushered in a new era allowing computer simulations to take their place alongside theory and experiment. Most of the recent advances in understanding beam instabilities (such as the electron cloud instability), or in optimizing colliding beam parameters, have been driven by computer simulations. Simulating the propagation of electromagnetic waves in complicated structures is an essential tool for the design of short-wavelength accelerating cavities. Future needs for simulations will benefit from increased access to the computer clusters (SCIDAC support has been very effective for this) and the training and integration of a new generation of computer-savvy accelerator physicists. Accelerator physicists have traditionally been quick to profit from the latest computer techniques and this should continue.

Superconducting RF Cavities

The decision to base the ILC on superconducting rf technology (SRF) has given a boost to R&D in the field. Prior to this, SRF was being pursued for HEP at Cornell (and at a low level at Fermilab), for NP at ANL, JLab and NSCL, and for BES at JLab (leading to the successful construction of the superconducting linac for SNS). Over the past decade the major advances in manufacturing and processing of superconducting cavities have come from the international TESLA collaboration centered at DESY and from KEK. Cornell was a major contributor to the original design of the cavities and has played an important role in understanding the basic mechanisms that limit cavity performance. Recently, FNAL has started an aggressive R&D program for the ILC. The present status of SRF R&D in the US reflects this recent change in priorities and a fully coherent program is still being developed. FNAL is the preferred US site for the ILC and should play a leading role in SRF development for ILC. The US ILC program should take advantage of the more than twenty years experience in SRF development and production gained by ANL, Cornell, TJNAF, TESLA and KEK.

The total cost of developing a complete SRF R&D program at Fermilab is estimated at over $100M. Given that about half of this sum has already been invested in existing R&D facilities at other laboratories, it is extremely important that there be an intelligent integration of the national SRF R&D effort. Such a program must make effective use of existing infrastructure and facilities, but must also develop the state-of-the-art facilities needed to meet the significant challenges associated with the development of ILC superconducting rf cavities.

It is important, however, that the large effort and momentum required for this development does not impede continued basic research towards an understanding of properties, materials and processes related to superconducting rf and progress towards other applications of superconducting rf technology.

High-Power RF Sources

There are two different regimes that are being studied, pulsed and CW. Pulsed rf sources are being developed for ILC while CW rf is required for the 12 GeV Upgrade, RIA and the ERL

Light Source. For superconducting cavities, there are special requirements for the power sources due to the wide power range required for different beam currents. Normal-conducting structures with high accelerating fields require the development of pulsed high power sources in a range of frequencies. Reliable, efficient and cost effective power sources (e.g. klystrons and modulators) will be critical for any Linear Collider. This is an area of R&D that industry is well suited to carry out. R&D on rf power sources is a high-priority program that should be actively pursued.

RF Controls and Feedback Systems

Controls are being developed for the pulsed high-power rf regimes relevant to the ILC. The main focus of attention is on flexible digital rf control modules, which can be programmed to use different control algorithms, to determine the resonant cavity frequency at turn-on, and to incorporate feed-forward for pulsed RF. The pulsed rf regime requires a system that can correct for the change in cavity frequency caused by Lorentz detuning as the gradient changes. This is addressed with a feed-forward system, often (and preferably) with an adaptive correction. The ILC relies on the concept of a single modulator-klystron power source supplying many cavities and the simultaneous coherent feedback and control of the cavity output. These systems are vital for ILC, and require continued R&D to develop robust solutions.

High Gradient Warm Cavity RF Systems

Advancing the state-of-the-art in high gradient warm rf systems is essential to the realization of a post-ILC, multi-TeV linear collider using two-beam rf power generation. Research is focused on determining the gradient potential of normal-conducting, rf structures, and on developing the necessary accelerator technology to achieve the highest gradients. The current program harnesses the momentum of the concluded NLC/JLC development programs in conjunction with ongoing CLIC studies, and will explore the possibility of pushing the useable acceleration gradient from the 65 MV/m reliably achieved for NLC up towards 150 MV/m or higher. Warm rf technology will also remain necessary to handle beams in special environments such as the positron capture sections for the ILC.

Cryogenics

The efficiency of the cryogenic plant can have a major impact on the operating cost of an accelerator using either high field superconducting magnets like the LHC or high gradient superconducting cavities like the ILC. R&D to improve this efficiency can significantly reduce the lifetime cost of the accelerator. Many laboratories have moderate to large 4 K cryogenic plants and a few have the 2 K plants like that required for operation of these new facilities. Generally, the engineering expertise for these 2 K plants resides in industry while the needed expertise for specifying these systems resides in the national laboratories. The large 2 K cryogenic plant currently being installed for the LHC represents the state of the art.

In the past few years, JLab staff have successfully improved the cryogenic plant operation at both BNL and SNS. The focus has been on improving the efficiency of the warm compressors (where 50% of refrigeration system inefficiency remains) along with maintaining high efficiency with the large dynamic load variations that result from operation with differing cavity gradients. Future opportunities for development include cold compressor operation, sub-atmospheric warm compressors, and their incorporation in the process flow cycle. Further R&D in this area would be most effectively carried out in collaboration with industry. Current demand for helium cryogenic refrigerator systems is at a 20 year high and should help this collaboration even though the number of US manufacturers has decreased significantly. Adequate support for R&D in this area, and for sufficiently large 2 K systems to carry out cavity and module tests, will be important for the ILC.

Electron/positron sources

This is another area that has received an enormous boost because of ILC. The requirements for the positron source in particular have spawned a world-wide effort to create closely-spaced trains of damped positron bunches with high charge. The production of polarized positrons adds another dimension of difficulty. In the baseline scenario, polarized positrons would be created by polarized photons generated by a high energy beam in a long undulator, and the R&D effort focuses on this scenario. Overall, the US is playing a major role in this effort well supported by SLAC, ANL and LLNL. An international collaboration recently completed the E166 experiment at SLAC which demonstrated the production of polarized positrons from a helical undulator. The attractive alternative scheme of photons generated by Compton scattering is being pursued in parallel by KEK. The involvement of additional institutions in this effort may be useful if they bring important experience or skills not already present.

Beam Diagnostics and instrumentation

R&D to develop new diagnostics is required as beam properties enter new regimes. For example, the ILC with high beam power and concurrent exceedingly small beam dimensions presents new challenges for diagnostic instrumentation. R&D towards these diagnostics requires a considerable breadth of understanding and is an area where both large and small institutions could make valuable contributions. The national laboratories should encourage other institutions to work with them to develop new diagnostics, as this R&D can provide excellent training opportunities for young scientists and engineers. Overall, this is an extremely active R&D topic where advances developed for one area are rapidly adopted elsewhere. This is both healthy and cost-effective.

Lasers

New electron machines, including the ILC, require lasers for producing the electron beam. The laser characteristics are very different from the usual research lasers and require unusual bunch patterns and high average power. The wavelengths involved need to precisely match the band-gap structure of the cathode material (particularly to produce polarized electrons). Much progress in laser development has come from their commercial use in the telecommunications field. The primary goal of the accelerator R&D should therefore be to adapt research done elsewhere to the specific needs of each project. This kind of R&D can be done well in a university because of the multi-disciplinary nature of a typical university physics department, so this area would benefit from closer collaboration between the national laboratories and universities.

More generally, lasers and laser-based technology, are being increasingly utilized in a number of aspects of accelerator science and technology. New diagnostics that rely on lasers are being developed, e.g. electro-optical sampling of electron bunches. Laser-based technology is being proposed for distribution of stable rf reference signals. Laser–beam interactions is also one of the most exciting areas of long range AARD.

Superconducting magnets

Superconducting magnet development has been the driving force for higher energies at hadron colliders. The US has played a leading role in this development starting with the Tevatron, the world's first large accelerator based on superconducting magnet technology, and later with the Relativistic Heavy Ion Collider, which is now a flagship facility for nuclear physics. The US is also providing specialized superconducting magnets for the LHC at CERN, and carrying out R&D for future IR magnet upgrades of LHC as part of the LARP program. The current R&D program is generally well integrated across the laboratories with each contributor addressing different aspects of the overall R&D. R&D towards high rate pulsed SC magnets may also be required for future projects.

At present, however, there is no approved or planned new accelerator facility based on superconducting magnets, so the US has a surplus of production capability. Adequate US capacity will be needed for the production and testing of prototypes to maintain momentum towards higher field magnets. This still leaves excess capacity, which should be converted to other uses. Some facilities at FNAL are already being converted to the production of superconducting cryomodules for ILC. As there are no plans on the twenty-year horizon for an accelerator based on superconducting magnets, R&D in this area other than for LARP is considered as longer-term AARD.

Energy recovery and energy efficiency

Energy recovery and energy efficiency will become increasingly important for future accelerators. The present concept of the Energy Recovery Linac (ERL) is an example. High power rf phase shifters needed to allow one klystron to drive many cavities are being developed for the proton driver and may have other valuable applications.

Muon Cooling

Intense neutrino beams could be generated using a muon storage ring, and a muon collider could provide lepton-lepton collisions in the several TeV energy range. Ionization cooling of muons and MW class targetry of proton beams are needed to produce the high energy muon beams required for these facilities.

International R&D on muon beams has been underway for several years. Early efforts focused on ideas for ionization cooling and on developing a coherent end-to-end concept for a Neutrino Factory. In the US, the Muon Collaboration has emphasized two areas of hardware development: cooling channel component and systems development (MuCool) and targetry. An international collaboration is building a demonstration cooling experiment (the Muon Initial Cooling Experiment - MICE) at RAL in the UK, with the US contributing hardware and manpower. The target R&D is aimed at handling beam power well beyond present capabilities. A mercury jet system embedded in a high field magnetic solenoid has been developed and the jet tested with beam, but without a magnetic field. A full test with both beam and magnetic field together is planned at CERN in 2007. DOE OHEP has provided significant funding for these activities along with funding for fundamental research relevant to muon storage rings and colliders. Direct grants to universities and national laboratories, and grants to small businesses have lead to substantial progress and encouraged innovation.

The NSF has supported a program for the development of low frequency (200 MHz) high gradient superconducting rf cavities suitable for accelerating these relatively large phase space muon beams. As part of this program, they have also supported ionization cooling simulation efforts at several universities along with the development of the thin high strength aluminum windows required to contain the liquid hydrogen absorber needed for ionization cooling. Funding for this program totaled 3.6 M$ but it is now ending. There is continuing modest support for the MICE experiment by the NSF.

An example of the kind of cutting edge R&D funded by a small business grant is Muons Inc. They have demonstrated that an 800 MHz rf cavity filled with hydrogen can sustain high surface gradients inside a magnetic field of up to 3T, a result critical to the concept of simultaneous acceleration and ionization cooling.

The presentations on muon cooling R&D revealed a tension in the overall balance of this program, with excitement over new results tempered by concern over funding. The investment needed to support the MICE experiment, despite being spread over several countries, has attracted most of the available resources for R&D, leaving insufficient funding for other initiatives. We support the MICE project as a critical feasibility demonstration for muon storage rings and colliders. A reasonable pace of progress on other necessary muon-related R&D tasks is not sustainable at the current level of funding. Without increased support, essential intellectual resources will disappear.

Technology development and technical infrastructure to support R&D

Major steps forward may require that technology development be undertaken long before starting project specific R&D. This development can require significant new or improved infrastructure with a greater initial investment than typical AARD and a multi-year time scale. Historically, the US has been less willing to make long term strategic speculative and diversified investments of this type. The TESLA collaboration in Germany has made a substantial investment in superconducting rf and, as a result, has a multi-year lead over the US. OHEP should pay close attention to promising technology developments and be positioned to make adequate long term investments to support the required infrastructure.

Assessment of Short and Medium Term AARD

We have considered the breadth of short and medium term AARD in the context of the relevant elements of our charge: national goals; the overall scope and balance of the program; the quality and relevance. The suite of R&D on enabling technologies is clearly driven by national goals for accelerator-based particle physics facilities. This includes operating, approved, or planned facilities as well as capabilities that may be required in the future. All of the enabling technologies discussed are relevant. The overall scope of the program addresses all of the key topics needed to realize these goals, although the pace of progress in some areas of research is slowed by limited funding. The program is generally well balanced given the level of available support, but we are concerned that the support for muon cooling is below what is needed to sustain this program.

A strong US program in superconducting rf is essential for progress in accelerator science for HEP and other planned US facilities. The focus on R&D for superconducting rf and associated technologies also reflects the priority of the ILC for OHEP. This component of the program will certainly grow with increased funding for ILC-related R&D. As the program develops, the distribution of R&D tasks should take account of all relevant available expertise and facilities nationally and internationally in a coherent and effective manner. It should also recognize that the US is currently behind Europe and Asia in capabilities, infrastructure and industrialization.

Within the LARP program, careful consideration should be given to the balance between producing hardware deliverables for CERN and activities such as commissioning that substantially enhance the intellectual and technical capabilities of the US accelerator community.

The superconducting magnet base program provides generic R&D that complements the LARP effort but is not narrowly focused on a deliverable and will be discussed in the section on longer-term R&D

We believe that the overall quality of the R&D on these enabling technologies is very high. There is a strong team of capable researchers, with infrastructure available to them in the national laboratories, universities and industry, supported by the strong commitment of the funding agencies. In the near term, the highest priority will be ILC R&D but in order to advance the enabling technologies needed in the future, a balanced R&D program that addresses all of the important topics must be maintained. Sustaining this excellence requires relatively stable funding, modernization of infrastructure when necessary, and a continuous inflow of well-trained new researchers. This challenge must be met if the nation is to continue to be well positioned to provide forefront accelerator-based capabilities for particle physics and other sciences.

5. Long-term Accelerator Research and Development

Overview of the Program

The long-term accelerator R&D supported by OHEP and NSF are unique programs that are effective and scientifically valuable. The original strategy for the OHEP Advanced Technology R&D program was laid out by the 1980 HEPAP Subpanel on Accelerator Research and Development, chaired by Professor Maury Tigner (DOE/ER-0067 UC-34). The subpanel emphasized that an advanced program in accelerator physics was essential for the health of HEP research and outlined the appropriate content. They recommended a stably funded, long-term R&D program with a strong university focus.

The program was formally established in 1982 with a mission "to foster fundamental research into particle acceleration and detection techniques and instrumentation. These in turn provide enabling technologies and new research methods to advance scientific knowledge in a broad range of energy related fields, including particle physics, and thereby advancing the DOE's strategic goals for science." The DOE long-term accelerator science program has repeatedly received the strong endorsement of review committees and HEPAP subpanels and has become a world leader.

Through this program, OHEP has played a historical role as the steward for accelerator science and technology, without ever establishing this as a formal goal. This role evolved because the elementary particle physics research community recognized that a strong technology R&D program was fundamental to their success. Particle physics research requires forefront accelerator facilities at the expanding energy and luminosity frontiers. The need for cutting edge technology has driven the strength and breadth of the AARD program.

The NSF has provided support for long term R&D for many years, but not under a formal program. The proposed new NSF program, Accelerator Physics and Physics Instrumentation (APPI), will be a major step towards recognition of the value of accelerator science. The accelerator-related parts of the SBIR/STTR programs are also essential components of the accelerator R&D program, including long-term R&D.

The OHEP program of long-term R&D consists of exploratory research aimed at developing new and innovative concepts in accelerator physics and technology, at new materials to advance these technologies, and at the fundamental physics, mathematics and understanding through simulations essential to the advancement of accelerator science. This program sustains beam physics and related disciplines as the fundamental, curiosity-driven sciences that they have become. The R&D can occur wherever the best science originates as put forward in peer reviewed proposals. The universities have an essential role because they educate future generations of accelerator scientists and engineers. User facilities at national laboratories provide essential and cost effective infrastructure for research by the university groups. The labs also provide an important reservoir of both intellectual talent and engineering resources.

The long-term AARD program is fundamental accelerator science and as such knows no boundaries. It provides a rich environment that fosters the next breakthroughs. It contributes to science in general and to all accelerator applications regardless of funding source or national boundary. The United States has been a leader in this field but other countries are also supporting such R&D at an increasingly robust level.

An example of this basic science and the long timescale needed for such exploratory research to reach fruition is the work on plasma acceleration that has led to the wakefield acceleration experiment carried out at the SLAC Final Focus Test Beam (FFTB) facility by a collaboration from universities and national laboratories. This experiment demonstrated that an incident 28.5 GeV electron beam gained an additional energy of 42 GeV passing through a short plasma column 90 cm in length. This remarkable result is excellent science and it illustrates the ingredients needed to carry out this type of research. National laboratories provide the infrastructure and expertise in the operation and use of such major facilities while the participant universities bring innovation and human resources through faculty, post-docs and students.

The R&D program to explore the use of plasma waves to accelerate charged particles began with a workshop at LANL in 1982. There are two advantages to ionized plasmas, the plasma is already broken down, and the electric field amplitude of the plasma wave can be very large resulting in unprecedented accelerating gradients, as much as 200 GeV/m. Two lines of research emerged from the 1982 meeting, charged-particle-driven plasma-wave generation and laser-driven plasma-wave generation. The US has been and remains the world leader in both of these areas, with strong R&D programs at UCLA, SLAC, LBNL, USC, U. of TX Austin, the Naval Research Laboratory, and the U. of MD. The US program in the area of charged-particle-driven plasma acceleration is unique because of the FFTB Facility at SLAC. In the area of laser-driven plasma acceleration, there are very competitive international programs, principally in France, Japan and UK.

At the 1992 meeting of the Advanced Accelerator Concepts Workshop, one of several workshops following the original LANL meeting, five criteria were presented that plasma accelerators would have to satisfy to demonstrate their competitiveness with conventional accelerators. Four of these were: (a) an energy spread in the accelerated bunch of less than a few percent; (b) emittance of the accelerated bunch must be preserved and be comparable to emittances achieved in current electron accelerators; (c) the charge per bunch must be greater than several nanocoulombs and as large as 30 nanocoulombs, depending on the application; and (d) acceleration length must approach meters in length. Some aspects of each of these have now been demonstrated during the last ten years in the US program. An experimental demonstration satisfying all of these conditions is now needed and the US is making good progress towards that demonstration.

Unfortunately for the charged-particle driven approach, the FFTB has been shut down in order to proceed with the construction of a new light source. A successor to the FFTB, called SABER, has been proposed, but it is not yet funded. We encourage an early review of this project in order not to hinder further progress in this critical area.

Scope of the Long-Term R&D Program

The scope of research in advanced accelerator R&D is broad given the modest resources that have been allocated. Appendix 6 of this report lists these activities in some detail. The research is carried out at many different facilities. In FY04, there were programs at six national laboratories and twenty five universities, two inter-governmental agreements and seventy nine grants to small business. A large number of professional meetings have been supported, as well as the highly effective US Particle Accelerator School. Research supported by this program has provided thesis topics for over 240 graduate students during the past decade.

The research covers nearly every advanced topic in accelerator science: acceleration using wakefields generated by laser or particle beams; direct acceleration by a laser using the inverse of possible radiative effects; acceleration by non-linear effects due to magnetic fields, dielectrics or boundary conditions; exotic new acceleration media, such as an inverted population or photonic band-gap; generation of short wavelength power sources; generation of extremely bright electron and ion beams; generation of extremely short pulses of beam and/or electromagnetic radiation; diagnostics to characterize extreme beams; acceleration of beams of short-lived particles such as muons and ionization cooling of such beams; focusing and guiding of energetic beams by plasmas; collective effects; high-gradient superconducting and normal-conducting cavities; new superconducting materials and new techniques to coax extremely high fields from these materials; studies of multi-particle beam dynamics, non-linear beam dynamics, chaotic phenomena in particle dynamics, feed-back and control of beams; high performance computing; high-power laser beams and short pulses; and the list goes on.

Generally, the overall quality of the US programs in accelerator and technology R&D is very high. Most of these programs are world class and, in many specific areas, world leaders. We single out only two areas for special attention.

