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A SCRF Infrastructure for Europe

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Abstract

A generic (green-field) superconducting RF facility for Europe is described. With the primary motivation for advancing the gradient of the ILC 1.3 GHz cavities such a facility will be useful for other applications. The (evolving) appendix addresses possible role models and the inclusion of existing facilities at CERN and DESY.

Introduction

Over the past decade, the TESLA Collaboration has reduced the cost per gradient of SCRF by approximately a factor of 20 over the then existing facilities. This was due in part to an increase in achievable gradient from ~5 MV/m to ~25 MV/m. The R&D program centred at the TESLA Test Facility (TTF) infrastructure at DESY has ultimately led to the proposal of a major new facility at DESY (the European XFEL) and the adoption of the technology for the International Linear Collider (ILC).

The current Global Design Effort (GDE) for the ILC has set itself the goal of achieving an operational gradient of 31.5 MV/m (qualifying gradient ≥35 MV/m) for some 15,000 cavities with a mass-production yield exceeding 90%. Although several proof-of-principle cavities with these gradients do exist, the currently limited statistics of the DESY sample falls significantly short of this ambitious production yield. It has been recognised by the international ILC community and expressed by the GDE that a new state-of-the-art production infrastructure is required, and that each region (Americas, Europe and Asia) should endeavour to set up such infrastructure within a globally coordinated and focused effort in a timely manner.

The following text describes the details of such a facility. It is focused on the needs of the ILC, which is the motivation for this effort. However, it is recognized that once such a facility has been established and the demands of the ILC have been fulfilled such an installation will be useful for other projects relying on superconducting RF technology. One example is the development of cavities for proton sources which will profit from the modularized design for the infrastructure described below.

Research and Development

Since the choice of the gradient goals for the ILC during the Snowmass workshop in summer 2005 the GDE has insisted that a concentrated effort is needed world-wide to improve the performance of superconducting cavities. The primary goal consists in establishing the manufacturing steps to achieve high gradient cavities for the ILC in a reproducible manner. While the basic production steps have been successfully developed

[1] The current version has not been proof read. Modifications to this draft are foreseen.

other salient parameters have to be determined and quantifiably controlled. In particular, the details of post-electropolishing rinses need to be determined in a systematic manner.

In the absence of a central laboratory for the GDE this development task falls onto the responsibility of individual laboratories. The production demands are such that they can only be met in a concentrated world-wide effort. In Europe, all such activities should be integrated in the larger R&D framework for the ILC.

We foresee two development steps in the process of an integrated SCRF system test. The currently existing cryomodule for the XFEL will be ameliorated for the needs of the ILC. Such a 4th generation cryomodule needs to be assembled and taken into operation with all required infrastructure. The second step extends this initial test to the construction of a full ILC RF unit comprising three cryomodules and requiring the production of at least 30 cavities.

Thousands of cavities can only be produced in industry. It is thus mandatory to transfer the knowledge on the production process and to translate the steps to a standard that is amenable to mass production. While industry has accompanied the production of TESLA cavities for TTF and will in a short while set out to produce some 1000 cavities for the XFEL the high gradient program will require special precautions that need to be considered in an integrated facility that addresses deficits in R&D setups existing today. The requirement to exceed the XFEL performance necessitates a reasonable amount of flexibility as the ongoing R&D work within the ILC framework will likely result in an altered and improved cavity preparation process. Hence, we foresee to work closely with industrial partners. We foresee that e.g. fabrication of the cavities and the first rough electropolishing will be done in industry while the facility concentrates on the validation of the final preparation process before the low-power acceptance test. As the test facility yields results on the details of the production process we plan to transfer these details to industry so that in the end the final preparation of cavities is accomplished in industry. The activities will include the integration of cavities in their cryostats.

This learning process will be beneficial for other applications. The accumulated knowledge will aid the understanding of production of other cavity types even if the required gradients are less ambitious. The accumulated knowledge on material treatment and the existing infrastructure will be made available.

