Report of the 3rd Meeting of the ILC Machine Advisory Committee

Daresbury, January 10-12, 2007

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Apologies: Leonid Rivkin, PSI; Yuri Shatunov, BINP, Claus Rode, JLAB

Introduction

The 3rd meeting of the Machine Advisory Committee (MAC) for the design of the International Linear Collider (ILC) was held at Daresbury (UK) and hosted by the Cockcroft Institute on January 10-12, 2007. The committee was charged to review the final Reference Design after significant efforts have been made to reduce the overall cost as compared to earlier versions of the design. These efforts involved changes with respect to previous versions of the design and imply slightly higher performance risks. The committee was asked to assess whether the resulting Reference Design is sound and consistent, especially in view of the recent design changes, to assess whether the performance risks are calculable and whether the resulting cost estimate is reasonable. The committee's mandate is appended to this report.

The meeting consisted of two days of plenary presentations by team members of the Global Design Effort (GDE) with focus on the evolution of the design and the result of the cost estimation process, and concluded in a closeout with the members of the GDE team and with participating members of the ILCSC (International Linear Collider Steering Committee). The meeting agenda is appended to this report.

The committee would like to express its thanks to the Cockcroft Institute for the excellent logistical preparation of the meeting and for its hospitality.

The committee would like to thank the attending members of the GDE for their efforts to provide comprehensive information on the ILC reference design and the cost estimate.
The committee had full access to comprehensive information on the design and the costing which enabled the committee to assess the project according to its charge.

The committee organized its findings, comments and recommendations around the following topics:

- **Cost Estimation**
    - General comments on costs
    - Cost of the cryogenic module
    - Cost of conventional facilities
    - Impact of cavity gradient on cost
    - Site dependent cost issues

  - Miscellaneous cost considerations

- **Soundness and Consistency of the Design** for the following subsystems

  - Injectors
  - RF
  - Cryogenic Modules
  - Damping Rings
  - Ring to Main Linac
  - Beam Delivery System
  - Machine Detector Interface

- **Plans for entering the next phase of the ILC design**

General Comments

The committee would like to acknowledge that a large amount of work has been accomplished since its last meeting.

The MAC applauds that considerable evolution of the design was achieved which was made possible by strong leadership and guidance by the GDE. Together these have resulted in a successful reduction of the total project cost as compared to the status of summer 2006. The numerous design changes that provide considerable cost reductions as compared to the baseline configuration are clear evidence that the performance driven baseline configuration was successfully converted into a cost conscious design. It is also remarkable that the difficult process of implementing these significant changes has not slowed down the momentum of the design effort but rather has strengthened the design team's focus. The committee would like to congratulate the GDE and the local teams in the laboratories for this achievement. It goes beyond what had been considered achievable under the given circumstances in a short amount of time.

The committee would like to discourage the GDE from using – at this stage - the phrase 'host-related cost' in contrast to 'shared cost' which is prone to be misunderstood. Terms like 'site-dependent' or 'site-independent' might be more appropriate and avoid the implication of prejudice on ILC funding.

Cost Estimate of the ILC

The GDE reported that the first assessment of the ILC cost as discussed in July 2006 resulted in a number deemed too large. A number of design changes aiming at lowering the costs were then proposed and analyzed. After an involved process of checking the consequences, the Change Control process, the changes have been accepted, rejected or delayed. This procedure resulted in cost reductions on the order of 25 % without reducing the scope of the ILC (centre of mass energy of 2 x 250GeV, a peak luminosity of $2{\cdot}10^{34}cm^{-2}s^{-1}$, an integrated luminosity of 500 fb^{-1} in 4 years, an energy spread not larger than 0.1% and the possibility of upgrade to 1 TeV c.m.).

The major components of this cost reduction program are:

- A central injector complex with a single positron damping ring and both e+ and e- damping rings housed in a common tunnel.

- A strong simplification of the Beam Delivery System with only one 14mr interaction region but with space for two detectors which can be moved alternately to the interaction point ("push-pull").

These are accompanied by numerous smaller changes all adding up to a cost saving with respect to the costs estimate of the summer of 2006 of 25%.

