Truncated Version, February 21, 2002

To:	H. Sugawara (Director, KEK)
From:	K. Saito, T. Shintake, T. Tauchi, N. Toge, J. Urakawa, K. Yokoya
Subject:	Trip Report (DESY, November, 2001)

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1 Purpose and Schedule of the Trip

This is a trip report by K. Saito, T. Shintake, T. Tauchi, N. Toge, J. Urakawa and K. Yokoya of KEK who visited DESY (Hamburg, Germany) in November of 2001. This visit was arranged based on an agreement made by the directors of KEK and DESY, H. Sugawara and A. Wagner, in the Summer of 2001. The primary goal of this visit on the part of KEK delegate is two-fold:

- Try to understand the status of the design, R&D of TESLA/TTF efforts at DESY and their future prospects, and report to the director of KEK,
- Try to understand the project cost estimate work for TESLA which was published with TESLA TDR in Spring of 2001, and report to the director of KEK.

It is also expected that the report by this KEK delegate will be made available to the DESY directorate and it may become of some use for the TESLA group for refining their future R&D strategies. In addition, this type of mutual visits is generally considered beneficial for long-term cooperative relationship among those laboratories who are engaged in development of linear colliders (LCs).

During this visit each member of the delegate has been assigned to cover some specific areas as their “specialty” as follows:

	Areas to cover	Visit dates
K. Yokoya	parameters, BD, IR, injectors	Nov.25 - Nov.29
J. Urakawa	injectors , BD	Nov.25 - Nov.29
K. Saito	SCRF, cavities	Nov.25 - Dec.1
T. Shintake	SCRF, RF sources, beam monitors	Nov.25 - Nov.29
T. Tauchi	Conv. Facility, BD, IR	Nov.25 - Nov.30
N. Toge	parameters, injectors, SCRF, Conv. Facility	Nov.25 - Nov.29

However, the division of these tasks is not a strict one. This document is a combined report based on contributions by all the delegate members. The discussion program took place as follows:

	AM	PM
Nov.25 (Mon)	Opening*	TESLA cost model*
	Introducing KEK delegate members	TTF tour*
	TESLA overview talk*	Dinner*
Nov.26 (Tue)	Civil engineering*	Civil engineering
		TESLA param, inj, BD
		RF power sources
		NLC IP feedback (seminar)
Nov.27 (Wed)	TESLA param, inj, BD	TESLA site tour
	RF cavities and BPMs	SPring-8 FEL project (seminar)
Nov.28 (Thu)	Tour to the Hamburg tunnel construction site	
	RF cavity technologies	
Nov.29 (Fri)	RF cavity technologies	

Programs marked with "*"s were attended by all six delegates from KEK. Other programs took place in parallel.

2 TESLA Design and R&D Overview

2.1 Introduction

The TESLA scheme (Fig. 1), developed by an international group centered around DESY, is based on superconducting niobium accelerator structures. Its Conceptual Design Report (CDR) was published in 1997[1] and the Technical Design Report (TDR) was released in 2001[2]. The present TESLA proposal aims to achieve $E_{CM} = 500$ GeV (TESLA-500) at a gradient of $E_{acc} = 23.4$ MV/m with $Q_o = 10^{10}$ in its first-phase operation. An upgrade path to 800 GeV (TESLA-800) is also considered for later time with $E_{acc} = 35$ MV/m.

The number of RF-related units in the TESLA main linacs are tabulated below:

item	value	unit
Main linac length	15.0×2	km
RF active length	10.9×2	km
# of cryomodules	876×2	
# of RF cavities / cryomodule	12	
# of RF cavities	10512×2	
# of klystrons (9.7 MW)	291×2	

The RF system (Fig. 2) consists of 286 stations per electron and positron main linac. Each station provides power at 1.3 GHz to a total of 36 sets of 9-cell accelerating cavities, which are grouped in 3 "cryomodules". The peak RF power needed for one superconducting cavity at full gradient and maximum beam current (23.4 MV/m and 9.5 mA) is 231 kW: the nominal

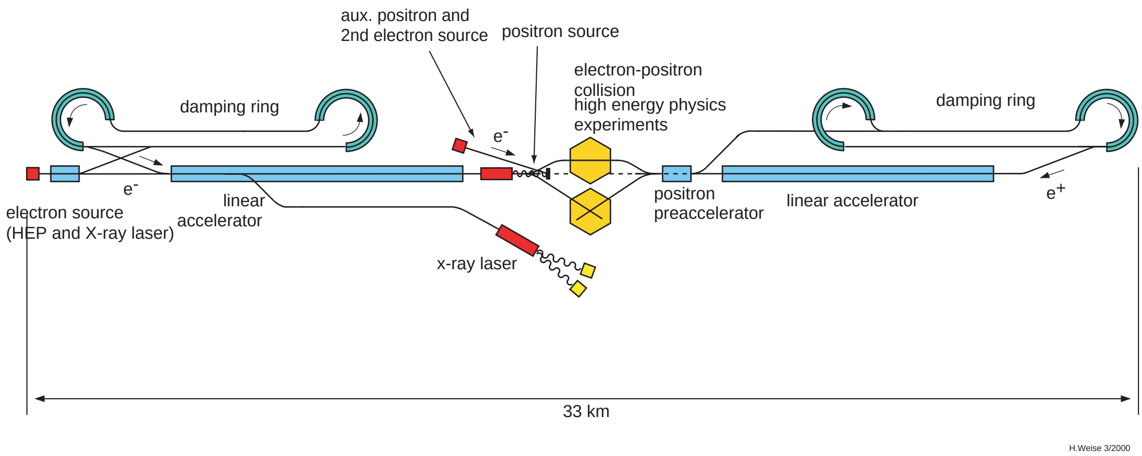

Figure 1: Schematic layout of TESLA.

peak power needed for 36 cavities is 8.3 MW/station. With regulation reserve of 10% for phase and amplitude control and also taking account 6% loss in the waveguide and circulator, the total of 9.7 MW/station is required. The RF pulse length is 1.36 ms, which includes the beam pulse length of 950 μs, and the cavity filling time of 420 μs. The repetition rate is 5 Hz for the major part of the linac. The 5-50 GeV section will run at 10 Hz to provide driving beam to the SASE-FEL user facility.

The length of an individual 9-cell cavity unit is 1.036 m. A cryomodule, each 16 m long (16.8 m with a quadrupole magnet every 2nd/3rd module), will contain 12 cavity units. The number of cryomodules quoted in the table above includes a reserve for 2% energy overhead. The cavities are operated at 2K in TM_{010}, π mode. The total number of cryomodules would be 1752 for the entire TESLA, and the total number of 9-cell cavities 21,024. The packing factor of the main accelerators is 73 % in the TDR configuration.

The important beam parameters are summarized below:

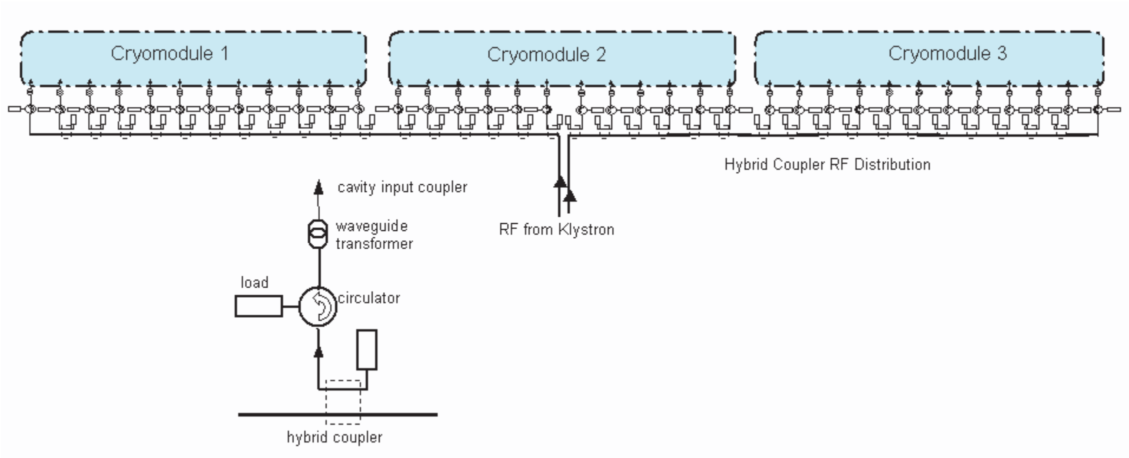

Figure 2: RF waveguide distribution of one RF station. Reproduced from Figure 3.3.5 in TDR II-97.

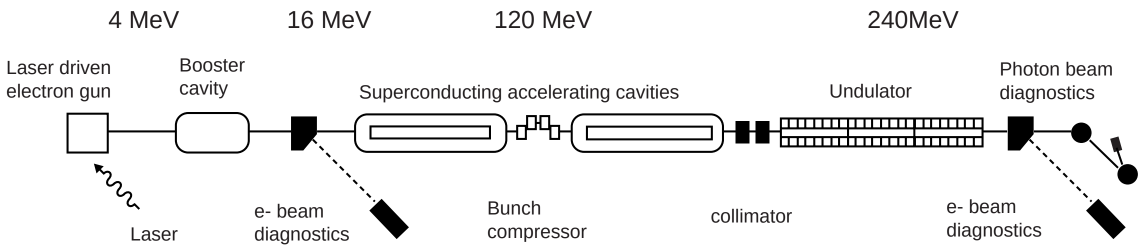

Figure 3: Schematic layout of TTF. Reproduced from Figure 2.2.1 in TDR II-49.

