A General Purpose Infrastructure at CERN for R&D and Test of Superconducting Radio-Frequency Cavities and Cryo-Modules

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CERN

OUTLINE OF PRESENTATION

- STATUS OF THE EXISTING EQUIPMENT
- PERFORMANCE SPECIFICATION OF AN SCRF INFRASTRUCTURE MADE-UP WITH EXISTING CERN EQUIPMENTS
- NECESSARY REFURBISHMENT OR UPGRADE OF THE EXISTING EQUIPMENTS AND M&P RESOURCES
- OPERATIONAL COSTS
- OUTLOOK
- CONCLUSION

This presentation is based on document:

A GENERAL PURPOSE INFRASTRUCTURE AT CERN FOR R&D AND TEST OF SUPERCONDUCTING RADIO-FREQUENCY CAVITIES AND CRYO-MODULES, *EDMS Id* 809834 *Ext. Ref.* CERN-AB-2006-008

STATUS OF THE EXISTING EQUIPMENT (2)

- **What equipment is *really* necessary for the central infrastructure?**
  - General-purpose installation
    - Metal sheet forming, vacuum furnace (outgassing, brazing),EB welding, surface cleaning (ultrasonic agitation)
  - Water rinsing stations
    - Ultra-pure particulate-free water, HPWR, online water monitoring equipment, closed installation or located in clean room
  - Clean rooms and “grey” assembly areas
    - Sufficient dust class (≥10) of filtered air, temperature and humidity control, appropriate operator equipment, online monitoring, “nesting dolls” layout, working and maintenance procedures, access policy
  - Surface preparation (polishing and coatings)
    - Chemical polishing, electro-polishing, coating installations (magnetron sputtering)
  - Cryogenics
    - Sufficient cryogenic power and low loss lHe distribution system; cope with heterogeneous sometimes contradicting requirements: refrigerator mode for module testing, liquefier mode for vertical testing; boiling vs. subcooled lHe

STATUS OF THE EXISTING EQUIPMENT (3)

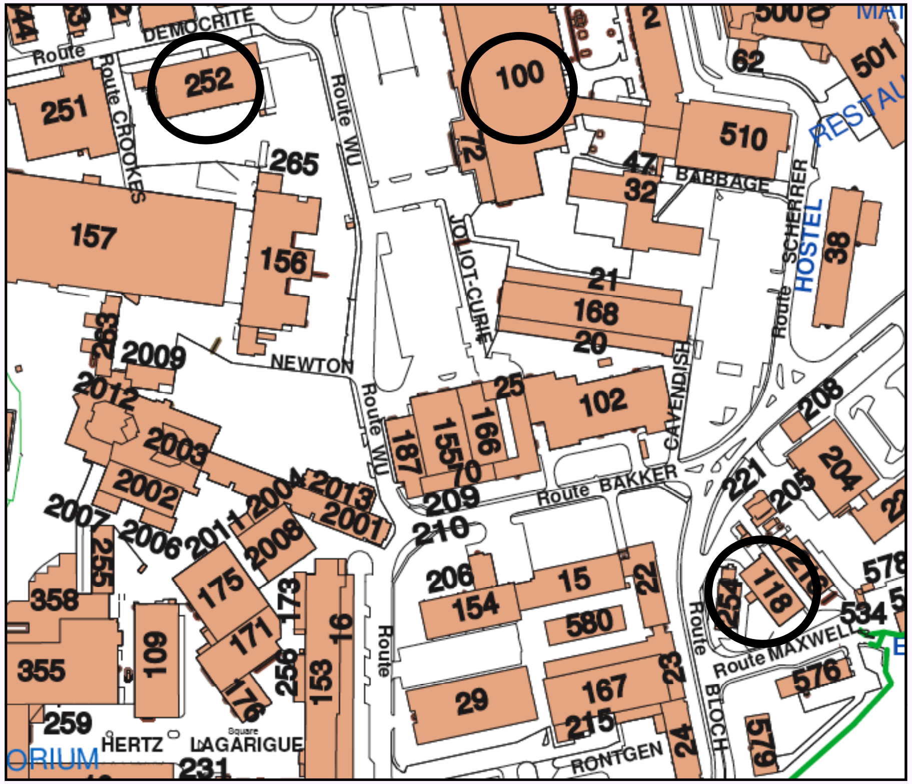
What equipment is *really* necessary for the central infrastructure? (cont'd)

