LINEAR COLLIDER COLLABORATION
Designing the world's next great particle accelerator

CHANGE REQUEST NO. ILC-CR-00XX	EDMS No: D*xxxx	Created: 31-12-2019
		Last modified: **10-1-2020**

SRF ACCELERATOR CRYOGENICS: HE INVENTORY

[Few sentences describing the main subject of the change request]

A change request of He inventory configuration for the ILC SRF accelerator cryogenics is provided in focus on helium resource conservation to respond to any operation and emergency modes, as follows:

- Helium (He) inventory is simply stored as He gas in multiple buffer tanks (at 20 bar$_{-max}$) at each satellite plant, as a primary concept, enabling quick and full He resource recovery during any shutdown of the SRF cryogenics including primary AC power outage,
- As a complementary concept, long-term helium inventory backup is proposed in liquid/supercritical phase in a dewar/container at a specified station/plant, to reserve additional He inventory with a fraction of 10 - 20% for the full amount of He (100%) necessary to the nominal ILC SRF system operation. and to flexibly link and distribute to each satellite plant with He-gas pipelines.

RATIONALE

[Outline briefly as possible the main reasons for requesting the change]

- LHe in the ILC SRF cryomodule has to be entirely evaporated within 3 days because of static thermal load (~ 20 W/CM) and acceptable pressure increase (limited to ≤2 bar-abs) in the cryomodules (CMs), in case of any shutdown of the cryogenics operation (see Fig. 1). Immediate recovery in gas phase is inevitable by using recovery compressors supported by emergency AC power generators.

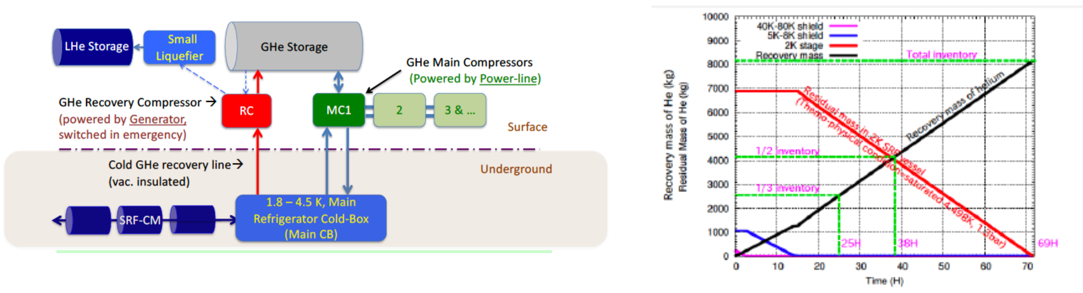


Fig. 1

-

- A large amount of helium resource may not be quickly delivered in particularly in Japan, because entire He resource in Japan is shipped and imported and it directly impact on the SRF accelerator operation availability. It is very important to conserve He inventory with minimum loss in any emergency modes of the cryogenics operation including AC power outage.
- Full recovery and storage of the He resource into GHe buffer tanks by using a recovery compressor system at 20 bar is a simple and very reliable strategy to conserve the He inventory.
- Just as a note, the previous CR (009) assumed that a half of He resource be liquefied and stored in a large LHe dewar. It takes one week (~7 days), and it might cause additional failure risks.

SCOPE

[Brief description of the overall scope of the modifications being proposed, including possible impact on other areas]

- We propose to modify the helium inventory to be simply stored in He gas buffer tanks (100%) at each ML satellite system, instead of mixture of gas/liquid (50/50%) storage system, for very reliable recovery of helium gas evaporated from the ML SRF system. It requires doubling numbers of He gas buffer-tanks (6 to 12) at each satellite cryogenics station. On the other hand, it may much simplify the recovery system with no requirement for the helium liquefaction system at each satellite surface site (see Fig. 2).

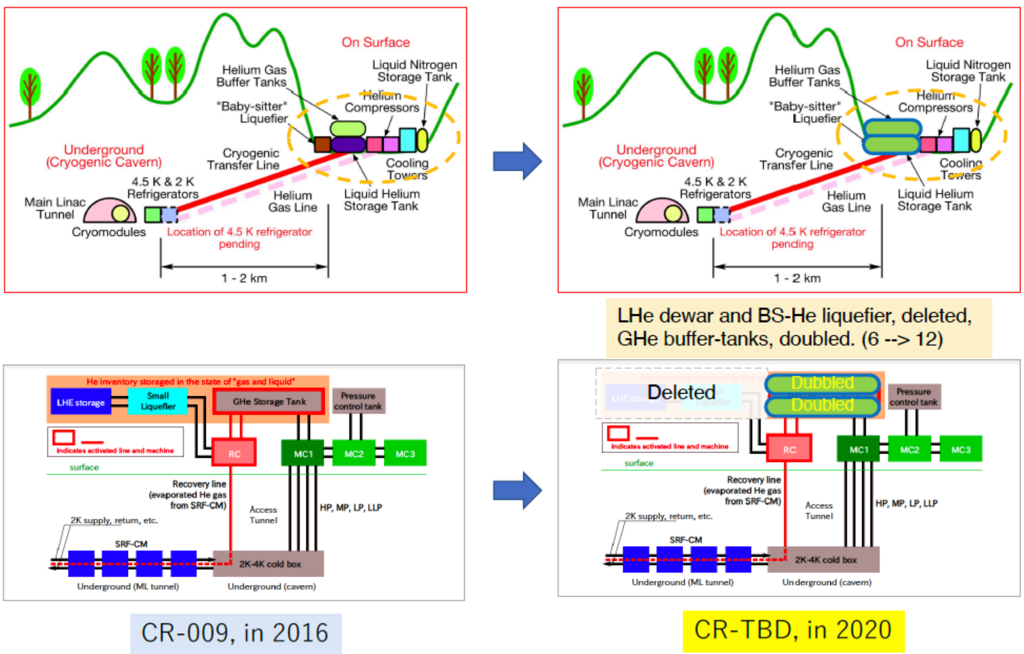


Fig. 2

- Helium inventory for long-term backup may be differently optimized by reserving possibly with LHe/supercritical phase in a large LHe container (dewar) assisted with a baby-sitter/small liquefier to maintain the helium inventory to be re-cycled/re-condensed.
- It may be placed at one location, possibly at the ILC IP/central region, and GHe inventory network/pipeline should be provided to flexibly distribute the helium resource for all satellite cryogenics plants along the ILC ML/DR (see Fig. 3).
- The station should also function as the reception to receive He resource commercially delivered possibly in a large LHe/supercritical phase.