One may wonder why existing facilities in Europe do not meet the goals today. In Europe facilities are available at DESY, in France, Italy and at CERN. The DESY facility was set up several years ago and was key to the improvement of accelerating gradients to the level of 25 MV/m. This facility was designed around the requirements of a specific cavity preparation process and optimized for an efficient implementation. The facility was also designed for the treatment of some 30 cavities. With the progress in understanding key aspects of the process have changed. These include the introduction of electropolishing to replace chemical etching as well as numerous other details like the extension of the high-pressure water rinse and a more vigorous component cleaning. This illustrates that the facility at DESY has aged to a degree where an improvement beyond minor modifications is needed. Streamlining the process to state-of-the-art production requires a new facility. The layout of the facility has to be kept sufficient flexible and easy to modify in order to accommodate additional rinsing processes, which are under investigation in the ongoing R&D program.

Most of the other installations are typically of R&D size and have been built to address the construction of single cells and to optimize their performance often in a judiciously labor intensive optimization procedure in order to maintain flexibility. Record-breaking single-cell cavities have been manufactured in this manner. However, throughput and reproducibility were of no particular concern. Typically these installations foresee a single line of production that comes to a halt should any of the chemical or mechanical production steps fail and require repair or maintenance.

Program of the new facility

The primary justification for the SCRF facility is the ILC. However, the facility can be conceived as a generic infrastructure to develop high performance cavities with a perspective to supporting other projects such as electrons, protons, neutrinos, muons and light sources at a later stage. It would enable R&D, industrialisation and tests of SCRF technology with various applications beyond the ILC.

The ILC program and goals will be integrated in the world-wide effort of the project under the guidance of the GDE. Specific requests related to other projects for different kinds of particles and extension to other cavity types will have to be investigated and adequately integrated. The infrastructure defined for ILC is based on a highly modular design that is expected to accommodate a large body of such requests.

ILC demands

In order of priority the demands for the ILC are summarized in the

- Creation of a new generation cavity production facility including auxiliaries
  - leading to processes transferable to industry
- Production of a 4th generation module
  - Integration of components (cavities, couplers, tuners, magnets, BPMs) in a 4th generation cryostat
  - Instrumentation for modules (alignment)
- Production of one or two complete ILC RF units

Demands for other projects

The demands for other applications of the facility to produce cavities adequate for proton, muon, neutrinos, light sources is less specifically described as

- Capability of preparing and testing cavities with state-of-the-art infrastructure
- Implementation of additional SCRF R&D requests compatible with the overall program of the facility

In this context it will be important to contrast requests for cavities of different size and shape with the high throughput goals of the ILC.

Detailed program

The production of high-performance superconducting cavities requires state-of-the-art surface preparation techniques and facilities. An integrated and optimized facility will allow significant improvement of the current preparation steps towards an industrial production-like level with adequate throughput, which is estimated at roughly 100 cavities/year. A phased approach is needed to eventually enable industry to prepare high performance cavities. The phases are detailed in figure 1.

Setup Phase

The setup is dominated by engineering work on the optimization of the layout of the facility. Existing facilities will serve as a good starting point of how to design such a facility. However, considerable thought will have to be given to individual production steps in the context of mass production. The installation of the clean rooms and chemical process facilities will conclude.

With the long lead-time in the procurement of RRR Niobium the set-up phase will demand considerable financial resources to place the orders for sufficient quantities in due time.

Components such as cavities and couplers should be fabricated in industry. The first rough electropolishing treatment will be carried out in industry which will have gained sufficient experience through the industrialization effort of the XFEL.

Research Phase

The research phase will explore the production of cavities according to current recipes in a controlled fashion. As optimization procedures in the treatment process become known they will be implemented and verified. A so-called rapid cycle test procedure will allow obtaining sufficient statistical samples of produced cavities. Key to this process is an optimized rinsing procedure and adequate heat treatment.

Transfer Phase

The transfer phase will be used to translate the optimized production steps into processes amenable to mass production in industry. The final surface treatment (electropolishing, high-pressure rinse and bakeout) should be carried out in industry whereas the cavity testing will be done at the test facility. After successful acceptance test industry should also perform the tank welding and the coupler assembly. In this phase all the cavities will still be tested in an intermediate individual high power test for quality control.

During this phase other projects could introduce the surface preparation modules (e.g. EP bench with correct dimensions) and start to perform the initial low-power cold tests.

Industrialization Phase

During this final phase industry takes over the module assembly. The SCRF facility will be predominantly used for module performance verification.

The test facility is open for other cavity projects which is otherwise needed mainly for ILC cavity repair.

