AARD HEPAP Sub-PANEL

FNAL, Feb. 16, 2006

Superconducting RF – Resource Needs for the Present and Future

Your Charge (in part)

…………we are requesting a comprehensive review of all aspects of the OHEP and NSF accelerator R&D programs………….. . The review should include: …………………………

- Resources: Estimate whether the program has adequate resources to carry out its scope of effort………..

Technical and management review of the Linear Collider…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…………….

Some Criteria for Assessing Resources Needed

Based on the assumption that achieving and maintaining "significant player" status is an accepted goal for SRF in the US:

- A relative criterion
  - What is needed to meet the competition in terms of investment in human and physical infrastructure and in ongoing support of principal scientific personnel?

- Absolute criteria
  - If the accomplishments needed are specified from outside together with a completion date (e.g. by the GDE), then the support needed can be calculated
  - In AARD there are thresholds for infrastructure investment and ongoing support to make steady, if slow, progress.

Assessing Currently Available Resources

(PLEASE NOTE THAT THE TABLES BELOW ARE DRAFTS!)

- Resources here defined as physical and manpower resources devoted to SRF R/D and the financial support for them
- The following assessments and evaluations were made by the participants themselves and recorded without editorial comment
- Intra US inputs are displayed in a table you have already seen in the talk from S. Chattopadhyay
- The regional comparison chart was obtained by summing the resources listed in the intra US table and asking colleagues in Europe and Japan for quantities corresponding to the various table entries
  - entries very approximate as our non- US colleagues do not use the same categories that we do and do not do their accounting the way we are accustomed to
  - There is a Canadian component not taken into account – TRIUMF is constructing a SC heavy ion linac currently

	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
JLAB	• 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 demonstration 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: $40M to date • Self-contained cavity and cryomodule fabrication, testing, processing & production • Test beam available in the FEL • Injector Test cave • State-of-the-art Surface Science Analytical Instruments and lab	• 30 FTEs • Students: 2-4 • 1 Ph.D./ year; Total: 17 to date • 1 Master's • R&D Profile: *85%/10%/5%	• Annual DOE Science & Technology Review • Institutional Management Review every 2 years • Recommendation implemented annually • Director's Reviews when needed • Ad-hoc External reviews	• ILC(GDE) • SNS (ORNL) • RIA (ANL, MSU) • eRHIC (BNL) • PD (FNAL) • TTC/XFEL (DESY
FNAL	• 3.9 GHz cavity R&D, 2 cavity types for Photoinjector & 4 cavity module for TTFII, also TESLA cavity operation 1998-2007 • ILC R&D, prepare for project 2005-? • Proton Driver R&D, be prepared to implement if ILC delayed, efforts complementary to ILC R&D 2005-?	• Provide FNAL experience in all aspects of SRF development & operation, initiating polarized gun effort • Develop necessary infrastructure • Initiate materials effort • Design concepts for a PD using ILC technology	• Bunch compression, diagnostic & crab cavity applications. efficient FEL SASE • ILC major future goal of HEP • PD major thrust for neutrino physics. Preproduction test vehicle for ILC	**SRF only** R&D (direct M&S+SWF) FY05 • 3.9 2M$ • 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, Vert Test • Chemical processing – joint facility with ANL for BCP & EP • Under construction –major CR facility, module assembly, Horiz & Vert 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 w Div Leaders • PD Program Leader • DOE reviews • FNAL AccAdv Com • GDE • Individual reviews and advisory committees	Strong collaboration with DESY MOUs w CU, JLab, ANL, MSU and others

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Cornell	• 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), Shangai 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 Eacc > 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 cavitieis 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 fab, 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), Shangai Light Source, BESSY (Berlin Light Source).
ANL	• 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: undergraduate 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-Leguaro, New Delhi, Sao Paulo, FSU, KSU Host visitors (JAERI, NSC New Delhi, TRIUMF, Orsay, etc.)

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MSU	• 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 Ph.D 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)
BNL	• 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 avg 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	• Collaboration in ERL w. JLab, AES
ORNL /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 JLab's construction and to SNS's personnel testing skills • 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

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LANL	Not active at present. Significant investment in the past (1990-1994)) in the context of technology development and for Pion Linacs (PILAC) via Laboratory Directed Discretionary Funds (LDRD), (1994-2001) towards DOE APT/AAA and (2001-2005) towards high Tc material research.	• 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 multicell 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 1 1 MW cw power coupler; • Demonstrated surface resistance of MgB_2 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.

PRELIMINARY - DRAFT*DRAFT*DRAFT - PRELIMINARY

Estimate of Infrastructure[1] Resources for SRF Work Directly Applicable to HEP Projects

Region	Asia	Europe[2]	US
Capital invested	??	126 M to date	60 M to date
Labor invested	??	2100 PY	1000 PY[3]
Current SRF R/D Budget (total)	5.5 M (80[4] FTE not incl)	6 M (86 FTE not incl)	23 M (FTE incl)
SRF budget for AARD	small	2.6 M[4]	0.7 M
No. Companies for Cavities + Cryostats	3 large	3 large	1 small
No. of Cavity qual. Nb suppliers	2	2	1 + 1(trying)
No. of Institutions seriously in SRF	1	~ 6	~ 6

1 Infrastructure here defined as facilities that can be used for producing, processing and testing SRF accelerating apparatus. Buildings are not included.
2 Taken to be primarily DESY TTF with contributions from TTF members; CERN past investment in Nb on Cu not counted
3 Scaled from Europe
4 scaled from Europe

- In terms of meeting the competition, it's clear that we have a long way to go. <u>How far</u> and <u>where</u> we need to go will depend somewhat on how the GDE weighs in on this subject. However the future unfolds, it is clear that our European and Asian colleagues have set the bar high for collaborative competitors – they each will have a SC linac test vehicle > 1 GeV

AARD Resources Needed

- Physical infrastructure needed for significant AARD include
  - cavity fab and processing facility adequate for multicell cavities (machining, chem. processing, HPP, high press. H_2O
  - test facility adequate to shield against giant resonance neutrons
  - Instrumentation for correlations of rf behavior with physical and chemical characteristics of surfaces e.g. Auger, SIMS, AFM……….
- Intellectual environment where many related sciences are “on tap” for consultation and collaboration such as in a large multipurpose lab or university community
- Intellectual environment including more than one independent unit engaged in related activities to provide stimulation to the activity – SRF AARD has been isolated in the past

- Personnel infrastructure including more than one scientist per independent unit (lab or university group) capable of and devoted to addressing the pressing problems that you have heard about (e.g. residual resistance, grain boundary effects, new materials, new fabrication and processing methods…………)
- Personnel infrastructure including the needed technical services such as mechanical, chemical, electronics and IT
- Small industrial contracts to work on scaling up processes
- and don't forget a couple of grad students……..

Most of the physical infrastructure items exist at 3 or 4 institutions – WHAT'S LACKING IS SUPPORT FOR THE PEOPLE INFRASTRUCTURE NEEDED TO MAKE PROGRESS IN SRF AARD

Following the recipe given in the above 6 bullets it is apparent that the support needed is of the order of ~ 4 M shared out over DoE/NSF and 3 or 4 institutions having the needed capabilities