There are currently programs in superconducting rf (SRF) at eight US labs and universities (Appendix 5.9). On average, less than 5% of this effort is on long term R&D. This seems inadequate given the need for basic understanding of the physics of SRF limitations, materials and surface properties. The limitation of the rf critical field is not well understood nor the properties that determine it. We believe that an appropriate goal for the SRF program is that the US achieve and maintain “significant player status” relative to Europe and Japan. Given this goal and the importance of SRF for future projects, we believe that support for fundamental SRF research must be increased. OHEP should also establish programs for SRF similar to those for superconducting magnets, which included the Conductor Development Program (CDP) and the Low Temperature Superconductor Workshop (LTSW) efforts.

Recommendation:

Given the importance of SRF as a growing technology and its many possible future applications for Office of Science and NSF programs, we recommend that OHEP and NSF build a healthy program to address the fundamental issues of SRF and cavity properties, materials and surface science.

The superconducting magnet R&D program represents an important national asset and so should be supported at a vigorous level. The major goal of this program is to develop the technology for building accelerator quality Nb3Sn magnets. This would be a significant achievement and open possibilities for higher energy accelerators using higher field strength magnets. This also has significant impact potential on other magnet applications in fusion energy (ITER) and industry (NMR). Exploration of the potential of other materials is important as well. It is essential that a well-coordinated, optimized research program be developed to avoid duplication of effort. There may be opportunities to redirect production capacity at the laboratories for a more effective use of resources.

Support of the Program

Long-term research in accelerators, as in other sciences, cannot maintain productivity in an environment of rapidly changing budgets. Long-term research is often the most vulnerable part of the program and needs to be given special protection during budget crises. The 1980 Tigner subpanel that led to the establishment of the OHEP grant-based program in Advanced Technology R&D strongly emphasized the importance of stable funding. We believe that stable support has been, and remains, critical to the success of this effort. The OHEP program is to be commended for its sustained support of long-term accelerator R&D over many years.

<u>Recommendation:</u>

Accelerator science funds should continue to be protected at both the agency and at the laboratory levels to maintain stable funding.

Stability of support requires both long-term investment in promising programs to allow the science to mature and bear fruit, and constant funding in real terms for ongoing programs. The temptation to fund new programs by squeezing other programs on a flat-flat budget must be avoided. In making decisions about these programs, the agency research managers need to consider the aggregate needs of the whole field, rather than the narrow concerns of individual experts, laboratories or universities. Input is needed from multiple sources: peer reviews, advisory panels, site visits and professional meetings. Peer reviews of multiple programs ranked side by side are important to guide the agency, so that promising areas can be preserved, while allowing growth in new areas and terminating less productive programs.

<u>Recommendation:</u>

The agency research managers should apply, in addition to the current system, an expert review process to consider and prioritize all programs, old and newly proposed. This will provide guidance to allow for terminating the worst rated programs while adequately supporting the leading ones.

The question of balance between longer term and nearer term research is a strategic issue, where the boundary is often unclear. The Tigner subpanel correctly recommended that an appropriate long term R&D program be based on funding that was a fixed percentage of the OHEP operating (i.e. non-construction) budget. This approach gives the long-term program the year-to-year stability essential to unstructured, innovative research and insulates it from nearer term needs. The level suggested was 4% and this has been maintained in the 2005 budget.

Today there is increasing demand for cutting edge accelerator capabilities for particle physics, other sciences and society. There is an urgent need to further strengthen accelerator science, technology and education in the US to meet the needs in coming decades. A critical aspect of addressing the scientific and technical challenges is a robust program of long-term accelerator R&D in the universities, laboratories and industry.

For energy frontier physics, the challenge is especially daunting. From the 1930s until the 1990s, the collision energy produced by accelerators increased roughly exponentially. This remarkable progress was achieved not by sticking to a particular technology but by continuously developing new technologies to take the place of the previous one that had reached its limits. The facilities planned over the next decade likely exhaust the reach of current accelerator technologies. To push the energy frontier significantly further will require a new cost and energy effective technology.

The next generation of particle accelerators must provide extremely high center-of-mass energy and unprecedented luminosity (because of the well known decreasing cross section for interesting events with increasing energy). At the same time, a realistic accelerator must be affordable by society and limit energy usage to keep operating costs under control. Both the cost per unit energy and energy utilization must be driven down by a significant factor compared to what is available today.

The challenge is to undertake and sustain the difficult and complex R&D needed to enable a feasible, cost and energy effective technology on the several decade horizon. Achieving these goals will require creativity and the development and maturation of new accelerator approaches and technologies. Since the optimal development path may not be evident today, multiple paths at the very frontiers of accelerator science must be pursued.

Recognizing the very difficult challenges of developing the technologies needed for accelerator-based particle physics in the several decade horizon, we recommend that the funding for long-term accelerator R&D in OHEP be increased over the next few years.

Recommendation:

The percentage of the OHEP budget assigned for long-term accelerator science should be 5% in FY07, and increase gradually and smoothly to 6% over the next ten year period. This includes the long-term accelerator research carried out both at the universities and at the national laboratories.

Management of the Advanced Accelerator R&D Programs

The OHEP accelerator science program has three essential components: the grant-based program in advanced accelerator R&D, the accelerator test facilities in the national laboratories and the accelerator-related part of the SBIR program. University faculty members are an essential element of accelerator science. The university provides the rich intellectual environment, the opportunity for cross pollination with other fields and the educational backbone for training accelerator scientists. We believe that the steady support of the grant-based OHEP program has been a major contributor to the spread of accelerator science programs among universities internationally. The new NSF initiative is an excellent mechanism for increasing support for this R&D.

Recommendation:

The proposed new NSF program in Accelerator Physics and Physics Instrumentation (APPI) is a concrete step towards the establishment of accelerator science as science. It should be funded.

Recommendation:

Medium and long-term programs in OHEP directed accelerator research should be subject to a yearly review by a broad-based committee of accelerator scientists, including members who are cognizant of the possible longer-term accelerator based needs of the other Office of Science and NSF programs. This committee should be appointed with overlapping terms to assure continuity.

Accelerator test facilities in the national laboratories provide large-scale infrastructure and expertise that support programs at multiple universities without having to duplicate expensive facilities. The laboratory staff can also carry out outstanding research. We believe that it is important to encourage and support advanced accelerator R&D at the national laboratories that has the potential for significant long-term impact. In recent years such R&D has been increasingly constrained to programmatic and project related goals. The result is a significant decrease in flexibility to pursue new ideas or technologies that could form the basis of a new and important capability in the several decade time-horizon. This is a very serious risk.

Recommendation:

OHEP should accept proposals from the laboratories to pursue longer-term accelerator R&D that has the potential for significant impact, and to invest in appropriate research and supporting infrastructure.

Recommendation:

Within OHEP, oversight for accelerator R&D at universities and laboratories should be the responsibility of a single team of program managers.

Long-term Accelerator R&D and the Issue of Stewardship

For many decades, the DOE Office of High Energy Physics and its predecessors have served as the primary stewards of accelerator science and technology in support of high-energy physics and the national needs. Accelerator science and technology R&D contributes to the nation in many ways, and benefits many of the Office of Science programs, including Nuclear Physics, Basic Energy Sciences and Fusion Energy. A recent example is the incorporation of the simulation code that was developed at LBNL to understand electron cloud effects in positron storage rings into the code for heavy ion driven high energy density physics related to inertial fusion.

We endorse the importance of this stewardship responsibility and recommend that it be explicitly recognized as an integral part of the mission of OHEP. Within its overall responsibilities and resources, the OHEP program should support research in accelerator science where the criteria for funding is the fundamental importance of the science being addressed as well as the potential impact on particle physics. The program should also support accelerator science and technology that has the potential for significant long-term impact on other DOE research. The stewardship responsibility of OHEP need not extend to research that has a narrow focus towards short or medium term applications, unless the particular research topic is fundamental.

<u>Recommendation:</u>

The stewardship role of OHEP for long-term accelerator R&D and relevant mid term accelerator R&D should be formalized and made permanent. The mission statement of OHEP should be modified to include the following:

"The Office of High Energy Physics (OHEP) provides program planning, oversight and funding for research in fundamental accelerator science and technology."

6. The International Perspective

Although this HEPAP subpanel is assessing advanced accelerator R&D funded by the DOE Office of High Energy Physics and the NSF Particle Physics Program, this assessment must take place in the context of the overall international effort in AARD.

As the scale and cost of forefront accelerator-based facilities for particle physics increases, the underlying R&D programs are becoming increasingly interrelated and often international in their scope and planning processes. It is natural and inevitable to evolve towards a global strategy for the field that both takes account of complementary capabilities and seeks to optimize the use of resources to best satisfy scientific and national interests. A global strategy would, of necessity, require a broadly accepted view of what R&D should be considered in a worldwide context and what is best left to regional or more local entities. It must also take into account the competitive nature of the international science enterprise, and the differences in national priorities.

R&D for major (billion-dollar scale) new accelerator projects is already becoming a worldwide effort. The scale and technical challenges involved require expertise and resources from the worldwide accelerator community. The challenge will be to develop effective organizations and advisory mechanisms to coordinate these kinds of large, distributed R&D efforts in a way that reflects the differing circumstances and histories of each collaboration.

R&D on new facility designs, such as the neutrino factory, which is still focused on feasibility demonstrations and bringing new concepts to practice, requires a more modest scale of resources and personnel. Broad collaborations, which can cross regional boundaries, are beneficial in bringing an expanded range of experience, techniques and facilities to bear on the problem. There remain many scientific and technical uncertainties and challenges so that multiple efforts and competition are often very healthy.

R&D on fundamental issues in accelerator science and technology is the foundation on which the future of accelerator-based particle physics is based. It also supports important applications of accelerators which benefit society at large. Support for this type of basic accelerator R&D must have very high priority. Funding agencies worldwide recognize the importance of accelerator science and support for the most forward-looking research has been forthcoming, despite severe near-term pressures.

We have surveyed activities in AARD in both Europe and Asia to better understand the needs and priorities for US AARD in the context of related worldwide activities. The information gathered on major efforts in AARD outside of the US is presented in appendix 7. The international efforts are dominated by the near term needs of particle physics, nuclear physics and basic energy sciences. Some of these projects involve worldwide collaborations (the LHC and the ILC) while others are regional (the European XFEL), and still others are undertaken at a national level. In order to understand the backdrop of the various AARD efforts, we provide a survey of such projects, and indicate the level of involvement by country.

One notable difference between the regions is that the US particle and nuclear physics programs have no new facility construction, while Europe has the LHC and Japan has the J-PARC project.

Another difference is that the European AARD activity emphasizes multi-national, multi-laboratory efforts, cross-institutional networking, and cross-disciplinary work between HEP, nuclear physics, light source, and laser acceleration laboratories. There has also been a recent flowering of ultra-high intensity, short pulse laser acceleration R&D in smaller institutes and universities, particularly in Asia. The US is rapidly being overtaken in this area, with US laser development oriented more towards NIF and related programs. With the closing of FFTB at SLAC and ensuing hiatus in the beam-based wakefield program, the US leadership in long range, plasma acceleration R&D is being effectively challenged.

Outside of HEP, US leadership faces major competition in 4th generation light sources based on an FEL. While the US LCLS project will be the world's first X-ray FEL starting in 2008, the number of foreign projects either started or proposed is impressive. These projects range from the DESY XFEL to others in softer X-ray regimes in Japan, Korea, China, the UK, Italy, and Germany. Development of the physics and technology of these light sources will occupy many of the world's accelerator scientists in the coming years. It is notable that many of the labs undertaking major FEL projects are traditional HEP accelerator labs (e.g. DESY, INFN-LNF).

Publications and participation in major conferences and schools can be a measure of the intellectual health of the foreign and US efforts. Foreign publication in the accelerator sciences in US journals such as PRL and PRSTAB has leveled off in recent years, after a period of significant growth. At the same time, accelerator research publication in foreign journals has increased. Attendance by foreign students in the USPAS has remained level for the past 5 years, but this has occurred during a period of growth in international schools in all regions, again indicating more accelerator training outside of the US. There are also more international accelerator conferences, exemplified by the initiation of the Asian Particle Accelerator Conference.

A final area of evaluation is the strength of industrial research, development, and marketing in accelerator-related technologies. The US in the past has been dominant in superconducting magnets and rf power technologies, in large part due to research support from governmental sources. US dominance in magnetic resonance imaging technology has eroded as industrial capability in other countries have developed. In rf technologies, US manufacturers have nearly vacated the market in many classes of power sources to foreign companies. US industry is also well behind Europe and Asia in the industrialization of superconducting rf cavities. The US is still dominant in many sectors of laser technology related to accelerators (*e.g.* photoinjector drive lasers and table-top TW systems for laser acceleration), but this position is not secure. While commercial applications are pushing the laser industry forward in the US, aid from federal research funding is not strong.

7. Strategic Framework for AARD

Throughout the history of HEP, forefront research has required ever-increasing collision energy and luminosity. Because the total interaction cross section decreases with increasing energy, processes of interest at the energy frontier can only be observed in a reasonable time period if the integrated luminosity is sufficiently high. A critical challenge facing particle physics is how to meet these ever increasing needs at an acceptable cost. Over the past 7 to 8 decades accelerators have grown from objects of a few inches in size to large installations tens of kilometers in size. Capital cost and power consumption have scaled with size and beam power. The accelerator complexes envisioned for next steps (LHC, ILC) appear to be at about the limit of size and cost that international society is willing to support for basic research. New ideas, concepts, breakthroughs, and inventions will be required in order to provide the accelerator tools of the future within societal limitations of cost, facility size, and power usage.

With cognizance of this issue and of the international setting of the field, OHEP should develop a strategic framework for its portfolio of medium and long term accelerator R&D that is consistent with the overall direction and needs of the field of particle physics and the anticipated needs of the Office of Science. This framework should guide the priorities for medium-term accelerator R&D in the context of existing and anticipated resources. The strategic plan should be consistent with the priorities set by the Particle Physics Project Prioritization Panel (P5) in its upcoming roadmap.

Recommendation:

We recommend that OHEP develop a strategic plan for medium-term AARD based on the upcoming P5 Roadmap for HEP. This plan should be reviewed by the committee referred to above and updated on a yearly basis.

A set of principles should guide the management of the long-term AARD program including:

The breadth of the longer-term AARD program should reflect the stewardship responsibility of OHEP for accelerator science and technology. High priority should be given to R&D that holds the promise of producing new techniques, approaches or technologies to extend the reach of accelerator-based physics and research of the highest quality that addresses fundamental aspects of accelerator science and technology. Activities that contribute to the education and training of students and postdocs and collaborative activities should be encouraged.

In considering a strategic vision for advanced accelerator R&D, we emphasize that both the OHEP and NSF must be cognizant of the long-term challenge facing accelerator-based HEP - the need to develop concepts for far-future accelerators that can provide higher energy and luminosity at a cost society is willing to bear.

8. Conclusions

Accelerator science and technology has had a profound impact on high-energy physics, on other sciences and on such important societal areas as health care, the economy, and national security. This important field of science receives strong support from the DOE OHEP and from the NSF.

The goal of accelerator R&D within OHEP is to enable state-of-the-art research and development in those aspects of accelerator science and technology that have a strong potential to advance the capabilities of particle physics research. Important additional considerations are the benefit to other programs in the DOE Office of Science and the national scientific enterprise, as well as the potential for significant impact in the economy, health, security and other sectors. The program has had a historical stewardship of accelerator science and technology for decades because of its broad impact on other sciences and overall benefit to the nation. We endorse the importance of this stewardship responsibility and recommend that it be explicitly recognized as an integral part of the mission of OHEP.

The NSF provides significant support for accelerator science and R&D at two major accelerator-based user facilities, Cornell University and Michigan State University, and several universities. Cornell and MSU conduct research in nuclear, particle and synchrotron radiation science.

Society as a whole benefits from accelerator science. There are well-established applications of accelerators in diagnostic and therapeutic medicine for research and routine clinical treatments. Accelerators and associated technologies have various important uses in industry for R&D, manufacturing, testing, and process control. National security is also enhanced by the development of particle accelerators. Accelerator techniques can be used to test the reliability and aging of nuclear weapons without detonation. Accelerator-based systems have been developed to allow rapid screening of cargo containers to discover contraband nuclear materials

As accelerator scientists continue to develop new technologies and capabilities, particle beams will enable continued discovery at ever smaller distances and at energies that allow us to understand the early universe just after the Big Bang. In parallel, the impact of accelerators on other sciences, industry, national security, medicine and society as a whole will continue to grow.

The nation is fortunate to have a strong, world-class program in accelerator science and technology. Maintaining and extending the health and vitality of this resource into the future is a challenge that must be met by the scientific community, funding agencies, universities, national laboratories and industry if the contributions of this field are to continue at the present high level.

To assure that there are sufficient accelerator scientists and engineers to meet the future needs of HEP, other sciences and the nation, opportunities for the education and training of such professionals must be expanded. There are currently a limited number of universities providing accelerator training. The DOE and NSF have been farsighted in encouraging and supporting these programs and should seek to increase the number of universities participating in such research.

The national laboratories often work in close collaboration with university faculty and students, and so strongly contribute to training in accelerator science and technology. The laboratory facilities for experimental accelerator science play an essential role both in faculty research and in the training of future accelerator professionals.

Accelerator science and technology is not yet broadly recognized as an essential, vital and exciting frontier research field, and this problem limits the number of universities providing an accelerator science education. In most universities it is not considered an academic subject worthy of faculty lines. Few incoming graduate students are aware of either its existence or its contributions, challenges, and promise. Until this is changed, the lack of educational opportunities will limit the pool of accelerator professionals and curtail the potential impact of accelerators on science and society. A graduate fellowship program would help attract the best students and improve the visibility and stature of the field.

In the area of medium term R&D, we have identified a number of major enabling science technologies where the associated R&D is either necessary or likely to be important for future particle physics accelerator facilities, as well as facilities for other sciences. These include accelerator theory, simulations, superconducting rf, high power rf sources, rf controls and feedback, high-gradient warm RF, cryogenics, electron/positron sources, beam diagnostics and instrumentation, lasers, superconducting magnets, energy recovery and energy efficiency, and muon cooling. In addition, we recognize the importance of long-term technology development and the technical infrastructure needed to support R&D. Research on each of these topics is being carried out in laboratories, universities and industry, sometimes independently, more often in close collaboration. The R&D synergy between the non-HEP and HEP projects is cost-effective and benefits both HEP and the broader applications of accelerators.

The suite of R&D on enabling technologies is clearly driven by national goals for accelerator-based particle physics facilities. This includes existing or planned facilities as well as capabilities that may be required in the future. The overall scope of the program addresses the key technologies needed to realize these goals, although the pace of progress in some areas of research is slowed by limited funding. The program is generally well balanced given the level of available support, but we are concerned that the support for muon cooling is below what is needed to sustain momentum in this program.

We believe that the overall quality of the R&D on these enabling technologies is very high. There is a strong team of capable researchers, with infrastructure available to them in the national laboratories, universities and industry, supported by the strong commitment of the funding agencies. Sustaining this excellence requires relatively stable funding, modernization of infrastructure when necessary, and a continuous inflow of well-trained new researchers.

The long-term accelerator R&D supported by OHEP and NSF are unique programs that are effective and scientifically valuable. The OHEP program is larger and older, having been formally established around 1982. The NSF has provided support for long term R&D for many years, but not under a formal program. The proposed new NSF program, Accelerator Physics and Physics Instrumentation (APPI), will be a major step towards recognition of accelerator science within the NSF.