	ILC Work	Other projects
Setup phase	• Installation of infrastructure • Procurement of parts (e.g. cavities)	Define cavity shapes etc.
Research phase	•Use of preparation and test systems •Defining the details of the preparation (e.g. rinsing parameters)	Design of infrastructure (e.g. EP bench)
Transfer phase	Transfer parameters for final cavity preparation to industry	Installation of infrastructure
Industrialization phase	Module assembly in industry	Use of Infrastructure

Figure 1:Overview on a phased approach of an ILC R&D program and options for a use in other projects.

Cryomodule Production Scheme

Once cavities have passed the low-power RF acceptance test a fraction of the produced cavities will be integrated into accelerator modules (cryomodules). The work-flow scheme is shown in figures 2. The two large building blocks are the cavity preparation infrastructure and the module assembly clean room with the respective associated test infrastructure. The figure also describes how more tasks are being transferred to industry while the project moves forward.

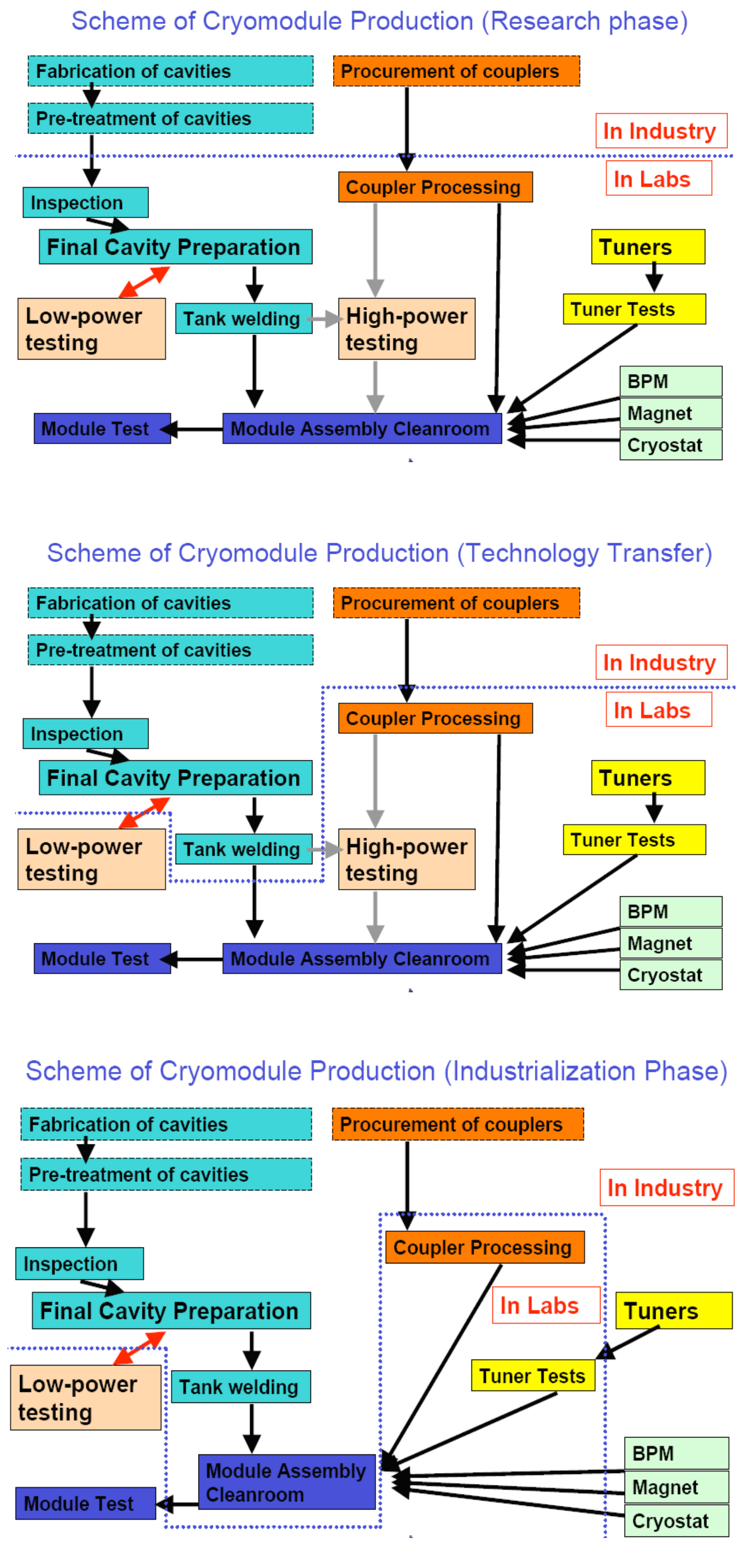

Figure 2: Sketch of the work-flow during an accelerator module assembly demonstrating the various phases of cryomodule production.