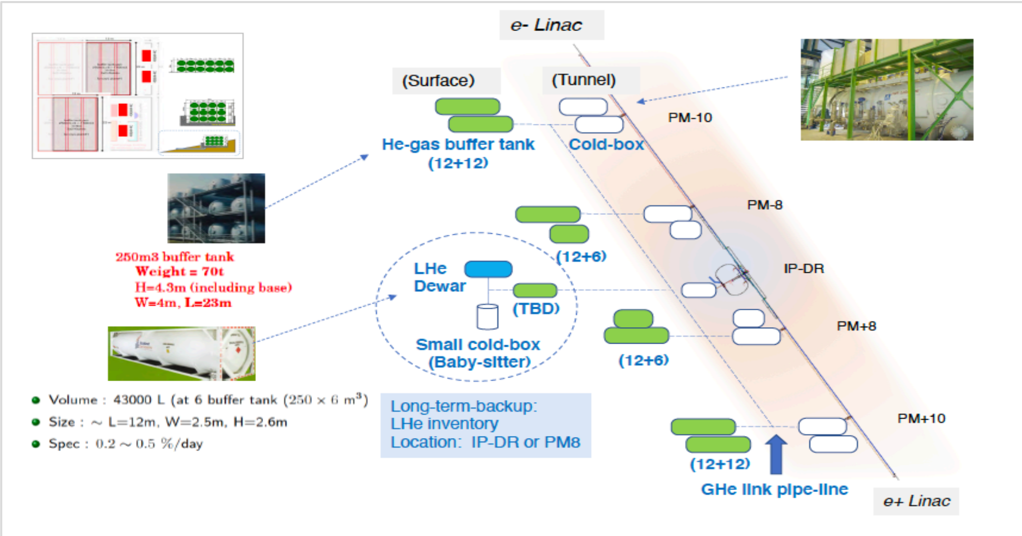


Fig. 3

- As a significant positive impact, helium resource may be very reliably conserved, and availability of the SRF accelerator operation may be much secured.
- No major effects are seen to other system, except for doubling GHe tanks including transportation to and installation work at the satellite cryo-plant site.
- Overall scope of the modification is summarized in Table 1, as follow:

Table 1.

	CR-09: current baseline	CR: proposed
Quick recovery at Satellite Plant:		
# GHe BufferTank	6 (3 x 2 layers)	12 (4 x 3 layers)
Emergency Recovery compressor	Yes	Yes
He liquefier for LHe storage	Yes	No
LHe Storage Reservoir	Yes	No
He recovery time:	7 days (2x3+a)	3 days
Emergency Power Generators:	≤ 1 MW	≤ 0.5 MW
Surface area required	≤ 1300 m^2	≤ 1,300 m^2
Long-term He backup (10-20%)		
LHe reservoir and He liquefier	Distributed at satellites	Centralized at IP-DR

VALUE/SCHEDULE IMPACT

[Brief explanation of the estimated value figure if available. Also if know, impact on construction schedule. Value should also include explicit labour if possible]

- The estimate value figure for the He recovery and gas storage (100%) in comparisons with the current baseline (CR-09) is summarized in Table 2, as follows:

Table 2.

Subject	Current Baseline (CR-09)	New CR (proposed)
Cost of ML Satellite Plant (each):		
GHe buffer tanks	3.4	6.7
Recovery compressors	0.7	0.7
Small He liquefier and LHe dewar	4.4 + 1	--
LHe dewar	1	--
Transportation and unloading	0.9	1.8
Site construction (CE)	0.6	1.2
Sum/plant	11.4	10.8
Total Cost for 2 x 3.5 (7 eq.) plants:	**79.8**	**75.6**
Additional Cost: Long-term He backup:		
LHe dewar + He liquefier + GHe Link	**+ α**	**4.4+1 + β**
Grand total	**80 + α**	**76 + 5 + β**

- The overall cost is similar in both cases, and no major effect is expected.
- The impact on the construction schedule should be minor.
- The operational cost including annual maintenance/inspection would be less in the new CR, because of the simplicity in the system configuration.

(end)

Requested and prepared by:	T. Okamura, H. Nakai, and A. Yamamoto

Attachments:

Number:	Original / Updated:	by:
1	Concepts of CR009 and follow-up (2016)	HN, TO, YM, AY
2	Report from WG3 on ILC-250 study (2017-7)	AY. HN. TO
3	Study of ILC ML Cryogenics, (2017-3) Originally reported at LCWS (2016)	TO, HN, AY
4	Cryogenics at CERN, ILC Cryog. WS (2013-11)	D. Delikaris
5.	Foot print: LHC-SM18, He Inventory Configuration, Image for 2 x 3 x 4 He tanks Configuration	DD, AY

Change History:

Version:	Created/modified:	by:	what:
1.0	31.12.2019	T. Okamoto, H. Nakai, A. Yamamoto	Preliminary Draft
1.1	5.1, 2020	T. Okamoto, H. Nakai, A. Yamamoto	Draft updated, including additional attachments.
1.2	8. 1, 2020	T. Okamoto, H. Nakai, A. Yamamoto	Draft updated,
1.3	10. 1, 2020	T. Okamoto, H. Nakai, A. Yamamoto	Appendix added (CERN SM18, He inventory example),

IMPLEMENTATION PLAN

Can be left blank for first submission.

Concerned Parties (Work Packages, Coordinators, Suppliers etc.)

