Warm / Cold Comparison – The methodology

A study commissioned by the
US Linear Collider Steering Group

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Status

- The work is done, 475 page report is written, but results are still being checked, so they won't be public until the end of January.
- There will be a link to the report at www.linearcollider.org when it becomes available.
- I will emphasize the process used so when the report becomes public you can read the executive summary and conclusions knowing that the work was done in a reasonable fashion and was reasonably unbiased.
- The report does **not** (and was never intended to) make a recommendation. It simply tries to put the needed information in a form that helps one decide.

Charge

- Two technology options are to be developed: a warm option, based on the design of the NLC Collaboration, and a cold option, similar to the TESLA design at DESY.
- Both options will meet the physics design requirements specified by the USLCSG Scope document.
- Both options will be developed in concert, using, as much as possible, similar approaches in technical design for similar accelerator systems, and a common approach to cost and schedule estimation methodology, and to risk/reliability assessments.

Task Force Membership

Had warm and cold experts on all task forces

Accel physics and tech

- Chris Adolphsen (SLAC)
- Gerry Dugan[1,2] (Cornell)
- Helen Edwards (Fermilab)
- Mike Harrison[2] (BNL)
- Hasan Padamsee[2] (Cornell)
- Tor Raubenheimer[2] (SLAC)

Civil design

- Dave Burke[2] (SLAC)
- Clay Corvin (SLAC)
- Dave Finley[2] (Fermilab)
- Steve Holmes[1,2] (Fermilab)
- Vic Kuchler (Fermilab)
- Marc Ross (SLAC)

[1]Primary liasion to USLCSG Accelerator Subcommittee
[2]USLCSG Accelerator Subcommittee member

DESY points-of-contact:
Cost/schedule and siting: Franz Peters
Design: Stefan Choroba

Cost and Schedule

- Dave Burke[1,2] (SLAC)
- John Cornuelle (SLAC)
- Dave Finley[2] (Fermilab)
- Warren Funk (Jefferson Lab)
- Peter Garbincius (Fermilab)
- Mike Harrison[2] (BNL)
- Steve Holmes[2] (Fermilab)
- Ted Lavine (SLAC)
- Cindy Lowe (SLAC)
- Tom Markiewicz (SLAC)
- Hasan Padamsee[2] (Cornell)
- Brett Parker (BNL)
- Kem Robinson (LBNL)
- John Sheppard (SLAC)

Availability design

- Paul Czarapata (Fermilab)
- Helen Edwards (Fermilab)
- Tom Himel[1] (SLAC)
- Marcus Huening (Fermilab)
- Nan Phinney (SLAC)
- Marc Ross (SLAC)

US LC physics requirements specified by the USLCSG Physics/detector Subcommittee

- initial energy 500 GeV c.m.
- upgrade energy: at least 1000 GeV c.m.
- electron beam polarization > 80%
- an upgrade option for positron polarization
- integrated luminosity 500 fb^{-1} within the first 4 yrs of physics running, corresponding to a peak luminosity of $2x10^{34}cm^{-2}s^{-1}$.
- beamstralung energy spread comparable to initial state radiation.
- site consistent with two experimental halls and a crossing angle.
- ability to run at 90-500 GeV c.m. with luminosity scaling with E_{cm}

Design group goals

- Make each design meet the physics requirements
- Make each design as good as possible in the time we had available: something we would want to build.
- Try to minimize the differences that are not RF technology related.
- Use same level of conservatism in both designs

Warm option reference design

New features of 2003 NLC configuration since TRC design:

- 2-pack modulator
- 60 cm, 3% v_g HDS structures
- EM quads in linac
- Improved damping ring design
- Improved positron source
- BNL-style SC final focus doublet
- “Low-energy” IR reach improved to 1.3 TeV

Differences between the warm option reference design and the 2003 NLC design:

• The use of an undulator based positron source, utilizing the high energy electron beam at 150 GeV, instead of the conventional positron source

Cold Option reference design

Difference between the cold option reference design TESLA design:

•An increase in the upgrade energy to 1 TeV (c.m.), with a tunnel of sufficient length to accommodate this in the initial baseline.

•Use of the same injector beam parameters for the 1 TeV (c.m.) upgrade as for 500 GeV (c.m.) operation

•The choice of 28 MV/m as the initial main linac design gradient for the 500 GeV (c.m.) machine.

•The use of a two-tunnel architecture for the linac facilities.

•A re-positioning of the positron source undulator to make use of the 150 GeV electron beam, facilitating operation over a wide range of collision energies from 91 to 500 GeV

•The adoption of an NLC-style beam delivery system with superconducting final focus quadrupoles, which accommodates both a crossing angle and collision energy variation.