Cavity Preparation Infrastructure

General description of cavity preparation

The following section details the treatment of ILC cavities. The process can be subdivided into five steps.

Inspection of incoming cavities: The delivered cavities undergo an initial acceptance test. After visual inspection of the cavity each cell is tuned to the resonance frequency. Length and eccentricity are determined in a sequence of mechanical measurements. The cavity surface is examined optically for defects and smoothness after the rough EP treatment in industry. Subsequently the cavities will be subjected to 800°C furnace treatment for hydrogen degassing and stress anneal. After this the field profile has to be adjusted.

Preparation for acceptance / vertical test: A thin layer (of 20-30 µm) is removed in a final electropolishing process. Subsequently the cavity is annealed at temperatures of 150°C. After final surface treatment the cavity assembly in a class 10 clean room may begin. The cavity is high-pressure (100 bar) rinsed (HPR) with ultra-pure water. The variable input power antenna for vertical tests is mounted.

Vertical test: The cavity is tested at low power in a vertical bath cryostat. A temperature mapping system will be used to diagnose the cavities..

Preparation for module assembly: In the next step the helium tank is being welded. The TIG welding to the helium vessel completes the welding step. The HOM coupler and pickup antennas are mounted at the end of the cavity. A high-pressure rinse removes remaining impurities. After assembling the power coupler the cavity preparation is completed.

A subsample of the cavities will undergo a horizontal high-power cavity test including all ancillary components. This will be a test of the CHECHIA type.

Module assembly: The module assembly consists of stringing the relevant cavities and inserting the string into the module including all auxiliary components. The assembly process is completed with the module test.

Sketch of the cavity preparation infrastructure

The newly setup infrastructure should improve over existing infrastructures in several ways. As mentioned before typical infrastructures today are single-line processing R&D installations. A failure of a single process in the chain leads to unacceptable delays in schedule. The new facility will foresee redundant production steps from the start. In addition, the processing steps should be modular, so that the facility is maintainable and adaptable to new demands. It will also allow the implementation of changes in the overall production scheme as may be suggested by the ongoing world-wide R&D efforts. Modularity is also key to accommodating other projects beyond the ILC.

A sketch of such an infrastructure is found in figure 3. The centrepiece is the clean room, where all critical assembly takes place. The needed cavity preparation processes are attached to this in a modular manner. Apart from the implementation of state-of-the-art cavity preparation processes, quality assurance / control processes will be implemented. Already at this stage mass production issues such as the cleaning of parts, e.g. screws are addressed. The clean room for cavity preparation and for module assembly will be kept separate to avoid conflicts in resources and space.

The goal is to achieve an equivalent production rate[2] of ~100 cavities/year. A total cavity production of 50-100 cavities is expected over the funding period (to be determined).