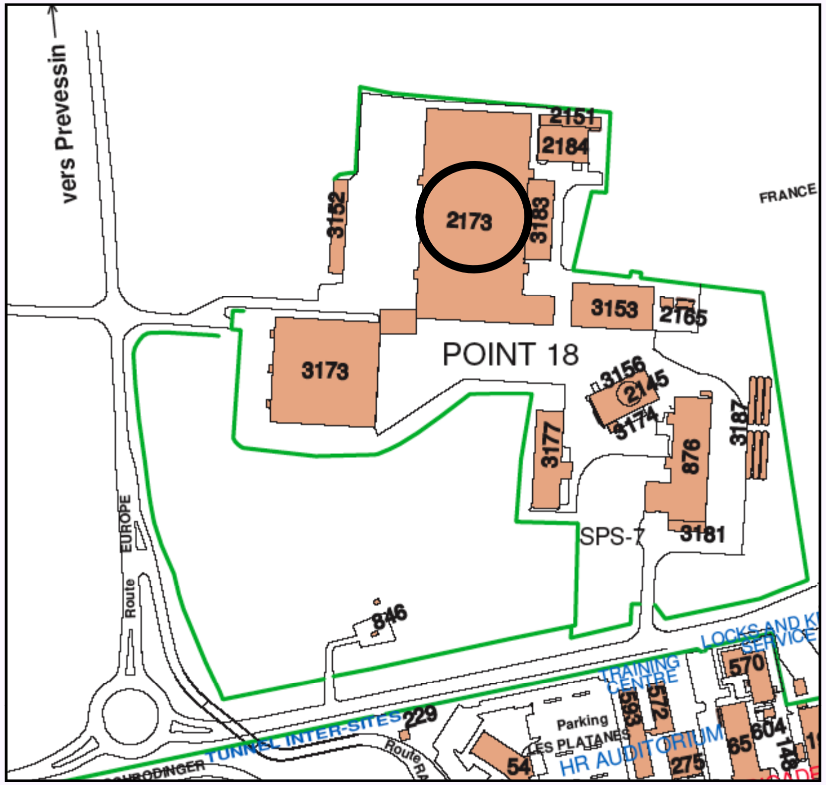
- RF testing at low temperature
  - Cryogenic equipment
    - Vertical cryostats allowing sufficient autonomy, options and diagnosis (T-mapping)
    - Horizontal cryostats allowing continuous lHe flow (refrigerator mode) at various temperatures
- RF test equipment
  - Large coverage of frequencies at low and high RF power
  - Largely automatic testing procedure and data acquisition
- Surface analysis and material characterization tools for samples including RF tests at low temperature
  - Optical inspection of inner cavity surface
  - SEM with EDX composition analysis
  - RF and DC characterization of samples (e.g. quadrupole resonator, T_c, RRR, etc.)

STATUS OF THE EXISTING EQUIPMENT (4)

The principal installations are housed in the

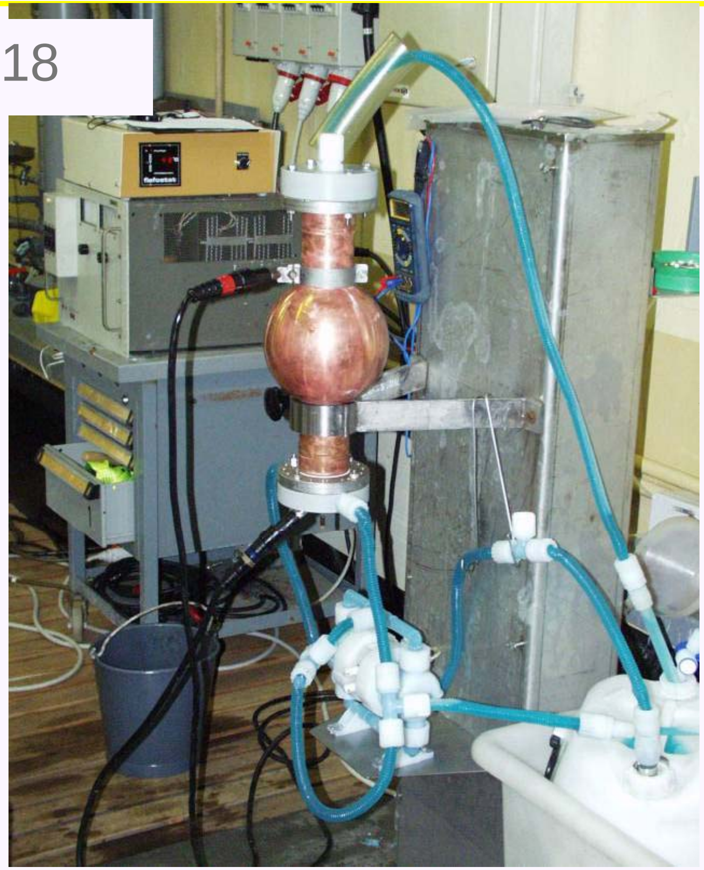
- CERN central workshop (B. 100);
- Surface treatment hall (B. 118);
- Assembly hall (B. 252);
- Assembly and testing hall (Building SM18) including the bunkers for the vertical tests and the horizontal tests, as well as the clean room for the cryo-module assembly.