WF/Area	

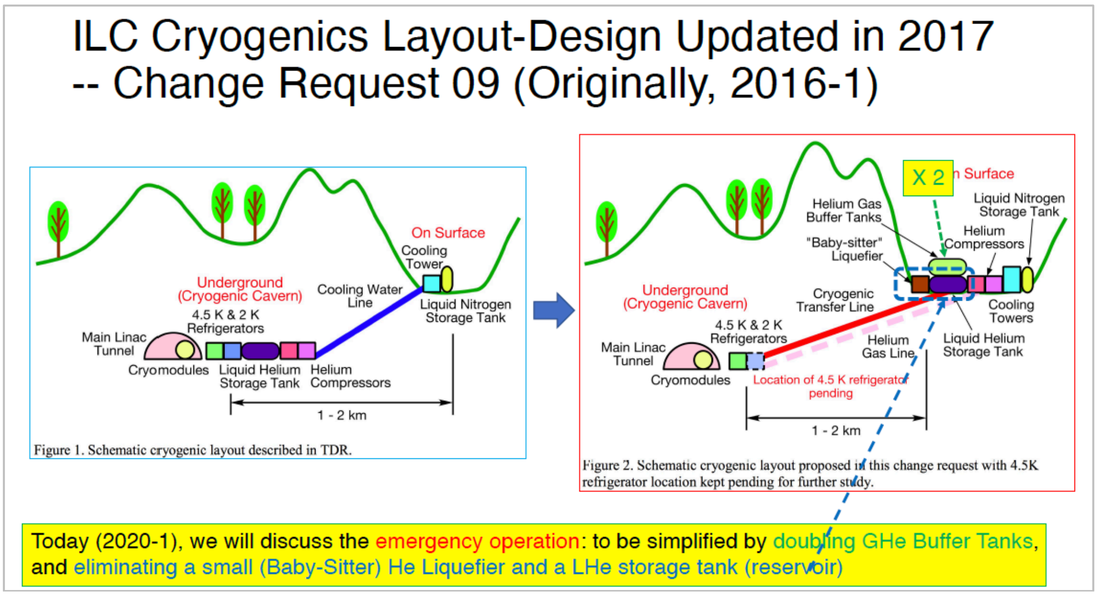
Affected documents

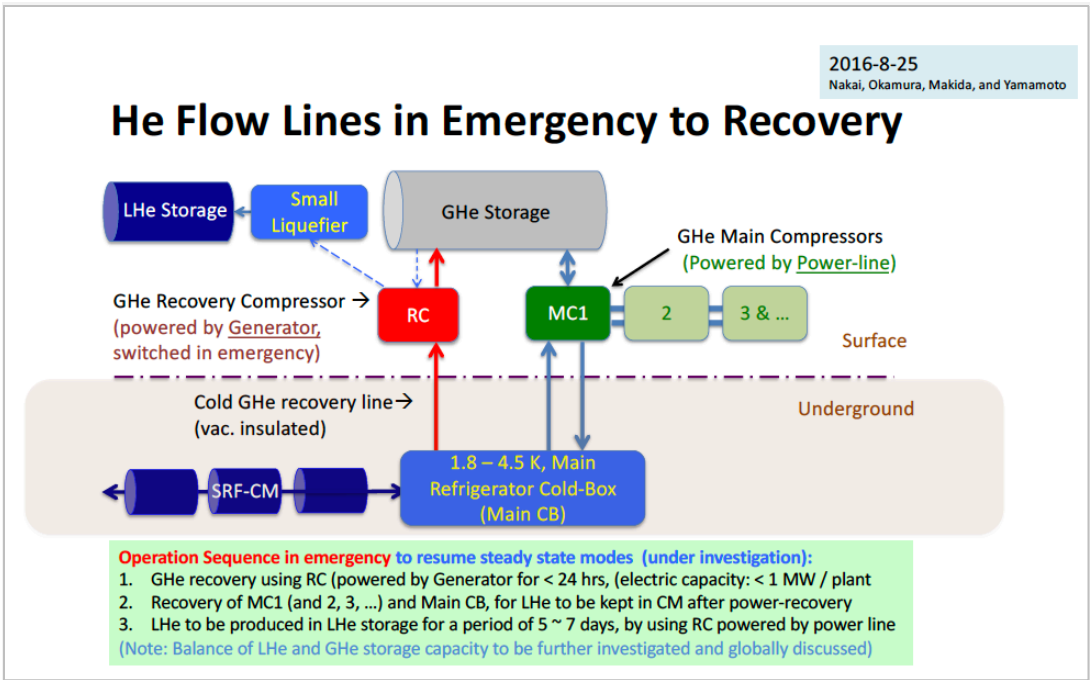
EDMS ID	Title	Remark

ATTACHEMENTS

[Place additional document here as needed. This can be used for adding a more detailed description of the CR]

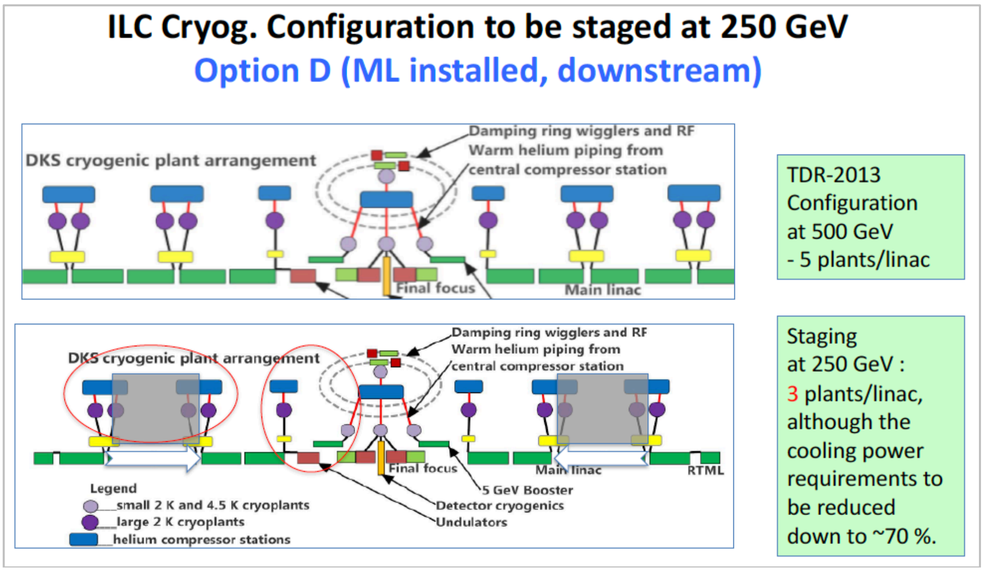
Attachment 1: CR009 (Nakai, Okamura, Makida, Yamamoto, 2016-2017)





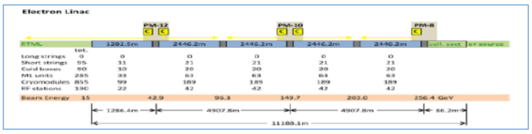
Attachment 2: Reports from ILC250 WG3

(A. Yamamoto, S. Michizono, and B. List: briefly extracted, 25 July, 2017)



