

UPDATE ON THE ITN COORDINATED EFFORT FOR ILC TECHNOLOGY DEVELOPMENT IN EUROPE*

L. Monaco[†], D. Sertore, Istituto Nazionale di Fisica Nucleare, Laboratori Acceleratori e Superconduttività Applicata, Segrate, Italy

E. Cenni, CEA Université Paris-Saclay, Gif-sur-Yvette, France

A. Yamamoto, High Energy Accelerator Research Organization, Tsukuba, Japan

T. Dohmae, S. Michizono, T. Saeki, H. Sakai, K. Umemori, Y. Yamamoto, High Energy Accelerator Research Organization, Tsukuba, Japan and The Graduate University for Advanced Studies, SOKENDAI, Kanagawa, Japan

K.-M. Schirm, S. Stapnes, European Organization for Nuclear Research, Geneva, Switzerland

Abstract

The ITN-EU consortium, coordinated by CERN with the support of CEA-Saclay and INFN-LASA, is advancing Europe's contribution to the International Linear Collider (ILC) through the development and validation of high-performance superconducting radiofrequency (SRF) cavities. Activities focus on establishing an optimized production chain, from single-cell R&D to the industrialization of 9-cell cavities. Material procurement and quality control have been completed, and prototype single cells are fabricated, and they will be used to assess advanced surface treatment strategies. EU partners are also preparing technical specifications and harmonizing production with Japanese High Pressure Gas Safety requirements. Europe will provide two fully prepared 9-cell cavities for installation in an ILC-type cryomodule assembled and tested at KEK, demonstrating Europe's integrated and strategic role in the global SRF program.

INTRODUCTION

Superconducting radiofrequency (SRF) technology has reached a high level of maturity through large-scale accelerator projects such as European XFEL and LCLS-II and, continues to evolve toward higher performance and cost-effective production. In this context, the realization of the International Linear Collider relies on the development of advanced SRF cavities and an industrially viable production chain. To address these challenges, the ILC Technology Network (ITN) was established in 2023 within the International Development Team framework, bringing together international partners around key accelerator technologies [1, 2].

Europe contributes strong expertise to the ITN through its experience with major SRF projects such as European XFEL and European Spallation Source. Within this framework, the ITN-EU consortium, coordinated by CERN with the support of CEA Saclay and INFN LASA, works in close collaboration with KEK to develop and validate high-gradient SRF cavity production for the ILC. Activities

include material qualification, single-cell R&D, industrialization of 9-cell cavities, and preparation for the assembly and testing of an ILC-type cryomodule at KEK, demonstrating Europe's strategic contribution to the global SRF program [3].

MATERIALS AND QUALITY CONTROL

Materials for the single-cell and 9-cell cavities were procured by KEK and delivered to CERN, which coordinates the ITN-EU activities. The technical specifications were defined to comply with Japanese High Pressure Gas Safety (HPGS) requirements. All cavities are fabricated from fine-grain (FG) niobium supplied by Tokyo Denkai, except one single-cell cavity that uses medium-grain (MG) niobium from ATI for cost-reduction studies. Additional spare components were also procured for R&D on surface treatments and for mechanical and welding qualification studies related to HPGS compliance and future large-scale production. To ensure the stringent performance requirements of the 1.3 GHz cavities, quality control was performed on all fine-grain and medium-grain niobium sheets using Eddy Current Scanning (ECS). In 2024, DESY carried out the ECS measurements as a contribution to ITN, confirming that all sheets satisfied the specification requirements and showed no critical foreign material contamination [4].

SINGLE-CELL ACTIVITIES

The strategy we developed focuses on High Gradient (HG) toward High-Q (HQ) cavity performance, since ILC needs to reach 35 MV/m, $Q_0 \geq 1 \cdot 10^{10}$. The optimized procedure developed on single-cell cavities will then be transferred to multicell structures toward cavity industrialization, as described below:

- **High-Q/High-Gradient process development** on two single-cell cavities, beginning with a baseline EuXFEL-like treatment (150 μm bulk EP, 900 °C annealing, 10-20 μm final cold EP, 120 °C baking), and evolving with advanced techniques such as mid-temperature baking (mid-T) and two-step baking. Performance validation will occur in different partner labs (LASA, CEA, DESY, KEK) to enable cross-comparison.
- **Technology transfer to multicell structures**, using two 9-cell cavities to test the industrialization process,

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[†]laura.monaco@mi.infn.it

including the integration of quality acceptance and control protocols (QA/QC) in view of possible large-scale production scenarios.

