14 June 2007

REPORT OF THE INTERNATIONAL COST REVIEW OF THE INTERNATIONAL LINEAR COLLIDER

A. EXECUTIVE SUMMARY

- The Committee commends the Global Design Effort (GDE) for the completion of the Reference Design for the International Linear Collider (ILC) to agreed-upon performance parameters.

- The Committee believes that the GDE is doing an excellent job of designing the ILC under the conditions that currently exist. The costing methodology is as good as can be done at the present time. For more accuracy on some items, further R&D and a designated site location for the ILC is needed.

- The Committee notes that the GDE has reduced the ILC cost by over 25% since July 2006, and that the technical design has been scrutinized in four reviews by the ILC Machine Advisory Committee (MAC). Because of this, the Committee concentrated on two major cost drivers: the Main Linac and Conventional Facilities, which together comprise 70% of the ILC cost, while reviewing the GDE presentations on all major ILC systems.

- The Committee, together with the GDE, sees further possible cost savings based on expected R&D results and further optimization of the following areas: the Main Linac, RF system, Damping Ring layout, tunnel diameters, the number and size of vertical access shafts, tunnel water cooling parameters, and potential adjustments in the fabrication and construction schedule.

- The three sample sites considered so far are all about 100 metres underground; a shallow site should be costed for comparison. One of the members of the committee considers the estimated tunnelling cost at the US site was too low.

- The methodology for the Main Linac design is the best that can be done at present. The cavity gradient goal is ambitious, but progress towards it is being made; further R&D should help, and experience at the European XFEL project over the next few years should be valuable. The Committee notes that if there is no improvement in cavity gradient beyond today's capabilities, the Main Linac length will have to be extended to meet the design goal, and the overall cost of the ILC will increase by about 7%.

- More industry involvement in ILC component design, R&D and fabrication would be very desirable, but with strong coordination by the GDE. Removal of risk from the industrial fabrication companies is still essential in the application of such new technology. Valuable experience in industrialization will be gained at the XFEL project.

- The impact of the proposed 7 year construction schedule (which appears to be

technically driven) should be better understood. Lengthening the construction period could allow cost reductions.

- Commissioning and operations costs during the construction phase should be noted, and there needs to be an understanding of total costs prior to construction start.

- Risk assessment and analysis have just begun. They should be pursued in more detail, and should be maintained in the construction phase; they should also be well correlated with the R&D program.

- Project management will need to be strengthened during the Engineering Design Report (EDR) phase; the reporting by engineers directly to the GDE management is especially important during this phase.

- The International Linear Collider Steering Committee (ILCSC) provides good scientific oversight of the project. However, more government involvement is needed for the creation of an international organization to support the EDR, for the preparation of the site, and for the establishment of an international laboratory. More government funding is needed to support a more centralized organization and more R&D, including industrial R&D and pre-prototyping of components. This will be critical to reducing the technical and schedule risk, and the overall cost.

B. REPORT

1. Introduction

The International Cost Review took place on 23-25 May 2007 at LAL, Orsay, France. The Committee was set up by ILCSC and the Funding Agencies for Large Colliders (FALC). Its membership, chosen by ILCSC and FALC, is given in Appendix I, its charge in Appendix II, and the Review agenda in Appendix III. The Committee members express their thanks to the Director of LAL, Guy Wormser, and his staff for their excellent hospitality and administrative assistance to the Committee and to the GDE members present; this all made the Review both enjoyable and very productive.

The Committee noted that there had been four technical reviews by the MAC over the past year of the ILC design up to the RDR and its cost, and the Committee did not attempt to duplicate this effort. It concentrated primarily on the two major cost drivers: the Main Linac cavities/cryomodules and RF power; and the civil engineering and conventional facilities.

The Committee was very impressed at how far the GDE has progressed technically so far. The current ILC design organization is probably unique amongst large scientific facilities, being led by the international particle physics community rather than by a single laboratory supported by one or more government funding agencies. This international effort, led by GDE Director Barry Barish, is spread over the three regions of Americas, Asia and Europe; funding for ILC activities worldwide is now of order US$100M annually, although mostly this funding is supplied by individual national funding agencies to laboratories that they control. The effort has progressed over the past two years through a baseline design, then a major cost reduction

activity, to the RDR, with estimated construction costs recently made public. The design is now entering a 3 year engineering design phase.

Although government funding agencies are not formally organizing the ILC design and R&D effort, they are aware of its activities through GDE reporting to FALC, and through the activities at national laboratories.