•An increase in energy overhead and emittance growth margins.

•Addition of diagnostics

Cold Damping Ring changes from TESLA

- The pole width of the damping ring wigglers has been increased from 40 to 60 mm to reduce nonlinear fields associated with the wiggler.
- The e- DR vacuum system pressure has been reduced to 10^{-10} Torr in the straight sections and 10^{-9} Torr in the arcs and wigglers to reduce the effects of ions.
- The e+ DR vacuum pressure has been reduced to 10^{-9} Torr in the arcs and wigglers to limit the number of primary electrons generated by gas ionization.
- A clearing gap of 600 ns (about 30 bunches) has been added to the e- DR to suppress the formation of ions
- Low secondary emission coatings have been added to the e+ DR chamber to suppress the formation of an electron cloud

Design Variants

- Single tunnel for cold design
- Conventional e+ source for warm and cold
- 35 MV/m for cold initial gradient
- Cavity superstructures for cold
- DLDS pulse compression for warm

Conventional facilities goals

- Evaluate two sites (CA and IL) for both warm and cold
- Do enough design and drawings to allow cost estimating. This includes power distribution, water cooling, cryoplants, tunneling, tunnel access, office buildings… The drawing stack is over 1 inch thick
- Average the two sites tunneling costs
- Primary differences (which effect cost):
  - Length: 46 vs 34 km (Cold is 35% longer due to lower gradient)
  - Cryogenic infrastructure needed for the cold linac
  - Warm site power is ~25% more than cold

Costing Methodology

- We did not set out to make new estimates for either technology, but to provide a level comparison of the two options.
- Comparison based on a U.S. Total Project Cost (TPC), but costs for land, detectors, escalation, and contingency were omitted.
  - Example: Management, oversight, business services, site management, R&D, commissioning, and pre-operations were included, but cost estimates were taken to be the same for each option.
- Cold estimate for injector systems (but not damping ring) is scaled version of warm (NLC) estimate (5 GeV instead of 8 GeV at entrance to the main linac).
- Cold damping ring re-estimated to account for changes in specifications.

Costing Methodology

- Main linac component estimates taken without change from TESLA and NLC/GLC Collaboration expectations of the prices to be charged by industrial suppliers in the required quantities.
- All other costs associated with the linac (R&D, engineering and design, handling, installation, and QC) treated on equal footing for warm and cold.
- Beam delivery costs set equal for warm and cold.
- Costs for all other activities and components set equal or scaled on a common basis to account for quantities that might differ between technologies.
  - E.g. Project support services, vacuum, magnets, dc power supplies, I&C, etc.

Costing results

- Only relative costs are given in the final report to avoid putting numbers out in public that would be taken out of context and abused.
- About 2/3 of the costs are common in the warm and cold designs. This means the error on the difference is actually less than the error on the total.

Availability Methodology

- Wrote a simulation that given the MTBFs, MTTRs, numbers and redundancies of components, and access requirements for repair can calculate average availability.
- Collected data on MTBFs and MTTRs of components in existing machines to guide our budgeting process
- Made up a reasonable set of MTBFs that give a reasonable overall availability. We allowed 25% downtime total. 10% was kept as contingency and MTBFs were tuned so the simulation gave 15% downtime.
- Iterated as many times as we had time for (one and a half iterations were done) to minimize the overall cost of the LC while maintaining the goal availability