Baseline treatments are also used to cross-check the performances at 2 K of FG vs. MG single-cell cavities. The development of the “best” recipe in terms of cavity performance will be done using only the FG single-cell cavity. Once the best process is identified, this will be applied to the MG single-cell for cross-check of performances at 2 K. The results obtained with MG would be a major contribution to the cost reduction studies. Figure 1 shows possible surface treatments identified for single-cell R&D.

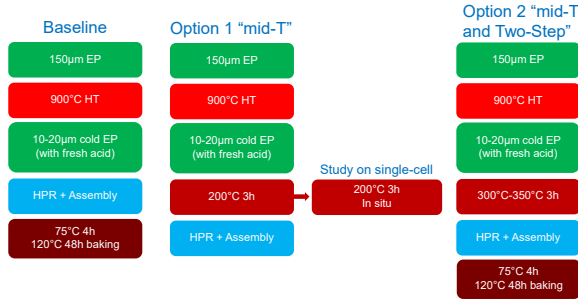


Figure 1: Surface preparation recipes for single-cell R&D.

Starting from 2024, activities have been devoted to the definition of the technical specifications for single-cell production, including all QC checks typically used for series cavity production, with the aim of early training EU industries.



Figure 2: ITN-S2M (left) and ITN-S1F (right) after mechanical fabrication at RI.

The single-cell cavities are being fabricated under a shared European–Japanese manufacturing and preparation plan defined between the ITN-EU partners and KEK, ensuring full consistency with the ILC performance requirements and surface processing strategy.

The baseline surface treatment sequence includes a bulk electropolishing (EP) removal of 150 µm performed while keeping the acid temperature below 22 °C, followed by a high-temperature heat treatment at 900 °C for 3 hours. A light EP removal of 20 µm follows applied under “cold EP” conditions with the acid temperature maintained below 7 °C. The final step consists of a standard low-

temperature bake at 120 °C for 48 hours to stabilize the surface and reduce high-field losses.

The industrial fabrication and surface treatment order of both FG and MG single-cell cavities was placed in March 2025 with a single vendor, Research Instruments (RI), to ensure strict process consistency and a reliable comparison between the two niobium grades. In April 2025, all materials were delivered to RI for the mechanical production that was completed in October 2025 (see Fig. 2). After the approval of all QC documentation, the surface treatment cycle was released for both single-cell cavities and completed in April 2026. The two single-cell cavities are now ready to be delivered for 2 K VT qualification. Technical follow-up, inspection at RI premises, and quality control has been performed by CEA Saclay and INFN LASA. Figure 3 shows the inspection of the inner surface of the FG (S1F) and the MG (S2M) single-cell cavities, respectively, after EBW, and after Bulk EP and annealing.

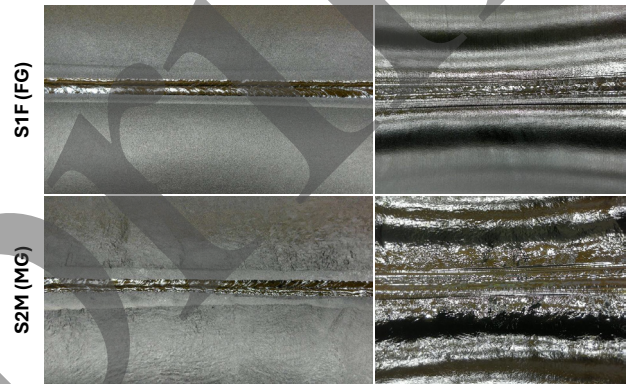


Figure 3: inner surface inspection of the FG and MG single-cell cavities, after EBW (left), and after Bulk EP and annealing (right).

In parallel with the cavity production, representative samples cut from the fine-grain (FG) sheet and medium-grain (MG) disc used for the fabrication of the single-cell half-cells were prepared for complementary material studies. The samples were inserted in the furnace together with the cavities during the 900 °C heat treatment performed for 3 h, allowing direct correlation between material characterization and the applied cavity annealing process.