2. Project Governance, Relations with Governments, and Relations with Industry

At present, the GDE, through its Director, is responsible for the design of the ILC project and the required R&D to achieve the performance goals and prepare for industrial fabrication. However, the funding directly available to the GDE is currently very small (several hundred thousands of US dollars annually). Most funding for ILC activities is from government funding agencies to their national laboratories; the GDE Director can only use persuasion to make any of these funds available for a coherent and coordinated effort towards realization of the ILC. While this has been quite successful so far, the next phase, leading to an Engineering Design Report by 2010, will require substantially more engineering support and R&D, which can only be obtained from the laboratories.

Up to now, direct financial support for the needed R&D on ILC components has not existed, and support available through the laboratories has been only for technical tasks at the laboratories. This has meant that essentially no funds have been available so far for industrial R&D (with the exception of work on the European XFEL), which will be a very important input for validating the costs assumed for a significant fraction of the ILC components. Also, industrialization can lead to competition and further cost savings.

In Europe, the involvement in the ILC of CERN and its member states directed by the CERN Council will be very important, since they are central to all European particle physics activities.

The lack of a chosen site for the ILC is obviously a hindrance to its design; many design decisions depend on details of the site, and this leads to uncertainties in costs and design conservatism until one specific site is chosen.

3. ILC Cost Estimate----General Considerations

In the short time available, the Committee concentrated mainly on the two biggest cost drivers, namely the Main Linac and the civil engineering and conventional infrastructure facilities, while the other systems were also reviewed to a level that the committee could be satisfied that no major items have been left out. The Committee believes that at this stage of maturity the overall cost estimate is reasonable within the error of 30% quoted by the GDE Director. The Committee believes that there will be opportunities for cost reductions in the future when some of the present uncertainties become better understood. The GDE has started a study of cost and technical uncertainties and risk analysis. The biggest cost/technical risks are the Main Linac accelerating gradient; electron cloud effects, which may affect the Damping Ring design; and the Beam Delivery System optics and design.

The Committee feels that there are areas where clarification of cost items is needed, including which costs are, and which are not, included in the RDR estimates. Examples include:

- No estimate is given for the costs of R&D,, prototyping, commissioning and operations prior to the start of construction, nor for commissioning and operating costs during construction

- Many costs are based on those in industrialized countries. This cannot be totally realistic, since many items might be produced with appropriate quality but at lower cost in the developing countries of the world

- A list of surface buildings included in the estimate should be given. In addition, a site may not be near to an existing laboratory; in this case, additional buildings such as shops and laboratories, a cafeteria, a library, etc. will be necessary, and their costs should be noted

- Manpower estimates should be separated into technical and managerial. In the proposed future work package structure, the manpower estimates should be specific and assigned to the relevant work packages

- An estimate should be available of the expected operating costs of the ILC after completion of the construction

- At present, no detector costs are given

One member of the Committee with experience in US tunnelling costs is of the opinion that the tunnelling cost at the US site is too low. It is indeed lower than that of the European site, and this was explained by the fact that it is assumed that the European tunnel would be fully lined, while the US tunnel would not. This should be clarified.

The currently assumed schedule is technology driven. The impact of the schedule on the cost and potential risk of the civil construction, installation, and fabrication of components should be assessed.

4. Main Linac Cavities and Cryomodules

The Main Linac cavities and cryomodules are the major high-technical components of the ILC, and are also a significant fraction of the total cost. The ILC design is based on an operating gradient of 31.5 MV/m at a Q of 1e10, necessitating an initial cryomodule acceptance of 35 MV/m (in the vertical position). While individual cavities have reached this performance, this has not yet been achieved with multi-cavity cryomodules. Even further away is proof of industrial production of 20,000 cavities reaching this standard. The present ILC design and costing is based on the assumption that future R&D, and future industrialization, will lead to the design performance and reliable fabrication within the projected schedule. The international R&D proposed by the GDE is well thought out, and will need to be well coordinated. In the next few years, cavity production for the DESY XFEL should provide some validation of these projections, and will calibrate the production learning curve. The XFEL has many similarities to the ILC (although with an operating gradient of only 23.6 MV/m). However, it should be noted that the XFEL will probably stimulate industry in Europe, but efforts need to be made to prepare industry in the other two regions. As for the LHC, a policy of minimizing the risk exposure of the industrial producers will be critical to containing costs.