Updated: 170724

Staging (250 GeV) effects on the SRF Cryogenic Systems



E = 31.5 MV/m, and L-eff = 1.0385 m
+V/cavity = 32.7 MV

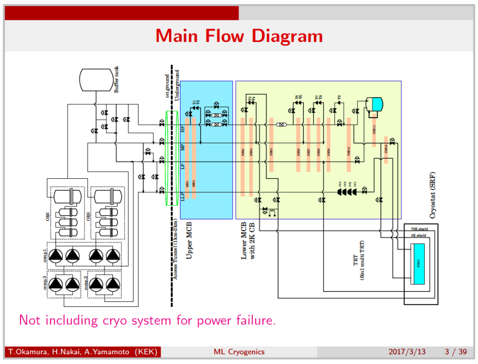
+V/st-Cryogenics) = 3 x 21 x 0.8505 = 53.6 GeV
+V/short-string = 2.55 GeV
+V/MLU = 32.71 x 26 = 850.5 MV
Cryogenics unit (short string) length (3 MLU)
= 3 x 37.956+2.5 = 116.368
RF unit (4.5 CM) length = 56.934 m
MLU blength (→3 CM) = 3 x 12.652 = 37.956 m
CM length = 12.652 m (pitch)

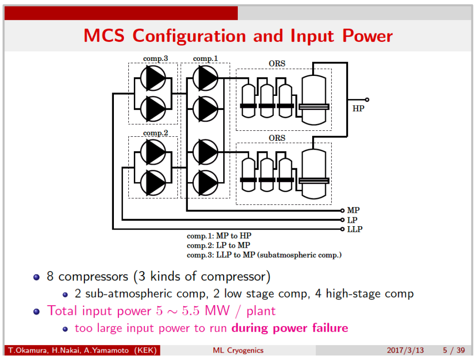
	MILC	%
e-, 2+	2 x 32.5	2 x 4.8
DR	26.0	3.9
RTML (unit)	38.1 19.1	5.6 (2.8)
ML (unit)	526.9 (58.54)	78.1 (8.6)
BDS	18.4	2.7
Sum	674.6	100

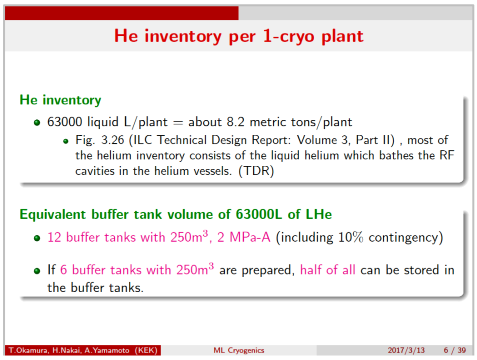
		RTM L-BC	ML-CM	PM -12 -u	PM -12 -d	ML-CM		PM -10 -u	PM -10 -d	ML-CM		PM -8 -u	PM -8 -d	e+ Booster	Sum	Cost Down
TDR-500	Cryo-Cost	19.05 + 29.27			58.54		58.54		58.54		58.54		32.54*		315.02	n/a
	# C-Plant	~ 0.2 + 0.5 = 0.7 → 1			1		1		1		1		> ~ 0.55*		5.5 systems	
	CP-Power	(19 kW @ 4.5 K)			19 kW @ 4.5 K		19 kW @ 4.5 K		19 kW @ 4.5 K		19 kW @ 4.5 K					
	# CM	51	99			189	189			189	189			24	930	
	E. Sum	10	28.1			53.6	53.6			53.6	53.6			5	257.5	

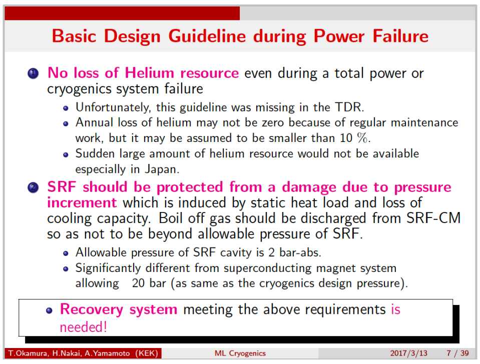
		RTM L-BC	ML-CM	PM -10 -u	PM -12 -d	ML-CM		PM -10 -u	PM -10 -d	ML-CM		PM -8 -u	PM -8 -d	e+ Booster	Sum	
Stage - 250 31.5MV/m 1E10	Cryo-Cost	19.05 + 29.27			---		---		58.54		58.54		32.54*		197.94	0
	# Cryo-P.	~0.2 + 0.5 = 0.7 → 1			---		---		1		1		~ 0.55		3.5 systems	
	# CM	51	45		---	---	---	---		189	189			24	498	
	E. Sum	10	12.8		---	---	---	---		53.6	53.6			5	135.0	
Stage - 250 +SRF R&D 35MV/m 1.6E10	Cryo-Cost	58.54									58.54 + 13 (for long distribution)				130	- 68
	# C-Plant	0.7 x (0.2 + 0.05 + 1) = 0.88 → 1 (TL reduction model: relatively lowered to ~ 70%, because of high-Q)									0.7 x (1+0.13) + x= 0.79 + ~0.x → 1				2 systems	
	# CM & (relative TL)	51	4.5		---	---	---	---		189 (132)	189 (132)			24 (17)	457.5	
	E. Sum	10	1.28		---	---	---	---		59.56	59.56			5	135.4	

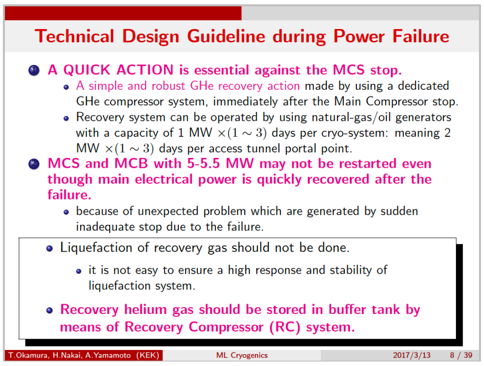
Attachment 3: ML Cryogenics (Okamura, Nakai, Yamamoto: briefly extracted, 2017)