9-CELL ACTIVITIES

The ITN-EU main goals for 9-cell cavities are:

- **Production** of 9-cell jacketed cavities **at the EU Industries**
- **Qualification of EU Industries** in terms of pressure vessel code (harmonization with **HPGS**)
- **Installation** into the **ILC-type cryomodule** of **2 EU cavities**

To accomplish the ITN tight time-plan, our priorities will be the cavity mechanical production at EU industries of four bare cavities, followed by the “best” surface treatment recipe resulting from single-cell activities. As for single-cell cavities, vertical tests at 2 K of 9-cell cavities will be cross-checked in different labs collaborating in ITN. The

involvement of both EU cavity producers (RI and Zanon Research and Innovation) will be pursued to finally reach their qualification in terms of HPGS for future cavity production in view of ILC. Once qualified, two bare cavities will be delivered to KEK for the jacketing phase (within Fall 2026) to be installed in the ILC-type cryomodule. CEA Saclay and INFN LASA will actively participate in the jacketing process at KEK, HPGS qualification, string assembly operation, and cryomodule test.

The plan for the other two bare cavities will be the jacketing in the EU industries for qualifying the process in terms of HPGS (to prove the capability to deliver cavities “ready for string assembly” as done for other projects like Eu-XFEL, ESS, etc.), and in terms of performance at 2 K (cross-checking the quality of the jacketing process). Even if these two cavities are not installed into the ITN cryomodule, this step is crucial for the qualification of the industrialization. Also in this phase, INFN LASA and CEA will be responsible for technical support to the EU industries involved in cavity production, including the QC of the entire process.

The activities on 9-cell cavities started in January 2025, with weekly meetings of a small team of experts for HPGS and technical specs preparation (ITN-EU and KEK). Specifications for the mechanical production of 9-cell bare cavities have been prepared considering the requirements of the HPGS, and their fabrication at EU industries, including the jacketing phase and the needed QC plan.

The same team also worked on identifying the most effective surface treatments and annealing processes that performed well with respect to the ILC request, based on R&D results conducted in various laboratories (KEK, FNAL, DESY, etc.) [5, 6].

As a first achievement, in July 2025, the technical specifications were used for the tender issued by KEK for the mechanical production of two 9-cell bare cavities (won by RI) that were delivered in April 2026.

The same technical specifications have been used for the ITN-EU tender of the mechanical production of four cavities, including baseline surface treatment and re-treatment as options, which was won by RI in December 2025. The subcomponents production is ongoing, and the four cavities will be ready for surface treatments in September 2026.

ITN EU plans foresee the preparation of the technical specifications for the jacketing process in EU industries compliant with HPGS. Moreover, we plan the procurement of another two 9-cell cavities (mechanical production and treatments) at a second European vendor, for its qualification for HPGS.

HPGS Specifications

The process was managed by KEK, iterating with KHK and Ibaraki prefecture.

All the requirements from Japanese HPGS are included in the “technical specification”. Between them, tracking of materials, thickness measurement, mechanical test of the welding sample, and welding samples.

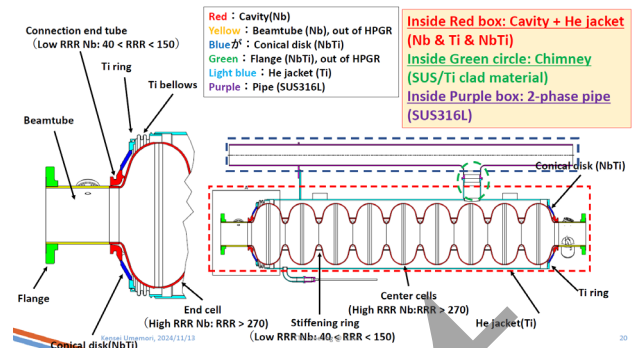


Figure 4: sketch showing ITN cavities in the jacketing configuration.

The pressure test will be carried out at KEK when the He jacket is welded. For ITN-EU, it is considered a possible option to perform a pressure test at EU vendors, as done for other large-scale series production, such as Eu-XFEL, LCLS-II, ESS, SHINE, to mention few, under compliance with Japanese HPGS (for EU vendor 1.5 times pressure test by gas). Figure 4 shows a sketch of the jacketed cavities, including materials, the He tank, and the two-phase pipe.

SUMMARY/OUTLOOK

The ITN-EU initiative, coordinated by CERN with CEA-Saclay and INFN-LASA in collaboration with KEK, is advancing toward an industrial SRF cavity production chain. Material procurement and quality control are complete, and two single-cell cavities are being built to test optimized surface treatments.

Next steps include scaling to 9-cell cavity production in the European vendors, meeting Japanese HPGS regulations, and preparing for cryomodule integration. A key milestone will be testing an ILC-type cryomodule at KEK with eight cavities, including two from ITN-EU, to validate Europe’s contribution.

The project will then focus on the qualification of European industries, harmonizing technical standards, and performance testing, strengthening Europe’s role in SRF technology and future accelerator projects.

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