The costs are expressed in terms of ITER-like value costs for all items that are procured from industry. The cost estimate distinguishes between site-independent value-costs for which the minimum cost resulting from a world-wide bidding procedure is assumed and site-dependent value costs which may be different in different regions. All costs associated with labor which could be carried out in or by ILC partner institutions, are expressed in terms of "institutional labor" (person-years) with no further diversification.

The major cost driver when sorted by area is very prominently the main linac. The by far most costly technical subsystems are the conventional facilities and the linac-RF system. The advertised accuracy of the presented cost estimate is 30%. Only costs which become effective after start of construction are taken into account in the cost estimate.

Comments and recommendations on Costs

General Remarks

The committee acknowledges that a tremendous amount of work has been accomplished by producing comprehensive cost estimation. The result of this work appears to provide a fairly detailed and suitable base of the cost estimate at this state of the project.

The committee considers the cost estimate procedure quite adequate given the special circumstances of a decentralized design effort and under the assumption that the ILC will be carried out as an international project.

The committee did not attempt to assess the costing of the subsystems in detail. However, by taking into account recent experience with previous projects, the committee judges that the distribution of the costs over the areas and technical subsystems is plausible.

The committee acknowledges that the RDR cost estimate refers to construction costs which become effective after the project has been started and thus do not contain pre-construction costs such as listed below. Nevertheless it was not obvious which costs were excluded from the estimate. The committee would like to encourage the GDE to provide a very clear description of where the line is drawn between costs included and costs excluded from the cost estimate since a large number of small cost items belongs to the pre-construction activities, such as prototyping, R&D, construction preparations, permits, geological studies, etc. A clarification of such 'omitted' costs should help to avoid unnecessary confusion.

The committee notes that no attempts to translate the available cost information into the cost models used in the various contributing countries have yet been accomplished. The committee believes that the cost information necessary to perform these transformations should be integral part of the cost estimate. This should be available by the time the final cost is presented. The committee believes that the presently available information is not yet sufficient to perform such a translation.

The risk associated with the choice of technologies and of the specific parameters of individual cost items have not yet been assessed due to lack of time to provide the complete necessary information and to include it in a systematic way into the cost estimate. It is quite non-controversial that this risk assessment must be an integral part of the cost estimate. While the committee agrees that it is not realistic to generate this information on a timescale of a month, it would like to encourage the GDE to make a preliminary assessment of the cost risk of the largest cost drivers before the preliminary cost estimate is presented to the ILCSC and the Funding Agencies. As much as possible should be accomplished by the time of an international cost review. The committee believes it to be necessary that a comprehensive cost risk analysis is presented together with the final RDR cost estimate.

Cost Consideration of the Cryogenic Module

The central technical component of the ILC is the cryogenic module which contains the superconducting cavities. It is also one of the major cost drivers.

The cost estimates made independently in the three regions differ significantly. The European cost estimate has been considered as the most reliable and mature of the three cost estimates and constitutes the base for the ILC cryogenic module cost estimate. The European cryogenic module cost estimate is derived from the TESLA cryogenic module cost estimate which is based on industrial studies. The ratio between the actual 2006 XFEL module cost estimate and the 2003 cost estimate of the TESLA-FEL supplement (same number of modules) was used to scale the TESLA cost estimate to a 2006 ILC module estimate, accounting for escalation, changes in material prices and continued effort in cost estimating. The scaling appears to be consistent with learning-curve scaling from the number of cryogenic modules in the XFEL to the number of cryogenic modules in the ILC. Such scaling is common practice in industry for series-produced components.

Given the importance of this component, the committee would like to recommend that a continued effort is needed to further reduce the uncertainties of the present cost estimate of the cryogenic module. More effort should be made to understand the significant differences between the regional estimates.

The committee notes that the estimated assembly effort for the cryogenic module differs largely from the experience of recent large cryogenic module assembly activities (SNS project). The committee would feel more comfortable with the presented cost estimate for the cryogenic module if the difference in assembly effort between SNS cryogenic module and the projected assembly effort for the ILC cryogenic module was clarified.

The committee recommends that the additional cost for assuring safe transportation of the cryogenic modules over long distances should be assessed.

In order to carry out the overall cost optimization, the design team should also determine what cost would be associated with providing the possibility for tilted or vertical transport of the modules. This would allow a smaller diameter of the transport shafts to the accelerator tunnel and may be a potential over all cost saver.