	TESLA	JLC	unit
Pulse repetition rate	5	150	Hz
# of bunches / pulse	2820	192	
Bunch spacing	337	1.4	ns
Bunch train length	950	0.27	μs
Bunch population	2×10^{10}	0.75×10^{10}	particles
Average beam power	11.28×2	8.65×2	MW
Wallplug power	97	$\sim$ 150	MW
Wallplug $\rightarrow$ RF	38.4	$\sim$38	%
RF$\rightarrow$ beam	60.7	$\sim$30	%
Wallplug $\rightarrow$ beam	23.3	$\sim$ 11	%
Beamstrahlung	3.2	5.4	%
ϵ_y	3×10^{-8}	4×10^{-8}	m
Pinch enhancement	2.1	1.52	
σ_z/β_y	0.75	1.0	
Luminosity	3.4×10^{34}	2.5×10^{34}	cm^{-2}s^{-1}

The electron bunches at TESLA will be produced with a polarized laser-driven gun. After accelerated to 5 GeV with a short SC linac, the electron beam is injected into a "dogbone-shaped" 5 GeV damping ring. The positron bunches at TESLA are produced with γ-conversion in a thin target. The photons are generated by passing the electron beam through a 100 m undulator located upstream of the interaction region. The produced positrons are then accelerated by a 200 MeV conventional L-band linac, a 5 GeV SC linac and injected into the damping ring.

The TESLA group has been operating the TESLA Test Facility (TTF, Fig. 1) since 1996. The TTF includes the devices for the FEL such as bunch compressor and undulator section, and the total beam operation time by now exceeded 9000 hours at a typical pulse repetition rate of 1 Hz. Acceleration of 800 μs bunch train with $I_b = 8$mA and $\sigma_E/E = 0.07$ % has been demonstrated. A TTF-style cryomodule is 12 m in length and it contains 8 cavities (rather than 12 planned for TESLA).

Some of the points that were made in the TESLA overview offered by R. Brinkmann during our visit are summarized as follows:

1. Efficiency (ratio of the beam vs wall-plug power) at TESLA is 23.3 %, compared to $\sim$ 11% at JLC. The considered wallplug power for TESLA includes what is required for operating the cryogenic plants.

2. With the fast intra-bunch feedback the orbit at the IP will be kept within a relative error of 0.1σ in offset and the angle. The simulations of the feedback, including the finite BPM resolution, noise and other effects showed that they should be able to limit the luminosity loss from orbit jitters to be within 3 % [1].

3. The linac tolerances (transverse, rms) corresponding to a 10 % emittance growth (normalized by the design emittance) at TESLA are summarized as follows:

item	value	unit
Cavities	0.5	mm
Quad magnets	0.3	mm

   The assumed BPM (cavity type) resolution is 10 μm and the injection jitter 0.5σ. Since the "filamentation" effects are small in the TESLA main linacs, SLC-style orbit bump tuning technique (amplitude $\sim$ 0.5mm) can be easily used to control the emittance growth. To desensitize the emittance growth with respect to injection jitters, the use of BNS damping is planned. The simulation studies show promising results. In addition, since the effects due to cavity HOMs are stable, the bunch-to-bunch orbit variation is expected to be very stable in consecutive machine pulses. Thus, a fast orbit feed-forward technique can be used to effectively remove their effects.

4. Concerning the production of SC cavities, major improvements were seen (1999 - 2000) in the welding method and quality control procedures at the companies. The so-called

[1] KEK note: The luminosity quoted for JLC includes effects of possible orbit mismatch between electron and positron beams.

"3rd-production" cavities consistently exhibit satisfactory performance for TESLA 500 without any prolonged training. These cavities will be tested at TTF in 2003. Development of SC cavities compatible with TESLA 800 (35 MV/m) is under way, too. Their R&D topics include:

- Use of electro-polishing surface treatment of cavities.
- Introduction of piezo-based active tuners to compensate the effects of Lorenz detuning.
- Use of superstructure concept, reducing the number of input couplers and increasing the cavity packing factor from 73 % to 77 %.

If the TESLA cavities can sustain 35MV/m, a luminosity of $(1 \sim 2) \times 10^{34}$ cm^{-2}s^{-1} can be delivered at $E_{CM} = 600 \sim 750$ GeV without introducing additional RF sources and cryoplants besides what are planned for TESLA 500. With upgrades to the RF sources and cryoplants, the luminosity of $(6 \sim 6.5) \times 10^{34}$ cm^{-2}s^{-1} can be delivered in the same energy range.

2.2 Remarks

Here are some of the random remarks from the part of the KEK delegate:

- **Alignment tolerance:** Owing to the order-of-magnitude larger aperture of the accelerating cavities than JLC, the single-bunch transverse wake force per unit displacement is about 1000 times smaller. This makes the cavity alignment tolerance much loose and allows large beta functions which make the magnet tolerance also loose. There is an unclear statement in the TESLA TDR about the unit of alignment but this point has been clarified during the discussion. According to their simulation, 300μm (rms) misalignment of each 9-cell cavities within a module together with a 200μm misalignment of modules lead to the emittance growth $\Delta\epsilon_y/\epsilon_y$ only 14%. (The same increase will result from $\sim$ 7μm misalignment for the case of JLC.) These numbers for the tolerance are more than one order of magnitude larger that those for the JLC. While a number of engineering details will need to be sorted out, the TESLA group believes that it should be possible to satisfy these requirements even if one takes into account the cavity size one order of magnitude larger than the JLC structure.
- **Cavity tilts:** One of the topics of the discussion was the effect of cavity tilts with respect to the beam direction. This causes a static transverse kick by the accelerating field. A report by one of the participants of the last Snowmass 2001 workshop says that the dispersive effect from the tilt cannot be corrected and that a 175μrad (rms) tilt in TESLA can cause 10% emittance increase, which sounds fairly tight for TESLA. A conclusion of our discussion, however, is that this tilt can be measured by turning off the input power (or by detuning) for each cavity or module, and can be corrected in principle. On the other hand, the similar effect from random stray magnetic fields cannot be turned off and therefore can be a potential problem (for JLC as well). We

need some more discussion and simulation studies on the tilt and stray field for final conclusions.

- **Orbit bumps:** Use of orbit bumps in the main linacs for controlling the emittance is a scheme which has been developed and proven at SLC. This also applies to the analysis of cavity tilts discussed in the previous point. An important consideration in case of TESLA is the fact since the filamentation across the main linacs is small, it would be sufficient to use a single emittance monitor near the linac end (or within the final focus) for this tuning purpose of each linac. In a more aggressive scenario the single luminosity information from the interaction point might suffice in principle. This is in contrast to the case of JLC (or likewise, NLC) where probably four or five emittance monitors are needed, distributed along each of the main linacs. Still, the need for solid engineering implementation of emittance monitors is noted. A beam intensity and emittance values of unprecedented magnitudes need to be handled there. As for the bunch-to-bunch orbit variation, a critical prerequisite for the assumed pulse-to-pulse stability is the stable operation of the electron/positron production systems and the extraction kickers at the damping rings.

- **Energy upgrade:** If the 800 GeV upgrade is to be considered a serious option for the long-term operation of TESLA, use of 35 MV/m accelerating gradient ought to be a high-priority part of the current hardware R&D program. Of particular importance would be the development of RF cavities which are compatible with stable operation at 35 MV/m from an initial stage of installation, even while they may not be operated at that gradient in early operation. This is because while the modulators and klystrons can be relatively easily replaced, the overhauling and replacement of cryomodules would incur major interruption in operation of TESLA.

3 Particle Sources, Injectors and Beam Delivery

We spent several hours with DESY experts, going through many of the issues associated with the particle sources, injectors, damping rings and beam delivery systems of TESLA. Remarks by the KEK delegate are summarized below for each subsystem:

3.1 Remarks on Electron Sources

- **Sources:** TESLA has three 500 MeV electron beam sources: unpolarized electron source, FEL electron source and polarized electron source. If they concurrently run the HEP and XFEL programs as discussed in their TDR, they have to switch the FEL and HEP electron sources with a pulsed dipole magnet, and the linac systems up to ~ 20 GeV (or in the maximum case ~ 50 GeV) need to operate at 10 Hz.

- **TTF:** The Photo-Cathode RF-Gun at TTF can produce a bunch train (800μs long) that consists of maximum 4 nC bunches, spaced at 444 ns. The typical normalized transverse emittance $\gamma\epsilon$ has been < 20 mm-mrad, measured with an injector spectrometer. The smallest normalized emittance of 3 mm-mrad has been obtained with a 1 nC bunch train at 17 MeV, achieved with the rms energy spread σ_E/E of 0.13 %, bunch length $\sigma_z = 3$ mm and the energy tail of 0.3 %. They are to be compared with the TTF goals: $\gamma\epsilon = 10$ mm-mrad at 4 nC (TESLA-type operation), 2 mm-mrad at 1 nC (XFEL-type operation); $\sigma_z = 0.8 \sim 1$ mm and $\sigma_E/E = 0.1$ %.

One of the subjects that require further efforts at TTF electron source is an issue with the dark-current that appears to come from the region between the cathode and rf gun backplane. An improvement of the rf contact around the cathode is expected to reduce the dart current below 0.2 mA, which is considered acceptable.

3.2 Remarks on Positron Source

- **Undulator Scheme:** The required charge in each pulse is 40 times larger than at JLC[2], although in case of TESLA the incident power on the production target is much more spread out in time than JLC, and thus the instantaneous heating of the target is a non-issue. The TESLA group adopted a method which was previously conceived for the VLEPP project, namely, to use photons of over several MeVs from a long (~ 100 m) wiggler section in the electron beamline and let them hit a thin metal target. The TESLA group points out an advantage of this scheme in producing positrons with lower p_t. On the other hand, this method has never been tested in a large scale accelerator. However, the processes of the radiation in wigglers and the positron production on a target by photons are basically calculable and known. The TESLA group does not foresee fundamental difficulties in this method, and we did not find any fundamental reasons to disagree with their assessment. If TESLA is to encounter some operational problems with this system, they are more likely due to general reliability and stability issues associated with the magnet power supplies, alignment and beam instrumentation or the machine protection systems rather than the concept of this positron production system itself.