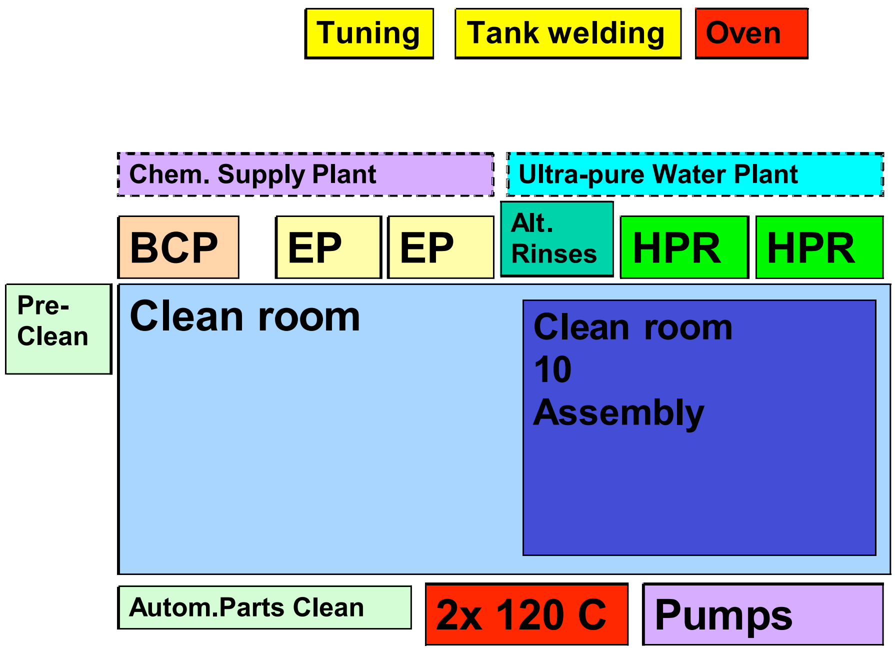

Figure 3: Sketch of the cavity preparation infrastructure.

Benefits of the new infrastructure

Apart from providing an independent test environment the new infrastructure will address in particular the cavity cleaning procedure. The electropolishing procedure which is still at a rather early stage in the technology of superconducting cavity production will profit from the redundancy of installations. Chemical treatment needs to be further investigated. Sulphurus contamination as a result of the acid treatment is a particular concern that will be paid attention to. It may be adequate to introduce an alcohol rinse to remove contaminants.

High-pressure rinsing is a key to obtaining highly operational cavities. It will be beneficial to include online particulars count in the drain water to assess the purity of the

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[2] This is not necessarily the cavity manufacturing rate. It may include re-cycled cavities rejected during the production process.

surface and effectiveness of the cleaning step. Since this step is so vital redundancy is required to maintain full operational status.

Many impurities are introduced when mounting external parts. It will hence be mandatory to introduce an automatic cleaning process for screws, spacers etc. to avoid excessive exposure to contamination.

Quality assessment and control will be introduced in the new facility and catered for in the layout of the facility.

The setup will be modular so that individual manufacturing steps can be optimized individually.

To summarize the facility will comprise two fully functional electro-polishing and two high-pressure rinsing installations. Two to three 120°C bakeout stations will be required to support the throughput. A single designated 800°C furnace will be required in addition. The pumping capacity will have to be adequate. Outside of the clean rooms an etching facility will be required to support cavity fabrication.

The modular design will probably be extended as the need for new developments is specified. One candidate processing step may comprise dry-ice cleaning.

Testing capabilities of the new infrastructure

The ultimate step in quality control is the low-power RF test of the cavities and the high-power RF test of the module. It is assumed that the facility provides the capability for both.

The vertical test stand will be prepared for low-power tests where a maximum of 100 tests per year is sufficient.

The horizontal test stand is considerably more involved and should be laid out for a few tests per year. It is critical to verify the assembly of the main input power coupler. It is conceivable that the existing installations in European partner laboratories are sufficient for this purpose. Cryostats are available at CryoHoLab (CEA), CHECHIA (DESY) and HOBICAT (BESSY). Two module tests should be expected per year and similar for coupler tests where re-assemblies are included. Concerning the coupler tests the installations at LAL are particularly suited.

Considerable developments are under way for tuners and various variants are discussed. The need for testing infrastructure still needs to be further evaluated and specified. It may be sufficient to use test installations that cool to liquid nitrogen temperatures to address thermal stability of the tuner. This test may proceed during the heat treatment step for cavities.

The beam position monitors (BPM) will require thorough test before installation. A first stage test is independent of the SCRF facility: an adequate test beam is required to assess the performance of the BPMs mounted in a standalone test stand. A second stage test will address the BPM performance in the cryomodule and requires a setup with beams. Initial tests can be envisaged for the FLASH facility at DESY. For larger samples one would have to refer to a proposed infrastructure in the international context. This aspect needs further evaluation.

The quadrupoles will be mounted inside the cryomodule. Infrastructure has to be foreseen to assess the alignment of the magnets in particular when mounted in the middle of the cryomodule. The field quality needs to be monitored.

Possible Schedule

The facility itself will be able to support various programs for which schedules are not known. The duration of the core project targeted to improve the production process for ILC cavities is estimated at 5.5 years total. This comprises a setup phase for the clean room for which two years have to be scheduled. Material procurement, in particular of the Nb, will take some two and a half years. The ordering of Nb constitutes the critical path and should be initiated early. The operation of the facility itself is scheduled for a time of 3.5 years unless boundary conditions change and require an extension.

Critical for the timely impact of the facility is hence the ordering of the raw material and the installation of the clean room, which due to the considerable number of specific components will require two years. Other test infrastructure described above are on less critical time lines since the service can be supplied at other locations with the possibly implied disadvantage of extra shipment of components.