Cost of Conventional Facilities

The costs of building the accelerator tunnel system is the most prominent item in the list of conventional facility costs of the ILC. The committee notes that the independent tunneling cost estimates performed in the three regions are very similar and consistent. The tunnel cost per meter appears to be in a reasonable range if compared with previous accelerator tunnel projects. The committee interprets this as an indication that the tunneling cost estimate is realistic.

A further prominent cost item within conventional facilities is the water cooling system. The temperature rise of the process water is specified to be as small as 10° C. The committee encourages the system designers to explore whether this choice offers an opportunity for further optimization of the basic cooling parameters with respect to cost trade-offs.

The committee is surprised that the assumed power dissipation into air and the corresponding costs to remove this power from the tunnel air turns out quite low (1% of the costs of conventional facilities, not presented at the meeting). The committee encourages the team to assess optimizing of the overall heat dissipation into the air to avoid a possible cost underestimation of the corresponding air conditioning system.

Impact of achievable gradient of the cost

A new version of the cost versus accelerating gradient based on the yield of high-gradient superconducting cavities achieved in a recent production series was presented. It is based on the assumption that all cavities which do not pass a certain high gradient acceptance criterion as obtained in a vertical test measurement would be rejected. The optimum gradient for minimum cost under this rather unrealistic assumption is quite low. The committee would like to suggest using this graph with great care since it provokes unnecessary misinterpretation.

The committee suggests applying a more realistic acceptance criterion to assess the impact of high-gradient cavity yield on cost, by using the average gradient as a basis for a cost-gradient optimization. This would result in a much lower increase of main linac cost as it implies full exploitation of a given high-gradient yield. This optimization appears to be particularly reasonable since a technical solution for a flexible distribution of RF power is under study and may prove feasible. The committee strongly recommends accelerated R&D on the variable coupler which, if successful, would allow a more favorable cavity acceptance criterion.

The committee would like to re-emphasize the importance of a successful cavity research program to improve the yield of high-gradient superconducting cavities. This is especially true since the present cost estimate is based on an improved but not yet demonstrated cavity yield. The cost risk in conjunction with cavities not achieving the anticipated average gradient is considered a serious issue. It should be noted, however, that the associated cost risk is well within the advertised overall cost accuracy of 30%. The committee would further like to re-emphasize that present data on vertical testing of cavity from a particular vendor indicates that an average gradient of 28 MV/m is possible if the variable power coupler is successful. It should also be pointed out that the yield curve would be shifted to higher values if all vendors were included in the yield curve.

Site-Specific Cost comments

No attempts have been reported so far to investigate the ILC costs assuming a shallow site. As mentioned in the previous MAC report, the committee expects that the choice of a shallow site offers the possibility for further substantial cost savings. The committee would like to reemphasize that shallow sites should be studied and considered as a serious alternative to the presently investigated deep sites.

The committee notes that only a few laboratory buildings are included in the reference design. The committee is aware that the number of necessary additional buildings will depend on the choice of the ILC site. However the additional buildings which are already known to be necessary such as intermediate storage and assembly space, on-site reception and testing of accelerator and detector components, should be included in the design and in the cost estimate. In order to avoid confusion, the committee suggests that there should be an explicit list of all buildings needed for the ILC with a clear indication which buildings are taken into account in the cost estimate.

The committee would like to mention that for further refinement of the conventional facility cost, specific site information along with the region's safety standards and construction practices will be required.

Miscellaneous Comments on Costs

The committee notes that the conversion from person-hours to person-years is not consistent in all parts of the cost estimate. The number of 2000 person-hours per person-year quoted at some places in the presentations is not realistic for many of the potential partner institutions.

The committee notes that the quoted institutional labor effort is somewhat ambiguous. Institutional labor should be categorized in several groups to allow translation into regional cost models. It is further unclear what part of labor provided by contractors is part of the institutional labor or part of the value costs. The committee would like to encourage the cost team to make the institutional labor effort more transparent.

The committee also notes that the effort for a central management team has been identified as part of the institutional labor effort. Given the importance of the role of a central management, the committee suggests the funding for central management be even more clearly highlighted in the cost estimate.