- **Issues:** Two accelerator issues were discussed during our visit: the yield of positrons (particularly in operation at lower E_{CM}) and the required accuracy of the wigglers. The latter, the TESLA group claims, is easier to satisfy than for FEL because the coherence is not required. The numbers of the yield that TESLA TDR quotes has a safety margin of factor two at the electron energy 250 GeV and one at 150 GeV.

  Overall the production quality of positron beams is, to a large extent, directly governed by the quality of electron beams. Thus, once a stable electron production and acceleration is established, the TESLA group expects to see a very smooth operation of the positron production system. However, how that concept actually maps to the practical commissioning scenario is less straightforward to predict. The TESLA group considers the use of an auxiliary positron system in initial check-out of the positron damping ring and the positron main linac system. However, its specifications and the planning as to how to proceed with the commissioning task are not clear in the TDR. It appears to be

[2] The positron charge population per pulse is 5.6×10^{13} at TESLA and 1.44×10^{12} at JLC. When averaged over time, they will be 2.8×10^{14}/s at TESLA and 2.2×10^{14}/s at JLC.

one of the areas which require some more studies together with many of the machine protection and commissioning issues.

- **Polarized positrons:** The polarized positron production is possible by using helical wigglers. The TESLA group does not plan this in the first stage, however.

3.3 Remarks on Damping Rings

- **TESLA damping rings:** This is one of the items that are thought to be more problematic in TESLA than in normal conducting colliders. A very long circumference of 18km is needed to accommodate the 3000 bunches. For most issues of beam dynamics, however, the length of circumference itself is not a problem because only the local field and current come into play. Problems may come from

  1. Those related to integrals over one turn (e.g., tunes) and
  2. Very weak-focusing structure in the long straight sections which are needed for minimizing the chromaticity and the cost.

- **Space-charge effects** The most important issue related to the item 1. is the space-charge tune shift. It amounts to $\Delta Q_y \sim 0.23$ in spite of the relatively high energy (5GeV) as a damping ring. This leads to an incoherent tune spread. Their simulation results suggest that a maximum tune shift of 0.1 is tolerable, and hence a reduction of more than a factor of two is required. Since the long straight sections account for $\sim 90\%$ of the ring circumference, they are also responsible for the major part of the space charge effects.

  The TESLA group invented a solution in which the apparent beam size is enlarged in the straight sections by introducing a set of skew quadrupole magnets at both ends of each section. Full local transverse coupling in the straight sections can reduce the vertical space charge tune shift by as much as a factor of five. This elegant solution seems to work at least in principle. However, there are some combined effects which have not yet been seriously investigated. The long vertical-horizontal-coupled section can be fragile against other effects such as the intrabeam scattering, photo-electron instability, fast-ion instability and others. We agreed through the discussion that the intrabeam scattering will not be worse than in uncoupled sections, although there is no rigorous theory. The TESLA group is about to start investigation of the effects of the photo-electron and the fast ion instabilities.

- **Stray fields:** One of the results of the weak-focusing section is the tight tolerance of the random stray field. TESLA TDR quotes 1μT for the time-varying component. This is hard to satisfy. A control method has to be developed for the feedback or the vacuum chambers be magnetically shielded.

- **Operational Stability:** Effects of remaining stray fields (previous point), combined with possible tunnel motions, on the performance of the damping rings appear worth some systematic simulation studies.

- **R&D?:** There is strong sentiment among many of the KEK delegate that exercises with existing storage rings (preferably with ultra-low emittance rings) on coupling manipulation across certain straight sections would be worthwhile. Unfortunately, a cursory look at the component layout at KEK ATF damping ring indicates that the ATF cannot quite offer an optimum platform for this testing. In addition, at TESLA damping rings the dispersion correction is required to be good within 1 mm in long wiggler sections. This is a fair challenge. A beam tuning test of some sort appears worthwhile.

- **Circumference:** Another issue concerns the circumference of the damping ring and tuning of the timing control of beam collisions at the interaction point. The TESLA TDR has no mentions on these subjects. However, as a solution TESLA can incorporate tuning tools for beam path-length control.

- **Kickers:** Development of fast kickers with a band-width of 50 MHz is required for the compression of bunch spacing from 337 ns in linacs to 20 ns in the damping rings. A 3 MHz operation of such kickers is very challenging and it must be thoroughly tested for comfortably satisfying the injection jitter tolerance that is assumed in simulations of the TESLA luminosity performance. This issue calls for substantial R&D, not complete yet, as acknowledged by the TESLA experts.

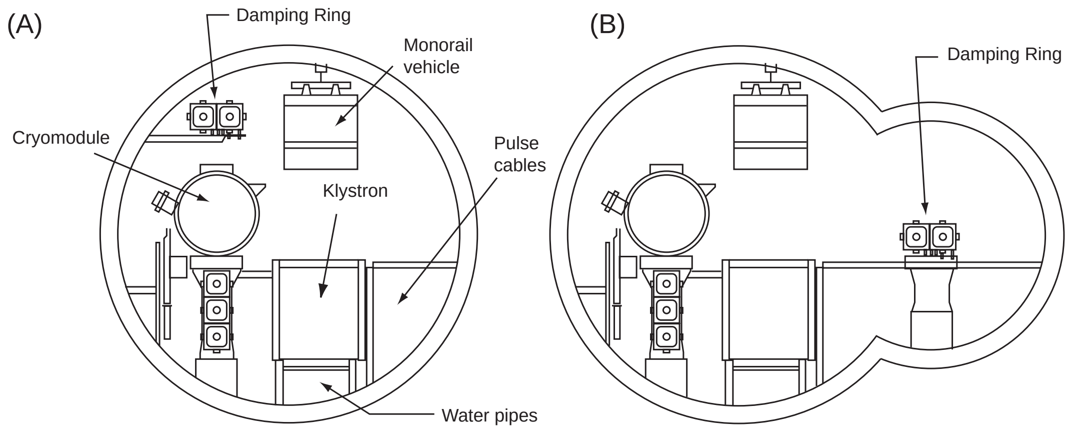

Figure 4: (A) Layout in the main linac tunnel that is explained in TESLA TDR (Image traced from Figure 8.2.7 in p.II-234). (B) Another possibility, drafted by a KEK delegate member. A TBM machine as shown in Fig. 5 might be applicable here.

- **Installation:** Some among the KEK delegate expressed concerns over the installation of TESLA damping rings which are placed on the support frame extending from the tunnel wall near the ceiling, as shown in Fig. 4 (A). The response from a DESY expert was that he did not expect fundamental difference in terms of alignment stability whether the ring is placed on the tunnel floor or hanging from the ceiling. Some of the KEK delegate remained unconvinced. In the present installation scheme, the TESLA damping ring is placed relatively close to the monorail which is also installed off the ceiling for carrying the equipment and beamline components. Short-term and

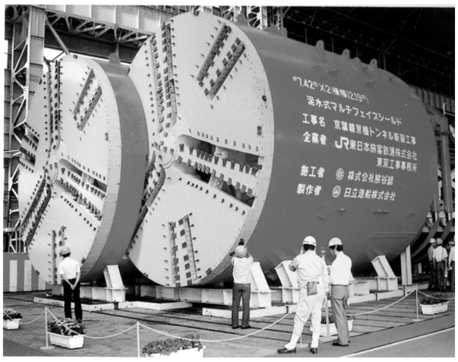

Figure 5: An example of a "dual-TBM" machine that was used for excavating a subway tunnel in the Tokyo area.

long-term alignment stability of this installation and possible counter-measures against instabilities or drifts appear worth some field studies. Use of "merged double tunnel" rather than a single tunnel installation (Fig. 4(B)) might offer better stability, easier sighting for alignment and an easier layout for controlling the vertical dispersion with a relatively modest cost increase in the opinion of some of the KEK members.

- **Contingency plans:** Cost estimation of injector system and beam delivery system, in our opinion, should include an ample amount of contingency (say 20% of total cost of both systems). We feel that unexpected issues can occur in these systems which include many challenging parts. Philosophical issues with the concept of "contingencies" will be discussed later in Section 8.

3.4 Remarks on Bunch Compressor

- **Compression ratio:** TESLA adopts a single-stage bunch compression system in contrast to JLC's two-stage scheme. This is because the final bunch length is three times longer (0.3 mm) at TESLA. However, it should be noted that a compression factor 1/20 (at 5 GeV) for TESLA is factor 2 stronger than the JLC's first bunch compressor (compression 1/10 at 2 GeV). This will require some more accuracy in the TESLA system. Fortunately the TESLA case does not suffer from the transient loading problem.

3.5 Remarks on Beam Delivery

- **Large disruption parameter:** When the so-called disruption parameter is large as in the case with TESLA ($D_y \sim 25$), the luminosity is certainly greatly enhanced in exact head-on collisions. However, the luminosity will be considerably more sensitive to a small displacement (both position and angular offsets) of colliding bunches due to kink instabilities.

At TESLA, to keep the luminosity above $2.5 \times 10^{34} \mathrm{cm}^{-2}\mathrm{s}^{-1}$, the offset must be maintained within $\sim 0.5\sigma_y^*$ (Figure 7.4.3 in p.II-197 of TESLA TDR), where σ_y^* is ~ 5 nm.

- **Luminosity stabilization:** The scheme considered by the TESLA group on this issue is a combination of the following two:

  1. Stabilization of the IP orbits of colliding beams (within $\sim 0.1\sigma$) with a fast orbit feedback system that uses the beam-beam deflection signals measured with BPMs (resolution $\sim 5\ \mu$m) located at high-β points, and
  2. Stabilization of the focussed beam sizes at IP with a slower orbit feedback system throughout the upstream part of the beam delivery using BPMs with typical resolution of $\sim 1\ \mu$m.