Cost and Resources

The costs and resource requirements have been studied and are based on a green-field site. It is understood that by attaching the facility to exiting infrastructure in one of the key laboratories considerable savings could be expected. The details for such an approach have been evaluated elsewhere.

The cost estimate is based on the hardware and running cost figures extracted from the operation of TTF and estimates for the XFEL cost which have been carried out in detail. The labor cost is based on a rate of 37.50 €/h.

With these assumptions the following numbers are obtained:

Cleanroom + EP etc.:	9.5 Mio €	
Test infrastructure:	15 Mio €	
Materials:	5 Mio €	
Operation:	5 Mio €	
Total cost:	34.5 Mio €	(including 5 Mio € ~129000 hours labor)

References:

Sergio Calatroni, Bruno Vullierme, Joachim Tückmantel, ”CERN Facilities for Superconducting RF”, Presented at “Electron Accelerator R&D for the Energy Frontier”, Orsay, 2006

Letter-of-intent for CERN Council Strategy Group, http://council-strategygroup.web.cern.ch/council-strategygroup/BB2/contributions/Wagner.pdf,

A SCRF Infrastructure for Europe; http://esgard.lal.in2p3.fr/Project/Activities/Current/Networking/N2/ELAN/Documents/2006/ELAN-Document-2006-004.pdf

CLEAN-ROOM FACILITIES FOR HIGH GRADIENT RESONATOR PREPARATION; K.Escherich, A.Matheisen, et al.; http://www-dapnia.cea.fr/Phocea/file.php?class=std&&file=Doc/Care/care-conf-05-033.pdf

Appendices

- Minimal program
- Role models
- CERN as a host
- XFEL side-order

Minimal program

Buy material for XFEL modules

Role models

Defined role models of the labs e.g.

- Main Lab
- Coupler Lab
- Tuner Lab
- + generic labs: A,B,C,D,E
- The work load can be re-distributed to some degree of course

Role models for SCRF facility for discussion

- All labs
  - Layout of facility esp. cleanroom
  - Define cryostats (in GDE context, of course)
  - Preparation of assembly cleanroom
  - Controls
    - Could be another Lab
- Main Lab
  - Hosts main part of infrastructure
  - Cavity preparation, vertical testing and module testing
  - Vacuum infrastructure incl. furnaces
  - Candidates: CERN, DESY, ?
- Coupler Lab
  - Coupler procurement, preparation and conditioning
  - Support assembly cleanroom
  - Assembly at main lab
  - Candidate: LAL
- Tuner Lab
  - Tuner procurement, warm + cold testing
  - Support module assembly cleanroom at main lab
  - Assembly at main lab
  - Candidates: CEA, INFN
- Lab A Candidates
  - EP Modules specification, procurement, installation at central facility
  - Support central team in cavity preparation
  - High-power testing of individual cavities
  - Candidate: CEA, DESY
- Lab B
  - BCP Module specification, procurement, installation at central facility
  - Support central team in cavity preparation
  - High-power testing of individual cavities
  - Candidates: CEA, ?
- Lab C
  - HPR Modules specification, procurement, installation at central facility
  - Support central team in cavity preparation
  - Candidates: INFN, CEA, ?
- Lab D

    - Eddy-current scanning of niobium
    - 800 C furnace
    - Candidate: DESY
- Lab E
    - Cryostat Specification, Procurement
    - Support module assembly
    - Candidate: INFN, DESY
    - Further Candidates

- Some parties are not yet included
    - Need to understand their interest better
    - Polish labs:
        - Strong expertise in controls
    - Britain:
        - Expertise in high-power RF e.g. Couplers
        - More general interest in SCRF capability
    - Industry
        - It is important to get industry involved
        - How much could we outsource?
        - E.g. BCP module, HPR station?