The mission of the DOE Office of Science requires a program of long-term R&D consisting of exploratory research aimed at developing new and innovative concepts in accelerator physics and technology, at new materials to advance these technologies, and at the fundamental physics, mathematics and understanding through simulations essential to the advancement of accelerator science. This program sustains beam physics and related disciplines as the fundamental, curiosity-driven sciences that they have become. The venue for long-term accelerator R&D is wherever the best science originates as put forward in peer reviewed proposals. This includes strong participation of the universities because of their essential role in educating future generations of accelerator scientists and engineers. It also relies on the test facilities at national laboratories that provide essential and cost effective infrastructure for research by the university groups. The multipurpose national labs also provide an important reservoir of both intellectual talent and engineering resources for the pursuit of research in basic accelerator science.

Accelerator science is, of course, a field of science with a strong international flavor. As the scale and cost of forefront accelerator-based facilities for particle physics increases, the underlying R&D programs are becoming increasingly interrelated and often international in their scope and planning processes. It is natural and inevitable to evolve towards a global strategy for the field that both takes account of complementary capabilities and seeks to optimize the use of resources to best satisfy scientific and national interests. A global strategy would, of necessity, require a broadly accepted view of what R&D should be considered in a worldwide context.

With cognizance of the international setting of the field, OHEP should develop a strategic framework for its portfolio of medium and long term accelerator R&D that is consistent with the overall direction of the field of particle physics and the anticipated needs of the Office of Science and the nation. This framework should be developed into a strategic plan for medium-term accelerator R&D to guide the program in setting priorities in the context of existing and anticipated resources.

An important driver for this strategic framework must be the serious challenge to identify and develop new concepts for future energy frontier accelerators that can provide the exploration tools needed for HEP within a feasible cost to society. The future of accelerator-based HEP will be limited unless new ideas and new accelerator directions are developed to address the demands of beam energy and luminosity and consequently the management of beam power, energy recovery, accelerator power, size, and cost.

To conclude, we emphasize the critical importance of accelerator science and technology in the US and the urgent need to strengthen this research in order to address long term needs of particle physics, other sciences and the nation.

Appendices

Appendix 1—Charge to the Subpanel

Charge letter to Professor Frederick Gilman, Chair of HEPAP:

Dear Professor Gilman:

Particle accelerators have long been a critical, enabling technology for high-energy physics – and have become a key element for advances in many other fields of science. The Advanced Technology R&D effort within the DOE Office of High Energy Physics (OHEP) and the Elementary Particle Physics program within the National Science Foundation are the major sources of US funding for the development of accelerators, both to meet the immediate needs of new accelerator facilities and to pursue novel acceleration concepts, RF structures, and magnets for broad use in the further future. The portfolio of projects supported by this effort includes research efforts in technology and materials, provision of test facilities, simulation work, and training of accelerator physicists. It is carried out in universities, several Federally funded national laboratories, two Federally operated laboratories, and in industry and has a total annual budget of about $68M in FY05, including R&D in support of future major accelerator facilities such as the ILC ($22.6M) and LHC (3.3$M). The results have been influential in developments for accelerators used for nuclear physics, materials science, biology, medical diagnostics and treatment, and for industrial uses.

Accelerator R&D partitions loosely into three categories: short term research, required for planned or approved new facilities; medium term research, to bring new concepts to practice so that they can be considered for the design of a new facility; and longer term, exploratory research aimed at developing new concepts for acceleration, new magnet technologies, new materials, and advanced simulation techniques. The training of accelerator physicists, engineers, and technologists is an additional important goal of this effort.

A number of recent developments, including the decision of the International Technology Recommendation Panel for the Linear Collider; the recommendation of the APS Study of Neutrino physics that a high intensity neutrino beam and R&D towards a muon storage ring should be pursued; and discussion of LHC upgrades, have placed renewed emphasis on accelerator R&D efforts in support of medium term high energy physics projects. At the same time, overall resources are more tightly constrained than ever, and accelerator R&D efforts have not been spared from the impact.

In light of this situation, we are requesting a comprehensive review of all aspects of the OHEP and NSF accelerator R&D programs with the exception of Linear Collider R&D and the LHC Accelerator Research Project, LARP (see below). The review should include:

- National Goals: describe in broad terms the needs and goals of US HEP accelerator R&D that are, in the sub panel's view, required for a rich and productive future program in accelerator based particle physics.

- Stewardship: Appraise how the DOE/HEP program should continue to maintain its historical national stewardship for accelerator science and technology in light of the increasingly constrained budget for the program.
- Scope: provide a description of the current scope of the DOE and NSF programs.
- Quality: Appraise the scientific and technical quality of the work being supported and how the US effort rates relative to the worldwide effort in similar areas.
- Relevance: Examine the work being performed and determine how well it matches the needs and goals of the high-energy physics program. Are there items missing, items that may be overemphasized, or items that are significantly under-supported? Is the balance between longer term and nearer term research appropriate?
- Resources: Estimate whether the program has adequate resources to carry out its scope of effort, and assess whether the program makes the most efficient use of those resources.
- Management: Examine how the work is managed and overseen, both in the field and in the agencies. Suggest how the management and oversight might be improved, if appropriate.
- Training: Accelerator R&D efforts play a major role in the training of future accelerator scientists and technologists. Is this aspect adequately addressed in the current programs? Are local partnerships between national laboratories and universities performing adequately?

Technical and management review of the Linear Collider R&D and LARP will not formally be part of this review, but your committee should understand and evaluate whether the overall scale and scope of these efforts is appropriate to an optimum overall accelerator R&D program within the DOE Office of High Energy Physics and NSF Mathematical and Physical Sciences Directorate.

It is requested that a preliminary draft of your report should be presented to HEPAP by the end of February 2006, with a final version by July 2006.

We thank you for your help in conducting this review by forming a HEPAP Subpanel; its advice will be important to program planning by both agencies. We look forward to working with you in this endeavor.

Sincerely,

Robin Staffin	Michael S. Turner
Associate Director	Assistant Director
Office of High Energy Physics	Mathematical and Physical Sciences
Department of Energy	National Science Foundation

Appendix 2—Membership of the Subpanel

Jay Marx (LBNL/LIGO, Chair)
Ilan Ben-Zvi (Brookhaven National Laboratory)
Jean-Pierre Delahaye (CERN, Switzerland)
Alex Dragt (University of Maryland)
Helen Edwards (FNAL)
Don Hartill (Cornell University)
Andrew Hutton (TJNAF)
Young-Kee Kim (University of Chicago/FNAL)
Katsunobu Oide (KEK, Japan)
Nan Phinney (SLAC)
Jamie Rosenzweig (UCLA)
Stew Smith (Princeton University)
Harry Weerts (Michigan State University/ANL)
Marion White (ANL)
Fred Gilman (Carnegie Mellon University, ex officio)

Appendix 3--- Agenda for the Subpanel's Meetings

First Meeting of the Advanced Accelerator R&D Subpanel
Quality Suites Hotel, Rockville, Maryland
November 1-2, 2005

Tuesday, November 1, 2005		
9:00 – 10:00 a.m.	Executive Session: Discussion of Charge, Scope of AARD, Plan for Subpanel, Overall HEP Context	
10:00 – 11:00 a.m.	Charge to the Subpanel and Discussion	Robin Staffin & Mike Turner
11:00 – 11:15 a.m.	BREAK	
	Overview of HEP Program and Budget – Program Overview & Subprogram descriptions, budgets (FY05 funding & FY 06 Request)	
11:15 – 11:45 a.m.	DOE/HEP	Glen Crawford
11:45 – 12:15 p.m.	NSF	Joe Dehmer
12:15 – 1:30 p.m.	Working Lunch	
1:30 – 2:00 p.m.	Overview DOE Lab-based accelerator R&D Program (including ILC & LARP) Scope, Mission, Scale, Budget, Current Tasks, Management, etc.	Aesook Byon-Wagner
2:15 – 2:45 p.m.	Discussion	
2:45 – 3:00 p.m.	BREAK	
3:00 – 3:45 p.m.	Overview DOE Grant based accelerator R&D Program- Scope, Mission, Scale, Budget, Current Tasks, Management, etc.	Phil Debenham
3:45 – 4:15 p.m.	Discussion	
4:15 – 4:45 p.m.	Overview NSF Accelerator R&D Program – Scope, Mission, Scale, Budget, Current Tasks, Management, etc.	Marvin Goldberg
4:45 – 5:15 p.m.	Discussion	
5:15 p.m.- 5:30 p.m.	Break	
5:30 p.m. – 6:30 p.m.	Community input	

Wednesday, November 2, 2005		
8:30 a.m. - 9:30 a.m.	Remarks	David Sutter
9:30 a.m. – 2:30 p.m.	EXECUTIVE SESSION With Working lunch	
	Subpanel Discussion and Lunch	
	Discussion of Presentations; Issues & Questions Raised	
	Draft response to R. Staffin request for input pre-Thanksgiving	
	Suggested Methodology to analyze AARD	
	Discussion/formation of Subgroups	
	Plans for Future Meetings	

Agenda for AARD Sub-panel Meeting; Palo Alto Ca.
December 21-22, 2005
(Times include question/discussion period)

December 21

8:30: Executive session	
9:30: SLAC	Ron Ruth — Overview
10:20: break	
10:35: SLAC	Sami Tantawi — Accelerator Technology and High Gradient Collaboration
11:15: Stanford	Bob Byer — Laser Acceleration
11:35: SLAC	Bob Siemann — Plasma Acceleration, Facilities, Opportunities
12:15: working lunch	
1:00: US-ILC	Tor Raubenheimer
2:00: LBNL	Steve Gourlay — Overview
2:15: LBNL	Wim Leemans — L'Oasis
2:45: LBNL	John Corlett — Center for Beam Physics
3:10:	break
3:30:UC Berkeley	Jonathan Wurtele
3:50: UCLA	Jamie Rosenzweig — on campus AARD
4:30: SIDAC/modeling	Rob Ryne
5:00: Break	
5:15: Town Meeting (1 hour)	

December 22

8:30: Executive session including working lunch
2:30 adjourn

Agenda-AARD Sub-panel at Fermilab; Feb. 15-17, 2006
(Times include question/discussion period)

February 15, 2006

8:30 Executive session	
9:00 Fermilab program	see below for details
9:50 break	
10:10 National scrf program	see below for details
12:10 working lunch	
1:15 LARP Overview & Accelerator Systems	Peggs
1:45 SC magnet program	see below for details
2:35 break	
3:00 SC magnet program	see below for details
4:00 Maryland	see below for details
5:00 Executive session	

Details of February 15 Agenda

Fermilab Program

Fermilab R&D Overview	Holmes (25 min.)
The A0 Photoinjector Program	Piot (20 min.)

The National SCRF Program

Issues and Challenges in SCRF	Padamsee (20 min)
Collaborations and other SRF R&D Overview	Chattopadhyay (20 min)
The Fermilab ILC &PD/SCRF Programs	Kephart/Foster (45 min)
R&D Programs, Current and Planned	Kneisel (20 min.)
Materials and Surface R&D	Gurevich (20 min.)
Funding status, perspective, and needs	Tigner (2/16 at 11 am)

SC Magnet Program

LARP Magnet R&D Program	Gourlay (20 min.)
Superconducting Materials R&D	Larbalestier (30 min.)
Individual Lab Reports (non-LARP activities)	TAMU- McIntyre (15 min.)
	LBNL- Sabbi (15 min.)
	FNAL- Ambrosio (15 min.)
	BNL- Wanderer (15 min.)

University of Maryland

Maryland Space-Charge Dominated Beam and Microwave Sources Research Groups.
O'Shea (20 min.)

Maryland Intense Laser Matter Interactions Research Group
Antonsen (20 min.)

Maryland Dynamical Systems and Accelerator Theory Research Group
Dragt (20 min.)

<u>February 16, 2006</u>

8:30 Brookhaven	see below for details
10:00 Cornell .	see below for details
10:45 break	
11:00 National scrf-Funding status, perspective, and needs	Tigner
11:20 NFMCC R&D	Zisman
12:20 working lunch	
1:15 AARD at Argonne	Gai
2:00 Beam Cooling & Manipulation	Lee
2:20 Beam Dynamics Theory	Berz
2:40 break	
3:00 Accelerator School	Barletta
3:30 UCLA/USC	Joshi
4:00 break	
4:15 Town meeting	
5:45 Executive session	

<u>Details of February 16 agenda</u>

Brookhaven program

Introduction--	Harrison (20 min.)
The Accelerator Test Facility and Optical Stochastic Cooling R&D	Yakimenko (35 min.)
The ATF users science, FFAG studies, solid target R&D, SC RF gun and SC ERL / electron cooling	Palmer (35 min.)

Cornell program

Facilities for AARD at Cornell	Rice (20 min)
Current Activities and Future Plans for AARD	Hoffstaetter (25 min)

<u>February 17—Executive session and working lunch</u>

8:00 High Freq. Microwave Approaches	Tempkin
8:30 Executive Session	
3:30 adjourn	

Appendix 4—Background Information Related to Education and Training

A4.1. Questionnaire Sent To National Laboratories

1. Argonne National Laboratory
2. Brookhaven National Laboratory
3. Cornell, Laboratory for Elementary-Particle Physics
4. Fermi National Accelerator Laboratory
5. Jefferson National Laboratory
6. Lawrence Berkeley National Laboratory
7. Livermore National Laboratory
8. Los Alamos National Laboratory
9. Oakridge National Laboratory
10. Stanford Linear Accelerator Center

A4.2 Questionnaire Sent To University Researchers

1. J. Wurtele, Advanced Accelerator Concepts, University of California, Berkeley
2. D. Pellett, Study of Hadron Produced Radiation Damage, University of California, Davis
3. D. Cline, Advanced Accelerator Physics Research, University of California, Los Angeles
4. C. Joshi, Experimental, Theoretical, and Computational Studies of Plasma-Based Concepts for High-Energy Accelerators, University of California, Los Angeles
5. J. Rosenzweig, Theoretical and Experimental Studies in Accelerator Physics, University of California, Los Angeles
6. K.-J. Kim, Research in Beam Physics, University of Chicago
7. J. Cary, Research on Chaotic Dynamics in Accelerator Physics, University of Colorado
8. T. C. Marshall, Research on Wake Field and Auto-Resonance Acceleration, Columbia University
9. G. Dugan, S. Gruner, L. Hand, D. Hartill, G. Hoffstaetter, H. Padamsee, D. Rubin, and R. Talman, Cornell University
10. G. Edwards and Y. Wu, Accelerators and Light Sources, Duke University
11. R. Williams, Research on Electron Beam Transport in Plasma Wave Accelerators, Florida A & M University
12. S. Van Sciver, Liquid Helium Fluid Dynamics Studies, Florida State University
13. G. Gollin, ILC Damping Ring Kicker R & D, University of Illinois Urbana-Champaign
14. D. Kaplan, Neutrino Factory R & D, Illinois Institute of Technology
15. S. Y. Lee, Research on Beam Cooling, Space Charge, and Beam Manipulation, University of Indiana
16. J. Shi, Study of the Stability of Particle Motion in Storage Rings, University of Kansas
17. A. Dragt, Dynamical Systems and Accelerator Theory Research Group, University of Maryland
18. W. Lawson, Studies of Microwave Sources for Colliders, University of Maryland

19. H. Milchberg, Application of Plasma Waveguides to Advanced Accelerators, University of Maryland
20. P. O'Shea, Study of Physics of Space Charge Dominated Beams, University of Maryland
21. C. Chen, Research on Periodically Focused Intense Charged-Particle Beams, Massachusetts Institute of Technology
22. R. Temkin, 17 GHz High Gradient Accelerator Research, Massachusetts Institute of Technology
23. M. Berz, Research on Advanced Map Methods for the Description of Particle Beam Dynamics, Michigan State University
24. J. Ellison, Investigations of Beam Dynamics Issues in Accelerators, University of New Mexico
25. I. Ben-Zvi and S. Peggs, Accelerators and Beams, State University of New York
26. C. Bohn, Simulations and Experiments for Nonlinear Dynamics of Intense Electron, Beams and Beam-Plasma Interactions, Northern Illinois University
27. G. Blazey, C. Bohn, D. Chakraborty, B. Erdelyi, M. Fortner, D. Hedin, and P. Piot, Northern Illinois Center for Accelerator and Detector Development
28. M. Velasco and D. Seidman, Research on Instrumentation for TeV Linear Colliders and Tomography of Niobium for Superconducting RF, Northwestern University
29. E. Collings, Research on Materials, Strands, and Cables for Superconducting Magnets, Ohio State University
30. L. Vuskovic, Investigation on Plasma Etching for Superconducting Surface Preparation, Old Dominion University
31. R. Davidson, Research on Nonlinear Dynamics and Collective Process in Intense Charged Particle Beams, Princeton University
32. K. McDonald, Research on Undulator-Based Production of Polarized Positrons, Princeton University
33. J. Fox, H. Wiedemann, and H. Winick, Stanford University
34. R. Byer, Experiments for Laser-Driven Acceleration, Stanford University.
35. T. Katsouleas, Program for Plasma-Based Concepts for Accelerators, University of Southern California
36. A. Chao, J. Irwin, R. Ruth, and R. Siemann, Stanford Linear Accelerator Center
37. W. Bugg, Research on Undulator Based Production of Polarized Protons, University of Tennessee
38. P. McIntyre, New Technology for Future Colliders, Texas A & M University
39. M. Downer, Laser Wakefield Acceleration, University of Texas at Austin
40. G. Shvets, Advanced Accelerator Studies, University of Texas at Austin
41. J. Bisognano, Synchrotron Radiation Center, University of Wisconsin-Madison
42. D. Larbalestier, High Field Superconductor Development and Understanding, University of Wisconsin-Madison
43. R. Prepost, Development of Polarized Photocathodes, University of Wisconsin-Madison

A4.3 Questions to and Summary of Responses from National Laboratories

1. What is your assessment of the future need for Accelerator Scientists? In your judgment and experience are there too few/enough/too many?

    Summary Response: The difficulties at all accelerator labs in finding workers trained in accelerator science makes it clear that we are short of people trained in accelerator science and technology. There are too few accelerator scientists worldwide. This is because in the US and also in the rest of the world, there are too few institutions offering Accelerator Physics as a research discipline. This contrasts with educational opportunities in Nuclear and Particle Physics. The scientific outcome of many experimental accelerator science groups is reduced because of a shortage of accelerator staff. Under-funding accelerator R&D does not allow us to reduce the cost for big projects such as the ILC. The primary indicator that there are not enough accelerator scientists in the U.S is that every new construction project needs to hire scientists away from other laboratories to get off the ground. This has happened because the utilization of accelerators in both the public and private sectors has grown rapidly over the last two decades, while the supply has grown more modestly. As one looks to the future one only sees this trend continuing, especially when contemplating the Office of Science Twenty Year Facilities Plan. Overall, we are probably dealing with a 20-30% shortfall. There are two sources that can be considered in making up this shortfall—students emerging from school with PhDs in accelerator physics and professional physicists that are being retrained. Both sources are necessary and should be considered in discussion of educational initiatives.

2. Describe both qualitatively and quantitatively what efforts your laboratory is taking in the area of Accelerator Science education at the undergraduate, graduate, and postdoctoral levels.
    a) Are there collaborative programs with universities that train students in Accelerator Science?
    b) Are there programs that encourage sabbatical visits by faculty working in Accelerator Science?
    c) Are there summer programs for students and/or faculty?
    d) Are there experimental facilities that can be used by students and faculty?
    e) Are there postdoctoral programs that provide training in Accelerator Science?

    Summary Response: Several of the Laboratories have active collaborative programs with universities that train students in Accelerator Science. Some provide faculty that teach Accelerator Science at nearby Universities. All contribute to the US Particle Accelerator Schools financially and/or by providing instructors, and by sending numerous students to the Schools. Some also take summer students at both the undergraduate (often through the DOE Science Undergraduate Laboratory Internships program) and graduate level, and some provide postdoctoral training. Several have experimental facilities that can be and are used by students and faculty. None have official sabbatical programs, but some do support, as funds permit, sabbatical visits when requested.