The committee would like to comment that the presented spending profile over the entire project period appears to be very preliminary. The spending has an unrealistically steep rise in the beginning and is rather flat over time. This seems to contradict experience with previous projects, such as the LHC, for which the integrated spending varied considerably during construction time. The committee suggests developing a more mature plan for project execution.

The committee would like to comment on the fact that the effort of reducing costs which resulted in a reduction of 25% was achieved mostly through redefinition of global design features, with no attempt to reduce cost on the component level. While one might argue that this would be mostly an issue for the engineering design phase, there are overall cost optimization issues across the project involving cost-sensitive design choices on the component level, which should be addressed in the conceptual design phase. An example is the above-mentioned transport shaft diameters depending on details of the cavity module cryostat design. As another example for possible cost reduction on the component level, one might consider the reduction of the different types of magnets in the beam lines and in the linac. Cost reduction issues should be an important aspect of the engineering design.

The Cost Reduction proposal 20 contains three fairly independent items which were treated as a package:

- Adjust RF units from 24 cavities to 26 cavities for a section of 3 cryogenic modules (9-8-9 configuration)
- Remove 3.5% RF overhead (which is recoverable by adding RF power later)
- Remove the additional capacity originally introduced to account for the ‘uncertainty factor’ in static heat load in the specification of the cryogenic plant.

The committee suggests investigating whether these changes could be considered and processed as separate (though not completely independent) items.

Regarding previous experience with other projects, the committee would like to comment that the estimate for materials and supplies for installation appears to be quite low, amounting to less than 10%. The committee suggests reviewing these costs.

Soundness and Consistency of the Design

The committee reviewed the overall ILC design. The committee did not encounter any major inconsistencies. The design is based on a centralized injector complex and a single IR and consists of well elaborated solutions for all area systems, the injectors, the damping ring, the ring-to-main-linac sections, the main linacs, and beam delivery. The effort made for the various systems appears to be well balanced and the overall result appears - to the extent that this can be stated after only two days of reviewing - as sound and consistent.

Conventional Facilities

The committee would like to remark that the process water return pipe might be a major source of heating of the tunnel air which then must be re-cooled at higher expense. The committee suggests investigating the benefit of an insulated process water return pipe, in particular the possibility of increasing the process water temperature rise which is expected to impact the diameters of water pipes, the amount of pumping power which is needed to be installed, the coolant velocity and the corresponding dimensions of cooling channels of the components.

On the other hand, the committee suspects that the estimated heat transfer to the air is too optimistic and suggests reassessment of these quantities.

The committee notes that the specified emergency power need is only 1.4 MW. The committee suggests reassessing this value since it appears quite low.

As mentioned above, the diameter of access shafts for module transport to the tunnel should be optimized in conjunction with the optimization of the mechanics of the cryogenic module. This requires an integrated project view and overall cost optimization.

The committee is further not convinced that the service access shaft and neighboring transport shaft needed for detector installation could not be combined with minor loss of functionality.

Central Injector Complex

The committee endorses the choice of a central injector complex with a single tunnel for the damping rings as an important cost saving design modification which promises to have a reasonably small impact on the performance of the entire accelerator complex.

The committee is somewhat concerned with the fact that a second positron damping ring may be difficult to install in this scheme without an increase of the tunnel diameter. The committee suggests assessing and clearly stating what kind of fall-back options remain in case of difficulty with a single positron damping ring.

The committee would like to acknowledge that as a consequence of the central injector concept, the 1.5 km long insert in the linacs can now be omitted in the design which contributes significantly to the achieved cost savings.

The specification of the so called keep-alive-source (KAS) to deliver 10% of the nominal intensity appears not fully justified. The committee can see that the average beam current in the positron damping ring could be maintained by accumulation of smaller intensity from the KAS. In order to maintain the high level of optimization of beam parameters in the main linac and in the beam delivery, the committee believes that mainly bunch intensity and number of bunches are relevant. The committee suggests reviewing the necessary beam power, and if possible adopting a lower intensity but more flexible keep-alive mechanism and considering this as an opportunity for further cost savings.

Main Linac RF Systems

The committee would like to acknowledge that considerable progress has been made in the main linac RF system. The committee is pleased to see that there is one klystron available from a single vendor, which meets the ILC specification and which has been operated for 1000 h by now. The committee is looking forward to learn which lifetime can be expected for this tube. The committee urges the RF team to continue the R&D program with more vendors in order to avoid depending on a single vendor for the ILC klystron production.