STATUS OF THE EXISTING EQUIPMENT (5)

Chemical surface preparation – bldg 118



Copper chemistry facility used for automated chemical polishing of cavities (cavities of 200 MHz have been treated here), low pressure water rinsing and alcohol drying.
Copper vertical electro-polishing facility used for polishing of 1.5 GHz cavities, followed by HPWR. The workings of this facility are constantly monitored and the operating parameters regularly checked by numerical simulation of the EP process

STATUS OF THE EXISTING EQUIPMENT (6)

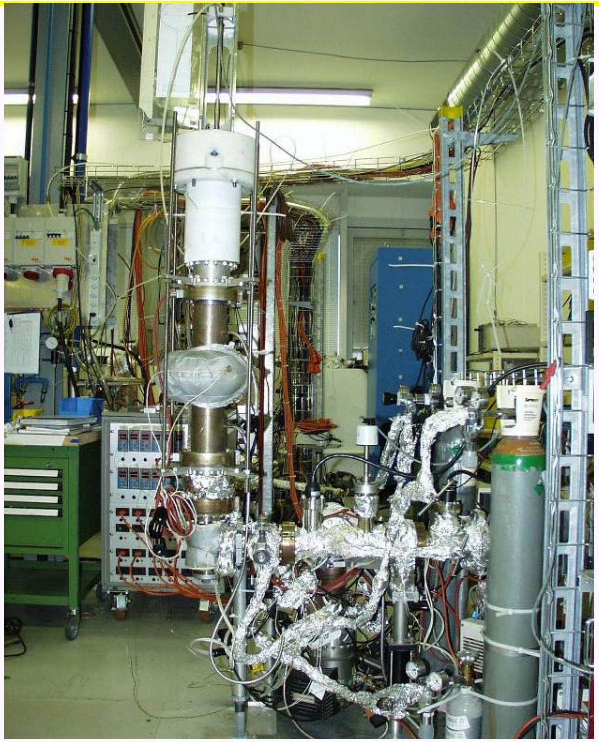
Class 100 clean room – bldg 252

External and internal view of the clean room in bldg. 252, close to the preceding “grey” zone, having a size of 8x5 m in class 100 with a personnel entry zone of 4x5m in class 1000. The clean air is blown from the ceiling down to the floor.

All the clean-rooms are professionally maintained (maintenance and cleaning contracts with external company) and the dust contents is constantly monitored.

STATUS OF THE EXISTING EQUIPMENT (7)

Niobium sputter coating facilities – bldg 252 and 101



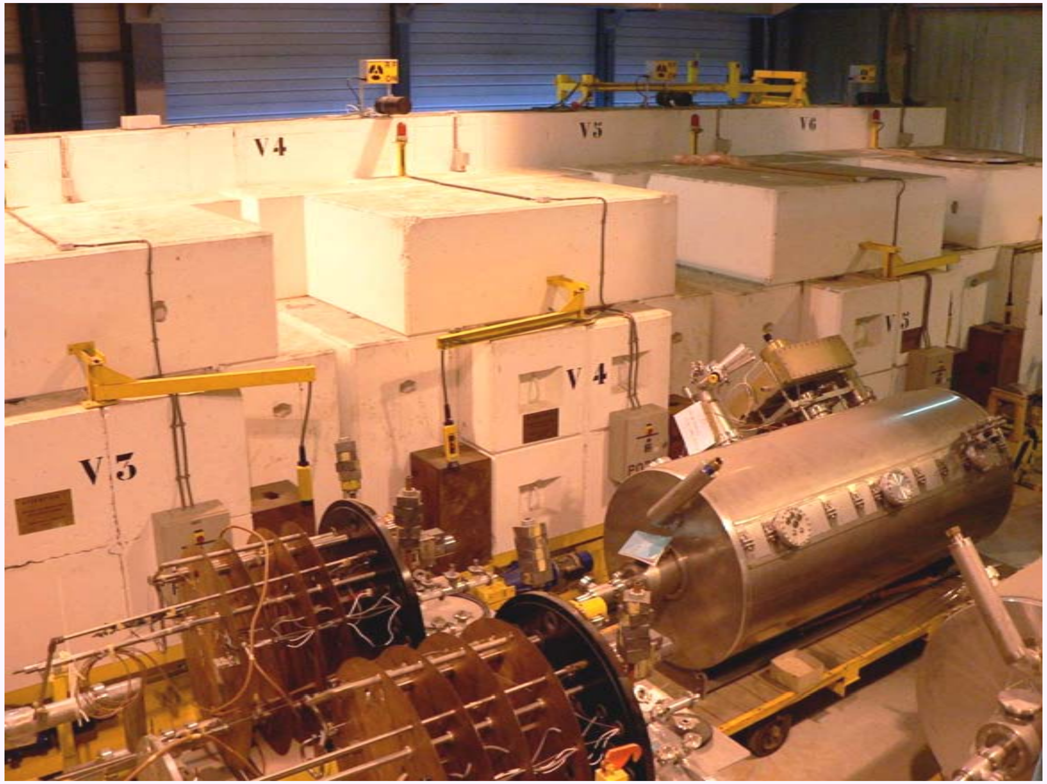
Sputtering facility for Nb coating of Cu cavities (a 200 MHz cavity from the Cornell/CERN project being coated is pictured)
Sputtering facility for Nb coating of 1.5 GHz Cu cavities. Another facility exists which allows the deposition of double layers, and which has also been used extensively for the copper coating of RF couplers extension tubes (these are made of stainless steel and connect the cold cavity to the warm part of the coupler).