  A technical issue with the former system is the use of robust BPMs with good timing separation capability, since these BPMs, located in the vicinity (or inside) the final quadrupole magnets, need to function in the presence of both incoming and outgoing bunches, and forward radiation, in a head-on collision environment. While the long bunch spacing (337 ns) at TESLA simplifies the issues of separating the signals from consecutive bunches, this BPM system is one of the critical development subjects at TESLA.

- **Banana effects:** Another consequence of large beam disruption at IP is a luminosity reduction due to the so-called "banana effects". It has been found from computer simulations that, when a bunch is distorted in a shape like a banana from the head to the tail (e.g. *correlated* emittance growth of up to 6 % is quoted in TDR), due, for instance, to instabilities in the linac, a sizeable reduction in the luminosity results at TESLA. It also gives rise to beam-beam deflection signals even when the centers of gravity of colliding bunches are in a perfect head-on collision condition, tending to generate some "fictitious" beam offset information.

  Fortunately the use of beam-beam deflection feedback, which is assumed to try to minimize the apparent deflection angle, tends to recover some of the luminosity. In addition, empirical re-steering in both position and angle, while directly looking at the luminosity as the quantity to optimize, has been found to recover much of (if not all) the luminosity in simulations done so far. Thus, the situation appears tolerable in as much as the "banana" distortions (correlated emittance dilution) remain the same (static) within 1 % on the bunch-by-bunch and pulse-by-pulse basis. The TESLA group states that this 1 % limit on the dynamic part of correlated emittance dilution is marginally achievable.

  The TESLA group is also considering the possibility of reducing the bunch length by half, thereby reducing the disruption parameter. The luminosity and the beamstrahlung will not change if one changes the IP focusing as β_y^* : 0.4 mm $\rightarrow$ 0.3 mm and β_x^* : 15 mm $\rightarrow$ 20 mm. This requires the bunch compressor to work for a compression ratio of 1/40, and the beamstrahlung at IP will be increased somewhat (from 3.2 % to 3.9 %), however.

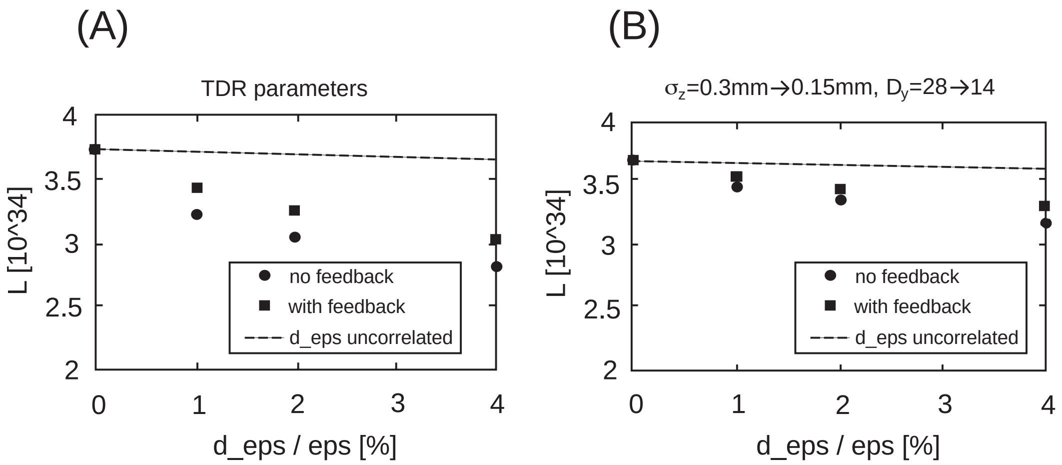

Figure 6: Simulated behaviors of TESLA luminosity as function of the *correlated* emittance growth of the beam. (A) Situation with the TDR nominal beam parameters. (B) Situation with the bunch length halved, β_y^* increased as $0.4 \rightarrow 0.3$ mm, and β_x^* reduced as $15 \rightarrow 20$ mm. In both figures the luminosity is reduced for increased *d_eps/eps* , due to "Banana effects", as shown by black circles, but case (B) exhibits improved robustness against *correlated* emittance growth. Some fraction of the luminosity will be recovered by turning on the IP orbit feedback, as indicated by rectangle symbols. Further luminosity recovery is expected when empirical IP orbit steering is applied, but it is not shown in this figure. For reference, the luminosity expected for *uncorrelated* emittance growth of the same magnitude are shown with broken lines. This data was provided by R. Brinkmann during our visit.

- **Luminosity prospects:** Overall, the benefits of smaller linac beam filamentation and larger bunch spacing at TESLA in the area of luminosity tuning and its stability, compared to the case of JLC, are somewhat offset by the effects due to the large disruption and sensitivities to the correlated emittance dilution. However, it is probably more fair to state that JLC/NLC and TESLA have some (probably similar) magnitudes of ambiguities in the achievable luminosity for different reasons coming from different design optimizations. More simulation studies will be needed and undoubtedly continue. The studies need to incorporate detailed evaluations on the expected stability performance of hardware components involved, namely, damping ring kickers, RF power sources, electrical and alignment stability of focusing magnets, cavities and beam monitors, etc. Development of commissioning and machine tuning strategies needs to be an integral part of such studies.

4 RF Power Sources – Modulators and Klystrons

A KEK member spent several hours with DESY experts on the design and development status of TESLA RF power source systems design. His remarks are summarized here:

- **Overview:** Technical requirement in the RF power source system for TESLA project is generally much easier than other linear collider schemes which rely on the normal conducting accelerator technology. The nature of superconductivity, very low loss and high-Q oscillator, allows to build up a high RF field with a relatively low RF power for a long pulse. Therefore, the TESLA RF-system does not require super high-peak power klystrons, like the 50$\sim$70 MW peak power klystrons required in the X-band (JLC/NLC) or C-band(JLC). The TESLA klystron will run at 10 MW level, only.

- **Klystron:** Thomson Tubes Electroniques has developed the TH1801 multibeam klystron. The TH1801 uses 7 beams, and the space charge effect is relaxed in each beam since the beam current is lower. This results in a higher beam-to-RF conversion efficiency. The TH1801 demonstrated 65% efficiency at 10 MW peak output with 1.7 ms. This is close to the design goal of TESLA RF-system.

  The gun voltage is as low as 110 kV. The gap voltage in the output cavity structure is at this level, too. Thus, no technical difficulty, related to the high-voltage break down, is expected.

  The cost of multibeam klystrons will be higher, probably a few times higher than single beam klystrons. However, the number of klystrons required is "only" 560. Consequently, it will not reflect much on the total construction cost of TELSA project.

  The klystron will be installed into the tunnel with the transformer tank with socket, in a horizontal arrangement. This is because of the limitation of the height that can be contained within the tunnel. While this arrangement will not affect the klystron performance, a careful installation design will be required for the cooling system.

- **Modulator:** A technical challenge in the klystron modulator for TESLA project is to generate a long HV pulse (1.5 ms) with good flatness ($< \pm 0.5\%$). Traditional PFN type modulator designs for this pulse length will require a large number (> 100) of series connection of LC circuit. The size and cost will be extremely high in that case.

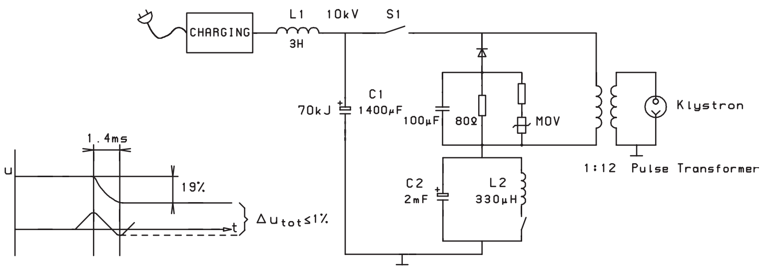

Figure 7: Conceptual circuit diagram of the TESLA modulator. Reproduced from Figure 3.3.3 of TDR II-91.

To solve this difficulty, TESLA RF-System uses "bouncer modulator" (Fig. 7, which consists of main capacitor bank C1 with main switch S1, and the bouncer circuit C2 and L2. Right before the switch S1 closes to start generating HV pulse, the bouncer circuit switch ON, whose oscillation current cancels the loading effect on the main capacitor bank C1.

Several modulators of bouncer type were built and are in use at TTF. Since the voltage level is as low as 10 kV, we do not see a technical difficulty in this modulator design, including solid-state switches used in switch S1, S2.

- **Power Feeding Cables:** In the current design, the klystrons and the pulse transformers will be installed in the tunnel, while the modulators will be located in the service hall. Therefore, the HV pulse power has to be transferred through cables (Fig. 8. The maximum distance of pulse delivery ~2.8 k m.

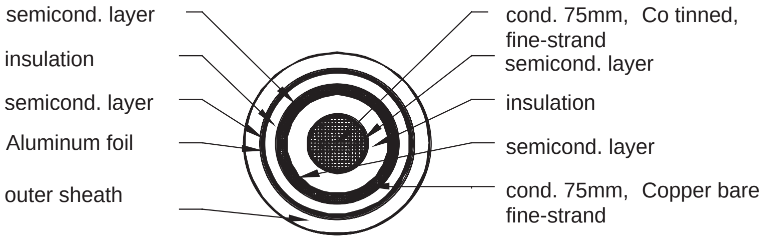

Figure 8: Construction of the pulse cable. Reproduced from Figure 3.3.4 of TDR II-93.

Since the voltage level is quite low (12 kV), if the fabrication of the cable is right, we do not see a risk of cable failures. However, in order to investigate actual fabrication quality, it will be definitely necessary to test this type of cable with actual HV pulse at TTF.