Missing equipments

- Central cleanroom installation
    - Cleaning modules (EP, BCP, HPR) must be new
    - Refurbishment of existing cleanroom seems more complicated
    - Distributed facility is not desirable strategy as QC is more complicated
- Vertical testing must be close to cavity preparation
    - Fast feedback from RF test needed
    - Distributed facility is questionable strategy for R&D phase
    - Will be done in the long run e.g. industrialization phase and also XFEL mass production scenario
- Vertical testing must include appropriate diagnostics i.e. t-mapping
    - Only at DESY for multi-cells

Available equipments

- Module assembly cleanroom
    - Could be SM18
- Parts (antennas, screws etc.) cleaning
    - Several options at CERN
- 800 C furnace
    - DESY
- Vertical test stands
    - DESY, CERN (would need more resources)

    - other labs could specialize (e.g. t-mapping)
- Horizontal test stands
    - CEA, DESY, BESSY, CCLRC
- Module test stand
    - DESY CMTB
        - Cheapest and quickest option provided we can trade for an additional XFEL test hall stand
    - CERN
        - Is probably more expensive than DESY option, but still not greenfield price
- Coupler test stand
    - LAL
- Tuner test stand
    - Saclay, INFN, CCLRC, BESSY
- Eddy current scan
    - DESY
- 'Savings' ~5 Mio € + ?!

Possible Implementation at CERN

A central facility at CERN will make use of existing infrastructure[3]. It will be complemented by a network of facilities coordinated to take advantage of the existing facilities in the national laboratories (CEA, DESY, IN2P3, INFN…). CERN general services are available as a support for several activities within the SCRF facility. Some of the specific installations are covered in the following.

Cryogenic

The general infrastructure exists in building SM18. Priorities need clarification (i.e. with future LHC requirements, coming for example from the magnet test stands or from RF tests for LHC cavity repairs.) with regard to the sharing of the installed 4K capacity. The 2K pumping capacity would need a significant upgrade of the gas purification system, while the RF cryogenic infrastructure would need a general upgrade for operation at 2K.

Vertical Test

4 x 4.5m pits available (see figure 3). Two pits are equipped with cryostats sufficient to handle nine-cell 1.3 GHz cavities. The diameter should also be largely sufficient for cavities of other frequencies. Historically, LEP and LHC cavities have been tested without compensating for the earth magnetic field. This is mandatory for niobium cavities and seems easily achievable. A test capacity for the LHC in case of repairs will be maintained.

Horizontal Test

The horizontal high-power testing is assumed not to be at CERN central facility. Several facilities are available for this task: Cryholab, Hobicat, DESY.

Module

Shielded areas for module testing (Bunkers) exist capable of handling LEP- or LHC-type cryomodules. The size is believed to be sufficient for ILC modules of about 12m length.

Figure 3: Vertical test cryostat area. Visible are only the concrete 'hats' for radiation protection. These can be rolled away on rails, uncovering below a test cryostat sunk into the ground; two with sufficient depth to contain a LEP 352 MHz cavity of 2.4 m length and the (heat) radiation shields above it, and one of

[3] Sergio Calatroni, Bruno Vullierme, Joachim Tückmantel, "CERN Facilities for Superconducting RF", Presented at "Electron Accelerator R&D for the Energy Frontier", Orsay, 2006

lesser depth used for single cell cavity tests. The 300 W solid-state RF power amplifiers with their circulator and load are housed behind the concrete wall (for low power cavity/module tests)

Space

About ~1000 m^2 will probably be made available after 2007(old magnet test stand). This space will be ideally suited for the cavity preparation facility. Some additional space will be needed for the cryostat assembly.

Surface Preparation

This will require refurbishing to meet the goals set above and have the desired redundancy.

Clean rooms

Ideally a new clean room for cavity preparation should be built in the free space mentioned above, although less optimal solutions might still be identified making use of old existing facilities. A large clean room for string assembly exists from the LEP and LHC production runs (see figure).
Parts cleaning/preparation exists.

RF Testing

Low-power RF exists (for VT), some refurbishment and upgrades are needed.

Figure 4: Picture of cleanroom for LEP- and LHC-module assembly. It is divided in two parts of equal size, each 15 m long and 4 m wide, separated by a large double door. The dust-filtered air is blown from the ceiling towards the floor. The entry part is in class 1000, and the working part is in class 1÷10, exceptional for an installation of this size. An object enters the front part, letting the dust settle, and is only then transferred into the main working part. Right of the main doors, the personnel entry door to a small space for the operators to change into special garments, with another exit door into the class 1000 zone. The 'front court' allows modules to be mechanically assembled or disassembled (critical volumes remaining closed, only opened inside) and set onto rails; these lead along the whole clean-room for easy transport.

Missing Infrastructure (tentative)

- Integrated surface preparation with clean room.
- Module test High Power RF
- Cryogenic pumping capacity