STATUS OF THE EXISTING EQUIPMENT (8)

Views inside the SM18 building: top, the class 10 clean room and its front court, the class 10000 mounting area behind the wooden cupboard and at the very end the concrete shielding of the RF test area.

STATUS OF THE EXISTING EQUIPMENT (9)

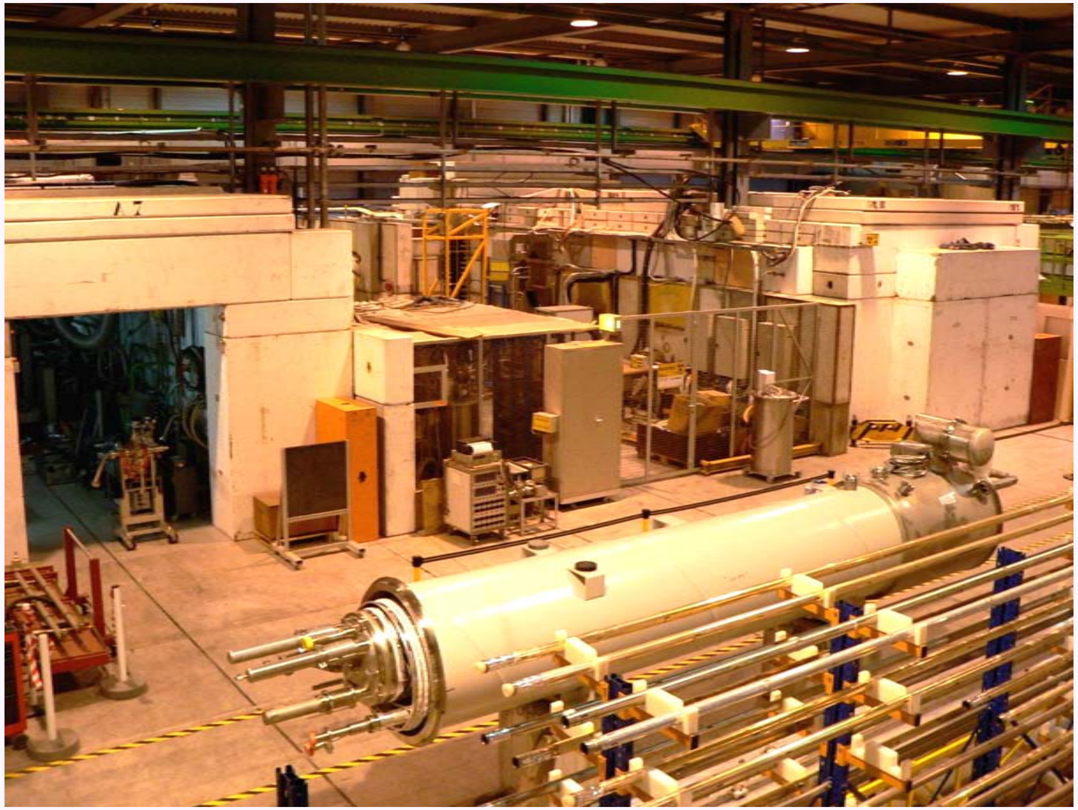
Vertical test cryostats
– SM18



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 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)

STATUS OF THE EXISTING EQUIPMENT (10)

RF bunkers – SM18



View on the RF measurement and conditioning bunkers. Left an open bunker, in the middle the klystron area (which housed another bunker during the LEP period), right a bunker in operation with closed concrete door (conditioning of LHC couplers on the module). In the front an LHC (quadrupole) magnet under preparation for testing.