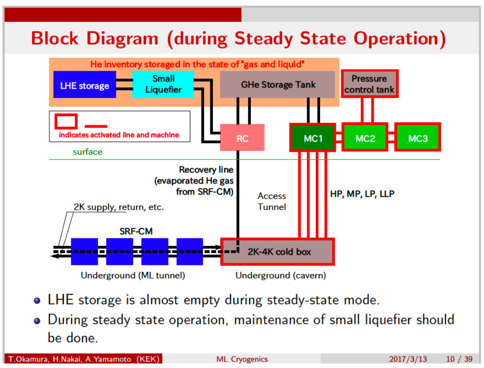


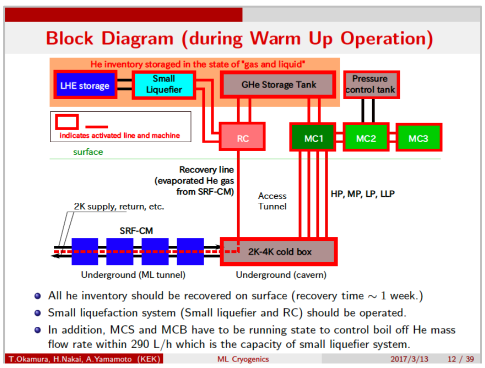


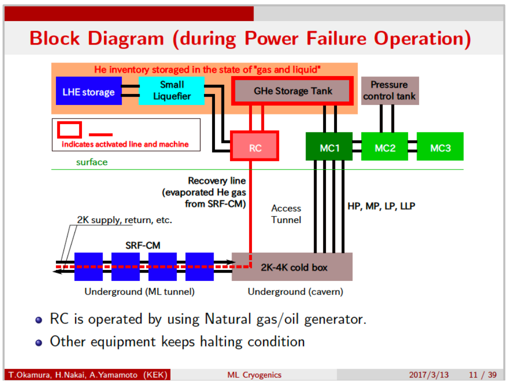


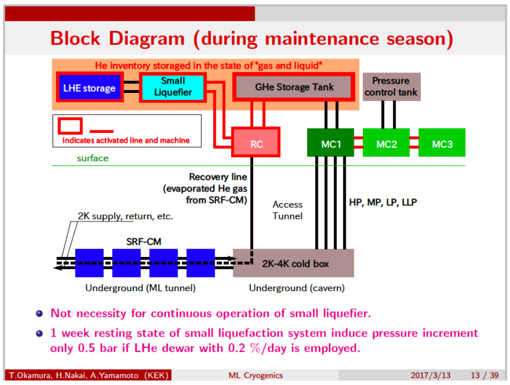


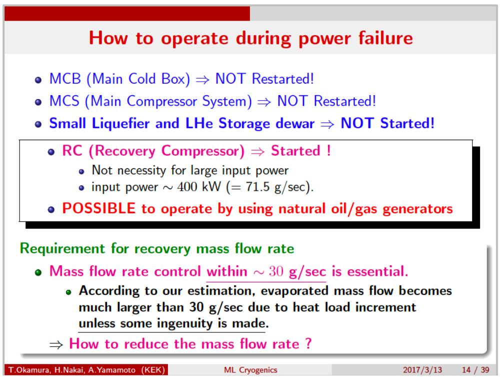


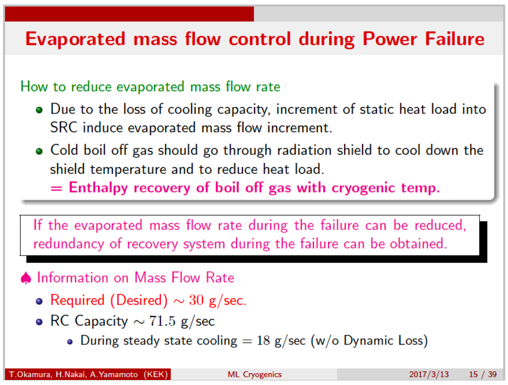


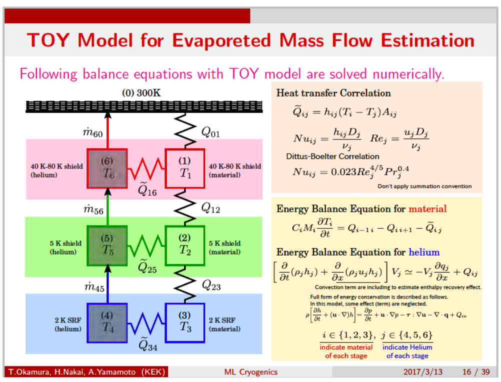


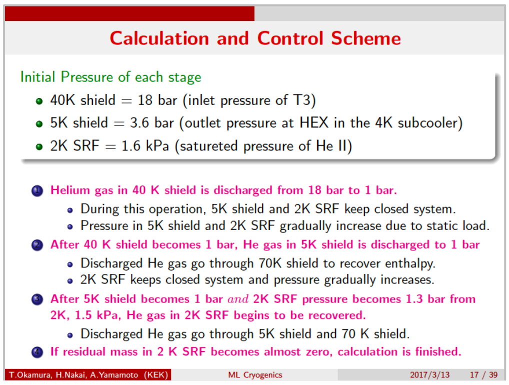

Block Diagram (during Power Failure Operation)
He inventory storaged in the state of "gas and liquid"
LHE storage
Small Liquefier
GHe Storage Tank
Pressure control tank
Indicates activated line and machine
RC
MC1
MC2
MC3
surface
Recovery line (evaporated He gas from SRF-CM)
Access Tunnel
HP, MP, LP, LLP
2K supply, return, etc.
SRF-CM
2K-4K cold box
Underground (ML tunnel)
Underground (cavern)
RC is operated by using Natural gas/oil generator.
Other equipment keeps halting condition
T.Okamura, H.Nakai, A.Yamamoto (KEK)
ML Cryogenics
2017/3/13
11 / 39

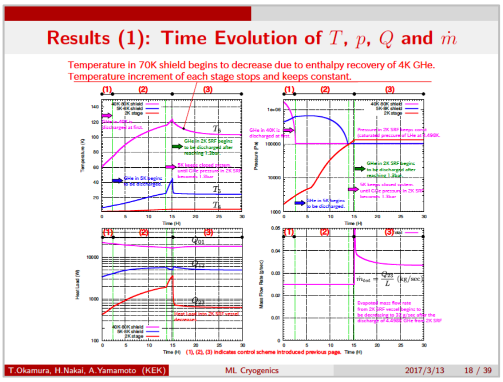

Block Diagram (during maintenance season)
He inventory storaged in the state of "gas and liquid"
LHE storage
Small Liquefier
GHe Storage Tank
Pressure control tank
Indicates activated line and machine
RC
MC1
MC2
MC3
surface
Recovery line (evaporated He gas from SRF-CM)
Access Tunnel
HP, MP, LP, LLP
2K supply, return, etc.
SRF-CM
2K-4K cold box
Underground (ML tunnel)
Underground (cavern)
Not necessity for continuous operation of small liquefier.
1 week resting state of small liquefaction system induce pressure increment only 0.5 bar if LHe dewar with 0.2 %/day is employed.
T.Okamura, H.Nakai, A.Yamamoto (KEK)
ML Cryogenics
2017/3/13
13 / 39