The Committee believes that the ILC gradient design goal is ambitious but achievable, assuming of course that sufficient R&D funding is available. Nevertheless, the Committee learned that, if it is assumed that there will be no further improvement in cavity gradient beyond that achieved to date, the ILC could still be built. This pessimistic scenario necessitates longer Main Linacs and tunnels than in the RDR, in order for the larger number of lower gradient cavities to achieve a total energy of 500 GeV. The Committee was informed that these changes would increase the overall cost by about 7%.

5. Main Linac RF

The Main Linac RF contains several components where R&D is currently in progress, and where cost reductions are likely if the R&D is successful. Work on a Marx generator RF modulator at SLAC looks very promising at the present time, and could lead to a significant cost reduction impact over the conventional modulator assumed in the RDR.

The Committee would like to see more than one klystron manufacturer meeting ILC klystron specifications. One manufacturer so far has delivered a klystron meeting the ILC specifications, although only limited lifetime testing has been carried out up to now. Two other companies are producing klystrons close to specifications. More manufacturers producing acceptable klystrons would lead to more confidence in eventual mass production, and to cost competition.

Successful construction of a sheet-beam klystron, currently under study, could have an impact on Main Linac RF costs.

Variable tap-offs for RF power distribution to the Main Linac cryomodules are under study; success would allow a larger acceptable variation in cavity gradient performance.

6. Damping Rings

The Damping Rings present a significant design challenge because of their crucial role in achieving low-emittance electron and positron beams and consequent high ILC luminosity. Also, electron cloud issues affect the positron ring. The Committee received a presentation on Damping Ring design. It felt that not enough justification was given for the individually adjustable quadrupole and sextupole power supplies; cost savings may be possible here. Also, the control system costs appear at first sight to be somewhat higher than might be expected based upon other accelerator projects. The main risk in the present damping ring design is the electron cloud instability in the positron ring. The NEG coating of the vacuum chamber developed for the LHC is a very promising remedy although R&D still needs to be done on the existing machines and it needs to be verified that the low activation temperature limited by the aluminium chamber is sufficient. If the emittance goals cannot be reached, the ultimate fallback is a second positron ring with its associated cost increase.

7. Beam Delivery System

The Committee received a presentation on the Beam Delivery System. There have been several cost-saving changes over the past several months, the major one (saving about US$200M) is the choice of a single beam delivery system, with one IR and a beam crossing angle of 14 mr; previously there had been two IRs, with crossing angles of 2 mr and 20 mr

respectively. A small design effort continues to study IR alternatives. One beam delivery system and IR leads to two detectors in a push-pull arrangement. Details of the (several days to one week) detector changeovers are still under study, with such problems to be solved as how to avoid disconnecting the final IR quadrupoles from their cryogenic system when the detectors (with the attached final quadrupoles) are moved.

The crab cavities needed for the non-zero IR crossing angle are a challenging system to design and build.

Another design change made recently is to have on-surface detector assembly (as for the CERN CMS detector), which will allow for a later occupancy of the underground hall, and save 2-2.5 years in the detector schedules.

8. Conventional Facilities

The Committee felt that some cost savings might be possible in the ILC conventional facilities. Among the items which it believes should be examined for further cost optimization are the following:

- The diameters of the Main Linac and Damping Ring tunnels
- The total number of vertical shafts
- The diameters of the vertical shafts
- The temperature rise of the tunnel component water cooling system
- The proposed 7 year construction schedule

C. APPENDICES

Appendix I. Review Membership

Sergio Bertolucci (Frascati)
Jia-er Chen (Peking University)
Mark de Jong (Canadian Light Source)
Lyn Evans (CERN) (Chair)
Norbert Holtkamp (ITER)
S. S. Kapoor (BARC)
G. S. Lee (National Fusion Research Center, Korea)
Vera Luth (SLAC)
Norihiko Ozaki (Institute for Techno-Economics, Japan)
Lucio Rossi (CERN)
Ed Temple (Fermilab)
Dieter Trines (DESY)
Toshihide Tsunematsu (JAEA, Japan)

Ex-officio
Shin-ichi Kurokawa (KEK)
Ferdinand Willeke (DESY)

Secretary
Roy Rubinstein (Fermilab)

Appendix II. Review Charge

21 March 07

Charge for the Review of the Preliminary Cost Estimate of the ILC Global Design Effort Reference Design Report

The ILC Global Design Effort (GDE), under the direction of Prof. Barry Barish, was established by ICFA in May 2005. The GDE is purposefully constituted as a tri-regional design team whose goal is to produce by 2009 an Engineering Design Report (EDR) which will contain a detailed, engineering-based design and cost for the ILC.