STATUS OF THE EXISTING EQUIPMENT (11)

Existing capital investment at CERN

Existing investment in B. 118/SM18+Annexes				
No civil engineering included				
What	**Bldg #**	**Where**	**Total final value (MCHF)**	**Share for B118/SM18**
Auxiliary buildings				
Modifications of SM18	2173	Pt18	0.39	0.39
Pumping station STP18	2165	Pt18	0.17	0.17
Fire detection		SH18, 2, 4, 6, 8	0.35	0.07
Cranes and lifting devices		SH18, 4, 6, 8, SR2	0.43	0.086
Equipment + installation				
Cooling and ventilation				
SH18 ventilation		Pt18	0.38	0.38
Cryogenics				
SM18 6 kW cryoplant		Pt18	10.40	10.40
SC Cavities				
Vacuum for Nb-sheet cavities		Hall 180, Pt2	1.20	0.3
SM18 facilities	2173	SM18	6.00	6.00
SM18 clean room	2173	SM18	0.72	0.72
Cavities' rinsing facilities	118	Bldg 118	1.40	1.40
				19.916

PERFORMANCE SPECIFICATION OF AN SCRF INFRASTRUCTURE MADE-UP WITH EXISTING CERN EQUIPMENTS (1)

- B. 118/Surface treatment hall
  - This hall is essentially equipped to handle with noxious chemicals.
  - The installations concerned with cavity production are:
    - Chemical polishing installation for “low frequency” Nb/Cu cavities;
    - High-pressure ultra-pure water rinsing stations for Nb/Cu and niobium sheet metal cavities in closed cycle operation, including equipment for monitoring the water quality;
    - Clean room facility for high pressure water rinsing of small ancillary equipment (RF components).
- B. 252/Assembly hall
  - This hall is essentially equipped to assemble the magnetron-sputtering cathode into the cavity, to perform the sputter coating, to rinse the cavity with ultra-pure water at low pressure, to dry it by alcohol, and to assemble the RF probes for the low power test before being transported to the RF test premises (SM18).
  - The installations concerned with cavity production are:
    - Ultra-pure water rinsing stations for Nb/Cu and niobium sheet metal cavities, including equipment for monitoring the water quality;
    - Niobium sputter coating equipment for “low frequency” cavities;
    - Class 100 clean room and “grey” assembly area including equipment for monitoring air quality.

PERFORMANCE SPECIFICATION OF AN SCRF INFRASTRUCTURE MADE-UP WITH EXISTING CERN EQUIPMENTS (2)

- SM18/Assembly and testing hall
  - This hall is essentially equipped to perform the
    - low power RF tests in vertical position of the individual “low frequency” cavities including temperature mapping
    - assembling in their horizontal vacuum tank, in a class 10 clean room, the individual cavities into cryo-modules, including couplers, RF probes, etc. and
    - the low or high power RF tests, depending on whether the power coupler is mounted or not.
  - The installations concerned with cavity testing are:
    - Three vertical cryostats of different depth including radiation shield (bunker) for cold low power RF tests with lHe supplied in closed cycle “liquefier mode”;
    - Temperature mapping system in vertical test cryostats for 2.5 – 3.5 K operation;
    - Class 10 clean room for assembly of cryo-module including equipment for monitoring air quality;
    - Horizontal radiation shielded testing installation at low or high RF power of cryo-modules (bunker) in “liquefier” mode.

Assessment of CERN facilities (for Nb/Cu cavities)

#	Production step: Building no./name	Description of activity	REX-ISOLDE ion beam (100 MHz)	e-/p storage ring (350 - 500 MHz)	SPL (700 MHz)	e- linac (1.3 GHz)	Singular cavities for R&D (1.0 - 3.0 GHz)
1	100/CERN central workshop	Manufacture of cavity body	yes	yes	yes	yes	yes
2	118/Surface treatment hall	CP and HPWR	no	yes	yes	yes	yes
3	252/Assembly hall (mainly used for sputter-coating)	MS, WR, drying and cavity assembly	no	yes	yes	yes	yes
4	SM18/Bunker for vertical tests of cavities	Cold RF tests of individual cavity at low RF power (solid state amplifier, TM)	no	yes	no	no	yes
5	100/CERN central workshop	Assembly of helium vessel	no	yes	yes	yes	yes
6	SM18/Clean room	Assembly of individual cavities into string of cavities	no	yes	yes	yes	n/a
7	SM18/preparation area	Assembly of string of cavities into horizontal cryostat	no	yes	yes	yes	n/a
8	SM18/Bunker for horizontal tests of cryo-modules	Cold RF tests of horizontal cryostat at low RF power (solid state amplifier)	no	yes	no	no	n/a
9	SM18/Clean room	Assembly of ancillary equipment (couplers, tuners) into cryo-module	no	yes	yes	yes	n/a
10	SM18/preparation area	Assembly of cryo-modules	no	yes	yes	yes	n/a
11	SM18/Bunker for horizontal tests of cryo-modules	Cold RF test of cryo-module at high power (e.g. klystron)	no	yes	no	no	n/a
	TOTAL sequence possible?		no	yes	no	no	yes

