Summary of Decisions from Main-Linac and SCRF Baseline Technical Review (BTR)

held at KEK, January 18 – 19, 2012

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Attendance:
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Decision Summary:

The Main-Linac and SCRF Baseline Technical Review (BTR) was organized to discuss baseline design and technology for the Technical Design Report (TDR) and its associated cost-estimate.

The agreed TDR design changes/updates to the 2007 RDR are as follows:

1. Main Linac Design and Integration:

a) The primary beam parameters for the main linac are as follows:

		Baseline 500	L upgrade 500	TeV upgrade
Charge per bunch	nC	3.2	3.2	3.2
Bunches per pulse		1312	2625	2450
Bunch spacing	ns	554	366	366
Pulse current	mA	5.8	8.8	7.6
Rep. rate	Hz	5*	5	4

*) 10Hz mode for e- linac for $E_{cm} \leq 250$ GeV

See:
http://ilc-edmsdirect.desy.de/ilc-edmsdirect/document.jsp?edmsid=D00000000925325

The Main Linac baseline (500 GeV) design (and cost) will include support for the luminosity upgrade (mostly CFS); the upgrade itself is essentially the addition of more klystrons and modulators to provide the increased beam power. The bunch spacing is consistent with timing considerations and constrained by the choice of damping ring harmonic number.

b) The basic linac unit retains the 2007 RDR 3-cryomodule-string consisting of a total of 26 cavities. The unit is constructed from two type A modules (9 cavities) and one type B module (8 cavities and 1 SC quad package at the centre), in an A-B-A arrangement.

c) For the Kamaboko HLRF solution, one 10MW MBK will drive 39 cavities, corresponding to 1.5 basic linac units (or 4.5 cryomodules). This choice infers a nine-module building block for the linac, driven by two klystrons.

d) For KCS, a single CTO will drive 26 cavities, or one basic unit (3 cryomodules).

e) To provide some level of redundancy, an additional energy overhead of 1.4% above what is nominally required for 250 GeV operation will be included. This corresponds to 3 basic linac units, or 9 cryomodules (~150-m tunnel length).

f) For the TDR, two site-dependent approaches to the tunnel will be adopted: For a 'flat-land' site using KCS, the tunnel will likely be constructed with a TBM and have a corresponding circular cross section. For the mountainous region site, the NATM construction method will be adopted with the so-called 'Kamaboko' cross-section. The single Kamaboko tunnel will be centrally divided by a shielding wall, providing the equivalent functionality of the two-tunnel 2007 RDR solution.

2. RF power system:

g) The flat-land variant will use the Klystron Cluster System (KCS) with additional shaft and surface buildings. See (d) and (f).

h) The mountain region site will be a similar scheme as proposed in the 2007 RDR, with the exception that one 10MW MBK locally drives 39 cavities (reducing to 26 cavities for the luminosity upgrade). See (c) and (f).

i) The baseline Klystron Modulator power supply is a Marx generator design.

3. Cryomodule and Cryogenics:

j) The Baseline cryomodule design consists of Cryomodule A (containing 9 cavities) and Cryomodule B of identical length (containing 8 cavities and 1 SC quadrupole / dipole correction magnet package at the center).

k) The cryomodule string unit consist of 3 CMs (9+4Q4+9) or 4.5 CMs as described above.

l) The superconducting quadrupole magnet strength will be optimized for 250 GeV operation in FDFD beam optics for the 500 GeV baseline. For the TeV upgrade, an FFDD lattice will be used, to avoid upgrading these magnets.

m) (*This item added from additional discussion after BTR*) Two quadrupole magnet designs might be required to minimize instabilities for lower magnetic field operations (lower beam energy): One for the energy range of 25 ~ 250 GeV, and one for less than 25 GeV. The cryomodule for the lower energy (< 25 GeV) including RTML will be moved physically during the TeV upgrade to the lower energy part of the (new) linac. In all cases, the magnet package support interface to the cryomodule cold mass should be kept identical, and located directly from the support post at the top of gas return pipe.

n) Simplification of the 5 K shield will be implemented for cost effective fabrication and for better accessibility for assembly and maintenance.

o) Cryogenics systems consist of 5 plants per linac with capacity spread of ~ 20%.

p) (*This item added from additional discussion after BTR*) The basic cryo-string (terminated by a ~2.5m cold box) will consist of twelve cryomodules. (Some short string of 9 cryomodules are foreseen.)