- **Pulse Transformer:** Because of the long pulse length (1.3 ms), the size of the transformer core becomes large, in proportion to the product of the voltage and the pulse-length. Each pulse transformer tank has the dimensions of 3.2 m(L) $\times$ 1.2m (W) $\times$ 1.4 m (H) and weighs 6.5 ton. They have to be installed underneath the walkway in the tunnel. Even with properly designed crane, handling of this pulse-transformer will be one of the most troublesome job in the tunnel.

Cost of the transformer will be high because of its volume. However, since the number of required transformer is "only" 570, its will not reflect much on the total construction cost.

5 Superconducting (SC) Cavities

5.1 Development Summary

The TESLA group plans to fabricate the cavities by using a conventional technology: niobium sheet material with RRR=300, then stamping, trimming, electron welding, chemical polishing, followed by 800°C and 1400°C annealing with titanium getter.

So far, about 60 cavities have been retained for use at TTF. Their performance is summarized in TESLA TDR and is reproduced in Fig. 9 (a) and (b). A more detailed, cavity-by-cavity performance summary sheet has been provided by Dr.Proch during our visit. It is reproduced in Fig. 10. At this moment (late 2001), the modules #2 and #3 are the ones installed at TTF. The modules #1 through #4 (and modules #7 and #8, which are considered spares) are based on cavities from production series 1 and 2.

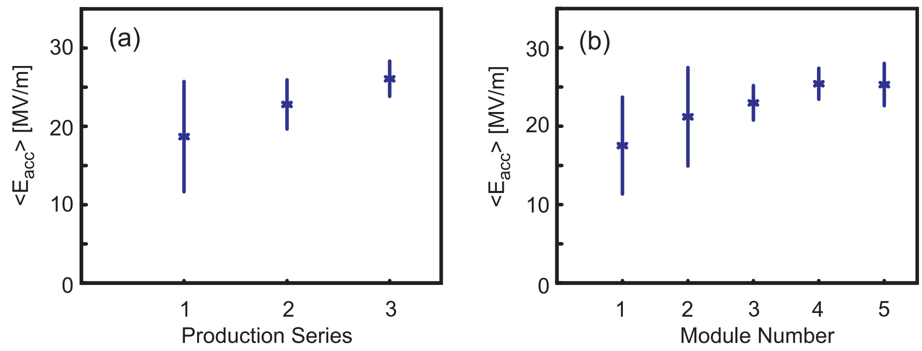

Figure 9: Average accelerating gradients at $Q_0 > 10^{10}$, measured in the vertical cryostat of : (a) the cavities in the three production series; and (b) the cavities installed in the first five cryomodules for TTF. (Reproduced from Figure 2.1.11 in p.33 of TDR)

Once assembled into a cryomodule, with equal RF power to all cavities, the one with the lowest gradient capability tends to define the performance of the entire group. Although a slight optimization is possible by adjusting the external Q of the RF coupler, it is generally more effective to pre-select "good" 9-cell cavities during the assembly stage to begin with. Thus, achieving a good performance yield in cavity production is a critical issue.

With improved welding techniques and implementation of rigorous QC process the excitation curves for 9-cell TESLA cavities from the most recent 99/00 industrial (3rd) production series show consistently a high ($> 10^{10}$) Q up to the design gradient of 23.4 MV/m and a maximum (quench limit) gradient of 27$\sim$30 MV/m at Q around 5×10^9 (see Fig 11(A)). With the 3rd production series, the success rate is above 90%, thus very few cavities have to be sorted out to build modules. The modules #5 and #6 will use cavities from this 3rd production series.

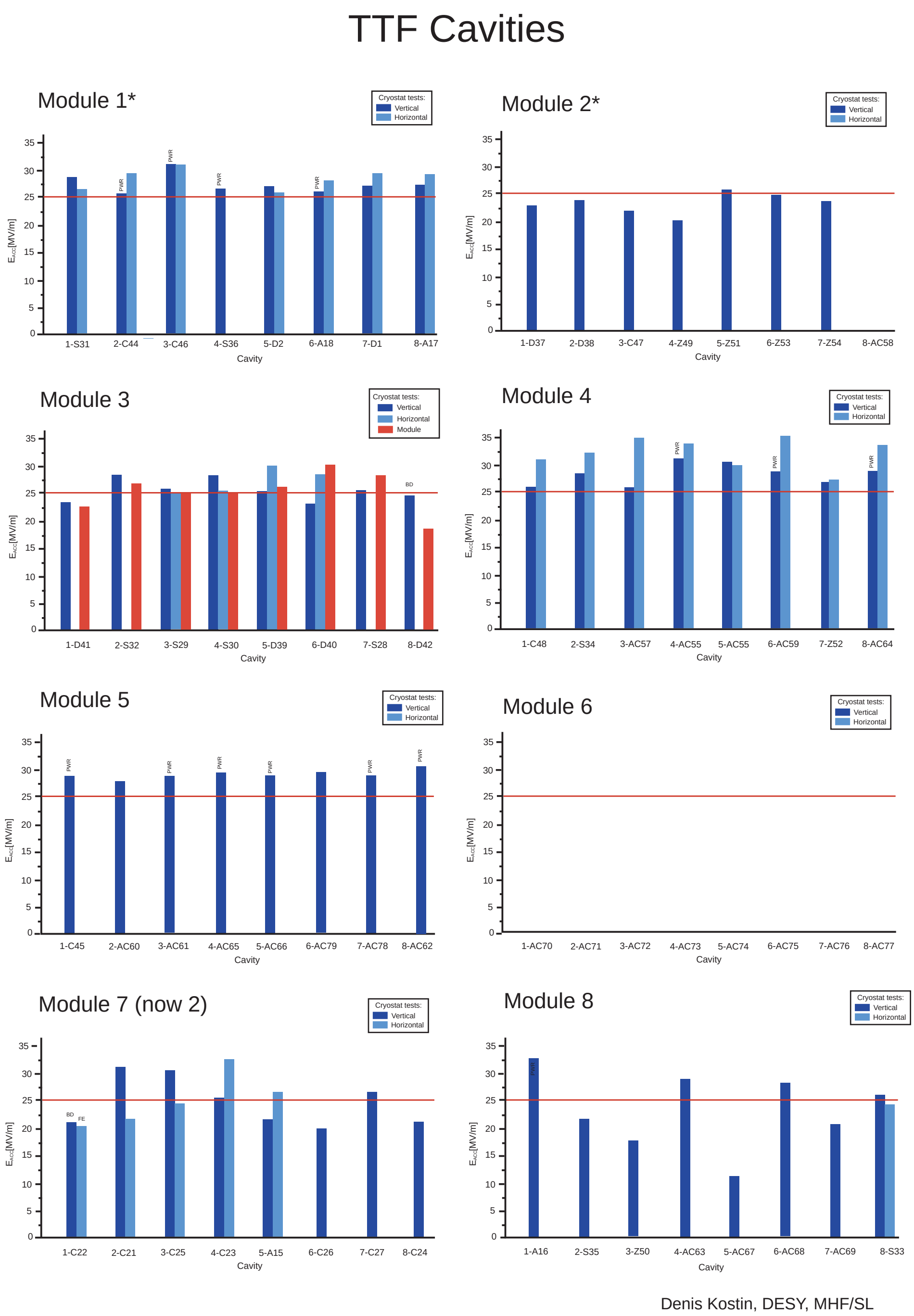

Figure 10: Summary of present performance of TTF cavities built so far (production series 1 and 2). Note: Some left-over cavities with less-than-optimal performance are assigned to Modules 7 and 8 for now. When these modules are actually assembled, they will most likely receive better cavities.

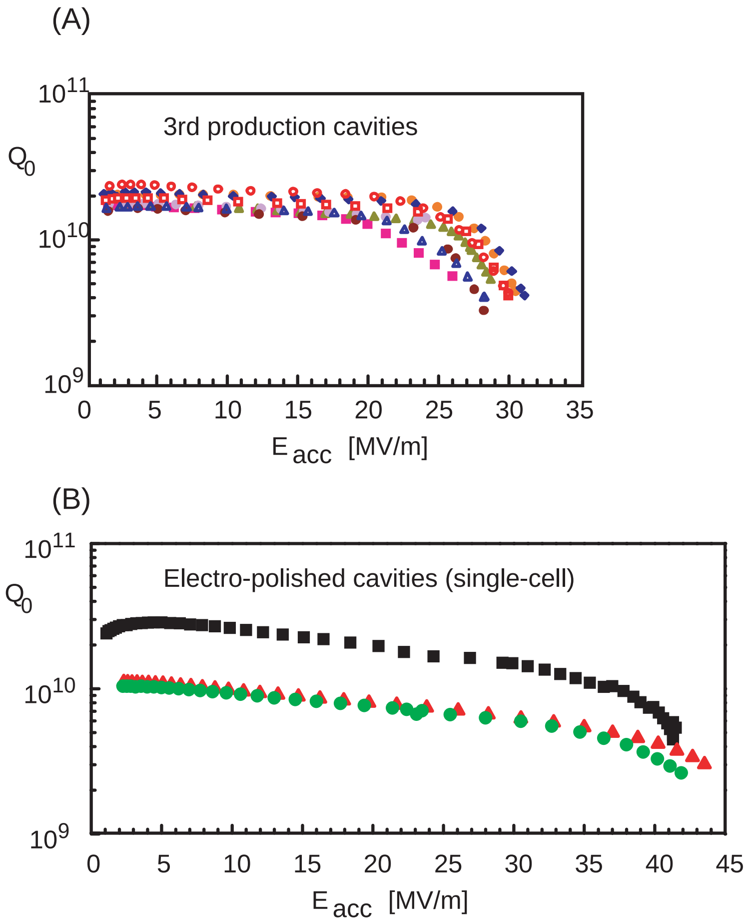

Figure 11: Q vs E_{acc} curves for: (A) 3rd production cavities (Image reproduced from Figure 2.1.10 in p.II-32 of TDR). (B) Electro-polished single-cell cavities (Reproduced from Figure 2.1.14 in p.II-37 of TDR)

5.2 Near-Future R&D Program

The main R&D issues at DESY at present are:

1. Development of superstructure,
2. High gradient cavity with $E_{acc} > 35$ MV/m, and
3. Accumulation of long-term operational experiences with high gradient at TTF.