Assessment of CERN facilities (for Nb sheet metal cavities)

#	Production step: Building no./name	Description of activity	REX-ISOLDE ion beam (100 MHz)	e-/p storage ring (350 - 500 MHz)	SPL (700 MHz)	e- linac (1.3 GHz)	Singular cavities for R&D (3.0 GHz)
1	100/CERN central workshop	Manufacture of cavity body	yes	yes	yes	yes	yes
2	118/Surface treatment hall	CP and HPWR	no	yes	yes	yes	yes
3	118/ Surface treatment hall	Electro-polishing	no	no	no	no	no
4	SM18/Bunker for vertical tests of cavities	Cold RF tests of individual cavity at low RF power (solid state amplifier, TM)	no	yes	no	no	yes
5	100/CERN central workshop	Assembly of helium vessel	yes	yes	yes	yes	yes
6	SM18/Clean room	Assembly of individual cavities into string of cavities	yes	yes	yes	yes	n/a
7	SM18/preparation area	Assembly of string of cavities into horizontal cryostat	yes	yes	yes	yes	n/a
8	SM18/Bunker for horizontal tests of cryo-modules	Cold RF tests of horizontal cryostat at low RF power (solid state amplifier)	no	yes	no	no	n/a
9	SM18/Clean room	Assembly of ancillary equipment (couplers, tuners) into cryo-module	yes	yes	yes	yes	n/a
10	SM18/preparation area	Assembly of cryo-modules	yes	yes	yes	yes	n/a
11	SM18/Bunker for horizontal tests of cryo-modules	Cold RF test of cryo-module at high power (e.g. klystron)	no	yes	no	no	n/a
	TOTAL sequence possible?		no	no	no	no	no

Classification of refurbishment work

- Generic equipment
  - The first class comprises generic existing equipment that is not or only partially working properly: non-operational clean rooms, controls and monitoring equipment
  - To the second class of generic equipment belong items that are needed but missing, or that reduces considerably the performance and capacity of the whole facility: lHe distribution system, 4th vertical cryostat, material characterization by DC methods
  - The third class of equipment is also generic in the sense that it upgrades the utility of the facility, as required by a particular application: cryogenic equipment for tests of cryo-modules at 2.0 K, electro-polishing for Nb sheet cavities, RF low power and high power equipment at a specific frequency
- Specific equipment
  - All other equipment is very specific for the particular application and should therefore be provided by the user of the facility: cavities and cryo-modules to be tested, specific diagnosis equipment

Class 2570	Building	Generic installation	Equipment item	Total investment costs [kCHF]	Manpower for refurbishment or upgrade [man-months	Total costs [kCHF]	Responsible group
1	118	Clean rooms	Clean room for HPWR of couplers, etc.	250	2	276	AB-RF
1	118	Surface preparation	Chemical polishing of LEP/LHC copper cavities	10	1	23	TS-MME
1	118	Surface preparation	EP of 1.3/1.5 GHz copper mono-cell cavities	25	3	64	TS-MME
1	118	Water rinsing stations	Upgrade of monitoring equipment (TOC, particle content)	150	3	189	TS-MME
1	118	Water rinsing stations	Upgrade of HPWR stations for 1300 MHz cavities (nozzle, etc.)	60	3	99	TS-MME
1	252	Clean rooms	Upgrade of monitoring equipment	50	2	76	AB-RF
1	252	Water rinsing stations	Upgrade of monitoring equipment (particle counter, etc.)	100	2	126	AB-RF
1	SM18	Clean rooms	Upgrade of monitoring equipment	50	3	89	AB-RF
1	SM18	RF testing at low temperatures	Temperature mapping equipment (without resistor arm)	100	6	178	AB-RF
1	SM18	RF testing at low temperatures	352/700 MHz test stand controls and cabling (bunker)	200	12	356	AB-RF
1	SM18	RF testing at low temperatures	352/700 MHz test stand controls and cabling (vertical)	100	12	256	AB-RF
1	SM18	RF testing at low temperatures	400 MHz test stand controls and cabling (bunker)	40	3	79	AB-RF
1	SM18	RF testing at low temperatures	Water distribution equipment for high power RF equipment	150	6	228	AB-RF
1	SM18	RF testing at low temperatures	Controls upgrade of the existing power converters	50	3	89	AB-RF
1	SM18	RF testing at low temperatures	Re-cabling and upgrade of control system of three existing vertical cryostats	200	12	356	AB-RF
1	SM18	Water rinsing stations	Upgrade of ultrapure water rinsing stations (revamping of filters, UV, additional de-ionizing)	30	1	43	TS-MME
1	SM18	Water rinsing stations	Upgrade of HPWR stations (cleaning, computer controls)	30	1	43	TS-MME