The committee endorses the choice of the bouncer-circuit modulator as a base for the RDR cost estimate and encourages continuation of the ongoing R&D for a Marx-type modulator. In view of the considerable potential cost saving, the committee urges considering alternative technical solutions such as for example oil-cooling.

The committee notes that the present plan for the RF distribution system allows distributing RF power in a flexible way to single cryogenic modules and a technical solution for this is being worked out. The committee would like to re-emphasize (see above) that this is a very important development which would allow accommodating a larger spread of performance of the superconducting cavities. This is an important factor in defining a well-optimized system. The committee suggests making a particular effort to complete the design and aim for an early demonstration of this system.

The committee notes that the S0 cavity improvement program has been started in some of the regions. During the MAC session, the Jefferson Laboratory reported on a breakthrough in processing a TESLA-type cavity resulting in 40 MV/m with high Q-value. The overall progress of this important R&D issue, however, appears to be marginal at this point. The committee urges the ILCSC to use their best influence to help this program become effective.

In view of the challenges of improving the yield of high-gradient superconducting cavities, the committee would like to encourage the effort of finding advanced cavity shapes which provide a larger gradient by a more optimum ratio of peak to accelerating fields.

Cryogenic Module Fabrication

The committee acknowledges a strong effort to design the type-4 cryogenic module which contains the superconducting cavities for the ILC. The design team appears to be structured and competent. It uses very efficient state-of-the-art design tools. The committee acknowledges the good collaboration between the involved groups.

The committee acknowledges the proposal of a cryostat configuration with 9, 8 and 9 cavities per cryostat which provides a central space for quadrupole magnets and correctors. This solution allows a compact linac design and improves alignment and stability. The committee would like to endorse this choice.

In refining the over-all design optimization, the design team should determine what technical changes are necessary to provide the possibility for a tilted or vertical transport of the modules through the access shafts into the accelerator tunnel. If the requirement of horizontal transport could be removed, the diameter of the transport shafts could be reduced. Given the fact the access shafts contribute significantly to the cost of civil construction, this optimization might lead to substantial cost savings.

The committee would like to remind that it will be most likely necessary to transport entire prefabricated cryogenic modules over large distances. The committee would like to point out that provisions have to be taken into account in the module design aiming at preventing any transport damage of the module.

The committee would like to point out that good communication and tight collaboration between cryogenic system and cryogenic module designers is necessary for optimum design and production of the cryogenic modules. In particular, the committee would like the type-4 cryogenic module design to incorporate pipe dimensions compatible with the cryogenic distribution system. While these communications seem to be well established at the main ILC partner institutions, this aspect must be kept in mind when transferring the technology to other laboratories and to industry.

The committee notes that a two-level thermal radiation shield is proposed in the cryogenic module design. The committee suggests assessing the cost-benefit ratio of this feature in the engineering design phase.

The committee was not convinced by statements made by GDE concerning the scope and the expected progress of the S0/S1 cavity R&D program. The committee is looking forward to learn about this issue in greater detail during its next meeting.

The committee is concerned by the amount of expectation concerning the benefit of the XFEL module production for ILC module production plans. The committee would like to point out that the XFEL experience might be available rather late in view of the present aggressive schedule envisioned for the ILC. Furthermore, the requirement for the ILC module production might evolve considerably so that XFEL experience might only be partially relevant.

The committee is further concerned by the fact that the R&D program which addresses the improvement of the cryogenic module design is making only slow progress. The committee suspects that in view of these difficulties, the aggressive ILC milestone plan might be to optimistic.

Ring to Main Linac Systems

The committee acknowledges a large and systematic effort in defining and optimizing the complicated ring to main linac sections with bunch compressors, spin rotators, complex matching and correction sections and collimation. The committee has no strong concerns regarding the ring to main linac system. The committee suggests paying attention to space charge effects in the long transport line from the central injectors to the beginning of the linac and to perform cost-to-performance trade-offs in the diagnostics sector.

Damping Rings

The committee acknowledges a systematic design effort for the ILC damping rings.