The initial step towards the EDR is to establish a Reference Design Report (RDR) which will define a self-consistent set of ILC design parameters and associated implementation scope. The RDR will also contain an initial estimate of cost at the 20% level which will be mostly parametric in nature. This initial cost estimate will be at sufficient detail to permit a) trend analysis for cost reduction/optimization and b) give guidance for the R&D and industrialization that must accompany the engineering design process of the EDR.

Consistent with the suggestion of the GDE Director, an international team should be convened prior to completion of the RDR to review those aspects of the RDR cost estimate that strongly influence the EDR. Given the intermediate nature of the RDR estimate as discussed above, it would seem premature to review in detail every aspect of an ILC cost estimate. Rather this review team should:

- review cost trends and relative costs of sub-systems. Comment on their relevance to potential changes to be incorporated into the EDR, and to the R&D program in support of the EDR.
- review the methodology used in the estimate to ensure that it is appropriate for establishing an accurate EDR cost assessment. Evaluate that the method and format of estimation can serve the needs of regional authorities as they develop plans for potential involvement as partners in the ILC.

Appendix III. Review Agenda

International Cost Review

Wednesday 23 May 2007

Executive Session - Room 166 (08:30-09:00)

Introduction - Laboratory Building 200, Room 101 (09:00-10:00)
- Speakers: BARISH, Barry

Reference Design Report - Laboratory Building 200, Room 101 (10:00-11:00)
- Speakers: YOKOYA, Kaoru

coffee - Laboratory Building 200, Room 101 (11:00-11:30)

Costing Methodology - Laboratory Building 200, Room 101 (11:30-12:30)
- Speakers: GARBINCIUS, Peter

lunch - Laboratory Building 200, Room 101 (12:30-13:30)

Main Linac - Laboratory Building 200, Room 101 (13:30-14:30)
- Speakers: ADOLPHSEN, Chris

Cavities, Cryomodules, and RF Power - Laboratory Building 200, Room 101 (14:30-15:30)
- Speakers: BIALOWONS, Wilhelm

coffee - Laboratory Building 200, Room 101 (15:30-16:00)

Conventional Facilities - introduction - Laboratory Building 200, Room 101 (16:00-17:00)
- Speakers: BALDY, Jean-Luc

Beam Delivery System design - introduction - Laboratory Building 200, Room 101 (17:00-17:30)
- Speakers: SERYI, Andrei

Executive Session - Laboratory Building 200, Room 101 (17:30-19:00)

Thursday 24 May 2007

Executive Session - Laboratory Building 200, Room 101 (08:30-09:00)

Damping Rings - introduction - Laboratory Building 200, Room 101 (09:00-09:30)
- Speakers: WOLSKI, Andrzej

Thursday 24 May 2007

Parallel session - Laboratory Building 200, Room 101 (09:30-12:30)
time title presenter

09:30 Main Linac and associated systems discussion (03h00') ADOLPHSEN, Chris
BIALOWONS, Wilhelm
PROCH, Dieter
STANEK, Rich
LARSEN, Raymond

09:30 Management and Planning discussion (03h00') GARBINCIUS, Peter

SHIDARA, Tetsuo
BARISH, Barry

10:30 coffee (00h30')

lunch - Laboratory Building 200, Room 101 (12:30-13:30)

Thursday 24 May 2007

Parallel Session - Laboratory Building 200, Room 101 (13:30-17:00)
time title presenter

13:30 Conventional Facilites, Damping Rings, Beam Delivery System (03h30')
- Conventional Facilites (01h30') KUCHLER, Victor
BALDY, Jean-Luc
ENOMOTO, Atsushi
- Damping Ring (00h45') GUIDUCCI, Susanna
- Beam Delivery System (00h45') SERYI, Andrei

13:30 Management and Planning (03h30')
- R&D Plans (00h45') HIMEL, Thomas
- Risk Analysis (00h45') PATERSON, Ewan
- Plans and Engineering Design (01h00') ROSS, Marc
- Discussion (00h30')

15:00 coffee (00h15')

Executive Session - Laboratory Building 200, Room 101 (17:00-18:30)

Dinner - Au Chien qui fume - Laboratory Building 200, Room 101 (20:00-20:20)

Friday 25 May 2007

Questions and Answers - Laboratory Building 200, Room 101 (08:30-10:30)

coffee - Laboratory Building 200, Room 101 (10:30-11:00)

Executive Session - Laboratory Building 200, Room 101 (11:00-12:30)

lunch - Laboratory Building 200, Room 101 (12:30-13:30)

Closeout - Laboratory Building 200, Room 101 (13:30-14:30)