3. Are there other questions/aspects related to education that you wish to address or you believe should be addressed? For example, are there other planned or existing education-related laboratory activities that we have missed? Is the quality of students and their training

sufficiently high? Are there subfields that are inadequately addressed? Are there others that should be emphasized less?

Summary Response: A critical need is for scientists and engineers expert in RF technologies. There is great difficulty throughout the world accelerator community in staffing to the required level in this area. The accelerator staff at laboratories contains a mix of those trained directly in accelerator physics and high-energy experimentalists who have converted. The latter play an important role in accelerator operations that support the HEP research program. They provide important communications links and an understanding of the needs of the experiments that greatly benefits the program. This class of scientists should be kept in mind in any discussion of education. Future Accelerator Scientists need to be broadly educated in material sciences, cryogenic and electronic (including RF) engineering and accelerator controls, in addition to the conventional fields.

The single most critical aspect in developing future Accelerator Scientists is funding. While some work can occur through the contributions of the labs and voluntary efforts by dedicated scientists, encouragement in the form of dedicated funding to support students, post doctoral fellows and sabbatical leaves will contribute to substantial progress in nurturing the future of Accelerator Sciences.

One of the barriers to producing more accelerator literate scientists is the fact that very few at the undergraduate level know that there are fascinating, challenging, and rewarding careers available in accelerator science. Not understanding the basic physics content of the field may also be a barrier to undergrads looking for a potential field in grad school. Collectively, we need to get together and devise a plan for increasing awareness and conveying the attractiveness of careers in accelerator work. Another factor in play today is the steady decrease in support for nuclear and particle physics which traditionally have provided the accelerator R&D support and thus the possibility for training students. One might suppose that this point is inconsistent with the claim that we need more accelerator scientists. The apparent inconsistency is removed when one observes that many of the new job opportunities for the accelerator literate come in sciences that do not support accelerator R&D but rely on others to train their employees.

A4.4 Questions to and Summary of Responses from University Research Groups

1. What is your assessment of the future need for Accelerator Scientists? In your judgment and experience are there too few/enough/too many? For example, what has been your experience in finding for your students both postdoctoral and permanent positions in Accelerator Science? What about permanent placement of postdocs? What fraction of your students/postdocs leave the field of Accelerator Science?

   Summary Response: Most faculties agree that the past, present, and future need for good accelerator scientists exceeds the present capacity of educating them. A significant amount of scientific research and technology development depends on accelerated particles, and advances in accelerators often lead to advances in science and technology. The frontier of high-energy physics has been determined to a substantial degree by accelerators, and condensed matter, materials, chemical and biological sciences are becoming ever more dependent on accelerators. The two most recent large projects in the

US – the SNS and LCLS – clearly illustrate this. Designing, constructing, and operating accelerators will also require trained accelerator scientists, and inventing the accelerators of the future will also. For these reasons there is and will continue to be significant need for trained accelerator scientists. Accelerator science offers a broad education in physics, applied physics, and engineering. Students trained in this field have career opportunities with accelerators and in a wide range of industries. Those who choose an accelerator career have little trouble finding positions after finishing their Ph.D. degrees or postdoctoral training. Some choose a different career, and they have found their training has suited them well. Many foreign students leave for industry because of visa sponsorship offers they get.

Some note that it seems fairly straightforward to find a postdoc, but significantly more difficult to find a permanent position. This situation is well-understood by graduate students and works to our detriment. Their experience is that the fraction of students that leave the field is somewhat uncertain. Roughly 40% stay in the field (including those in accelerator-related industrial jobs), 30% stay in a technical job (faculty, industry, national lab but not in accelerators), and the remainder move on to the financial world. Others cite a much higher retention rate.

2. Comment briefly on the difficulty/ease of recruiting high-quality graduate students in competition with other areas of physics/engineering.

   Summary Response: Attracting high-quality graduate students encounters two difficulties. First, there is significant competition with high-profile fields such as nonlinear dynamics, quantum information science, high-energy astrophysics and cosmology, and biophysics. Second, the field of Accelerator Science (because of its broad interdisciplinary nature) is more amorphous and much less well known to American students. (There are numerous foreign applications, mostly from China.) However if special efforts are taken to reach American students early and apprise them of the field, then they can be recruited. What is needed is increased awareness of and increased stature for the field.

3. Please provide information on the number of current and past students and postdocs, and their placement.

   Summary Response: See the information already provided to DOE for inclusion in the 2005 Advanced Accelerator R&D "Year Book".

4. Describe briefly any courses offered in Accelerator Science.

   Summary Response: Schools directly associated with accelerator facilities such as SLAC and CESR typically off a rich suite of courses in Accelerator Science and Technology. Other schools typically offer much less.

5. Describe briefly any complementary courses offered.

   Summary Response: See item 8 below.

6. Describe briefly in what areas of Accelerator Science you provide graduate training and whether this training is in theory or experiment or both. If applicable, please describe briefly what experimental facilities are available at your university for Accelerator Science.

Summary Response: See the information already provided to DOE for inclusion in the 2005 Advanced Accelerator R&D "Year Book". Schools that have experimental facilities typically teach both experimental and theoretical training, often with an emphasis on experimental work. Those without experimental facilities train only theory students.

7. Describe briefly any undergraduate programs.

   Summary Response: Those schools with experimental programs or close affiliations with local accelerator laboratories often have paid informal summer programs for undergraduate students in which they work with some research group. Some also have outreach to area high school teachers. In general there are no formal programs, and quite limited course offerings.

8. Describe briefly what complementary areas of research exist in your university and are available to your students/postdocs (e.g. material sciences, plasma physics, nonlinear dynamics, laser physics, low temperature physics, etc.).

   Summary Response: Several Universities have complementary research in the above areas, and students in Accelerator Science frequently take courses in these areas.

9. Describe briefly what university/departmental support is provided for research and training in Accelerator Science (e.g. faculty positions, postdoctoral support, student support, secretarial support, travel funds, computer support, laboratory space and facilities, shop support, etc.).

   Summary Response: University/departmental support is quite varied. Some universities have faculty positions. Those near national labs welcome adjunct positions. Several indicate no additional support beyond office space and lab space (if experimental work is funded). Others cite computer support including an 11 TFlop supercomputer, limited support for graduate students through TA positions, and limited secretarial support. A few cite partial support for an administrative assistant, visiting lecturer, some travel, and very modest research funds.

10. Describe briefly your interactions, if any, with the U.S. Particle Accelerator School.
    a) Have you sent students to the school?
    b) Have you taught in the school?
    c) Has your university hosted a school?
    d) Have publications produced by the school been useful?
    e) What is your overall evaluation of the school, and do you have any suggestions for the school?

    Summary Response: Essentially all University programs have made extensive use of the school, and several have hosted and/or provided faculty to the school. The school is uniformly highly praised with no suggestions for change or improvement.

11. Describe briefly (in the area of Accelerator Science) your interactions or collaborative programs with National Laboratories, if any, and any improvements or arrangements you would like to have.
    a) Collaborative programs that train students in Accelerator Science?
    b) Programs that encourage sabbatical visits by faculty working in Accelerator Science?
    c) Summer programs for students and/or faculty?
    d) Experimental facilities that can be used by students and faculty?

e) Other?

Summary Response: Schools that are near National Labs often have interactions and collaborative programs with them for their students, and more are contemplated. Many students make use of experimental Accelerator Science facilities at SLAC, Fermilab, Argonne, and Brookhaven. The Laboratories are supportive of these programs as funds permit, and these programs are definitely needed. A significant fraction of Accelerator Scientists at National Laboratories are strongly interested in teaching accelerator physics courses at a University and supervising graduate students. A sabbatical program for faculty would be welcome, and would do much to foster closer Laboratory-University ties including ties with more distant universities.

12. Describe briefly any national/international collaborations in which you are involved.

Summary Response: Most university groups are extensively involved in national and international collaborations including Colliders, ILC, Neutrino Factory, Muon Collider, MICE, SciDAC, SPIN, LARP, CLIC, high gradients, laser and plasma acceleration, cavity modeling, wake-field calculations, wake-field acceleration, beam manipulation, beam diagnostics, superconducting RF, advanced RF sources, and high magnetic fields.

13. What is the typical training of those you hire as postdocs?

Summary Response: Accelerator physics, theoretical physics, computer science, numerical methods, plasma physics, laser-plasma physics. Many are trained abroad.

14. Are there other questions/aspects related to education that you wish to address or you believe should be addressed? For example, are your departmental and university colleagues supportive of research in Accelerator Science? When the recruitment of new/replacement faculty in Accelerator Science is contemplated, are there sufficiently well qualified applicants in Accelerator Science to compete with applicants from other fields being considered for other positions?

Summary Response: Schools that are supportive of Accelerator Science (particularly those without large experimental facilities) are rare. Accelerator Science is not considered as an academic subject worthy of faculty lines in most universities. Some faculty who do Accelerator Science do so under other rubrics such as nonlinear dynamics, plasma physics, laser physics, and high-energy physics. Moreover, there is keen competition against truly outstanding candidates for other prominent and exciting fields ranging through nanoscience, quantum information, astrophysics and cosmology, and biophysics. Very few potential candidates in Accelerator Science can match them. Much needs to be done to increase the recognition of Accelerator Science as a valuable, challenging, and exciting field in its own right.

Appendix 5- Short-term AARD:

Templates of the following Tables were sent out the National Laboratories and other Institutions that are involved in accelerator research and development, and information was received from virtually everyone. Replies were received from the following people:

Courtland Bohn, NIU
Alex Dragt, UMD
Persis Drell, SLAC
Jack Ekin, NIST
John Galayda, SLAC
Steve Gourley, LBNL
Mike Harrison, BNL
Steve Holmes, FNAL
Kwang-Je Kim, ANL
David Larbalestier, Wisconsin
Peter McIntyre, Texas A&M
Brian Rusnak, LLNL
Michael Sumption, Ohio State
Tsuyoshi Tajima, LANL
Maury Tigner, Cornell
Steven Van Sciver, FSU
Richard York, MSU

The results were collated with data from presentations to the Subpanel and are shown in Tables A5.1 – A5.6. In addition, the Subpanel received a collation of the R&D at the National Laboratories. The data on the US Superconducting magnet program is presented in Table A5.7 and the data relevant to AARD is presented in Table A5.8.

Figure A5.1 R&D in Support of Major Operating Facilities

		Expenditures								
		FY04			FY05			FY06		
Facility	Laboratory or Institution	Total Budget	Procure-ments	FTEs	Total Budget	Procure-ments	FTEs	Total Budget	Procure-ments	FTEs
PEP-II	SLAC*	$1,236k	$50k	6	$1,306k	$73k	6	$1,500k	$53k	7
	LBNL	-	-	-	$300K	60.5K	1.15	163.6k	-	0.5
TEVA TRON	FNAL*	$18,700k	$10,600k	58	$14,400k	$5,300k	62	$5,900k	$900k	33
	LBNL	140K	$0k	0.75	140K	$0k	0.75	140k	$0k	0.75

Table A5.2 R&D Activities at Operating Facilities that are Applicable to Other Projects

Facility	Laboratory or Institution	Activities	FY05 Expenditures Total Budget	Procure-ment	FTE's
PEP-II	SLAC*	Electron cloud instability studies	$100k	$0k	0.43
		Beam-beam interaction studies	$100k	$0k	0.43
		Longitudinal bunch feedback	$200k	$30k	0.86
		Interaction region design	$50k	$0k	0.21
		Higher order mode studies of vacuum	$100k	$0k	0.43
		High power vacuum chamber design	$100k	$0k	0.43
		Beam size monitoring instrumentation	$100k	$10k	0.43
		Detector background monitoring studies	$50k	$0k	0.21
		Higher order mode absorbing structures	$100k	$10k	0.43
		Lattice coupling control	$50k	$0k	0.21
		Lattice tune control near half integer	$50k	$0k	0.21
		High power RF control of ampere beams	$100k	$10k	0.43
	LBNL	Transverse multi-bunch feedback upgrade with digital delay & filter	$300k	60.5k	1.15
		Preliminary testing of electron cloud density measurement - microwave technique	$5k	$0k	0.05
		Lattice studies, to improve luminosity	$25k	$0k	0.10

Table A5.2 R&D Activities at Operating Facilities that are Applicable to Other Projects (continued)

			FY05 Expenditures		
Facility	Laboratory or Institution	Activities	Total Budget	Procurement	FTE's
Tevatron	FNAL*	Electron Cooling (cooling of relativistic hadron beams)	$1,085k	$350k	5
		Electron Lens (Collider beam-beam compensation)	$691k	$250k	3
		Tevatron tune tracker (Real time tunes & chromaticities)	$147k	$0k	1
		Target beam sweeping (High power density targetry)	$157k	$10k	1
		Lithium lens improved gradient (improved secondary particle collection)	$531k	$90k	3
		Main Injector slip-stacking (increased beam power)	$294k	$0k	2
		Tevatron Ionization Profile Monitor (non-destructive profiles)	$177k	$30k	1
		Ted OTR profile monitor (single turn profiles)	$177k	$30k	1
	LBNL	Abort gap diagnostics with synchrotron radiation	$40k	$0k	0.2
		Beambeam3D [LBNL code] support for Tevatron applications	$5k	$0k	.05
		ImpactT [LBNL code] support for FNPL injector studies	$5k	$0k	.05
		Electron cloud studies, and transfer of LBNL e-cloud code to Fermilab	$25k	$0k	0.1
		Long range beam-beam studies	$40k	$0k	0.2
		Antiproton lifetime sensitivity studies	$25k	$0k	0.1

Table A5.3 R&D in Support of Major Approved Facilities

		Expenditures								
		FY04			FY05			FY06		
Facility	Laboratory or Institution	Total Budget	Procure-ments	FTE's	Total Budget	Procure-ments	FTE's	Total Budget	Procure-ments	FTE's
LCLS	SLAC*	$1280k	$75k	8	$3,270k	$150k	20			
	ANL	$150k	$2k	1	$470k	$150k	2			
	LLNL	$400k	$5k	2	$0k					
	LBNL	$10k			$50k		1	Under negotiation †		
	UCLA	$160k		2	$210k	$25k	2	$231k	$12k	2
12 GeV	JLab*	-	-	-	$81k	$40k	4	$920k	$190k	6

* Host Laboratory

† Negotiating involvement in timing & synchronization systems

Table A5.4 R&D Activities at Approved Facilities that are Applicable to Other Projects

Facility	Labor-atory or Institu-tion	Activities	Future Projects	FY05 Expenditures Total Budget	Procure-ment	FTE's
LCLS	SLAC*	Bunch compression	ILC, all FELs, ERL			
		Diagnostics for short high-current bunches	ILC, all FELs, ERL			
		High precision electron beam position monitors	ILC, all FELs, ERL			
		real-time mechanical alignment systems	ILC, all FELs, ERL			
		high brightness electron guns	all FELs and ERLs	$273k	$0k	2
	ANL	Diagnostics for short high-current bunches	ILC			
		High precision electron beam position monitors	ILC	$17k	$0k	
		Diagnostics for short x-ray pulses	all FELs, ERL	$78k	$0k	1
	UCLA	Numerical modeling of self-amplified spontaneous emission	all FELs	$130k	$0k	1
		Electron beam diagnostic development	ILC, all FELs, ERL	$80k	25k	1
	LBNL	Numerical modeling of self-amplified spontaneous emission	all FELs	$50k	$0k	1
12 GeV Upgrade	JLab*	Develop and test prototype high-gradient cryomodule	RIA, ERL	$1,200k	$400k	9
		Design and build new LLRF Control boards	RIA, ILC, ERL	$950k	$350k	4
		SRF Cavity Studies to improve cavity shape, bulk niobium properties, (single crystal & large grain), thin films	RIA, ILC, ERL Super Neutrino,	$1,800k	$400k	10
		BBU studies to predict thresholds in ERLs	RHIC-II, e-RHIC, ERL	$110k	$0k	1
		Develop photocathodes with polarization >85%	e-RHIC	$160k	$60k	1
	Cornell	Design prototype LLRF control boards				

Table A5.5 Support of Facilities from National Laboratories and Institutions

	Facility															
Laboratory Or Institution	PEP-II	Tevatron	LCLS	12 GeV	RIA	ILC	SNS 2-4 MW Upgrade	SNS Second Target Station	RHIC-II	NSLS Upgrade	Super Neutrino Beam	ALS Upgrade	e-RHIC	APS Upgrade	LHC (LARP)	ERL
ANL			X		X	X								X		
BNL					X	X			X	X	X		X		X	X
CORNELL				X		X							X			X
FNAL		X			X	X					X				X	
JLab				X	X	X	X						X			X
LANL						X										
LBNL	X	X	X			X	X		X	X	X	X			X	
LLNL			X													
ORNL							X	X								
SLAC	X		X			X									X	
FSU						X									X	
Maryland	X					X									X	
MIT (Bates)						X			X				X			
NIU		X			X	X										X
NIST		X													X	
NSCL (MSU)					X	X					X					
Ohio State															X	
Texas A&M															X	
UCLA			X													
Wisconsin															X	

Table A5.6 Enabling Technologies for Facilities

	Facility															
Enabling Technologies	PEP-II	Tevatron	LCLS	12 GeV	RIA	ILC	SNS 2-4 MW Upgrade	SNS Second Target Station	RHIC-II	NSLS Upgrade	Super Neutrino Beam	ALS Upgrade	APS Upgrade	e-RHIC	LHC (LARP)	ERL
Acceleratory Theory	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Antiproton Sources & Stochastic Cooling		X							X					X		
Cryogenics		X		X	X	X	X		X		X			X		X
Diagnostics	X	X	X			X									X	
Electron Cooling		X							X					X		
Electron/Positron sources	X		X		X	X								X		X
High-Power RF Sources	X		X	X	X	X	X				X					
Ion Sources					X				X							
Lasers			X			X								X		X
RF Control and Feedback Systems	X		X	X	X	X	X		X		X			X		X
Superconducting Magnets		X			X	X			X			X		X	X	
Superconducting RF				X	X	X	X		X		X			X		X

Table A5.7 Enabling Technologies at National Laboratories and Institutions

	Laboratory										Institution								
Enabling Technologies	ANL	BNL	CORNELL	FNAL	JLab	LANL	LBNL	LLNL	ORNL	SLAC	FSU	Maryland	MIT (Bates)	NIU	NIST	NSCL (MSU)	Ohio State	Texas A&M	Wisconsin
Acceleratory Theory & Computer simulations	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Antiproton Sources & Stochastic Cooling				X									X						
Cryogenics			X	X	X						X					X		X	
Diagnostics	X	X		X		X	X			X			X	X					
Electron Cooling		X		X															
Electron/Positron sources	X	X	X		X		X			X			X					X	
High-Power RF Sources			X	X	X	X				X		X	X			X			
Ion Sources	X	X		X		X	X									X			
Lasers		X			X	X	X			X		X							
RF Control and Feedback Systems	X	X	X	X	X	X	X			X						X			
Superconducting Magnets		X	X	X			X			X	X				X	X	X	X	X
Superconducting RF	X	X	X	X	X	X	X		X							X		X	

Table A5.8 Summary Information on the US Superconducting Magnet Program

BNL Superconducting Magnet Program (3/23/06 P Wanderer)