In the superstructure, a pair of 9-cell cavities are welded together at the center of beam tube and the RF power is supplied through a common input coupler located on one end of the beam tube. It allows to reduce the number of input couplers by 1/2. The power to handle with each input coupler will be 705 kW. This scheme eliminates one beam tube and results in an improvement of the fill factor by 6 % (73 % $\rightarrow$ 77 %). In this R&D, beam testing in the TTF is very important. DESY is preparing it using the first prototype with $E_{acc} = 15$ MV/m particularly in conjunction with the HOM behaviors of the input coupler. Recently they built an excellent EBW machine costing 1.7 M-Euro for the welding process of superstructures.

The combination of superstructure and high gradient operation at $E_{acc} = 35$ MV/m (Fig. 11(B)) brings an attractive upgrade path to TESLA-800. However, for such an upgrade scenario, it is strongly preferred to install high gradient cavities in the initial stage of TESLA-500. Otherwise, they will have to replace the modules in the upgrade. The development of high gradient cavities with $E_{acc} > 35$ MV/m is strongly supported by the European high energy physics community as a very urgent issue. The strategy of the TESLA group is to introduce electro-polishing (EP), inspired by the work initiated at KEK. They are constructing an EP system in the neighborhood of the present TTF chemistry lab. It will undergo a safety inspection in March of 2002 and will be ready for operation by April, 2002. It is expected that a horizontal electro-polishing method developed at KEK can be applied without problems to a 2.4m-long superstructure (TRISTAN SC cavity was 2m long).

A collaboration program exists between KEK and DESY concerning some test electro-polishing of TESLA cavities. The TESLA group has sent 8 TTF 9-cell cavities to KEK. Electro-polishing of these cavities were done in Japan and they have been already sent back. DESY will install the cavities in the cryostat and conduct a beam test in the TTF for the high gradient operation.

Another R/D topic associated with the high-gradient operation is development of active tuners based on piezo devices to compensate for Lorentz detuning. Initial prototype testing has been successful (the detuning was reduced by an order of magnitude during the pulse). A long-term test of the piezo is in progress.

Current operation plans for TTF is laid out as follows:

Period	Program
through 2001 and 2002	2-module operation for TESLA/FEL.
	Try 22 MV/m operation with module #3
	May try 25 MV/m operation with module #1*
Jan. - Sep. 2003	9-month shutdown
	Expansion of TTF site to accommodate 6 modules
Sep. - 2003	Commission TTF FEL facility for user use

At this moment (November, 2001) two cryomodules (#2 and #3) are operating at TTF. The module #1* with $E_{acc} > 25$ MV/m is ready now. Discussions are ongoing concerning its high gradient operation at TTF in summer of 2002. The present TTF cavity performance is shown in Fig. 10.

During the downtime in 2003 the TTF beam line is expanded by ~ 100 m so as to create room for 6 TTF-style cryomodules for accelerating the beam up to 1 GeV. In the initial stage, four cryomodules based on production series 1 and 2 cavities, and two modules from production series 3 cavities will be installed. One of the modules (#6) will incorporate cavities that are electro-polished in Japan. Also, one spare slot that is compatible with a TESLA-style module will be created during this down time.

The constraint to begin XFEL user service at 1 GeV by TTF near the end of 2003 is a rigid one. Best efforts are being made to meet this goal while interleaving the work with installation and testing of better cavity modules. However, testing of cryomodules incorporating 3rd production cavities (including electro-polishing) at TTF will have to wait the completion of the TTF upgrade near the end of 2003. Full-scale high-power testing of superstructure-based TESLA-style cryomodule at TTF will have to come probably after that. The current strategy by the TESLA group concerning the superstructure is to address the technical issues as separate individual blocks (i.e. coupler, piezo-tuner, high gradient) for now, and consider the combined system testing at a later stage.

5.3 Remarks

Remarks and comments by the KEK delegate are summarized below:

- **Long-term testing:** At TTF, with the two modules installed and driven by a single klystron, E_{acc} has been limited to 19-20 MV/m by module #2 until the recent past in standard operation. High gradient tests in module #3 were done by temporarily making another klystron available to drive modules separately, achieving the average gradient of 22 - 23 MV/m. In addition, the typical repetition rate of beam operation at TTF has been 1 Hz. Since the RF pulse length at TTF has been about factor 1/2 shorter than TESLA design, the accumulated 9000 hours of operation time at TTF so far corresponds to 700 hours operation in TESLA parameters. On the other hand, in terms of exposure of the cavities to the field, several hours of CW-operation on the test stand already corresponds to 1000 hours of effective TESLA time. With all these reservations in mind, nonetheless, full qualification of the TESLA project is considered to require operation of the linac with full gradient, pulse length and repetition rate over an extended amount of time in the condition that is expected exactly at TESLA.

- **TTF operation and schedule issues:** The photo-cathode RF gun at TTF has been working well and could generate 4 nC/bunch, 1800 bunches/pulse with bunch spacing of 444 ns (2.25 MHz). This is very impressive. At this moment, however, TTF operation is not done according to the full design specifications due to considerations for technical safety issues with beam operation with the FEL undulator[3]. All of the operation up to now has been performed with a small number of bunches per pulse. High power beam operation would require an improved machine protection system. It is also noted that since SASE FEL does not require full-spec beam operation, there are certain incentives in staying with low beam power, low field gradient operation at TTF.

  Indeed, the tests for high gradient operation have to be scheduled in context with TTF also being an FEL test facility which eventually will operate as a pilot facility for FEL photon beam users. This appears to be a fairly complex scheduling challenge already now, considering the major shutdown and upgrade planned for 2003. It will be even more so, once TTF begins 1 GeV FEL operation.

- **Prospects:** Overall, while the technological progress made so far by the TESLA group is very impressive, a number of R/D efforts still need to be pursued such as:

  1. Electro-polishing surface treatment,
  2. Active tuners,
  3. Superstructure assembly,
  4. Improved operability of couplers.

  In addition, close scrutiny should be given to engineering design details of the cryomodules. Establishing the smooth daily beam operation procedures for the cryomodules and beam tuning methods at TTF is another agenda. And they need to be coordinated so as to smoothly converge onto a major system validation test at TTF. The TESLA group appears not to have established (yet) or not being very explicit with a definitive set of time-lines concerning solid "system validation" of 35 MV/m SC cavity operation with TESLA-style cryomodules for a prolonged period of time (say, a few thousand hours) at TTF. This actually is a kind of situation more or less similar to JLC and NLC efforts as well, arising from a lack of or uncertainties in the near-future R&D funding, compounded by the inevitably volatile nature of the technical problems. Coexistence with the FEL operation at TTF is another large source of complication in case of TESLA efforts.

  On the other hand, the recent achievement made corroborates the conviction on the part of the TESLA group that with suitably concentrated efforts and intensified collaboration with the industry, adequate engineering solution for 35 MV/m beam acceleration should be developed on the TESLA SC technologies eventually. We failed to discover any fundamental obstacles against such a projection.

[3]TTF-II configuration will include a bypass beamline which allows to bypass the undulator

Figure 12: Three samples of geologies.

6 Site, Tunnels and Conventional Facilities

6.1 Basic Tunnel Scheme

The present TESLA tunnel design is based on a single-tunnel scheme[4]. A frequently asked question concerning this is on the fact that the klystrons are to be installed in the beam line tunnel. According to a DESY expert, with a klystron lifetime of 40,000 h, one klystron would be out of service in every 60 hours out of the entire TESLA[5]. Consequently, about 12 klystrons will need to be replaced each month while turning off the accelerator. The TESLA group considers that it is acceptable. It is also noted that the TESLA group in general prefers not to open the tunnel housing unless absolutely necessary, based on experiences at HERA.

The depth of the TESLA tunnel is chosen to be the same as that of HERA tunnel so as to allow possible *ep* collisions. The earth coverage ranges from 6 m to 12 m above the tunnel, where the soil temperature is nearly constant at 10°C through the year. The coverage is considered sufficient for radiation safety and strong enough for construction of building on the surface[6].

Geology around the tunnel is mostly sand, strongly compressed by 300 m-thick ice during the ice age. Some soil samples were shown and were offered during our visit. Unfortunately we decided against taking those samples back to KEK, because of the difficulties we may encounter during customs clearance.

[4]At the time of TESLA-CDR (1997), a double-tunnel scheme was considered for an S-band linear collider. There, the two tunnels had to be connected via 300 mm ϕ pipes every 25m. An escape shaft would be necessary every 1 km.

[5]The total number of klystrons for the whole TESLA-500 is $\sim$ 600.

[6]The DESY expert considers that the minimal coverage must be 2 times tunnel diameter for sufficient strength as ground at the TESLA site.

Figure 13: Concrete segments of the HERA tunnel.

At this moment there are 16 boring sites along the tunnel. Each boring hole reaches 30 m below the sea level (20 m below the tunnel level). A week before our visit, a collaboration between DESY and universities (technical university in Hamburg etc) was formed for ground motion measurements at these boring sites. The tunnel crosses Highways (German-7 / Euro-1), small rivers, rail roads as well as populated towns. The ground-motion data to be obtained from this study will be of great interest in analyzing the effects of various cultural noises.