4. Cavity Integration:

q) The baseline cavity design consists of the 'Tesla type' cavity with a 'Blade type' tuner. The magnetic shield cylinder surrounding the cavity will be mounted inside the LHe tank, with a separate segmented magnetic shield covering the interconnect region.

r) The cavity is to be delivered from industry with the helium tank and internal magnetic shield installed.

5. Cavity gradient performance:

s) The baseline production yield target is 90 % including a second surface processing cycle if necessary.

t) The fabrication and surface-process recipes include the application of a surface optical inspection system.

6. Cavity and Cryomodule Performance Testing

u) All cavities will be performance tested in a low-power *cw* vertical test to their limiting gradient.

v) All power couplers will be warm conditioned to their nominal (maximum required) power rating.

w) During peak production, 1/4 to 1/3 of the cryomodules are to be performance tested. (The exact number will be determined by cost considerations). 100% testing is expected during production ramp-up (lower production rate).

Background:

The process followed to reach the above decisions was:

- evaluate designs to ensure they satisfy ILC technical requirements and are consistent with 'plug-compatible' interfaces;
- choose the most cost-effective design for the TDR baseline.

Notes

1. Main Linac Beam Integration:

The TDR main linac design has now been optimized for the baseline reduced bunch-number 500 GeV parameter set 'SB2009'. The two different single-tunnel designs (TBM constructed circular tunnel, and NATM 'Kamaboko' tunnel) provide flexibility and allow the development and consideration of main linac CFS, cryogenics and HLRF for two very different site topographies and geologies (flat-land and mountain regions). The wide Kamaboko tunnel with the centrally located dividing shielding wall provides the same two-tunnel functionality proposed in the 2007 RDR, but at a significantly reduced cost. Both solutions therefore provide access to the HLRF and other hardware during beam operations.

The adopted 1.4% energy overhead (above the nominal 250 GeV beam energy) provides some margin for failure or degradation in cryomodule performance and – for the Kamaboko solution – provides an additional three redundant klystrons (i.e. RF power). (For the KCS solution, additional redundant klystrons are supplied in the surface clusters and do not require additional linac length.) The SB2009 availability analysis predicted the failure of a cavity mechanical tuner system every 2½ days (corresponding to 10^6 hour MTBF). With an assumed 5-year linac cryomodule maintenance cycle, this implied that on average roughly 3.5% of the linac was not available due to tuner failure. The availability analysis further assumed no acceleration would be provided by a cavity with a failed tuner – a worst case. It is assumed the tuner MTBF will be improved to 10^7 hours. The (availability) benefits of the additional 1.4% linac still need to be quantified.

The 400 meter empty-tunnel extension included in the 2007 RDR tunnel layout has been discarded.

While the TDR baseline assumes a water-level linac, it was agreed that tilting the linac by approximate 0.5% was technically feasible for the cryogenics. Such a tilt may be necessary to optimize overall alignment and minimize access tunnel lengths in a complex mountain site topography or urban layout, thus providing site-dependent flexibility. To accommodate the tilt, the cryogenic system requires additional space for inter-module valve control assemblies. The increase in linac length is estimated at ~100 m for 0.5% tilt.

2. RF power system

The RF power source remains the 10 MW MBK as described in the 2007 RDR. However, the MBK will now be driven by the Marx solid-state modulator.

While the basic power source remains the same for both tunnel layout configurations, the power transport and distribution system differs significantly.