2570

Class	Building	Generic installation	Equipment item	Total investment costs [kCHF]	Manpower for refurbishment or upgrade [man-months]	Total costs [kCHF]	Responsible group
2	101	Surface analysis tools (DC & RF)	DC characterization of samples (T_c, RRR, …)	200	3	239	TS-MME
2	252	Surface preparation	High peak power magnetron sputtering	160	3	199	TS-MME
2	SM18	Cryogenics	Upgrade of cryogenic installation (counter flow G/L Heat exchangers, JT valves, pumping header, redesign of interface distribution system - cryostats)	1000	12	1156	AT-ACR
2	SM18	RF testing at low temperatures	Cabling and refurbishment of 4th vertical cryostat	100	4	152	AB-RF
2	SM18	RF testing at low temperatures	RF equipment for 4th vertical cryostat	100	4	152	AB-RF
2	SM18	Surface analysis tools (DC & RF)	RF characterization of samples (e.g. quadrupole resonator)	200	2	226	AB-RF

2124

Class	Building	Generic installation	Equipment item	Total investment costs [kCHF]	Manpower for refurbishment or upgrade [man-months]	Total costs [kCHF]	Responsible group
3	118	Surface preparation	Electropolishing apparatus for niobium sheet cavities	200	6	278	TS-MME
3	SM18	Cryogenics	Upgrade of cryogenic installation (remote control, including helium pumping and helium purification processes)	1000	24	1312	AT-ACR
3	SM18	RF testing at low temperatures	RF low and high power equipment at 1300 MHz	400	1	413	AB-RF
3	SM18	RF testing at low temperatures	Upgrade beyond 200 kW up to 350 kW of circulator load and water cooling for 352 MHz	100	3	139	AB-RF
3	SM18	RF testing at low temperatures	Pulsed high power equipment at 352, 700 (1 MW) or 1300 MHz	1200	12	1356	AB-RF

3498

TOTAL 8192

Distribution of costs:
AB-RF: 4547
AT-ACR: 2468
TS-MME: 1177

Benefits of the refurbishment for equipment in

- Class1:

  To comply with the performance specification as outlined before. In particular would it make possible again to produce and test Nb/Cu e-/p storage ring cavities (350 - 500 MHz) and fully equipped cryo-modules at 4.5 K and allow the rapid start up of production and test or singular cavities.

- Class 2:

  To permit the usage of the forth vertical cryostat, in case a more rapid throughput of cavities should be required. Such a step is only expedient if accompanied by an upgrade of the existing lHe distribution network.

- Class 3:

  To extend the existing infrastructure to other applications beyond Nb/Cu e-/p storage ring cavities. It would allow production and test of Nb sheet metal "high frequency cavities", including horizontal tests of **fully equipped** cryo-modules at 2 K, or pulsed high power tests at different frequencies.

OPERATIONAL COSTS

- The total operational (Material and Personnel) costs are composed of
  - recurrent costs for maintaining the facility operational as base load without any significant project related activities, and
  - ad hoc costs related to the specific project that depend on the workload with regard to full capacity of the facility.
- The recurrent costs incur by the base load and do not depend on the throughput of cavities for a specific project
  - operation of cryogenics installations
  - electrical power
  - maintenance of water stations and clean rooms, consumables, etc.
- The ad hoc project dependent costs depend largely on the requested throughput of the facility and shall be imputed to its user.

OPERATIONAL COSTS (2)

Recurrent operational costs per year (base load)

Generic Installation	Cost relevant parameter	Value of cost relevant parameter	Costs per year [kCHF]
Cryogenics	Manpower base operation costs per year		250
	Refrigerator power [kW]	3	
	Costs per kWh electricity [CHF]	0.05	
	Running time per year [h]	8000	
	Total cryo-power warm [kW]	1200	
	Electricity per year		480
	Maintenance material and other consumables		250
	SUM		980
Surface preparation	Maintenance manpower costs per year		50
	Consumables		50
	SUM		100
Clean rooms	Maintenance manpower costs per year		80
	Clean room power demand kW/m^2]	0.1	
	Total area of clean rooms [m^2]	214	
	Total clean room power [kW]	21	
	Running time per year [h]	8000	
	Electricity per year		9
	Consumables		20
	SUM		109
Water rinsing stations	Maintenance manpower costs per year		20
	Consumables		10
	SUM		30
RF testing at low temperatures	Maintenance manpower costs per year		10
	Consumables		10
	SUM		20
Surface analysis tools (DC & RF)	Maintenance manpower costs per year		10
	Consumables		10
	SUM		20
TOTAL SUM			1259

OPERATIONAL COSTS (3)

Adhoc project related operational costs

(for maximum possible throughput for cryo-module)