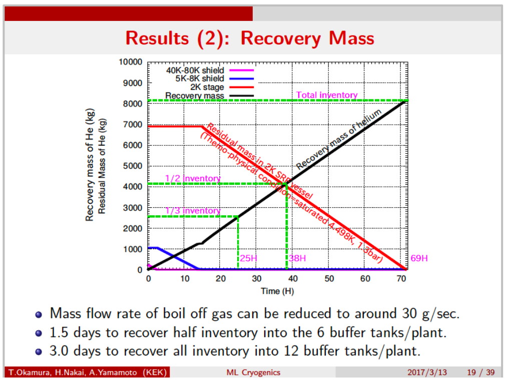

How to operate during power failure
MCB (Main Cold Box) ⇒ NOT Restarted!
MCS (Main Compressor System) ⇒ NOT Restarted!
Small Liquefier and LHe Storage dewar ⇒ NOT Started!
RC (Recovery Compressor) ⇒ Started !
Not necessity for large input power
input power ~ 400 kW (= 71.5 g/sec).
POSSIBLE to operate by using natural oil/gas generators
Requirement for recovery mass flow rate
Mass flow rate control within ~ 30 g/sec is essential.
According to our estimation, evaporated mass flow becomes much larger than 30 g/sec due to heat load increment unless some ingenuity is made.
⇒ How to reduce the mass flow rate ?
T.Okamura, H.Nakai, A.Yamamoto (KEK)
ML Cryogenics
2017/3/13
14 / 39


Evaporated mass flow control during Power Failure
How to reduce evaporated mass flow rate
Due to the loss of cooling capacity, increment of static heat load into SRC induce evaporated mass flow increment.
Cold boil off gas should go through radiation shield to cool down the shield temperature and to reduce heat load.
= Enthalpy recovery of boil off gas with cryogenic temp.
If the evaporated mass flow rate during the failure can be reduced, redundancy of recovery system during the failure can be obtained.
Information on Mass Flow Rate
Required (Desired) ~ 30 g/sec.
RC Capacity ~ 71.5 g/sec
During steady state cooling = 18 g/sec (w/o Dynamic Loss)
T.Okamura, H.Nakai, A.Yamamoto (KEK)
ML Cryogenics
2017/3/13
15 / 39


TOY Model for Evaporeted Mass Flow Estimation
Following balance equations with TOY model are solved numerically.
(0) 300K
40 K-80 K shield (helium)
40 K-80 K shield (material)
5 K shield (helium)
5 K shield (material)
2 K SRF (helium)
2 K SRF (material)
Heat transfer Correlation
Dittus-Boelter Correlation
Don't apply summation convention
Energy Balance Equation for material
Energy Balance Equation for helium
indicate material of each stage
indicate Helium of each stage
T.Okamura, H.Nakai, A.Yamamoto (KEK)
ML Cryogenics
2017/3/13
16 / 39

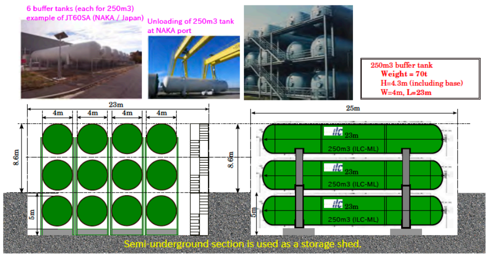

Calculation and Control Scheme
Initial Pressure of each stage
40K shield = 18 bar (inlet pressure of T3)
5K shield = 3.6 bar (outlet pressure at HEX in the 4K subcooler)
2K SRF = 1.6 kPa (saturated pressure of He II)
Helium gas in 40 K shield is discharged from 18 bar to 1 bar.
During this operation, 5K shield and 2K SRF keep closed system.
Pressure in 5K shield and 2K SRF gradually increase due to static load.
After 40 K shield becomes 1 bar, He gas in 5K shield is discharged to 1 bar
Discharged He gas go through 70K shield to recover enthalpy.
2K SRF keeps closed system and pressure gradually increases.
After 5K shield becomes 1 bar and 2K SRF pressure becomes 1.3 bar from 2K, 1.5 kPa, He gas in 2K SRF begins to be recovered.
Discharged He gas go through 5K shield and 70 K shield.
If residual mass in 2 K SRF becomes almost zero, calculation is finished.
T.Okamura, H.Nakai, A.Yamamoto (KEK)
ML Cryogenics
2017/3/13
17 / 39


Results (1): Time Evolution of T, p, Q and ṁ
Temperature in 70K shield begins to decrease due to enthalpy recovery of 4K GHe.
Temperature increment of each stage stops and keeps constant.
T.Okamura, H.Nakai, A.Yamamoto (KEK)
ML Cryogenics
2017/3/13
18 / 39


Results (2): Recovery Mass
40K-80K shield
5K-8K shield
2K stage
Recovery mass
Total inventory
1/2 inventory
1/3 inventory
Recovery mass of He (kg)
Residual Mass of He (kg)
Time (H)
25H
38H
69H
Mass flow rate of boil off gas can be reduced to around 30 g/sec.
1.5 days to recover half inventory into the 6 buffer tanks/plant.
3.0 days to recover all inventory into 12 buffer tanks/plant.
T.Okamura, H.Nakai, A.Yamamoto (KEK)
ML Cryogenics
2017/3/13
19 / 39

How to set up buffer tanks

- 6 buffer tanks / plant. ⇒ 12 tanks / location.
- Transportation and unloading scheme should be considered carefully.



T.Okamura, H.Nakai, A.Yamamoto (KEK) ML Cryogenics 2017/3/13 20 / 39

BOG behaviour during planned outage

Dewar Specification

- Volume : 43000 L (at 6 buffer tank (250 × 6 m^3)
- Size : ∼ L=12m, W=2.5m, H=2.6m
- Spec : 0.2 ∼ 0.5 %/day

During planned outage (3days continuously shutdown)

- (1 bar, 4.2 K) ⇒ (1.60 bar, 4.70 K) (@ 0.5%/day)
- (1 bar, 4.2 K) ⇒ (1.24 bar, 4.44 K) (@ 0.2%/day)

No problem during 3 days outage

T.Okamura, H.Nakai, A.Yamamoto (KEK) ML Cryogenics 2017/3/13 21 / 39

Small Liquefaction System (Small Liquefier)

Definition

Small Liquefaction System can be defined as follows.