The 'Kamaboko' type single tunnel utilizes a dividing shield wall to provide the same functionality as the twin-tunnel RDR solution, and consequently the same HLRF concept can be used. To reflect the lower beam power (compared to the RDR), one 10MW MBK will be used to locally drive 39 cavities, as opposed to the original 26 in the RDR. (The luminosity upgrade will revert to the 26 cavity unit, adding more klystrons and modulators in the tunnel.)

The Klystron Cluster System (KCS) solution places all the klystrons in surface buildings ('clusters'). A cluster is ~35 10MW MBKs, plus additional klystrons for redundancy. The total RF power of the cluster is combined into a single over-moded waveguide, which is then used to transport ~35MW RF power into the single accelerator tunnel. CTOs are used to locally tap off the required ~8MW to drive a unit of 26 cavities (the original RDR 'RF unit'). The luminosity upgrade requires additional klystrons to be added to each cluster.

Initial technical performance validation of the KCS over-moded waveguide and couplers is encouraging and cost evaluation is underway. Further cost estimation activity for both KCS and RDR local power distribution system is a task to be completed for the next plenary meeting.

For the 'Kamaboko' HLRF solution, the klystron power overhead is ≥10% which should be sufficient for LLRF control.

3. Cryomodule and cryogenics

The baseline cryomodule design consists of Cryomodule A (containing 9 cavities) and Cryomodule B (containing 8 cavities and 1 SC quadrupole magnet at center), the same as the 2007 RDR. Both modules have the same length, which is defined to be 12,652 mm including 850 mm for the interconnect bellows (so-called 'slot length').

The SC quadrupole magnet design needs to satisfy very wide range of beam energy (i.e. magnetic field strength). A standard magnet design will be optimized to cover the energy range of approximately 10% to 100% of 250 GeV beam energy operation, based on the requirements of a FoDo like lattice. The same magnets can be used to accommodate beam energies of 260-500 GeV for the TeV upgrade, using a FoFoDoDo lattice. We may need to have an additional magnet design specifically in the lower energy operation below 10% of the full magnetic field (<25 GeV beam energy operation). In this case, the magnet field strength can be stronger and the length shorter, in order to minimize the associated field instability. It is likely prudent to separate the quadrupole magnet from dipole corrector magnet, placing them adjacent along the beam-line axis. The exact design and configuration of the SCRF magnets remains an important action item. However, it is assumed that all magnet package solutions will fit the single defined interface conditions in the cryomodule, thus avoiding the need for more than one cold-mass variant.

The simplification of 5 K shield over the 2007 RDR design is adopted since it is considered to be cost effective in both fabrication and maintenance work. The sheet-metal lower shield is to be replaced with a flexible shield that provides easier accessibility yet retains good cryogenic insulation performance.

The Baseline will have 5 cryogenics plants per linac. This is consistent with a practical access shaft / tunnel spacing. The cryogenic plant capacity has roughly 20% cryogenic power overhead, allowing the linac tunnel access points to be shifted ~20% as needed to accommodate a given site topography. The overhead will also help to cover requirements from RTML and source booster accelerators that are located at the low-energy and high-energy ends of the main linac, respectively.

The control of two-phase helium flow requires a cold-box/end-box with a phase separator to be spaced at even intervals along the linac. This requires an additional space (~2.5m) between cryomodule strings. The original cold-box spacing (cryo-string length) in the 2007 RDR was 12 cryomodules, which is to be retained for the majority of the TDR cryo strings. This has ramifications for the HLRF PDS systems, which will need to accommodate the cold box spacing. It should also be noted that accommodating a tilt to the linac will influence the cryo-string length.

4. Cavity Integration:
The baseline cavity design is the 'Tesla type' cavity, with which there is now well over ten years experience, and a solid industrial manufacturing base (especially in Europe with the cavity production for the European XFEL). The mechanical tuner will be the 'Blade type', which has been tested at S1-global and NML (and also at TTF/FLASH).