The basic geology of the proposed TESLA site is considered essentially the same as that for DESY/HERA, where extensive ground motion data is available. Many of the TESLA studies concerning civil engineering issues are based on this assumption. This assumption is considered by the TESLA group to be on a conservative side, since HERA is built in a busy area in the city of Hamburg, while the bulk part of TESLA will be in a more rural province, particularly the IR/FEL areas (Ellerhoop). Exceptions are: one cross-over with the Highway (the same Highway comes close to the tunnel in Pinneberg, but it does not cross), and three cross-overs with the train lines. The northern end of TESLA (Westerhorn) is in the neighborhood of a train station. Experiences from HERA indicates that the motions of the TESLA tunnel would be of O(mm) per year. At HERA, the experimental hall moved vertically for ~ 0.5 mm per 1 m water table change. A long-term drift, a gradual upward motion, was observed for 30 - 40 years at DESY. Typical ground water speed is several cm/day at DESY-site, which is very similar to that at KEK.

The tunneling method considered for TESLA corresponds to what is called a "shield boring method" in Japan. It uses water-tight concrete segments or "tubbings" (30 cm-thick, high-technology pieces with quoted machining accuracy of 0.1 mm). The tubbings are tightly joined both transversely and longitudinally by bolts with neoprene gaskets (EPDM rubber). Tunneling machines (TBM) with 6 m boring diameter are considered. At HERA, average boring speed was 10 $\sim$ 14m/day. This is the basis for the TESLA group's estimate of 3.5 years of tunnel boring time using 4 boring machines. In addition, micro-tunneling method may be used for small diameter tunnels such as dog-bone arcs with 3m diameter. The micro-tunneling uses complete concrete pipes which are moved by huge hydraulic cylinders. This is a more economical solution than the shield method, but is not assumed in the TDR cost estimate.

Beam dump consists of pressurized (9 bar) water originating from law-regulation for nuclear plant, where light elements must be used for short-lived radiations. There is also concrete of 5 m thickness around the water tank, while the regulation requires 3 m thick one. There shall be no exchange of water until the end of TESLA. However, its circulation is necessary to filter out radioactive elements such as tritium, Be, Li etc. Some R&D of the circulation must be performed according to the local expert.

For safety reasons against He explosion ($\sim 2\ l$ Liq.He/cavity), free space in the tunnel is needed at any time, and this space is allocated. The exit shafts are necessary every 5 km along the tunnel. However, no oxygen mask is necessary for personnel during access, in terms of safety regulations, since no liquid N_2 is used.

6.2 Site Tours

We were given a tour to the new TTF-tunnel (100 m long), which has been built for phase-2 configuration of TTF. It has been constructed with the same inner diameter (5.2m) as the TESLA although it is on the surface rather than built using a tunnel boring machine.

We were also given a tour to the proposed TESLA site. On our way, we stopped by the church (Rellinger Kirche) where the tunnel would go underneath its premise. Many alignment marks have been installed by the TESLA group inside and around the church building of Rellinger Kirche. They will be used as reference points for measuring the motions of the church during construction of the tunnel. Measurements of natural motions would be starting soon. We then visited the towns of Ellerhoop (the experimental hall and FEL facilities will be located there) and Westerhorn (far end of the tunnel, 32.8 km from DESY in the North-North-West direction). The Ellerhoop site is dominated by a horse ranch. The TESLA group had already talked to owners who said they would move to another place, provided by the federal government, for a new ranch. We confirmed a water table level there, which is almost at the ground surface. The Westerhorn site is a corn field and is very close to railway station . There is a house where an old couple is living, who are also willing to move when the TESLA is approved. We also saw power lines in existence along the proposed TESLA tunnel line.

On Nov.29, we had an opportunity to visit a tunnel-construction site near DESY, but not directly related to it. This tunnel will be used as a water reservoir in case of storms. It has an inner diameter of 3.5 m, and about 1 km long and 20 m deep under ground. The spot is located in a public park by Elbe river. The micro-tunneling method is being used. Since the geology is “marl” which does not let water pass, the boring machine is an open shield type, which can be pressurized when ground water appears. Sites of such tunnels are usually under roads and parks since people hate them right under their houses.

Figure 14: Picture of the construction spot with micro-tunneling.

6.3 Remarks

- **Design integrity:** While the TESLA proposal of containing klystrons within the beam tunnel is somewhat out of ordinary compared to the standard room-temperature linear accelerators, it is probably an acceptable scheme for TESLA, since the number of 10 MW klystron units to use is quite small ($\sim$ 570), and the peak RF power and voltage handled by each klystron is modest[7]. However, validation of the long-term reliability of these TH1801 klystrons is highly desirable, before freezing the final tunnel design. Also, it may be worthwhile including some extra power source capabilities in far-upstream ends of main linacs.

- **Tunnel stability:** The existing HERA tunnel has $A \sim 4 \times 10^{-6}$ $\mu\text{m}^2\text{m}^{-1}\text{s}^{-1}$ (coefficient that appears in the ATL law). If the TESLA tunnel offers this range of A, the main linac system is considered operable. As discussed in the preceding subsection, boring studies are ongoing at the proposed TESLA site to confirm this assumption. The JLC, on the other hand, has been assuming $A < 10^{-6}$ $\mu\text{m}^2\text{m}^{-1}\text{s}^{-1} = 10^{-18}$ m/s. A hypothetical question of how the JLC would be operable if it were built in the proposed TESLA tunnel is of great interest for some. While it is generally considered somewhat on the difficult side, detailed simulation work has not yet been done on this particular question.

- **Tunnel depth:** The planned depth of the TESLA tunnel is substantially shallower than ours (JLC). They estimated a damping coefficient of about 20m as $1/e$ at 5Hz for such noises. Our experience (KEKB) indicates that at least 30m of earth-coverage is necessary for reducing the effects from climate and surface(cultural) noises to a negligi-

[7] SLC had $\sim$ 240 S-band klystrons, 50 MW each.

ble level. This difference might be due to the difference of transmission characteristics of noises/vibrations of the soil. Results from their boring studies will be quite interesting.

7 Public Communication Efforts by the TESLA Group

7.1 Web Information for TESLA and Design Office

The TESLA project home page is accessible at: `http://tesla.desy.de/` , where some public project portfolio, TDR and information on the TESLA collaboration are available. In addition, a large amount of information on TESLA is publicly posted at:

`http://www.desy.de/tesla-planung /tesla_planung_e.htm`.

They include: virtual picture library, photos, animations, reports, posters, lecture slides, press articles and others. This web page is managed by the TESLA design office (Planungsbüro), which was founded in summer of 2000. Its task is to prepare the project for the official permission process. The office operates independently from the common DESY-group structure and is meant to be a seed cell for planning activity in the TESLA-project. Members from various DESY-groups work closely together with external offices.

The TESLA design office currently consists of 20 people, half of which are DESY employees and the other half being experts from companies outside contracted at 2M Euro/year. To complete all the design work it is expected that the number of members must increase to 200 in the future. It was stated that some consulting engineers have been contracted as web designers since 1998.

Importance is emphasized for the use of 3-D graphics in a ground-up way at both conceptual and engineering design phases of the efforts for both official drawings and presentation purposes. It is helpful for communicating the idea with both the general public and the engineering experts, where, for instance, tunnel boring machines needs 3-D data for directions. A 3-D CAD system has been in use at DESY since 1996.

7.2 Relation with Local Residents

German laws on land ownership is similar to the Japanese ones. The property rights on land extends from the sky to the center of the Earth. The DESY laboratory, as a project proponent, must explain the TESLA project to the affected residents along the tunnel path and must obtain their agreement. This is definitely the preferred courses of actions to take, although the federal government later can in principle overrule the local oppositions, if any.

The proposed TESLA tunnel runs across two states in northern Germany. It has to be noted that the government layer structure in Germany consists of federal, states, districts and cities (Hamburg is a state, not a city by way of exception). Construction of TESLA cannot start without the consent of both the state and federal governments. However, negotiation process with the former does not have to wait for the formal approval of the latter. Thus the dialogue with the local residents have been in progress since $\sim$ 1999. Studies of environmental impacts have been also conducted. Assessment of impacts on objects with cultural values, such as churches and old trees has been done in addition to the studies of underground water. The report will be ready for submission in mid-2002.

For the public presentation, the location of the TESLA tunnel have been explained to be unique, that is, there is no other option, in order to convince the people who live on right above the tunnel path. A special local law has been written for TESLA in order to procure a land with 30m width along the tunnel, in addition to the site area for interaction region, FEL lab and service buildings.

As stated earlier, DESY has already talked to the people and the states, where the project has been received generally with fairly favorable views. An official process involving federal government is scheduled to start in December of 2001. DESY will meet with officers from the Ministry of Finance and other federal government offices to prepare an official letter of intent to the people, where the TESLA project is explained as an international facility and any opinions are called for on how they like the project.

7.3 Remarks

Remarks and comments by the KEK delegate are summarized below:

- **Something to look up:** The TESLA efforts in the area of public relations or public information services are impressive. They are substantially more advanced than the similar efforts at JLC. It is worth some serious studies at KEK for introducing a structured system that is similar to their Planungsbüro.

  Aggressive use of 3-D CAD, as being done by the TESLA group, is worth serious studies, too. For instance, past similar attempts with a 3-D CAD system in the design stage of KEKB accelerator complex may be revisited. It is noted that concerted efforts with the Engineering groups is essential in this type of "cultural revolution".

- **Unique site proposal:** The current TESLA proposal assumes its site to be adjacent to the Hamburg campus of DESY. We do not know how it is being perceived in Germany, but this certainly is not a type of assumption that is allowed in Japan (or perhaps in US). We observe that it greatly simplifies the discussions on the site studies for the TESLA proposal.

- **German system:** Because of the characteristic governmental structure in Germany, the TESLA group could start communicating many aspects of the project proposal with the local government bodies and residents before gaining certain project approval by the Federal government. This is something that is very difficult to do in Japan.

  We wonder how the arbitration process would proceed should there arise any conflicts of opinions between the local and federal governments, but for now the negotiations seem to be starting fairly smoothly.