#	Production step: Building no./name	Description of activity	Characteristic duration per production step [days]	Throughput per individual production step: Number of cryo-modules per month for existing production lines	Consumables per month [kCHF]	Number of operators needed per production step (FTEs)	Costs per month for individual production step [kCHF]	Costs per month [kCHF]
2	118/Surface treatment hall	CP and HPWR	1	5.0	14	2	40	4
3	252/Assembly hall (mainly used for sputter-coating)	MS, WR, drying and cavity assembly	3	1.7		2	26	8
4	SM18/Bunker for vertical tests of cavities	Cold RF tests of individual cavity at low RF power (solid state amplifier, TM)	5	4.0		3	39	5
6	SM18/Clean room	Assembly of individual cavities into string of cavities	5	0.5		2	26	26
7	SM18/preparation area	Assembly of string of cavities into horizontal cryostat	5	0.5		2	26	26
8	SM18/Bunker for horizontal tests of cryo-modules	Cold RF tests of horizontal cryostat at low RF power (solid state amplifier)	5	1.0		3	39	20
9	SM18/Clean room	Assembly of ancillary equipment (couplers, tuners) into cryo-module	*5*	0.5		2	26	26
10	SM18/preparation area	Assembly of cryo-modules	5	0.5		2	26	26
11	SM18/Bunker for horizontal tests of cryo-modules	Cold RF test of cryo-module at high power (e.g. klystron)	10	0.5		3	39	39
	TOTAL		n/a	0.5		n/a	n/a	179

OUTLOOK

A GENERAL PURPOSE INFRASTRUCTURE AT CERN FOR R&D AND TEST OF SUPERCONDUCTING RADIO-FREQUENCY CAVITIES AND CRYO-MODULES
Contact person: **Wolfgang Weingarten, CERN, CH 1211 Geneva 23, wolfgang.weingarten@cern.ch**

Type of the anticipated proposal: **JRA**	
List of (potentially) interested institutes (to be confirmed): CEA DAPNIA Saclay (F), CERN (CH), Cockroft Institute (GB), Daresbury (GB), DESY (D), INFN (I), IN2P3 LAL Orsay (F),	
Estimated duration: 4 years	Estimated Cost (including manpower): 9.6 M€

… SCRF has become a key technology for advanced accelerators and is finding multiple applications in a variety of fields…

- the **International Linear Collider (ILC),** supposed to provide electron and positron beams for collision experiments up to 1 GeV c.m. energy;
- the **SPL** at CERN, a superconducting 4 to 5 GeV H - linac to be used as proton driver for the luminosity upgrade of the LHC, possibly a high intensity radioactive beam facility and future neutrino facility;
- new generation of **light sources** to be based on a SCRF linear accelerator with energy recovery (ERL = Energy Recovery Linac);
- Energy upgrade of **radioactive ion beams in REX-ISOLDE** at CERN.

OUTLOOK (2)

Estimates of the budget profile (according to the revised version of the paper (Jan. 2007))

	year 1	year 2	year 3	year 4	Total
Investment (M&P)	**1.1 M€**	**1.5 M€**	**1.5 M€**	**1.0 M€**	**5.1 M€**
Operation base load (M&P)	**0.6 M€**	**0.7 M€**	**0.8 M€**	**1.0 M€**	**3.1 M€**
Operation at 27 % capacity of exploitation (M&P)	**0.2 M€**	**0.3 M€**	**0.4 M€**	**0.5 M€**	**1.4 M€**
Total	**1.9 M€**	**2.5 M€**	**2.7 M€**	**2.5 M€**	**9.6 M€**

OUTLOOK (3)

- Prepare the bid as a Joint Research Activity for the EU up till end of 2007 according to the predefined timetable;
- Contact (in parallel) other laboratories throughout Europe possibly interested in participating in this infrastructure: Cockcroft institute (UK), Laboratories of Orsay and Saclay (France), Desy (Germany), University of Rome and INFN (Italy) as well as CERN (Isolde, Linac4/SPL);
- Validate CERN SCRF processing and test installations for the purpose of operation and maintenance of LHC cavities: Have an existing high performance cavity processed and tested in order to identify shortcomings of the existing infrastructure.

CONCLUSION

- A staged approach is presented, based on the SCRF facilities existing at CERN, towards an infrastructure for producing and testing individual SCRF cavities and fully equipped cryo-modules.
- The first stage comprises the repair or replacement of rotten or obsolete equipment that is needed for the start up of any exploitation for tests of storage ring cavities (LHC) and singular cavities for R&D purposes.
- Further stages of refurbishment extend the performance of the existing infrastructure towards cavities and cryo-modules for other applications.
- The costs estimation is provided.
  - A distinction is made between investment costs and operational costs.
  - The operational costs are further split into basic costs for maintenance, services, energy, etc., and project related costs that depend on the throughput required.
- A LoI for JRA within FR7 is in preparation.