The committee was not quite convinced about the arguments concerning momentum compaction factors in conjunction with the choice of bunch lengths and corresponding RF voltages. The committee suspects that this might be an issue which deserves further optimization.

The committee suggests revisiting the choice for vacuum chamber cross section in the arcs, regarding the photoelectrons. The material of the beam pipe should also be subject to review, considering the shield of the synchrotron radiation to the outside.

The committee suggests that the issue of space for a second positron ring in the single damping ring tunnel should be clarified. The committee would like to emphasize that given the difficulty of installing a second positron damping ring, the importance of being able to control the electron cloud issue has become more critical. The study of appropriate measures to suppress electron cloud effects should be given high priority.

The committee encourages further study on the emittance tuning scheme of the damping ring to determine the requirements on the diagnostics and tuning devices. The committee would like to mention that it would be worthwhile to examine whether small vertical orbit bumps could eliminate a large number of skew quadrupoles.

Beam Delivery System

The strongly simplified interaction region has been presented to the committee. The committee is pleased by the fact that a number of technical and R&D options has been resolved by this dramatic design decision.

The committee discussed a few minor concerns. The committee is not quite convinced about the practicality of the push-pull configuration of the two detectors, especially when given the objective of a one-day switchover, and suggests that the logistics should be reassessed more thoroughly.

The committee notes that the required phase stability of the crab cavity appears to be beyond the state of the art. Given the huge impact of this device on the luminosity, the committee suggests assessing and clarifying this issue.

Accelerator-Detector Interface

The committee would like to encourage continuous communication between the detector collaborations and the accelerator designers which should result in further convergence of accelerator and detector issues.

Post RDR-Plans

The committee learned about preliminary plans for the post RDR phase. The committee is aware that it is not its primary responsibility to comment on this complex issue. However since it was presented during the MAC, the committee would like to offer the following advice.

The committee would like to suggest considering a transitional approach to enter the engineering design phase. The committee recognizes that the readiness to take a larger step in the direction of engineering design varies among participating regions, which calls for a moderate pace. The committee notes that the overall effort of the engineering design implies quite substantial expenses compared to the total cost of the project. This requires proper formal structures, funding, and accountability in the three regions and a strong central management with sufficient authority over the resources.

Next MAC Meeting

The next ILC-MAC meeting will be held by the end of April 2007 in the USA. Dates and location are still tentative at the time this report is submitted.

Appendix: Mandate of the MAC and meeting Agenda

22 March 06

ILC Machine Advisory Committee (MAC) Mandate

1. The oversight of Global Design Effort (GDE) activities is by the International Linear Collider Steering Committee (ILCSC); MAC will assist ILCSC in one of ILCSC's oversight functions.
2. MAC will meet two or three times per year until ILCSC and the International Committee for Future Accelerators (ICFA) approve the Reference Design Report (RDR).
3. MAC will review GDE accelerator activities; it will report to ILCSC.
4. MAC will review the following aspects of the Baseline Configuration Document (BCD):

a) Is the conclusion of BCD reasonable and consistent with the overall ILC system? Is the BCD design consistent? Is it optimized to produce maximum physics output? Is the plan to upgrade the machine to 1 TeV appropriate?

b) Are there any BCD items that MAC feels should be reconsidered?

c) Are there any issues that MAC thinks should be discussed in a broader context by ILCSC?

5. MAC will review the process that will lead to the RDR:

a) Is the organization of GDE appropriate for this activity?

b) Is the accelerator design process appropriate?

c) Is the cost estimate process appropriate?

d) Are the milestones envisioned in the RDR appropriate and realistic?

6. In addition, MAC will review the RDR for the following:

a) Is the RDR design reasonable and consistent with the overall ILC system? Is the RDR design consistent? Is it optimized to produce maximum physics output? Is the plan to upgrade the machine to 1 TeV appropriate?

b) Is the estimated cost reasonable?

c) Is the envisioned project schedule reasonable?

Meeting Agenda

The agenda of the meeting and copies of the presented slides can be found on the internet at the following address:

http://ilcagenda.cern.ch/conferenceDisplay.py?confId=1208

Please note that access to this information is protected. You need to agree to GSE confidentiality rules to obtain access information (please contact Maxine Hronek via email for information, maxine@fnal.gov).