Accelerator Facilities: Goals and time scale of achievement	Five accomplishments	Impacts to HEP	Budget (FY06)	Facilities	Effort Near/Mid/ Long Term	Management Oversight and Review	Service to Others
• RHIC magnet system heavy ions + polarized protons operational since 2000 • LHC 20 NbTi IR dipoles 1996 – 2006 LHC upgrade R&D (LARP) prototype Nb3Sn IR quad 2004 – 2009 (present scope) • ILC large-angle IR magnets magnet/optics input from GDE R&D includes vibrations meas. 2003 - ? • RIA high temperature superconductor for fragmentation separation quad. Cost-effective design build, test model quads 2004 - ? • HERA, BEPC II NbTi magnets for IR upgrades 1998 - 2006 • FAIR SIS300 at GSI fast-ramp NbTi model dipole 2000 - 2006 • J-PARC neutrino facility correctors for proton transport line; 2002 – 2007 • NSLS II arc dipoles high temperature superconductor. 2006 - ?	• RHIC magnets • LHC sc IR dipoles • IR magnets for DESY, BEPC, ILC • First use of high temp. superconductor. In accel magnets (RIA, NSLS II) • 10 T Nb_3Sn dipole (react-and-wind)	• LHC magnets completed on schedule. • RHIC magnet procurement was a reference point for LHC magnet procurement • Increased physics from HERA, BEPC, J-PARC • Integrated design of ILC wide-angle IR Options available for LHC upgrade • High temp. superconductor in accelerator magnets	• FY2006 HEP $3.5M NP $5.3M WFO $1.5M	• RHIC/LHC magnet tooling • Cryo testing of magnet, conductor • Cryo plant for testing • CAD/CAM precise coil winding machine • Furnaces to react Nb_3Sn • Magnetic field measurements	50 FTE's 8 scientists HEP effort distribution: 0%75%/25%	DOE HEP annual DOE NP annual BNL annual Project-specific, e.g. LHC, LARP, ILC, RIA	• Make 1-of-a-kind magnets • Magnet test and measure • Superconductor tests • Magnet design, mfg. advice • Specialized IR design

Table A5.8 Summary Information on the US Superconducting Magnet Program (continued)

FNAL Superconducting Magnet Program (3/23/06 AV Zlobin)

Accelerator Facilities: Their Goals and time scale of achievement	Five Accomplishments	Impacts to HEP	Budget	Facilities	Effort *Near/ Mid/Long Term	Management Oversight and Review	Service to Others
• HFM: Support LHC Accelerator Research Program (LARP) in developing of full size Nb_3Sn quadrupole prototypes for LHC IR upgrade allowing luminosity increase, and bring Nb_3Sn technology for accelerator magnets to full maturity • Deadlines: - 4m long quadrupole cold mass tested by end of FY2009 - 6m long quadrupole magnet (including cryostat) tested by end of FY2012 • ILC/PD: Develop full prototypes of compact SC solenoids actively shielded, and other magnets for linear accelerators (focusing quadrupoles, transfer line dipoles, sextupoles, etc.) • Milestones: - First solenoid prototype tested by end of 2006 - First quadrupole prototype tested by end of 2007	• Developed and fabricated large-aperture NbTi quadrupoles for the LHC interaction regions • Developed cost-effective Nb_3Sn magnet design and technology allowing significant reduction in cost and assembly time, and suited for length scale-up and industrialization • Found stability limitation of present Nb_3Sn high-current-density conductors and their effect on magnet quench performance, understood cause, and successfully implemented solution • Demonstrated quench performance and field quality reproducibility in Nb_3Sn accelerator magnets, developed simple and effective passive correction of coil magnetization effect • Developed DSP magnetic measurement systems which allow for high speed (~6 Hz) continuous read of harmonic coils; and Single Stretched Wire system for measurement of the magnetic axis of quadrupoles	• An important contribution to the LHC construction, possibility for the LHC luminosity upgrade • Availability of reliable technology for use of Nb_3Sn magnets in future accelerators (ILC, MSR/MC, VLHC, etc.) • Knowledge of field quality and possibility of expansion of a dynamic field range of Nb_3Sn accelerator magnets • Prototypes of actively shielded small solenoids and small quads for the ILC and for FNAL Proton Driver • An important input to strategic planning of national and international HEP Programs • Guidance for national HFM and Conductor development programs	• Core program: $2-5M/yr • LARP: $1.8M in FY06	Magnet development facility (16000 sq ft) for SC magnet R&D (L<6m) Magnet test facilities: • Vertical Magnet Test Facility (VMTF) (L<4 m, 1.8-4.5 K, Imax=30kA) • Horizontal Magnet Test Facility (HMTF) (L<15-m, 1.8-4.5 K) Supporting Labs: • SC R&D Lab - Short Sample Test Facility (Bmax=17 T, 1.8-300K) • Cable Development Lab – 42-strand cabling machine • Material Lab	• HFM: 5 physicists, 8 engineers, 2 designers, 9 technicians (~22 FTEs) • ILC/PD: 3 physicists, 5 engineers, 2 technicians (~3.5 FTEs) • Near/ Mid/ Long R&D: 0%/85% /15%	• HFM: Technical Division Magnet Steering Committee 3-4 times per year, Internal reviews almost every year, DOE and FNAL-director's reviews occasionally, LARP reviews every 6 months (limited to LARP funded activities) • ILC/PD: This is a new project and the reviewing process is under development, an internal technical review was performed when the design of the first solenoid prototype was completed before starting fabrication.	• Tevatron: scientific and technical support • LHC: present IR quads (fabrication, test and commissioning) • BTeV project support (cancelled): C0IR quadrupoles • ILC: responsible for magnets for damping ring and beam delivery system

Table A5.8 Summary Information on the US Superconducting Magnet Program (continued)

LBNL Superconducting Magnet Program (3/24/06 GL Sabbi)

Accelerator Facilities: Goals and time scale of achievement	Five accomplishments	Impacts to HEP	Budget (FY06)	Facilities	Effort Near/Mid/ Long Term	Manage-ment Oversight and Review	Service to Others
• Program goal: develop the enabling high-field magnet technologies required for future HEP accelerators • LHC project: IR Quad magnetic design, cable R&D and fabrication LHC luminosity upgrade: leadership and key technical contributions to the magnet development program • ILC: contribution to magnet feasibility assessments, design and costing Milestones: Demonstrate 90 mm bore Technology Quadrupoles by 2007 Demonstrate viability of Nb3Sn technology for Quad-first LHC upgrade by 2009 (high gradient and long models) • Demonstrate a 15 T, 35 mm bore arc dipole prototype by 2007 • Demonstrate 18 T field in a small bore dipole using HTS inserts by 2010.	• Achieved record dipole fields in 3 geometries, up to 16 T (4-5 T above closest competitor) • Key advances in 3D modeling techniques, diagnostic tools, mechanical support and assembly concepts for very high field magnets • Leadership of the DOE/HEP conductor development program, which has led to Nb_3Sn strand with high critical current density at high field, reduced reaction times, high RRR and long piece length . • World leading expertise on fabrication of Rutherford cables using traditional and advanced wires; optimization of Nb_3Sn cabling process to avoid strand damage while retaining mechanical stability; development and first large production of Bi-2212 HTS cables • Development and optimization of the leading "wind-and-react" technologies for Nb_3Sn coil fabrication	LBNL high field Nb3Sn prototypes have provided a technology base for a new generation of HEP facilities, including the "absolutely central" LHC luminosity upgrade • Leading the collaboration to develop large-aperture Nb3Sn quadrupoles required for the LHC and ILC interaction regions • The program is well positioned to demonstrate the feasibility of arc dipoles operating at about twice the field of LHC • Technology transfer: sub-scale magnet technology, modeling & analysis methods, diagnostics tools, mechanical structures & assembly techniques • Leadership of DOE/HEP Conductor Development Program	• Core program: 3445 k$ LARP: 2246 k$ • DOE conductor developmen t & procuremen t contracts for HEP and LARP: 840 k$	• Cable R&D and fabrication: 60-strand machine • Strand critical current testing (15 T, 2 kA) • Conductor characterizatio n: SEM Lab and Sample Prep. Shop • Complete facility for fabrication of short models: coil winding, reaction furnace, vacuum vessel, 100,000 lb. press • Testing System for mechanical properties of materials (room temperature and cold) • Magnet testing: 4-m vertical pit, 3 cryostats, 3 top headers, 15 kA supplies, 200 W refrigerator	• 10% near term • 40% mid term • 50% long term • 8 Physicists , 5 Engineers , 8 Techs (total 22 FTE)	• DOE review of LBNL magnet program (1/year) • DOE review of the LBNL/H EP program (1/year) • Director's review of the AFRD division (1/year) • LARP program reviews and advisory meetings (3/year)	• Cabling services: FNAL, BNL, TAMU, CERN, Twente, Showa • Testing services: TAMU, HIF, CEA • Program advisory and review: LHC, GSI, NHMFL • Chairing and membership of program and editorial boards for major conferences (ASC, MT) • Reviews of SBIR proposals: ~15/year • Review of journal and conference papers: ~50/year • Workshop organization: CHATS, WAAMS, Erice, LARP collaboration meetings • Technical contributions to GSI, Twente Univ., CERN, CEA, ITER projects • Development of Nb_3Sn undulators for light sources • Development of Superconducting Quads for HIF • Development of open-volume NMR magnets

Table A5.9 Profiles of SRF Capabilities and Efforts at the DOE and NSF Laboratories

ANL							
Accelerator Facilities: Their Goals and time scales of achievement	**Five Accomplishments**	**Impacts to HEP**	**Budget**	**Facilities**	**Effort *Near/Mid/ Long-term**	**Management Oversight and Review**	**Service to Others**
• ATLAS (NP): 50 MV, 64-cavity SC ion linac, Nuclear Structure near the coulomb barrier, Atomic Physics with ion beams. Operations and Upgrades 1978 - present. • ATLAS upgrade to 70 MV (NP): 2007 • RIA (NP): Rare-isotope production facility, 1 GeV multi-ion SC driver linac (proposed).	• First SC ion linac - set standard for reliable and flexible performance • Extended SC velocity range down to 0.01c (ATLAS Positive Ion Injector) • Extended SC velocity range up to 0.63c (spoke cavities) • Phase-stabilization of a wide variety of SC cavities • Design, construction, processing, and testing of high-performance TEM-class cavities @ Epk>40 MV/m	• Reliability - longest time operating with SC cavities • Extended SC technology for high-energy proton linacs	• $1.5M/year (NP) • $300K/year (HEP)	• Cavity and cryomodule development, fabrication, processing, testing, • Cavity production integrated with U. S. vendors • Processing and test facility replacement value $5M	• 5 FTEs Students: undergrad trainees 2/yr; 1 PhD student • R/D profile 80%/15%/ 5%	• Annual DOE Science & Technology Review • Institutional Review every other year	• RIA(NP) • PD (FNAL) • ILC (FNAL) • Numerous SC ion linacs world-wide (INFN-Legnaro, New Delhi, Sao Paulo, FSU, KSU Host visitors (JAERI, NSC New Delhi, TRIUMF, Orsay, etc.)
• APS (BES): 7-GeV Storage Ring for x-ray synchrotron radiation. > 3000 physics, biology, chemistry, materials. science users/y. • Ops since 1996, > 5000 hr/y, > 98% available.	• Highest availability accelerator-based user facility • Photon diagnostics, x-ray BPMs • Lattice design and beam-based lattice correction. • Orbit control and stability 1micro-meter • EPICS • High-brightness guns	• Availability is crucial at ILC • Diagnostics can be used at ILC, LCLS, all light sources • Orbit control & EPICS helps all acc. facilities. • Guns – ILC, light sources	•	• APS Complex, includes gun test stand.	•	• DOE and U of C reviews	• ILC, FNAL, LCLS, RIA

BNL							
Accelerator Facilities: Their Goals and time scales of achievement	**Five Accomplishments**	**Impacts to HEP**	**Budget**	**Facilities**	**Effort *Near/Mid/ Long-term**	**Management Oversight and Review**	**Service to Others**
• RHIC e cooling 2009 • eRHIC future	• Design and construct ampere class ERL cavity 700 MHz • Design, build and test laser photocathode gun at 1.3 GHz • Advanced design of ampere class average current high brightness SC laser photocathode RF gun at 700 MHz • Advanced development stage diamond amplified photocathode • Ampere class ERL under construction	• Potential use of SRF gun for flat beam, low emittance polarized electrons for ILC • Potential use of high current gun for driver of a two-beam accelerator	• 4M/yr (NP+ONR)	• Investment ? • ERL under construction	• 15 FTE • 2 PhD to date • 1 student / yr • R&D Profile 100% medium term	• Managed as group in Collider-Accelerator Dept. • Annual review by DoE, bi-annually by MAC	• Collabora-tion in ERL w. JLab, AES

Table A5.9 Profiles of Accelerator R&D at the DOE and NSF Laboratories (continued)

Cornell							
Accelerator Facilities: Their Goals and time scales of achievement	**Five Accomplishments**	**Impacts to HEP**	**Budget**	**Facilities**	**Effort *Near/ Mid/Long-term**	**Management Oversight and Review**	**Service to Others**
•SRF development for high energy synchrotrons and storage rings: 1970 – 1985, CEBAF Adopted Cornell SRF Technology and Cavity Design in 1986, Gradient > 5 MV/m •High Luminosity Storage Rings CESR (1998): First Storage Ring to Run Entirely on SRF Cavities, Ea = 7 MV/m, I = 700 mA •Storage Ring Light Source Using CESR technology (2000 – 2010: CHESS (Cornell), Canadian Light Source, Taiwan Light Source, Diamond Light Source (UK), Shanghai Light Source, BESSY (Berlin Light Source). •Linear Collider: Parameter developments, Technology Developments (1987 – 2025) •Energy Recovery Linac Light Source : Concept development (collaboration with JLab) (2002 – 2004), Prototype (under construction) (2005- 2008), ERL (2010) •Neutrino Factory and Muon Collider Accelerator technology Development 2000 – 2030	•1975: First Test of SRF Cavities in a HEP Accelerator (2.86 GHz, Ea= 4 MV/m, 110 mA, 4 GeV) •1994: First Demonstration of 500 MHz High Current Operation (Ea = 5 MV/m, 200 mA) •1995: First Demonstration of Each > 25 MV/m for LC, several 5-cell cavities •2002 First Test of 200 MHz Nb-Cu Cavity (in collaboration with CERN) •2005 Record accelerating gradient 47 in single cell with new shape (re-entrant) and 52 MV/m in collaboration with KEK	•Development, demonstration and implementation of SRF cavities for high current high luminosity machines, CESR, KEK-B •First International Linear Collider (TESLA) workshop at Cornell LEPP – 1990, Baseline parameter set •TESLA (now ILC) collaboration activities •Muon collider conceptual design •Neutrino Factory Conceptual designs • First multi-cell meeting TESLA requirements	• Currently 1M/yr NSF, 0.3M grants and subcontracts DoE • Formerly 1.5 M /yr NSF	• Investment 15M to date • cavity and cryostat fabrication, test, process, synch and storage ring and low emittance gun for beam tests • surface analytical instruments – sem, auger, sims	• 10 FTE • 2-4 students • ~ 6-PhD grads 5 masters in SRF • R&D Profile: * 90%, 5%,5%	• Director's reviews • Ad hoc external reviews • NSF reviews	ILC, Canadian Light Source, Taiwan Light Source, Diamond Light Source (UK), Shanghai Light Source, BESSY (Berlin Light Source).

Table A5.9 Profiles of Accelerator R&D at the DOE and NSF Laboratories (continued)

FNAL							
Accelerator Facilities: Their Goals and time scales of achievement	**Five Accomplishments**	**Impacts to HEP**	**Budget**	**Facilities**	**Effort *Near/Mid/Long-term**	**Management Oversight and Review**	**Service to Others**
• 3.9 GHz cavity R&D, 2 cavity types for Photoinjector & 4 cavity module for TTFII, also TESLA cavity operation 1998-2007 • ILC R&D, prepare for project 2005-? • Proton Driver R&D, be prepared to implement if ILC delayed, efforts complementary to ILC R&D 2005-?	• Provide FNAL experience in all aspects of SRF development & operation, initiating polarized gun effort • Develop necessary infrastructure • Initiate materials effort • Design concepts for a PD using ILC technology	• Bunch compression, diagnostic & crab cavity applications. efficient FEL SASE • ILC major future goal of HEP • PD major thrust for neutrino physics. Preproduction test vehicle for ILC	**SRF only** R&D (direct M&S+ SWF) FY05 •3.9 2M$ •ILC 3.2 M$ •SRF Infra & Mat Dev 2.1 M$ •PD 0.5 M$ FY06 •3.9 2.8M$ •ILC 4.4M$ •SRF Infra & Mat 3.2 •PD 2M$	• 3.9 modest facilities developed- CR, UPW, HPR, oven, Vet Test • Chemical processing – joint facility with ANL for BCP & EP • Under construction – major CR facility, module assembly, Horizontal & Vertical Test dewars, module test area	**SRF only** •3.9 ~11FTE FY05, 20 FTE FY06 •ILC 9FTE FY05, 10 FTE FY06 •SRF infrastr & Mat 6FTE FY05, 12 FTE FY06 •PD 3FTE FY05, 10FTE FY06 •20%/80%/0%	• ILC Program Director with Division Leaders • PD Program Leader • DOE reviews • FNAL Accelerator Advisory Committee • GDE • Individual reviews and advisory committees	Strong collaboration with DESY MOUs w CU, JLab, ANL, MSU and others

Table A5.9 Profiles of Accelerator R&D at the DOE and NSF Laboratories (continued)

JLAB							
Accelerator Facilities: Their Goals and time scales of achievement	**Five Accomplish-ments**	**Impacts to HEP**	**Budget**	**Facilities**	**Effort *Near/Mid /Long-term**	**Manageme nt Oversight and Review**	**Service to Others**
• CEBAF/CEBAF-II (NP): Study Quark Confinement and Strong QCD; Construction 2008-2011; Operations 2011-2020 • ELIC (NP); Study transversity and exotic quark-gluon color glass condensates; Construction 2015-2020; Ops 2020 • 10-100 kW FEL in IR and 2 kW in UV (DOD); Basic and Applied Sciences of materials, nano-structures, micro-fabrication and life sciences; 5-10 year program; future x-ray facility beyond 2020 • ILC Contribution: cost-effective SRF for >1 TeV cm collider for Higgs; 2015-2025 • World's first Energy Recovery Linear acceleration demo at high currents of 10 mA CW in 2000 - 2004; basis for Daresbury, Cornell and BNL ERL designs • Embodies US national SRF developments for NP, HEP, BES and DOD • Linear Collider parameter developments 2001-present • SRF-based Linear Collider Cost estimates, 2003 and continuing	• 5 MV/m → >20 MV/m operating gradient in CEBAF from 1985 to present • Large-scale robust operation of SRF linacs 1995 to present • Medium-scale SRF production capability, 2005 (e.g. SNS SRF linac) • Single crystal/large grain niobium @ 46 MV/m with minimal processing, promising cost-effective ILC at greater than 1 TeV cm energy, 2005 • World's first demonstration of High Current 10 mA CW SRF/ERL in 2000-2004	• Demonstration of reliable and robust "SRF" operation in large-scale in CEBAF • Cost reduction via simplified design and processing • Enhanced technical reach beyond 1TeV cm energy for electron-positron colliders • Leveraging of already existing infrastructure and investments at JLab to benefit US-HEP developments in SRF and ILC • First US national kick-off collaboration meeting at JLab in September 2004 amongst all US labs in the wake of the ITRP decision on "cold technology" • Muon cooling cavity development for Neutrino factories and Muon Colliders • Novel muon cooling schemes without solenoids • "TESLA/TTC" contributions	• $4M/year (NP): Mostly in support of Operations of CEBAF with R&D at $0.5M/ year level. • $1M/year (HEP) • $.0.5/year (DOD), mostly in support of FEL SRF cryomodule production, testing and operation	• Investment: $40M to date • Self-contained cavity and cryomodule fabrication, testing, processing & production • Test beam available in the FEL • Injector Test cave • State-of-the-art Surface Science Analytical Instruments and lab	• 30 FTEs • Students: 2-4 • 1 Ph.D./ year; Total: 17 to date • 1 Master's • R&D Profile: *85%/10%/ 5%	• Annual DOE Science & Technology Review • Institutional Manage-ment Review every 2 years • Recommen dations implemente d annually • Director's Reviews when needed • Ad-hoc External reviews	• ILC(GDE) • SNS (ORNL) • RIA (ANL, MSU) • eRHIC (BNL) • PD (FNAL) • TTC/XFE L (DESY

Table A5.9 Profiles of Accelerator R&D at the DOE and NSF Laboratories (continued)

LANL						
Accelerator Facilities: Their Goals and time scales of achievement	**Five Accomplishments**	**Impacts to HEP**	**Budget**	**Facilities**	**Effort *Near/Mid/Long-term**	**Management Oversight and Review**
• Set up lab; fabricated 3 GHz cavities; performed about 100 tests on five 3 GHz cavities. • Built 1st double-sided Ti heat (before iris-welding) treated 4 cell beta = 0.85 niobium cavity at 805 MHz for high gradient pion acceleration; • Built first reduced beta elliptical cavities at 700 MHz at beta = 0.5,0.62 and 0.8; built multi-cell elliptical cavities at 700 MHz; demonstrated the effects of proton irradiation on an operating SRF cavity, rebuilt and upgraded the SRF laboratory space, built and tested a 1 MW cw power coupler; • Demonstrated surface resistance of MgB2 lower than niobium at 4K and Q0 dependence with magnetic field much less than YBCO and other high Tc materials.	SRF Technology development	1990-1992: approx. $1M/year by LDRD for technology development; 1992-1994: approx. $1M/year by LDRD for Pion Linac (PILAC); 1994-2001: funded by DOE APT/AAA funds at approx. $70M total over 7 years; 2001-2005: approx. $400 k total for high Tc material research for SRF cavity applications.	Cavity fabrication, processing and testing facilities and laboratory space.	No one is funded for SRF activities at present. There were 11 people (1 manager, 6 scientists/engineers, 1 designer and 3 technicians) who were directly involved in SRF activities in the past.	LANL management and DOE reviews in the past.	Contribution to SNS RF systems at ORNL.