The cavity is to be delivered from industry complete with the LHe tank and inner magnetic shield, ready for vertical testing. Thus a cavity that does not require a second processing cycle will remain sealed and will not be opened again until it is connected to the string. Also, the cavity will not have to be returned to the weld-shop for tank installation. This shortens the 'industrial path' and therefore reduces QA/QC and transportation. This is the approach being taken in the European XFEL cavity production, and we will benefit from their experience.

5. Cavity Gradient Performance:
The baseline production yield target is 90% including a second surface processing, if necessary. This reduces the required cavity overproduction to ~11% compared to the RDR assumption of 25% (80% yield, with no reprocessing). However, the cost for the 2nd processing cycle and test requires further investigation to evaluate the net benefit of this reduction.

The industrial fabrication and surface-process baseline recipe should include the application of an optical inspection system and repair process during cavity manufacturing. We expect that this will reduce the number of cavities that fail to exceed a gradient of 20 MV/m. It is currently understood that such failures are most likely due to manufacturing mechanical defects.

The above proposals to the standard recipe should result in a net cost reduction.

6. Cavity and Cryomodule Performance Test:
All cavities will be low-powered vertically tested to their limiting gradient as part of the

acceptance test for industrial production. 100% testing appears prudent given the assumption of the need for a second-pass chemistry to achieve the specified yield of 90% (implicit ~68% single-pass yield).

All power couplers will be warm conditioned before cavity string assembly to their nominal power rating, corresponding to full gradient, full current performance. The maximum average power requirements for warm processing must be checked. For cryomodule assembly, the cold and warm parts of the coupler are divided and reconnected. Additional conditioning will be required, including short-pulse high-peak power operation, and this is to be done following cryomodule assembly/installation.

Full power cold tests of all cryomodules before installation are not foreseen due to cost and schedule constraints. Cryomodule performance testing rate during peak production will be of the order of 25-33%, as part of the QA/QC for the mass production process. 100% testing is assumed during ramp up and commissioning of the production when production rates are lower. This testing strategy is based on the assumption that cavity performance should not change during string assembly, and that the level of non-conformant modules is low (commensurate with the sample testing rate). The production of the 100 modules for the European XFEL – for which 100% testing is assumed – will be used to evaluate this strategy.

Homework by Korea meeting.

The following remaining subjects have been identified as action items to be completed by the next GDE plenary meetings (to be held in Korea, on April 23 – 26).

ML Integration	- Provide a complete ML lattice with 9+4Q4+9 cryomodule unit, - Confirm requirement of energy overhead (1.4%) w/ additional ML length for operational availability (provide rationale) - Fix total numbers of CM including ML, RTML, e-source (# add. CMs to be fixed) - Q + corrector +BPM package design (w/ energy dependent design?) - Plan for full power upgrade at 500 GeV, and scenario up to 1 TeV (→ such as quad. configuration, FDFD up to 500 GeV, and FFDD at 1 TeV?
HLRF	- Required RF power overhead, more detail (in KCS and RDR) - Cost saving of PDS, Klystron, Marx Generator etc - Catalogue local power distribution variants and conceptual designs - Estimate waveguide losses and heat loads
CM and Cryogenics	- Confirm CM slot length to be fixed: 12,652 mm in RDR, and it need to be reflected to the current ILC-CM drawing which has currently 12,644 mm (11794+850) in FNAL-CM4. - Asses the need for accessibility and maintenance of active components (tuner motors) - Cryo-string length, additional length of Cold-box for phase-separation, to adapt new RDR-like RF unit and/or tilting tunnel and effect on add. Total main linac length.
Cavity Integration	- Cavity-slot length to be well established (to be 1326.7 mm) - Feasibility of magnetic shield inside LHe tank at central region and outside at inter-connect.
Cavity Gradient	- Update fabrication process and recipe; re-definition of production yield (documentation)
Coupler processing	- Determine specifications for peak power processing - Evaluate solution for tunnel in-situ processing