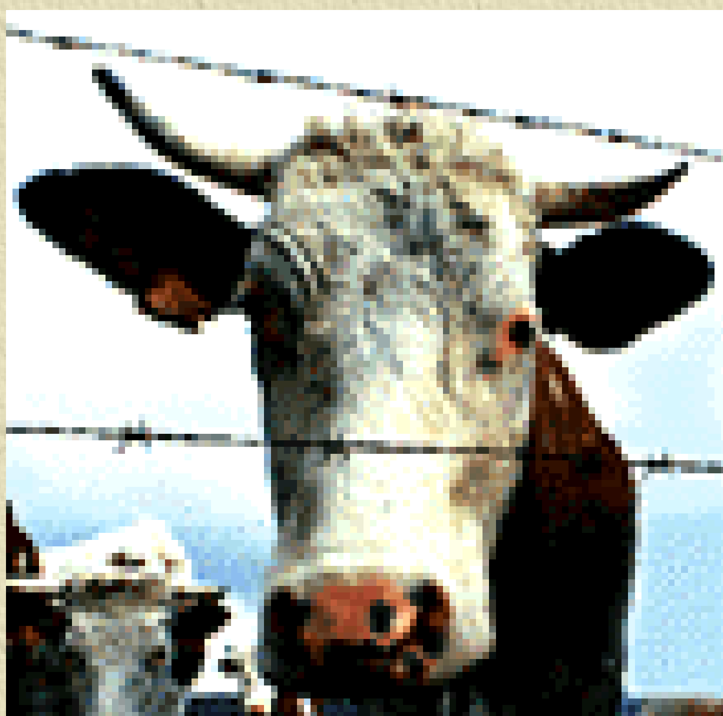
Availability Results

- Without improved MTBFs the linac and DRs were down about 4 times more than desired.
- This could be fixed by improving the MTBFs of a few types of components (e.g magnets and power supplies) by factors of around 10 (non-trivial engineering, but not too costly)
- Warm/cold differences were small
- Undulator e+ source magnifies problems compared to conventional e+ source for both warm and cold.
- The 1 tunnel cold variant requires much better MTBFs and 8% more energy overhead to attain the 25% downtime total. The added cost of these reliability improvements cancels about half of the 1 tunnel cost savings.
- More in my talk in the accelerator simulations parallel session

Risk Analysis

- This was done together by people from all the task forces.
- First we educated each other by preparing and then giving about 12 hours worth of talks about how the technology worked and why it wasn't as impossible as it appeared.
- Then agreed on how to do the risk analysis (a customized version of methods given in text books and used by industry) and assigned pairs of people to each region of the LC to it. The same pair did warm and cold for their region.
- The whole group spent about 15 hours together going over and refining the work of the pairs.
- We all learned a lot. It was painful.

How to identify if your cow has MAD COW disease



If your cow sounds like this, then fire up the barbecue..

If your cow sounds like this, then may we suggest the fish.

Quantifying Risk - multiply 4 factors

Beam Physics		
	5	No Theoretical Model and No Data
	4	Theoretically Understood Data Indicates Problem
	3	Poor or Ambiguous Data Indicates Problem
	2	Best Theory Indicates Problem, No Data to the Contrary
	1	Understood Theory and Data Indicate No Problem
Engineering/Design		
	5	Beyond Current Engineering Solutions
	4	Feasibility of Engineering Solution is Uncertain
	3	Engineering Feasible, but Untested Design
	2	Tested R&D Design
	1	Tested Industrial Design or Similar Design in Hand
Technology		
	5	Beyond State of the Art
	4	State of the Art - Should be Able to Do It but No Proof
	3	R&D Prototypes, but Extrapolation Remains
	2	Available, but a Specialty Item
	1	Commercially Available Off The Shelf

Other 3 risk factors

Severity Ranking Table

Limiting	5	Effect on Parameter is a limit less than design.
Steep	4	Effect on Parameter is quadratic or steeper.
Linear	3	Effect on Parameter is linear.
Marginal	2	Effect on Parameter is less than linear.
Contributing	1	Parameter dominated by other effects.

Detection Ranking Table

PreOps	3	Not detected until facility preoperations.
PED	2	Not detected until project engineering and design.
R&D	1	Detected by R&D.

Consequence Ranking Table

Impossible	5	Would be impossible or too expensive to fix.
R&D	4	More R&D would be needed.
Major	3	Possible, but would require major redesign or rework.
Minor	2	Alternate design available, would need new plan or minor rework.
Ops	1	Alternate operating point will meet mission goals.

Risk Analysis results

- The assignment of numbers (1-5) to risk components is not always unambiguous. Discussions were lively. Compromises were made. It is easy to argue that some numbers should be changed by one, but the group was well run by Gerry Dugan and bias is minimal.
- The risk analysis helped me realize that both warm and cold have considerable risks left and a lot of R&D remains.
- 42 items were evaluated and the report summarizes it with a graph showing the 42 risks by region
- Many risks are nearly the same for both temperatures.
- MPS and items in the beam delivery system come out as the riskiest because the problems may not be found until commissioning. Details in Tor's talk in the BDS session
- The cold DR looks somewhat worse overall than the warm and the warm linac looks somewhat worse overall than the cold.
- The RF risks will be covered in Chris Adolphson's talk in the RF session

Overall results

- No recommendation is made. That is up to the International Technical Recommendation Panel (ITRP). They had **better** use this as part of their input.
- Some people reading the report think it makes the decision clear. Others don't.
- In hallway and lunchtime conversations one often hears, "Technology y has problem x so it is the wrong choice." The problem is not that simple. If it were, the choice would be obvious to everyone. One must look at all aspects in making the decision.
- The task force has done a lot of very good work. Be sure to look at the results when they become available. There will be a pointer at www.linearcollider.org