• MSU							
Accelerator Facilities: Their Goals and time scales of achievement	**Five Accomplishments**	**Impacts to HEP**	**Budget**	**Facilities**	**Effort *Near/Mid/Long-term**	**Management Oversight and Review**	**Service to Others**
• RIA: Rare Isotope Accelerator (NP): Study of nuclei far from stability to understand the stellar processes leading to the production of the heavy elements: Complete cavity and cryo-module prototyping in 2006 • Develop elliptical cavities for FNAL Proton Driver (β=0.47, 0.61, 0.81); 2005-2008 • Develop half-reentrant cavity for ILC	• Prototyping of quarter-wave and half-wave cavities for RIA • Prototyping of reduced-beta multi-cell elliptical cavities for RIA • Low-beta prototype cryomodule design for RIA • Medium-beta prototype cryomodule for RIA: design, fabrication, and testing • Prototyping of single-cell reduced-beta cavity for FNAL proton driver	• Alternative cavity and cryomodule designs for cost reduction • Alternative cavity fabrication techniques for cost reduction • Cavity performance improvement studies: materials science, surface science, heat transfer	~$1.5M/year (DOE/NP, NSF/NP, DOE/HEP	• Self-contained cavity and cryomodule fabrication, testing, processing & production	• ~10 FTEs Students: 6 PhD R/D profile *60%, 25%, 15%	• National Superconducting Cyclotron Laboratory • NSF Nuclear Physics User Facility	• RIA (DOE) • ILC (GDE) • Proton Driver (FNAL) Materials Science (FNAL)

Table A5.9 Profiles of Accelerator R&D at the DOE and NSF Laboratories (continued)

SNS							
• SNS will generate high flux neutrons by Spallation at various energies for studies of a variety of materials. Beam on target for production of neutrons is expected in Spring 2006. • Ramping to 1.4 MW proton beam will occur by early 2009. • The energy of the 1 GeV protons is provided by a pulsed superconducting linac, the core components of which were designed, processed, assembled and tested at JLab. • Beam energy in excess of 950 MeV has been achieved and is being maintained routinely • Superconducting linac has been operated with beam both at 2.1K and 4.2 K. • A power upgrade to a 1.3 GeV beam with 3 MW power will be completed by 2012.	Installation of the superconducting cryomodules and all auxiliary components has been achieved in record time. • The testing and commissioning of the superconducting linac has been performed for the first time at 4.2 K. • Gradients in pulse mode exceeding the design values have been achieved thanks to construction by JLab and to testing skills of SNS personnel • Low Level RF systems in place for pulse operation at SNS are being used for other pulse SRF applications • High peak current operation (40 mA) has been achieved in pulse mode	• New experience in operating pulse SRF linacs • Better understanding of the fundamental and accessory limitations of pulsed SRF at various temperatures • Proof of principle of pulse SRF-based proton drivers • Highest energy "Proton" superconducting linac in operation	• In the process of developing the SRF program for Operations support and for the Power Upgrade	• High pulse power (up to 5 MW) 805 MHz test facility • Fundamental power coupler test stand • Planned: test cave for cryomodule testing and single cavity horizontal cryostat testing • Planned: large clean room for disassemble and repair of existing cryomodules • Planned: simple chemistry processing facility for restoring cavity performance in installed cryomodules	• In the process of defining the scope of the SRF program for Operations support and for the Power Upgrade	• Internal evaluation of the facility priorities • DOE semi annual review • DOE power Upgrade formal reviews • Accelerator Systems Advisory Committee Reviews	• ILC • TTC • Provide operating experience of RF, SRF and pulse power components and systems to the community

Appendix 6: Data on the Scope of Long-Term Accelerator R&D

A6.1 Overview of Program

A6.1.1 Venue of R&D

(Institutions, SBIR/STTR and percent of total FY 04 R&D dollars for these):

- National Laboratories (ANL, BNL, Fermilab, LANL, LBNL & SLAC) 67%
- Universities (25 grants)12%
- Intragovernmental (4 interagency agreements, NRL and NIST) 1%
- Industry (1 direct grant)<1%
- Industry (SBIR 76 grants, STTR 3 grants) 19%
- Other1%

A6.1.2 Support for Education: Contribute to development of next generation of accelerator scientists.

A. US Particle Accelerator School since Inception (1982):

Two week Programs Two Times per year;

Extensive Published Documentation of the Field;

Also support for U.S./CERN/Japan School

B. More Than 240 Ph.D.s in Accelerator Physics & Technology since 1982.

C. VU Beam – online virtual university by MSU

A6.1.3 Support of meetings

- Advanced Accelerator Concepts workshop – biannual
- Low Temperature Superconductor wire workshop – annual
- International Linac Conference – biannual
- Applied Superconductivity Conference – biannual
- U.S. Particle Accelerator Conference – biannual
- Other workshops –RF Sources, Instrumentation, Non-linear Dynamics, Computational Accelerator Physics, etc.

A6.2 Scope of DOE-funded Long-Term Accelerator R&D by Location

A6.2.1 R&D at National Laboratories

Table A6.1 Summary of OHEP Accelerator R&D programs at the National Laboratories (FY 2005)

Lab	R&D Area	Funding	Contact	Operating Test Facility
ANL	wake field acceleration	**$1.5M**	**Gai**	AWA
BNL		**$3.8M**	**Harrison**	
	accelerator test facility	$2.1M	Yakimenko	ATF
	muon accelerator	$1.7M	Palmer	
FNAL		**$0.7M**	**Holmes**	photo injector
	muon accelerator	$0.7M	Geer	
LBNL		**$4.8M**	**Barletta**	L'Oasis
	accelerator science	$4.1M	Leemans/Corlett	
	muon accelerator	$0.7M	Zisman	
SLAC		**$9.8M**		FFTB
	accelerator science	$5.5M	Siemann	
	generic accelerator development	$4.3M	Ruth	
TOTAL		**$20.6M**		

ANL

Advanced Wakefield Accelerator at ANL

- Dielectric RF and wakefield acceleration
- High gradient structure R&D
- High power RF sources
- High-brightness electron sources

BNL

Accelerator Test Facility at BNL

- Users' Facility for a broad range of users, experiments and science
- High-brightness electron sources
- High-power CO2 laser R&D
- Advanced electron beam diagnostics
- Photocathode R&D
- Laser acceleration
- Plasma laser guiding
- Ultra-short bunches

BNL Superconducting Magnet Division

Ultra-high field Nb3Sn magnets

MgB_2 super-conductor

High-Temperature Superconducting Magnets

Superconducting magnet material R&D

Advanced Accelerator Group

Muon cooling experiments

Muon accelerator feasibility studies

Simulations

High power targets

FNAL

Photo-injector Laboratory

FNAL Magnet R&D

Superconducting magnet R&D

Ultra-high field Nb3Sn magnets

Muon acceleration R&D

LBNL

L'OASIS at LBNL

Plasma channeling

Laser wakefield acceleration

Center for Beam Physics

Non-linear dynamics theory

Advanced code development

Advanced Accelerator Concepts

Superconducting Magnet R&D

Ultra-high field Nb3Sn magnets

Continued improvement to NbTi strand & cable superconducting magnets

Muon acceleration R&D

SLAC ARDA, ARDB, ACD

Theory and simulations

Model Independent Analysis

Beam-beam simulations

Collective effects (CSR, rough surface wake…)

Dark currents in HF RF structures

Electromagnetics and beam dynamics combined code

Facilities and experiments

FFTB, NLCTA and proposed SABER

Wakefield acceleration

Laser vacuum acceleration

Optical dielectric accelerator

SLAC (NSF)

Wakefield acceleration

High gradient structure R&D

A6.2.2 R&D at Intergovernmental Laboratories

Naval Research Laboratory

Laser wakefield acceleration
11.4 GHz magnicon source
High gradient structure R&D
High power RF sources
Advanced Accelerator Concepts

NIST

Superconducting Magnet Technology & Materials Development

A6.2.3 R&D at Universities

Institution	Principal Investigator	Title	FY05 Funding
Columbia University	Marshall	Experimental Research on a Laser Cyclotron Autoresonance Accelerator	$ 140,000
Cornell University	Padamsee	Research in Superconducting Radiofrequency Systems	$ 140,000
Florida A&M	Williams	Electron Beam Transport in Advanced Plasma Wave Accelerators	$ 100,000
Florida State University	Van Sciver	Liquid Helium Fluid Dynamics Studies	$ 205,000
Illinois Institute of Technology	Kaplan	Participation in Muon Collider/Neutrino Factory Research and Development	$ 115,000
Massachusetts Institute of Technology	Temkin	17 GHz High Gradient Accelerator Research	$ 305,000
Massachusetts Institute of Technology	Chen	Theoretical and Computational Investigation of Periodically Focused Intense Charged Particle Beams	$ 180,000
Michigan State University	Berz	Advanced Map Methods for the Description of Particle Beam Dynamics	$ 330,000
National Institute of Standards and Technology	Costrell	Data Acquisition Systems	$ 90,000
National Institute of Standards and Technology	Ekin	Electromechanical Properties of Superconductors for DOE Applications	$ 130,000
National Institute of Standards and Technology	Goodrich	Critical-Current Metrology for Nb3Sn Conductor Development	$ 50,000
Naval Research Laboratory	Sprangle	High Energy Laser-Driven Acceleration Based on the Laser Wake-Field Accelerator: Theory, Simulations	$ 375,000

Institution	Principal Investigator	Title	FY05 Funding
Naval Research Laboratory	Gold	Development and Testing of Advanced Accelerator Structures and Technologies at 11.424 GHz	$ 400,000
Northern Illinois University	Bohn	Nonlinear Dynamics of High-Brightness Electron Beams and Beam-Plasma Interactions: Theories, Simulations, and Experiments	$ 100,000
Northwestern University	Velasco	Development of Beam Instrumentation for CLIC at the CTF3 Facility at CERN	$ 45,000
Ohio State University	Collings	Material, Strands, and Cables for Superconducting Accelerator Magnets	$ 235,000
Princeton University	Davidson	Collective Processes and Nonlinear Dynamics of Intense Charged Particle Beams for High Energy Physics Applications	$ 225,000
Stanford University	Byer	Proposed Physics Experiments for Laser-Driven Electron Linear Acceleration in a Dielectric-Loaded Vacuum	$ 400,000
State University of New York, Stony Brook	Ben-Zvi	Development of Electro-Optical Detectors for the Temporal Characterization of Sub-Picosecond Beam Bunches	$ 29,988
STI Optronics, Inc.	Kimura	Laser Wakefield Acceleration Driven by a CO2 Laser (STELLA-III)	$ 385,000
Texas A&M	McIntyre	Superconducting Dipoles for Future Hadron Colliders	$ 610,000
University of California, Berkeley	Wurtele	Advanced Accelerator Concepts	$ 275,000
University of California, Los Angeles	Cline	Advanced Accelerator Physics Research at UCLA	$ 310,000
University of California, Los Angeles	Rosenzweig Pellegrini	Theoretical and Experimental Studies in Accelerator Physics	$ 780,000
University of California, Los Angeles	Joshi	Experimental, Theoretical and Computational Studies of Plasma-Based Concepts for Future High Energy Accelerators	$1,350,000
University of Colorado	Cary	Chaotic Dynamics and Advanced Computation for Beams and Accelerators	$ 190,000
University of Indiana	Lee	Physics of Beam Cooling, Space Charge Effects, and Beam Manipulation Technologies in High Energy Accelerators	$ 210,000
University of Kansas	Shi	Study of the Stability of Particle Motion in Storage Rings	$ 90,000

Institution	Principal Investigator	Title	FY05 Funding
University of Maryland	Dragt	Advanced Methods for the Computation of Particle Beam Transport & Computation of Electromagnetic Fields & Beam-Cavity Interactions and Multi-particle Phenomena	$ 295,000
University of Maryland	Milchberg	Application of Plasma Waveguides to Advanced High Energy Accelerators	$ 235,000
University of Maryland	O'Shea	Accelerator Research Studies (Tasks A, B, and C)	$1,485,000
University of New Mexico	Ellison	Investigations of Beam Dynamics Issues at Current and Future Hadron Accelerators	$ 155,000
University of Southern California	Katsouleas	Program for Plasma-Based Concepts for Future High Energy Accelerators	$ 490,000
University of Tennessee	Bugg	Undulator-Based Production of Polarized Positrons at SLAC Final Focus Test Beam Facility (LCRD 2.37)	$ 40,000
University of Texas	Shvets	Theoretical Investigations of the Plasma-Based Particle Accelerators	$ 175,000
University of Texas	Downer	Laser Wakefield Acceleration: Channeling, Seeding, and Diagnostics	$ 185,000
University of Wisconsin	Larbalestier	High Field Superconductor Development and Understanding	$ 530,000

Total: $11,385,000

A6.2.4 R&D at Industries

Industries receiving SBIR and/or STTR Funding

Accelerator Technology Corporation (3+2)
Advanced Energy Systems, Inc. (4)
Advanced Magnet Lab, Inc. (2)
Alabama Cryogenic Engineering, Inc. (5+2)
Alameda Applied Sciences Corporation (3)
Alchemet, Inc. (2)
Allcomp, Inc.
Amac International, Inc. (2)
Ambp Tech Corporation
American Magnetics, Inc. (+1)
American Research Corporation of Virginia (2)
American Superconductor Corporation (2)
Amplification Technologies, Inc. (2)
Apeak, Inc. (2)
Applied Plastics Technology, Inc. (2)
Applied Pulsed Power, Inc. (2)
Asgard Microwave (2)
Betadot
Black Laboratories, LLC (2)
Boston Applied Technologies, Inc. (2)
Burle Industries, Inc. (2)
Calabazas Creek Research, Inc. (21)
California Tube Laboratory, Inc. (3)
Cermet, Inc. (+1)
Champion Research (3)
Composite Technology Development, Inc. (3)
Corporate Computer Services, Inc. (2)
Creatv Microtech, Inc.
Cremat, Inc. (2)
Dac International (2)
Dayton Reliable Tool And Manufacturing Company
Digital Optics Corporation (+1)
Diversified Technologies, Inc. (23)
Dsp Alloys Inc. (3)
Duly Research, Inc. (10)
Elcon Inc. (formerly Macrometalics) (4)
Energen, Inc. (5)
Epion Corporation (2)
Euclid Concepts, LLC (2)
Eurus Technologies, Inc. (+1)
Far-tech, Inc. (7)
Fivesight Technologies, Inc. (2)
Fm Technologies, Inc. (8)
FutureTek USA Corp (+1)
G. H. Gillespie Associates, Inc. (3)
Genvac Aerospace Corporation
Giner Electrochemical Systems, LLC
Global Research and Development, Inc. (5+1)
Haimson Research Corporation (8)
Hyper Tech Research, Inc. (10)
Hypres, Inc. (2)
Hytec, Inc. (3)
Icarus Research, Inc. (3)
Innovare, Inc. (4)
International Power Group, Inc.
Ion Optics, Inc.
Ionwerks, Inc.
Isa Corporation
Kapteyn-murnane Laboratories, Inc.
Lawrence Semiconductor Research Laboratory, Inc. (2)
L'garde, Inc.
Lmc, Inc. (2)
Ludlum Measurements, Inc. (+2)
Luxel Corporation (2)
Manhattan Routing, Inc.
Micramics, Inc.
Mission Research Corporation (2)
Mount Blodgett Design, Inc.
Multiphase Composites (4)
Muons, Inc. (5+6)
Nano Systems, Inc.
Nanomaterials Research Corporation (3)
Nanohmics, Inc. (+1)
Nanosciences Corporation (2)
Ngimat Co. (4)
North Star Research Corporation
Nycb Real-time Computing, Inc. (3)
Omega-p, Inc. (45+3)
Optiswitch Technology Corporation
Particle Beam Lasers, Inc.
Paul D. Jablonski
Pavilion Technologies, Inc. (+1)
Photodigm, Inc.
Physical Sciences Inc.
Piocon Technologies, Inc.
Pmd Scientific, Inc.