8 TESLA Cost Estimate Overview

8.1 Cost Breakup

We heard an overview of the TESLA cost breakup and how they were computed. Total project cost is 3.1 B-Euro for the e^+e^- collider part of TESLA, as quoted in TDR. Additional 0.24 B-Euro is considered for FEL hardware and 0.29 B-Euro for FEL infrastructure. As stated in TESLA DTR, it is assumed that the manpower required for the various stages of the project (i.e. preparation, procurement, testing, assembly and commissioning) will be supplied by the existing manpower in the collaborating institutes, although some of this manpower may have to be hired. For this reason the manpower is quoted separately[8], and is not included in the total cost.

No contingencies are included. It was noted that HERA (1.3 B-DM) and PETRA were built without resorting to contingency budget. Part of Table 10.1.1 from TESLA TDR (II-368) is reproduced below:

Subsystem	cost (M-Euro)
Main linac modules	1131
Main linac RF system	587
Injection systems	97
Damping rings	215
Beam delivery	101
Civil engineering	546
Infrastructure	336
Auxiliary systems	124
Collider total	3137

The cost estimates are mostly done by companies who have extensive experiences in dealing with specific technologies in the related fields. The cost numbers have been estimated by evaluating the construction (start up $\sim$ 1 year) and operation (3 $\sim$ 3.5 years) of production lines of the components in question.

The costs for magnets and klystrons have been estimated by the industry as well. The cost for tunnel construction was studied by a company which has a large amount of experiences handling the DESY tunnel construction.

8.2 Remarks

- **Cost estimate work:** As stated earlier, the TESLA cost estimates are done based on
    1. The expenses needed to build fabrication/assembly/testing facilities with adequate production capabilities for the required components, and

[8] A total of 6,933 man years is quoted in TESLA TDR.

2. The cost for the raw materials (or components) and
3. The cost for operating the production facilities for the planned period of time.

Although we did not have chances to take a very close look at all the details of their work breakup sheets, we generally feel that the TESLA group has done the cost estimate work according to the correct guiding principle.

- **Contingency:** The TESLA project cost estimate does not include contingencies, and the TESLA group does not expect needs for resorting to contingencies in the actual project construction. While the former is simply a matter of presentation style of the cost estimate, the latter was difficult for us to understand and to agree with. It was stated that construction of HERA and PETRA did not require resorting to contingencies. In general the contingency budget is not necessary if -

  1. Complete understanding of the technology: No additional design revisions or schedule delays are incurred during construction, and
  2. Perfect execution of the contract: The contractors deliver on time and without extra cost, or
  3. Hidden contingency plans: The base budget already includes the fund that corresponds to the contingency budget but not called as such.

  We were unable to reach a satisfactory understanding as to how which of these are considered to apply in case of the TESLA cost estimate.

- **Basic labor cost:** In our discussion with the TESLA folks we were told that a typical labor cost at DESY is about 50,000 Euro/year. This is for an average person, although naturally there are wide variations of salaries from expert scientists/workers to non-experts. Likewise, the typical salaries given in the industrial study on the cavity preparation and module assembly is 60,000 Euro/year.

  Comparison of labor costs in different countries, in conjunction with the purchacing powers of currency, quality of life, benefits, insurance and so on, will be one of the critical issues in studying cost estimates of many of the components for TESLA, JLC, NLC and CLIC. This is something to be reviewed by adequate experts.

9 Cost Estimates for Cryomodules and Cryoplants

The bulk part of this section is not for public release. Only the outline and purely technical discussions are shown here.

9.1 Cost Details of the TESLA main Linac Cryomodules

9.2 Cryoplants

9.3 Remarks

- **Incredibly low cost for cryomodules:**
- **Cryoplants understandable:**
- **Further cost reduction:** One possibility to consider for further cost reduction is the use of Nb seamless cavity. It is expected to bring more reliability in performance and it may lead to a reduced cavity cost (some of the DESY experts disagreed, however, because the cost for beam pipes could still dominate).

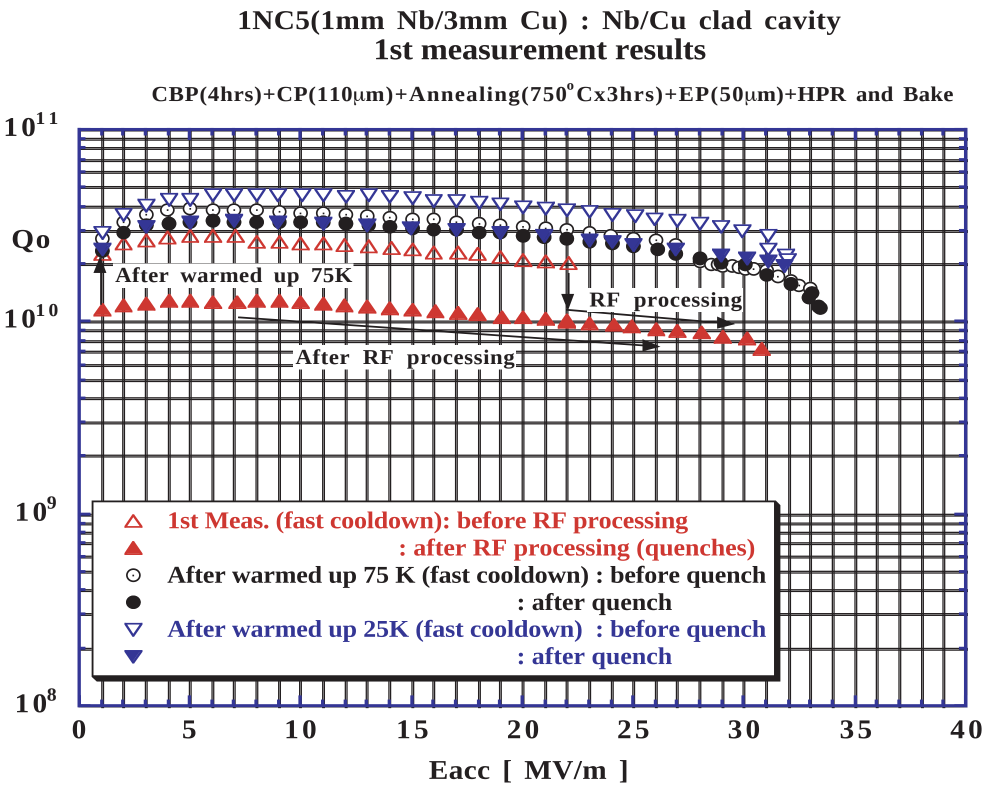

Figure 15: Recent result of Nb/Cu clad cavity in KEK/DESY.

Another possibility is the use of Nb/Cu clad seamless cavities. This will help to reduce the material and fabrication cost at the same time. Excellent cavity performance by this technology has been demonstrated : $E_{acc} = 33$ MV/m in KEK and $E_{acc} = 40$MV/m in JLAB without any major problems of frozen flux degradation. Its performance is shown in Fig. 15. In an estimate by a KEK member[9], the material cost for niobium will be reduced by 1/2 compared to the TDR. Cost reduction in the cavity fabrication process is also expected. With the KEK-style electro-polishing it may be possible to entirely eliminate the 1400°C annealing process which is very expensive. Thus, there is still a room for reducing the TESLA cryomodule cost by up to 20% in the opinion of a KEK delegate member.

10 Cost Estimates for Site, Tunnels and Conventional Facilities

This section is not for public release.

10.1 Methods of Cost Estimate

10.2 Remarks

- **Main tunnel:**
- **Access shafts:**
- **Access roads:**
- **Need for more comparative studies:**

[9] K. Saito

11 Future Prospects for TESLA

We had a discussion with Prof.A.Wagner and Prof.D.Trines on the future prospects for TESLA. Here is the summary:

- Evaluation of the TESLA proposal is currently under way at German Science Council among several other proposals on large scientific projects, such as European Spallation Source (ESS), Heavy Ion facility at GSI (Darmstadt), VUV FEL in Berlin and ice-breaking research ship for exploration of north-pole sea and the Antarctica. The council has spawned sub-working groups, consisting of leading scientists, to review and evaluate the scientific values, readiness and international context of each of these proposals. Written reports by these sub-working groups are scheduled to come out in November of 2002. A government response is expected some time in 2003.
- This series of events were triggered to start by DESY's submission of the TESLA proposal. Germany has not seen similar review processes for large scientific projects like TESLA in the past.
- Interim statements, which have been verbally related to Prof.Wagner from the Council for now, are -
  1. The LC part of the TESLA proposal has been very positively received.
  2. Concerning the FEL part of the TESLA proposal, it was suggested to perform joint strategy studies with the VUV FEL project in Berlin.
  3. Importance of accelerator gradient of 35 MV/m is noted.
- Wagner stated that in case of TESLA before the project formally starts there will be two major milestones to pass through. The first one is to obtain an approval of construction of the tunnel. The second is an approval of budget where international commitments might be required. These processes will be pursued in parallel.
- Concerning the technology choice of normal vs. superconducting technologies for the next LC, Wagner stated that he believes in "the sooner the better" philosophy. It is because, in his opinion, that "the sooner" should help keep the momentum on the part of accelerator and physics people and their united force. He stated that he believes it is also better in terms of rapid formation of an international collaboration with clear mutual understanding on the contributions to be made by participating laboratories worldwide.

  He also stated that the concept of the "Global Accelerator Network" (GAN) should be an integral part of the LC project, so as for each participating laboratories to feel intimately part of the LC operation, without overly compromising the integrity of individual institutes. Wagner said that operation of TTF has been already successfully exercised from Milan. Discussions are under way for holding one or two workshops on issues surrounding GAN in the coming year (2002).

- The current funding level that is available for R&D work at DESY is 20 M-Euro/year. This is out of the 300 M-DM total annual budget. About half of it goes to people's salary, and 20 M-Euro for the AC power.

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