- Compressor : (Recovery Compressor is used.)
- Small Liquefier : (Cooling capacity can be determined automatically from input power of RC.)

Assumption

- If 6 buffer tanks are employed, half inventory should be stored in LHE dewar.

Specification

- Liquefier : maximum liquefaction capacity=290 L/h
  ⇒ MCB has to be continuously operated to keep this condition.
- Required mass flow : 80 g/sec (410 kW = RC power)
- Half inventory can be liquefied for 4.5 days (within 1 week).

T.Okamura, H.Nakai, A.Yamamoto (KEK) ML Cryogenics 2017/3/13 22 / 39

Discussion on Storage Scheme

- GHe and LHE mixing storage scheme has a source of unrest shown below from the view point of inventory loss.
  - In the case of severe damage of MCB such that MCB can not be operated within 1.5 days
  - In the case of severe damage of small liquefaction system such as liquefier and LHE dewar.
- Recovery time can be reduced from 1 week to 3 days in the case of GHe storage scheme.
- Manufacturing cost without small liquefaction system is a little bit cheaper than half and half mixing storage scheme.
- Required surface area is almost same each other. (if config. shown P19 is applied)

Storage Scheme unit : (**)		buffer tank	Small liquefaction system	Other, Transport etc.	Total Cost
12 buffer tanks	w/o small liquefier	6.72	0	4.1	10.82
6 buffer tanks	w/ small liquefier	3.36	5.4	2.6	11.36

Storage Scheme unit : (m2)		buffer tank	Small liquefaction system	Other, Transport etc.	Total Area
12 buffer tanks	w/o small liquefier	46m x 25m	8m x 14m (RC)		1263
6 buffer tanks	w/ small liquefier	23m x 25m	30m x 23m (RC, Liquefier, LHe dewar)		1265

T.Okamura, H.Nakai, A.Yamamoto (KEK) ML Cryogenics 2017/3/13 23 / 39

Summary (1)

Power Failure

- Instead of Storage Scheme introduced in TDR, not only LHE dewar but also GHE buffer tanks are employed for preventing loss of He inventory during power failure.
- Recovery compressor (RC) should be located on surface but its capacity should be enough small to be operated using LNG generator during the failure. Several hundreds kW can be acceptable. (MW order can not be acceptable.)
- To perform this, recovery mass flow rate during the failure should be reduced. Enthalpy recovery operation seems effective way to reduce the mass flow rate.
- According to the simulation based on toy model, mass flow rate can be reduced to around 30 g/sec. In this case, if 6 tanks with 250 m3 are located on surface, resting state of MCS and MCB for 1.5 days can be acceptable.

T.Okamura, H.Nakai, A.Yamamoto (KEK) ML Cryogenics 2017/3/13 25 / 39

Summary (2)

Maintenance and other operation

- When all inventory is recovered for maintenance season, small liquefier is needed. RC can also be applied to small liquefaction system.
- Fraction between Liquid and Gas can be optimized by considering site environmental condition.
  - Recently, we considered 1/2 in Gas and 1/2 in LHE.
  - to be discussed further with Tohoku group.
- Recovery time for the total inventory is within 1 week by using small liquefaction system. To perform this, MCS and MCB have to be operated continuously during recovery mode.
- Tentative stop of the Small liquefaction system such as planned outage can be acceptable. To ensure it, allowable pressure should be 10 bar or so and less heat load into the dewar such as 0.2-0.5 %/day should be used.

T.Okamura, H.Nakai, A.Yamamoto (KEK) ML Cryogenics 2017/3/13 26 / 39

Back Data

T.Okamura, H.Nakai, A.Yamamoto (KEK) ML Cryogenics 2017/3/13 28 / 39

Detailed comparison

Comparison Item		12 buffer tanks scheme	6 buffer tanks and LHE Dewar scheme
Cryo components for recovery system	buffer tanks	12	6
	recovery compressor	400kW	400kW
	small liquefier	-	280L/h
	LHE dewar	-	42000L
	cryogenic pipe	-	4 cryo pipes (3-5m)
	cryo control system	-	necessary
Piping through access tunnel	HP	318.5mm	318.5mm
	MP	508mm	508mm
	LP	406mm	406mm
	LLP	406mm	406mm
	Recovery line	165.2mm	165.2mm
exclusive area on surface(m2)		1265	1265
necessity for building		-	necessary
Cost	buffer tanks	6.72	3.36
	recovery compressor	0.7	0.7
	Cold box	-	4.4
	LHE dewar	-	1
	Transportation	1.8	0.9
	unloading crane	0.4	0.4
	Site construction	1.2	0.6
	SUM	10.82	11.36

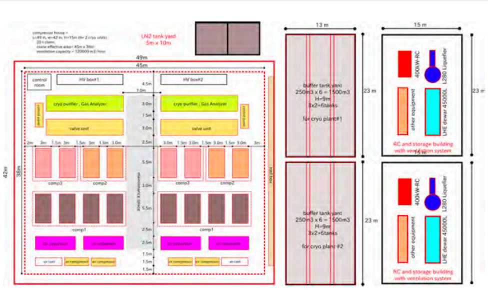
- **ILC site-specific utility designs are same for each storage scheme.**