Positive Light, Inc.
Quantum Research Services, Inc.
Radiabeam Technologies, Llc (3)
Radiation Monitoring Devices, Inc. (5)
Ralph B. Fiorito Company (+1)
Red Cone Research, Inc. (2)
Robertson Precision, Inc. (2)
Rwbruce Associates, Inc. (2)
Sandiaview Software, Inc.
Saxet Surface Sciences (+1)
Sci Engineered Materials, Inc.
Sci-eng Solutions, LLC (3)
Sigma Technologies International, Inc.
Simulation Technology and Applied Research (4)
Sine Nomine Associates
Solidica, Inc.
Square One Systems Design
Stangenes Industries, Inc.
Sti Optronics, Inc. (5)
Supercon, Inc. (19)
Superconducting Systems, Inc. (8)
Superconductive Components, Inc. (2)
Supergenics I, LLC (11)
Surface Manufacturing Inc.
Sv Systems, LLC
Svt Associates, Inc. (3)
Synkera Technologies, Inc.
Tai-yang Research Corporation (2)
Technology Assessment And Transfer, Inc.
Techsource, Inc.
Tech-x Corporation (19)
Tempest Microsystems (4)
Tpl, Inc.
Tristen Technologies
Triton Services, Inc., Electron Technology Div., Uhv Technologies, Inc., Utron, Inc. (4)
Wenzel Associates, Inc.
World Physics Technologies, Inc. (3)
Xgamma Corporation
Y. Y. Labs, Inc. (2)
Zmation, Inc. (3)

A6.3 Scope of NSF-funded Long-Term Accelerator R&D by Location

Table A6.3.1 NSF Elementary Particle Physics support for Universities in FY2005

Item	PI	FY2005		
Cornell/CESR	Tigner	$16,620,000	Cornell	
Cornell/ERL	Gruner	$5,150,000	Cornell	
CESR	Holtzapple	$92,379	Alfred U.	Career
MICE	Kaplan	$100,000	IIT	
			UC Riverside	
			New Hampshire	
MICE	Kaplan	$750,000	IIT	MRI
			Fermilab	
ORION	Katsouleas	$50,000	USC	
			UCLA	
FEL	Rosenzweig	$50,000	UCLA	
	Spentzouris	$133,386	IIT	Career
ILC R&D	Tigner	$15,181	Cornell	
			NC A&T	
			Minnesota	
			Vanderbilt	
			SUNY Albany	
ILC R&D	Tigner	$118,843	Cornell	
			Colorado State	
			SUNY Albany	
			Minnesota	
ILC	Tigner/Dugan	$84,995	Cornell	
			Cornell	

Table A6.3.2 NSF support for meetings

Meetings/Workshops		
PAC05	Holtkamp	$7,000
Snowmass ILC Workshop	Nauenberg	$37,000

A6.3.2 Other NSF support in accelerator science:

(1) Nuclear Physics:

Michigan State University NSCL: $1-1.5M, R & D related. (PI Richard York)
Indiana Cyclotron Lab: $100k/yr, (PI S-Y Lee)

(2) Division of Materials Research
van Tol, Florida State University, $1,842,219, IMR-MIP: Concept and Engineering Design of a Free Electron Laser

A6.3.3 Scope by subject

- 3D theory of asymmetric beams in klystrons
- Code development
  - Beam dynamics
- Diagnostics for extremely small bunches
- ERL R&D
- High-brightness electron sources
- High power, short wavelength RF sources
- High field structures
- Hydraulic characterization of superfluid He as cooling medium
- Laser acceleration
  - Laser wakefield acceleration
  - Laser channeling
  - Laser ion acceleration
  - Laser acceleration – other (in vacuum, IFEL, Cyclotron Resonance)
  - Laser plasma acceleration
  - Laser plasma diagnostics
- Muon colliders / neutrino sources
- Muon Accelerator R&D:
  - High power target
- Non-linear beam dynamics experiments
- Non-linear dynamics theory
- Photoinjectors
- Photonic bandgap accelerator structures
- Plasma Wakefield acceleration
- RF driven dielectric structure acceleration
- Staged laser acceleration
- Superconducting magnets
  - Ultra-high field
  - New geometries
  - Ultra-high field Nb3Sn magnets
  - Continued improvement to NbTi strand & cable superconducting magnets
  - MgB_2 super-conductor
  - Superconducting magnet material R&D

Superconducting cavities
- High gradient SRF

Theory
- Beam-beam interaction
- Beam halo theory
- Compression physics
- Lie algebraic methods
- Non-linear dynamics theory
- Space charge dominated beam dynamics

Ultra-bright beam physics
Ultra-fast control and beam manipulations
Ultrafast Optical Detector
Ultra-high space-charge ring
Wakefield acceleration in plasma
Wakefield accelerations in dielectrics

Appendix 7 International Efforts in Accelerator Research and Development

A.7.1 Overview

This appendix is intended to give a survey of foreign activities in advanced accelerator research and development. It is broken down by region — European and Asian efforts are considered separately — and further by nation for the countries having major research efforts. Europe is singled out particularly for the high degree of coordination between EU member states, and for the unique international effort at CERN.

A.7.2 Europe

In the European region, there are two major HEP projects pushing forward near-term AARD, both centered at CERN: the LHC collider and the CNGS neutrino beam. All member states are involved in the AARD oriented towards these projects at some level. Other proposed HEP related projects which impact medium range R&D include the FAIR (Facility for Antiproton and Ion Research) project centered at GSI-Darmstadt., and EURISOL, a radioactive ion beam project which is in the design stage. 28 European institutes have joined forces to participate in a Design Study, so-called "EUROTEV", focused on the key issues of an International Linear Collider (ILC) based on Super-Conducting RF technology in the TeV energy range and the possible upgrade into the multi-TeV energy range further in the future with a novel high gradient technology of the Compact Linear Collider (CLIC, an effort centered at CERN). The UK effort, on the other hand, is oriented towards an aggressive approach to muon collider/neutrino factory development. A significant number of major light source projects are now underway or in the final preconstruction stages in Europe, among them: XFEL at DESY, 4GLS (CCLRC), Fermi (Trieste), SPARC/SPARX (Frascati), BESSY FEL, FEL at PSI, and upgrades to the ESRF at Grenoble.

We structure the examination European AARD efforts by first looking at the overall coordination of European laboratories and universities in this area. This discussion will identify and explain the thrust of a large number of joint projects involving many institutions. We then discuss the multi-national program at CERN, and finish with a country-by-country survey of activities.

A.7.2.2 European Coordination in Advanced Accelerator R&D

European priorities in advanced accelerator R&D within the context of pan-European efforts are set by the European Steering Group for Accelerator R&D (ESGARD). ESGARD was established by the directors of CCLRC, CERN, DAPNIA/CEA, DESY, LNF, Orsay/IN2P3, and PSI in consultation with ECFA, with the mandate of developing proposals to optimize and enhance research and technical development in the field of accelerator physics in Europe. It has a particular aim of preparing a coherent strategy in applying for EU funding within its Framework Programs.

Following the recommendation made by ECFA in the 2001 report on “the future of accelerator-based particle physics in Europe”, several major accelerator R&D programs, promoted by ESGARD, have been launched with the support of the national funding agencies and European Commission within the sixth Framework Program. The EU funded collaborative programs at present are CARE, EUROTeV, EUROFEL, EURISOL and EuroLeap. They represent a major strength for the European HEP and light source communities and aimed at both improving existing accelerators and related infrastructure as well as developing new accelerators and related infrastructures. The 6th Framework Program will come to completion in 2007 and 2008. ESGARD is now asking for proposals for the 7th EU Framework so that it may continue to successfully coordinate EU funding for accelerators, which is obtained in competition with other branches of science.

All of the EU-funded programs mentioned above are HEP-oriented except for EUROFEL, which is concerned with 4th generation light source development. The HEP programs are summarized in Table A7.1, which gives the class of program (I3 means Integrated Infrastructures Initiative, DS signifies Design Study, and NEST indicates New and Emerging Science and Technology), the type of beams, the start and duration of the project, and its total cost, with the fraction borne by the EU.

Table A.7.1 HEP related accelerator R&D programs with EU support.

Program	Type	Beam Type	Start	Duration (years)	Total Cost	EU Contribution
CARE	I3	All future HEP colliders (e, p, μ)	1/05	5	55 M€	15.2 M€
EUROTeV	DS	e^+e^- (Linear Colliders)	1/05	3	29 M€	9 M€
EURISOL	DS	Ions, protons, muon-beams	1/05	4	33 M€	9.2 M€
EUROLEAP	NEST	e^- plasma accelerator	3/06	3	4.1 M€	2 M€

CARE

The CARE (Coordinated Accelerator Research in Europe) program addresses the improvements of HEP accelerator infrastructure in Europe, as listed in Table A.7.2. The CARE goals are to support:

- Electron-positron linear colliders with energies ranging between 500 and 3000 GeV in the COM system, using SC high gradient accelerator structure technology recently developed by the TESLA collaboration, and aiming at exploiting two-beam techniques for obtaining ultra-high gradients at developed by the CLIC collaboration.
- Facilities providing intense neutrino beams (e.g. Nufact) using improvements to the existing methods based on intense proton beams, and more novel techniques based on radioactive ion or muon beams.
- Ultra-high intensity/energy proton beams facilities, aiming at very large hadron colliders; also LHC luminosity and energy upgrades.

CARE has two missions in aiding its goals, Networking Activities (NA, for support of personnel exchange and scientific meetings), and Joint Research Activities (JRA, for specific projects). The CARE networks at present are

- ELAN (Electron Linear Accelerator Network) for electron accelerators and linear colliders.
- BENE (Beams in Europe for Neutrino Experiments for neutrino and muon beams.
- HHH (High-energy High-intensity Hadron beams) for hadron rings and colliders.

The joint research projects that CARE supports are as follows:

- SRF: The development of SC cavity technology for acceleration of electrons with a gradient of >35MV/m and the development of general supporting SCRF technology.
- PHIN: An R&D program for improving the technology of photoinjectors, in particular to match the rigorous needs for demonstrating 2-beam acceleration concepts.
- HIPPI: The integrated development of normal and SC structures for the acceleration of high-intensity proton beams as well as beam chopping magnets.
- NED: Development of SC magnet technology for very B- field (>15T) and high current densities (>1500 A/mm^2).

A large number of European institutes with significant facilities listed in Table A.7.2 are participating in the CARE project, coordinated by the European Steering Group of Accelerator R&D (ESGARD): http://esgard.lal.in2p3.fr/Project/Activities/Current/Participants/ .

Table A.7.2. Existing EU infrastructure participating in CARE

Laboratory	Accelerator	Description
CCLRC-RAL	ISIS	Accelerator complex for neutron and muon facility
CEA	IPHI, CryHoLab	High intensity proton injector Horizontal cryogenic test stand
CERN	PS, SPS,LHC CNGS CTF3	Proton accelerator complex Neutrino beam Electron two-beam linac test facility
CNRS-Orsay	NEPAL	Test stand with photoinjector Coupler test laboratory
DESY	PETRA, HERA TTF	Electron and proton accelerator complex Electron superconducting linac test facility and FEL

FZR	ELBE	Electron linear accelerator
GSI	SIS, ESR	Heavy-ion accelerator complex
INFN-LNF	DAFNE	Electron-positron collider
PSI	SINQ	Accelerator complex for neutron and muon facility

EuroTEV

EuroTEV is a pan-European collaboration focused on forward-looking aspects of a linear collider. Its aim is to use help from EC to make a "coherent approach on Linear Colliders in Europe". To this end 28 European institutes have joined forces to participate in a Design Study for a Linear Collider in the TeV energy (ILC) and possible upgrade path into the multi-TeV energy regime (CLIC). This effort obtains overall guidance from the ILC GDE. The future concepts emphasis for the ILC is also influenced by the desire in the EU community to create some synergy with CLIC and XFEL research.

EUROTeV "Working Packages" resulting from these goals are organized as follows:

- Beam Delivery System
- Damping Rings
- Polarized Positron Sources
- Diagnostics
- Integrated Luminosity Performance Studies
- Metrology & Stability
- Global Accelerator Network and Mobile Virtual

In the Framework program 7 proposal plan which is due soon covering 2007-2011, the EC would like to take a more active role in planning ILC, and intends to disburse some structural funds to aid in site construction.

In addition to EUROTeV, the EC has funded a design study for the radioactive ion accelerator complex termed EURISOL, investing significant resources. At a smaller level, long range research into laser-plasma acceleration has been.

Finally, we note that an ambitious proposal has been generated by a large European collaboration led by Ecole Polytechnique: the Extreme Light Infrastructure (ELI) initiative. This proposal, which is being developed for the next cycle of EC funding (7th Framework Program), aims to capitalize on recent rapid advances in electron acceleration in laser wakefields. By developing the laser infrastructure, it is envisioned that a wide variety of beams at energies ranging from 100 MeV to 1 TeV may be generated through the laser-plasma interaction.

ELI has been called a "science integrator" that will bring many frontiers of contemporary physics, i.e. relativistic plasma physics, particle physics, nuclear physics, gravitational physics, nonlinear field theory, ultrahigh pressure physics, and cosmology together. ELI seeks to provide a new generation of compact accelerators delivering ultra short (fs-as) and energetic particle and radiation beams for European scientists. It is envisioned that ELI will work in close contact with synchrotron X-ray and FEL communities. The emphasis of infrastructure development in ELI can be understood from Table A.7.2.

Using existing lasers (first row), one may obtain, as has been demonstrated at LBNL, an electron beam that is trapped and accelerated to above 1 GeV. By scaling to the 100 PW level, one may obtain electrons above a TeV in a single stage accelerator. Using this laser infrastructure, one may also build light sources based on Compton scattering, and produce a plethora of other types of particles, including few GeV proton beams, directly from the laser-plasma interaction. A lab based on this infrastructure would be a potential trail-blazing approach to many physics disciplines in the coming decades.

Letters of Intent for activities to be co-funded by the EU Framework Program 7 (FP7) covering the period 2007 - 2013, are presently under preparation.

A.7.2.3 CERN

Accelerator research and development at CERN is wide ranging, and employs approximately 100 FTEs, as indicated in Table A.7.3, which also indicates some of the related material costs. Beyond the day-to-day development needed for running machines at CERN as well as building the next large projects, we can break down the CERN AARD program into the following categories, most of which have already been introduced:

- **GRID**. The mission of the LHC Computing Project (LCG) is to build a data storage and analysis infrastructure for the entire LHC-user high energy physics community.
- **CARE.** CERN's role in the EU supported Coordinated Accelerator R&D in Europe consists of participation in managing the project, a large part of the Networking Activities and Joint Research Activities related to the LHC upgrade, high field superconducting dipoles, high intensity proton linacs, high charge photo-injectors, neutrinos and radioactive ion beams.
- **LHC upgrade.** The main objectives of the High Intensity, High Energy, Hadron Beams (HHH) network in the frame of the EU supported CARE project are:
  - To identify, evaluate and make a comparative study of the various technologies for achieving hadron beams with energies and intensities above those currently at hand.
  - To propose an integrated R&D program and a road map to validate the best solutions.
  - To study how these solutions can be implemented on the existing infrastructures (including LHC) to improve their performance.
  - To establish a roadmap for the construction of a future hadron collider post-LHC.
- **Next European Dipole (NED).** This program is a first unique step towards integration and coordination of superconducting Nb_3Sn accelerator magnet R&D in Europe by the involvement of most interested parties, with three main objectives:
  - to promote the development of high performance Nb_3Sn wire in collaboration with European industry,
  - to develop a parametric design of a large-aperture (up to 88 mm), high-field (up to 15 T) Nb_3Sn dipole magnet, and
  - to execute a limited scientific program on insulation development and heat transfer studies ofNb_3Sn conductor technology. The program should lay the

ground for a Nb_3Sn dipole magnet model that could push the technology well beyond present LHC limits.

- **EURONS** is the Integrated Infrastructure Initiative involving European nuclear structure scientists from 44 institutions in 21 countries reflecting the community at large and within an equal opportunity structure. It is a coherent and complementary ensemble of Networking**,** Transnational Access and Joint Research Project Activities underpinning new European large-scale projects and commitments.
- **CLIC.** The Compact Linear Collider (CLIC) study is a site independent feasibility study aiming at the development of a realistic technology at an affordable cost for an electron-positron Linear Collider in the post-LHC era for Physics up to the multi-TeV center of mass colliding beam energy range (0.5 to 5 TeV). The CLIC collaboration consists of over 20 participating institutions, including some outside of the EU (e.g. Turkey, USA). CLIC researchers participate in the EU EUROTEV design study, the EU ELAN network and the PHIN Joint Research Activity in the frame of the EC-supported CARE project.
- **SPL**. The Superconducting Proton Linac (SPL) is a 3.5 GeV H^- linear accelerator for 4 to 5 MW beam power, to be used as a driver for neutrino facilities and/or EURISOL, modernizing and improving at the same time the injector for the PS, SPS & LHC. It reuses RF equipment from the old LEP machine. The normal conducting part of the SPL, called LINAC-4 can be built in a first stage as new injector for the CERN Booster. The SPL Front-end will be built in 2006-08 as the 3 MeV Test Stand. SPL research is enhanced by participation in the EU HHH network and the EU HIPPI JRA in the framework of the CARE project.
- **Neutrino Factory.** CERN participates in world-wide development of a Neutrino Factory in the context of the EU BENE network.
- **DIRAC**. The CERN effort is directed towards common development between CERN accelerators and the FAIR project at GSI.
- **EURISOL**. The EURISOL project is aimed at the design - and eventual construction - of the 'next-generation' European ISOL radioactive ion beam (RIB) facility. The first phase was a 4-year feasibility study (2000-2003) supported by the European Commission during the 5th Framework Programme (FP5), as a Research and Technical Development (RTD) project in Nuclear Physics. The EURISOL Report has now been published.

Table A.7.3 CERN accelerator R&D programs with personnel and material effort

Subject	Type	Short description and WWW site		Material	TOTAL
			FTE	MCHF	MCHF
GRID	short	Web site: http://lcg.web.cern.ch/LCG/	33	20.6	25.7
CARE	short	http://esgard.lal.in2p3.fr/Project/Activities/Current/	0.5	0	0.05
LHC upgrade	short	http://esgard.lal.in2p3.fr/Project/Activities/Current/Networking/N4/N4_vers_08.09.03.doc	3	0.12	0.45
NED	short	http://esgard.lal.in2p3.fr/Project/Activities/Current/Joint/JRA4/NEDResV4.doc	0.5	0.32	0.37
EURONS	short	http://www.gsi.de/informationen/jofu/EURONS/	7.8	0.38	1.1

CLIC	medium	http://clic-study.web.cern.ch/CLIC-Study/ http://www.eurotev.org/ http://esgard.lal.in2p3.fr/Project/Activities/Current/Networking/N2/ELANsept2.doc http://esgard.lal.in2p3.fr/Project/Activities/Current/Joint/JRA2/PHIN_26_9_03.doc	40	4.16	8.6
SPL	medium	http://project-spl.web.cern.ch/project-spl/ http://esgard.lal.in2p3.fr/Project/Activities/Current/Joint/JRA3/HIPPI-modif-26-09-03.doc	10	0.85	1.6
Neutrino Factory	medium	http://muonstoragerings.web.cern.ch/muonstoragerings/Welcome.html WWW site: http://bene.web.cern.ch/bene/	0.9	0.03	0.13
DIRAC	medium	https://www-new.gsi.de/gsitools/gast.shtml?kennung=dokumentenablage&folder=1080571983&language=_e	3	0.9	1.24
EURISOL	medium	http://www.ganil.fr/eurisol/	16	0.28	2.05
TOTAL			**114.7**	**27.6**	**41.3**

A.7.2.4 France

French AARD activities in the HEP arena are heavily geared towards the EC-supported collaborations. French labs at Saclay and Orsay have played a large role in the development of TESLA technology through the DESY-centered collaboration. This momentum has carried through to the present time in the emphasis in France on ILC-directed research, especially in the EUROTeV context. Current ILC activities in France can be summarized as follows:

- Positron sources. There are significant activities at CNRS/IN2P3/LAL-Orsay in development of polarized positron sources from Compton scattering. These efforts are concentrated on short pulse, high power laser and high finesse Fabry-Perot cavity development.
- Superconducting RF cavities and cryomodules.
  - At CNRS/IN2P3/LAL-Orsay, there are efforts in development of prototype power couplers, studies on conditioning of power coupler, technology development (surface studies, thin-film deposition). Industrialization studies of the TTF-III coupler for the European XFEL are also underway.
  - At CNRS/IN2P3/IPN-Orsay, characterization of piezoelectric components for cold tuning systems is being performed.
  - At CEA/DSM/DAPNIA-Saclay, research into electropolishing of cavities, development of piezo-tuner prototypes, and integrated RF tests of cavities in the horizontal cryostat CryHoLab is underway. Other activities include developing a cold BPM, HOM studies of beam based alignment, and studies of cavity quench properties and baking, as well as industrialization studies of piezo-tuners for the XFEL.
- Beam delivery systems.
  - At CNRS/IN2P3/LAL-Orsay, there is a long term effort in beam-beam simulation code development. There are also post-collision diagnostics lattice studies,
  - At CEA/DSM/DAPNIA-Saclay, there are studies of collimation and final focus optics, and of beam stability in collisions.
- Management. The French labs are also active in developing the management infrastructure for global and European ILC efforts.

In areas beyond the ILC, French labs GANIL and CEA-DAPNIA played a large role in the design study EURISOL for a new radioactive ion beam facility in Europe. The EUROFEL program drives French efforts in long-range light source development. Researchers at ESRF and SOLEIL take part in infrastructure development and experiments on seeded FELs in this context.

Long range R&D in accelerators is a bright spot in the French national program. The Ecole Polytechnique has been a historical leader in laser wakefield accelerators and other areas of laser-plasma interaction. As such, French researchers play a lead role in the existing EuroLEAP laser accelerator research collaboration, and the new laser infrastructure initiative ELI which we have discussed above.

French industry has been quite active in developing products for the accelerator community. In particular, Thales stands out as a prime supplier of RF power sources in the world; it is also developing lasers for photocathode drive systems.

A.7.2.5 Germany

DESY has in the last decade shifted its emphasis from developing the HERA e-p collider, to taking a leading role in the R&D on high field superconducting cavities within the framework of the international TESLA collaboration. The outstanding success of the corresponding R&D demonstrated in the TESLA Test facility (TTF) led to the technology decision in favor of superconducting cavities for the ILC linacs and the launching of the challenging European XFEL project to be built as an international (predominately European) collaboration. The TTF, which presently holds the world's record for the shortest wavelength SASE FEL, will be transformed in a VUV-FEL facility with limited time available for SRF development.

In the longer term, however, Germany remains a leader in global SRF research, having 11 contracting partners in SRF CARE, leveraging a total EU support SRF of 5.1 M€. The SRF effort is split roughly in half for manpower and half for prototyping and consumables. Additional lab support is at least equal to the EU support. DESY is also very active in other components of ILC research, including damping rings and final focus/beam delivery systems.

With the success of the path-breaking TTF FEL facility, DESY and other German partners also play a lead role in all aspects of the EUROFEL project, developed with EU funding. In particular, a state-of-the-art electron source facility has been has developed at DESY-Zeuthen, which serves as a hub of high brightness electron beam research in Europe. The drive to 4th generation light sources using FELs has been adopted in a proposal by the BESSY synchrotron lab, which is now designing a free-electron laser in the few nm wavelength region.

Accelerator research at GSI (Darmstadt) has concentrated on developments in high current proton and antiproton beams. Ion beam experiments are carried out using the UNILAC linac, SIS heavy ion synchrotron, and the ESR storage ring, which stores stable and radioactive ions. In addition, there is a strong program at GSI to study more unconventional laser-plasma based ion acceleration. An ambitious and challenging project, the Facility for Anti-Protons and Ions Research (FAIR), which envisions upgrading the present performance of the GSI accelerator complex by several orders of magnitude, has been launched as an international collaboration. It requires the development of pulsed superconducting magnets with high magnetic field. It has been the subject of detailed design studies which involved a large collaborative effort between GSI and CERN; it is also based on experience at Julich in developing the COSY cooler synchrotron.

DELTA (Dortmund Electron Accelerator) in Dortmund is a research accelerator dedicated to forward-looking developments on circular accelerators. This complex puts equal emphasis on basic accelerator physics and development of the facility as a light source, including an FEL component. Because of this unique mix, there is no comparable machine for accelerator research in the US. Elsewhere in the German universities, one finds Rossendorf and Wuppertal, which have pioneered superconducting RF guns, and TU-Berlin, with a strong high frequency electromagnetic accelerating structure program. Munich is now developing a strong effort in laser-plasma acceleration.

German industry in accelerators and related technology is world leading, with companies such as Accel (SRF cavities) and Siemens (medical linacs) among the most notable. The ability of German (as well as Italian) industry to respond to TESLA developments was a strong component of the advantage given to the choice of superconducting RF cavities for the ILC.

A.7.2.6 Italy

The high energy physics-directed advanced accelerator research efforts in Italy take place in the near term context of strong involvement in the LHC, and in support of the ongoing program at the DAFNE e^+e^- collider (INFN-LNF, Frascati), which is presently operated as a ϕ-factory. In addition, there are several light source projects now underway with Italian participation: the XFEL at DESY, in which INFN has played a strong collaborative role, the soft-X-ray FEL projects FERMI at Elettra (Trieste) and SPARX (INFN-LNF, Frascati). SPARX is a follow-on to the LNF-led SPARC high brightness beam and FEL test facility. These new projects have been taken on despite a severe budget crisis in Italian science. Another significant investment in Italy is being put into hadron therapy, with the CNAO project (Pavia).

Table A.7.4 Italian accelerator R&D programs with personnel and material effort

Project	Description	Funding (M€/yr)	Manpower (FTE)
SPARC	High brightness electron beam and FEL physics at new INFN-LNF facility. ENEA (Frascati) is a major collaborator	2	20
DANAI	DAFNE upgrade scenario studies	0.2	4
PLASMONX	Advanced accelerators at SPARC/SPARX. Includes Pisa-led laser-plasma acceleration	0.7	5
FERMI	Soft X-ray, narrow-band SASE FEL	15	12
SPARX	Soft X-ray SASE FEL	10	5
EuroFEL	EU support for advanced electron sources, diagnostics and cascaded high-harmonic FEL studies at SPARC	1.8	9
TESLA TTF	Collaboration on advanced photocathodes and SRF cavities (INFN-Milano centered)	0.5	6
EUROTEV	EU support for ILC design studies		
ILC	Damping ring studies and fast-kicker	0.2	2
CTF	RF deflector development for CTF3	0.5	3
CNAO	Hadron therapy machine	10	12
INFN-Catania	Ion source development	1.4	10
INFN-Legnaro	RFQ development	1.1	10
	Totals	**43.4**	**98**

Because of strong participation in the European Union networks, Italian efforts in accelerator R&D mirror those of EU partners. In particular, while they support high energy physics both in the near term and also long-range, through CARE and EUROTeV, there is an increasing emphasis, especially concerning national infrastructure development, on 4^{th} generation light sources. The short wavelength FEL projects SPARC and SPARX will occupy much of the personnel effort in the main Italian HEP lab in LNF, with a transformation in lab focus analogous to that now occurring in the US at SLAC.

Both international and Italian projects are typically organized as multi-lab collaborations. Italian involvement in European networks is coordinated at the national level (through INFN and ministerial administration). A description of the characteristics of the Italian AARD program is given in Table A.7.4. We note that the national effort in personnel terms is nearly equivalent to that of CERN.

Italian industry gives strong support to the development of accelerator technologies, in particular in superconducting RF cavities and in accelerator-grade power systems.

A.7.2.7 United Kingdom

After a long period of relatively low activity, accelerator research in the UK is resurgent. Various UK institutes have recently been restructured in order to promote and develop accelerator science in UK and train new generation of accelerator scientists and engineers:

- The ADAMS institute, which reorganizes the Particle Physics Department of Oxford University and the Royal Holloway University of London (RHUL).
- The Cockroft Institute, which is a joint venture of Lancaster University, the Universities of Liverpool and Manchester, the Council for the Central Laboratory of the Research Councils (CCLRC) at the Daresbury and Rutherford Appleton Laboratories, the Particle Physics and Astronomy Research Council (PPARC), and the North West Development Agency (NWDA). It aims to develop a broad-based, multi-disciplinary approach to accelerator research and development.

The UK high energy physics effort is mainly focused on muon collider/neutrino factory development, especially via the construction of the Muon Ionization Cooling Experiment (MICE) at Rutherford: an international Collaboration aiming at the feasibility demonstration of ionization cooling. This effort is aimed at establishing the accelerator technology needed to proceed with muon colliders and/or neutrino factories on a much faster time scale than envisioned in the US. The UK plays a major role in the design and R&D of a Linear Collider Beam Delivery System (LC-BDS).

In terms of light sources, a 3^{rd} generation light source termed DIAMOND has been built recently adjacent to the CCLRC Rutherford Appleton Laboratory. In addition, there is a highly significant effort underway at Daresbury to design and prototype aspects of an ambitious 4^{th} generation, ERL and FEL-based light source termed 4GLS. A large international collaboration is underway at the University of Strathclyde on the TOPS (Terahertz to Optical Pulse Source) project, which marries an electron beam and ultra-short laser pulse.

Imperial College, using the resources of the Rutherford Appleton Lab, has proven itself over the past 15 years to consistently be at the cutting edge in laser-plasma acceleration, and proposes to be highly involved in the ELI project.

UK industry is well known in accelerator (and related) fields. Examples of successful British industrial concerns in these areas are Oxford Instruments (superconducting magnets, etc.) and QMC (terahertz detectors).

A.7.2.8 Elsewhere in Europe

There is a considerable amount of accelerator research in Europe outside of the labs and nations listed above. A survey includes:

- In the former Soviet Union, severe budget pressures have lowered the profile of what was, up until 1990, a leading program in AARD. International collaborations, especially with CERN and DESY, play an increasingly important role in Russian accelerator science. At JINR, the Nuclotron deuteron accelerator is now being put into use. The Budker Institute has existing facilities for synchrotron radiation production, but puts much of its efforts into external collaborations, especially for electron cooling (for FNAL, BNL RHIC, GSI), a technology which was invented there.
- In Armenia, there is a new light source under construction termed CANDLE. Armenian scientists also contribute to advanced accelerator theoretical research.
- Eastern European institutes, most notably in Poland, have maintained some vigor in AARD through close ties with, and funding dependence upon, work in Western European high energy physics labs and light sources.
- Notable efforts in FEL and high-brightness electron beam development in the Netherlands, at the FOM Institute (FELIX FEL) and the Univ. of Eindhoven.
- At Aarhus, much cutting edge work in electron and laser-cooling of stored ion beams is conducted at a ring facility unique in the world, ASTRID. There is also another novel ring for accelerator research, ELISA, which is based on electrostatic fields alone. The Aarhus facilities have no US analogues.
- In Uppsala (Sweden), advanced research at the Svedberg lab has been focused on collaborating on the FAIR project, as the lab has lost its status as a national facility.
- The Swedish laboratory MAX-lab (Lund) is now proceeding with plans for a next generation light source, and is developing a dedicated program in laser-accelerator physics.
- Scandinavian companies continue play a strong role in providing accelerator technology in components and instrumentation, as typified by Danfysik.
- In Spain a next generation light source termed ALBA is under construction.
- At the Paul Scherrer Institute in Zurich, a new light source SLS has been built, and plans for an FEL-based 4th generation system are proceeding.

A.7.3 Asian AARD

A.7.3.1 Overview

Major accelerator projects for high energy physics in Asia are concentrated in China and Japan. In Beijing, BEPC (a two-ring e+e- collider) is undergoing an upgrade to perform as a tau-charm factory. At KEK, the B-factory is also planning an upgrade. This is the lab's major focus beyond ILC work, in which KEK has played a central role. Elsewhere in Japan, the emphasis in high energy physics is on secondary beams, in particular neutrinos, where the Japanese program has found success. JPARC is a dedicated facility for high flux proton beams, which compares in capability to the existing US effort at the SNS and the proposed Proton Driver. The Australian Light Source in Melbourne, Australia, a third- generation 3 GeV synchrotron light source, is now being commissioned.

There is considerable effort developing in Asia on advanced accelerator concepts based on lasers and plasmas. This effort has strong historical ties to the US program through collaboration and training of foreign students in the US. The infrastructure in laser acceleration throughout Asia, notably in Taiwan, Korea, China, Japan and India, is now growing explosively, as is documented in the tables given below. Many of the recent advances in laser-plasma acceleration have taken place in Asia, a trend that is sure to increase when the planned new infrastructure becomes available.

Perhaps even more noticeably than in the US and Europe, the growth in HEP-directed advanced accelerator R&D in Asia is matched or exceeded by advanced light source work. In addition to the numerous existing light sources, especially in Japan and Korea, major new light sources are now planned in Thailand, India, Singapore, Shanghai and Jordan. Forward-looking light sources based on short wavelength FEL are the focus of major research efforts at large labs such as Spring-8 in Japan and Pohang in Korea. In addition, many smaller labs and universities are examining advanced concepts in FEL and Compton scattering, including those based on laser-plasma electron sources.

Asian universities are now showing strong interest in training accelerator scientists, in support of the burgeoning research effort. Regional accelerator schools are also on the increase in Asia, in coordination with international partners from other regions. The growth in accelerator R&D in Asia is perhaps best measured by the emergence of the Asian Particle Accelerator Conference as a near equivalent the US and European PACs.

Asian industry, especially in Japan (Toshiba, Hitachi, Mitsubishi, Sumitomo), is very active in accelerator technology. In China, many of the commercial efforts are spin-offs from major research labs such as IHEP, which manufactures high power RF equipment.. In Japan, the large corporations maintain strong ties to national labs, and participate in cutting edge developments typified recently by ILC RF sources and structures, and FFAG research and development for muon colliders. In addition, medical accelerators are a major focus of Japanese industrial activity, and this effort is also leveraged off fundamental R&D at the national labs.

In the subsequent sections, we list major Asian AARD efforts, their sites, infrastructure, funding, and personnel efforts. It is broken down in two categories, Japanese research, and work elsewhere in Asia.

A.7.3.2 Japan

Table A.7.3.5. Near to mid-term accelerator R&D in Japan.

Projects	Site	M$ JFY 2006	FTE	Students	Goal
ATF	KEK	2	12	7	Creation and diagnostics/handling of small emittance beam for ILC.
ATF-II	KEK	1	5	5	Nanometer beam final focus.
STF	KEK	5	12	3	Prototype of the ILC linac.
SuperKEKB	KEK	3	10	1	High current vacuum & RF components.
Induction Accleration	KEK	0.6	5	2	Ion sources for medical & material application.
XFEL Japan	SPring-8	16	30	3	Compact SASE source with C-band linac.
Spring-8	SPring-8	3	10	0	High intensity and short pulse ring light source beyond 3rd generation.
NewSUBARU	SPring-8	0.15	3	0	Stable production of coherent mm-wave / THz radiation, etc.
Total		**30.75**	**87**	**21**	

Table A.7.3.6. Near to mid-term to far-term accelerator R&D in Japan.

Projects	Site	M$ JFY 2006	FTE	Students	Goal
FFAG ADSR	Kyoto Univ,	0.65	5	1	Accelerator-Driven Subcritical Reactor with FFAG ring.
PRISM	Osaka Univ.	0.7	4	2	Phase Rotated Intense Slow Muon source with FFAG ring

Table A.7.3.6. Advanced accelerator research infrastructure in Japan.

Institute	Facility	Activities	Personnel
JAEA-APR	Laser:100TW, 20fs, 10Hz Laser: 10 TW, 70fs, 10Hz Microtron:150MeV, 0.5nC, 60Hz	Laser-plasma electron/ion acceleration	Staff: 9 Student:1
ILE-Osaka U.	Laser: 15 J, 0.5 ps	Laser-plasma electron acceleration	~10
ISIR- Osaka U.	Linac: 38 MeV, 1.3GHz 20-30 ps, 100 nC/bunch Wiggler: 2 m, 0.37 T	Compton scattering X-ray using SASE FEL	~5
ICR-Kyoto U.	Laser: 10 TW, 50 fs Linac: 150 MeV e- Storage ring: 150 MeV e-	Ion generation/ its RF bunching	~5
AIST	Laser: 5TW, 50fs	Laser-plasma e- acceleration	Staff: 4 Student: 2
KEK	1.3GeV linac/damping ring Laser: 400mJ, 200ps	Polarized positron generation by Compton γ	~10
NERL- U. Tokyo	Laser:12TW, 40fs, 10Hz Linac: 17MeV & 45MeV	Laser-plasma e-acceleration, Gas jet development	Staff: 4 Student: 4
Hiroshima U.	150MeV-Microtron & Storage ring	Compton scattering, Basic beam physics	~10
GUAS	Laser: 2 TW, 100 fs	Plasma channel development, Laser-plasma X-ray microscope	Staff: 1 Student: 4
CRIEPI	Laser: 30 TW, 30 fs	Laser-plasma electron, ion acceleration	~5
Okayama U.	Laser (planned)	Fundamental Physics	Staff: 4 Student: ~3
AIST-FESTA	Laser: 4TW, 50fs, 50Hz Linac: 38 MeV	Femtosecond Compton X-ray THz source	11
SHI	Laser: 4TW, 50fs Linac: 38MeV, 1nC, 3ps	Compton X-ray studies	4

A.7.3.2 Elsewhere in Asia

Table A.7.3.7. Advanced accelerator research infrastructure in Asia outside of Japan

Institute	Facilities	Research	Manpower
CHINA			
CAS-IOP	30TW, 30fs laser 200TW, 30fs (under development)	Laser-plasma X-ray/electron generation, channeling, laser-plasma electron acceleration.3D simulation for laser-plasma interaction	Staff:~6 Student:20~30
CAS-SIOM	30TW, 30fs laser 1PW, 20fs (under development)	Laser-plasma X-ray/electron generation. Cluster experiment	
CAEP-LFRC	5TW, 20TW, 300TW, 30fs 500TW, 30fs (under upgrade)	Laser-plasma X ray/Ion/Neutron Generation; Laser-plasma electron acceleration under international collaboration	Staff:~5 Student: ~10
Tsinghua U.	Linac: 16MeV, 2856MHz, 35ps Laser:2J, 10ns YAG 20TW,30fs (plan)	Compton X-ray; Laser plasma acceleration experiment; Plasma channel development (plan)	Staff:5 Student:~9
Fudan U.		Vacuum Laser Acceleration Theoretical work	Staff:2 Student:~3
CAS-IHEP		Laser-plasma accelerator R&D (plan)	~6 FTE
INDIA			
CAT-Laser Plasma Div.	Laser:10TW, 40fs	Laser-plasma accelerator Laser-plasma X-ray/Ion generation Discharge plasma channel	15
CAT-Beam Physics & FEL Lab.	10MeV PWT Linac-Undulator	Compact Ultrafast Terahertz FEL Inverse Free Electron Laser acceleration	~10
TIFR	Laser:10TW, 40fs	Laser plasma X-ray	~10
ISRAEL			
Hebrew U.	Laser:1TW, 100fs	Discharge plasma channel Air channeling	~6 FTE
Technion		Structure based laser acceleration-Theoretical work	~4 FTE
Tel Aviv U.	MeV van der Graaf	FEL super-radiance	~5 FTE
KOREA			
KERI	Laser: 1.4J, 0.7 ps (2~3TW)	Laser-plasma electron acceleration	10 FTE
GIST-APRI	Laser: 100TW, 30 fs	Laser-plasma electron acceleration, Ion/X-ray generation	~10 FTE
KAERI	Laser: 10TW, 30 fs Superconducting linac: 40MeV 4~7 MeV Microtron-FEL	Laser-plasma X-ray/Ion generation Compton X-ray, Compact THz FEL	7 FTE
PAL		X-FEL, FIR-FEL	
SINGAPORE			
SSLS-Nat'l U. Singapore	700MeV Storage ring	Superconducting mini-undulator Linac Undulator Light Installation	~5 FTE

Table A.7.3.7. Advanced accelerator research infrastructure in Asia outside of Japan (continued)

Institute	Facilities	Research	Manpower
TAIWAN			
IAMS	Laser: 10TW, 40fs	Laser-plasma electron acceleration Laser-induced plasma channel	~4 FTE
National Tsinghua U.	Relativistic Photon-Electron Dynamics Laboratory (under construction) 25MeV Linac-FEL	Structure Laser Acceleration THz super-radiance FEL	~4 FTE
National Central U.	Laser: 100TW, 30fs (under construction)	Laser plasma accelerator (plan)	~5 FTE
NSRRC	X- & S-band photo injectors 20-30 MeV Linac	THz pre-bunch FEL Femtosecond electron bunch	~5 FTE
National Taiwan U.		Collaboration with SLAC Laboratory Astrophysics	~5 FTE
UKRAINE			
NSC-Kharkov Institute Phys. & Technology	Linac:4.5MeV, 0.5A, 2μs	Wake field excitation in dielectric waveguide and resonator	~5 FTE