- Brief cryogenic equipment is summarized in following table

			Input Power		Specification			Size	Weight
Surface	MCS	Main Compressor System	5-5.5 MW	6.6kV	Pout=2MPa	8 comps	1614 g/sec	(L5.7m x W2.8m x H3.3) x 8 sets	13t x 8sets
	RC	Recovery Compressor	370-410 kW	6.6kV	Pout=2MPa	1 comp	71.5-85.5 g/sec	(L5.5m x W3m x H2.9m) x 1 set	18.5 t
	BT	Buffer Tank			250m3 x (4+2)	22000 L @LHE		(L23m x W4m x H4.3m) x 6 sets	70 t x 6 sets
	SD	Storage Dewar				44000 L @ LHE		OD3.5m x L13m	under investigation
	SL	Small Liquefier with Turbines		3P200V	290 L/h				
	CE	Cold Evaporator		3P200V	10000 L				
Access Tunnel	HP	High Pressure Pipe			Single , SUS304TP-A	not insulated	1606 g/sec, 300K	OD=318.5mm	
	MP	Middle Pressure Pipe			Single , SUS304TP-A	not insulated	1235 g/sec, 300K	OD=508mm	
	LP	Low Pressure Pipe			Single , SUS304TP-A	not insulated	234 g/sec, 300K	OD=406mm	
	LLP	Negative Pressure Pipe			Single , SUS304TP-A	not insulated	136 g/sec, 300K	OD=406mm	
	RP	Recovery Pipe			Single , SUS304TP-A	with drain	30g/sec, 80K-300K	OD=165.2mm	
	CR	Cable Rack			W600mm x 2 stages		LAN Cable, Signal Cable	W600mm x 2 stage	
Cryo Cavern	Upper MCB	300K to 70K Main Cold Box		3P200V	see Flow diagram and TS diagram			L9.1m x W3.7m x H4.35m	34 t
	Lower MCB	70K to 1.8K Main Cold Box		3P200V	see Flow diagram and TS diagram			L14m x W3.5m x H4m	50 t
	SCB	Sub Control Box for MCB	3P200V, 2P200V, 2P100V		under investigation			L5m x W600m x H2.1m	
	TCR	Tentative Control Room		2P100V				L4m x W2.5m x H2.5m	
Access Tunnel to ML	TRT	Transfer Tube			6 pipes in one Jacket /			Jacket OD=650A-750A	
					2 for 70K shield / 2 for 5K shield / 2 for 2K shield			70K shield (sup/ret) OD=72mm/80mm	
					under investigation			5K shield (sup/ret) OD=56mm/70mm	
								2K (sup/ret) OD=70mm/300mm	

- small equipment described as follows are not listed in the table.
  - air compressor for control valves
  - cryo purification system
  - Gas analyzer
  - dryer
  - vacuum pump
  - 6.6 kV High voltage control unit for MCS
  - cooling water system for MCS and turbines installed in MCB
  - etc...

Surface Layout for 2 plants



Evaporated mass vs Buffer tank volume

Recovery Time and Buffer tank volume are shown at around 30 g/sec.

HE Inventory (kg / plant)		evaporated mass flow (kg/sec)	recovery time (H)	recovery time (Days)	Number of 250m3 Buffer tank: required	Number of 250m3 Buffer tank: contingency
40K shield	246	0.03	2	0.1		
5K shield	1068	0.03	10	0.4		
2K SRF	6901	0.03353	57	2.4		
1/3 inventory	2738	0.03	25	1.1	4	2
1/2 inventory	4108	0.03	38	1.6	6	2
Total inventory	8215	0.03291	69	2.9	11	-

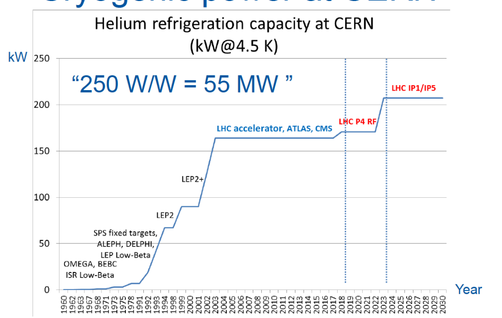
Time to fill up at 30 g/sec.

- 4+2=6 tanks (1/3 inventory) ⇒ 25H
- 6+2=8 tanks (1/2 inventory) ⇒ 38H
- 11 tanks (total inventory)⇒ 69H

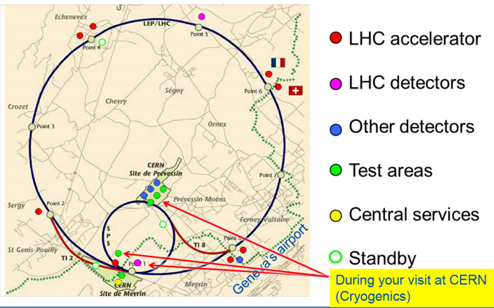
Further detailed dynamic simulation will be performed continuously instead of using TOY model.

Attachment 4. Cryogenics at CERN (by D. Delicaris： briefly extracted, 25-11-2013)

Cryogenic power at CERN



Cryogenic Plants at CERN



Management of Cryogenic Fluids

- Total **HELIUM** inventory at CERN: 170'000 kg
- LHC (accelerator & detectors) helium full inventory: 136'000 kg
- Additional strategic permanent storage during operation: 15'000 kg

- LHC (accelerator & detectors) liquid **NITROGEN** needs for a full cool down: 11'500 ton

(LHC accelerator full cool down: 10'000 ton in 33 continuous days; equivalent to 500 standard transportable containers delivered by industrial suppliers)

- In situ helium liquefaction for central services (up to 350'000 liter per year) and distribution by means of mobile containers ranging from 100 to 2'000 liter (users without dedicated cryogenic plant)

Helium & Nitrogen Storage

Storage infrastructure (in brackets: capacity dedicated to LHC)

Gas & liquid helium storage capacity at CERN

Gas tank capacity [m³]	250 (at 2.1 MPa)	80 (at 1.5 & 2.1 MPa)
Number of units at CERN	58 (58)	65 (40)

Liquid tank capacity [liter]	120'000 (fixed)	25'000 (fixed)	11'000 (mobile)	6'000 (fixed)
Number of units	6	1	2	1

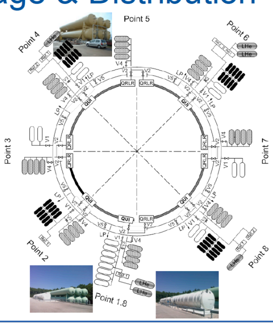
Liquid nitrogen storage capacity at CERN

Container capacity [liter]	50'000	40'000	27'000	20'000	15'000	10'000	6'000
Number of units	14 (13)	2	1	2	2	1	7

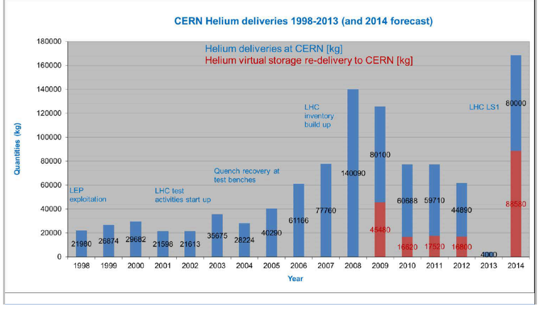
Helium Storage & Distribution

LHC helium storage & Distribution (high grade helium ring line, 2 MPa, 27 km long, for LHC operation)

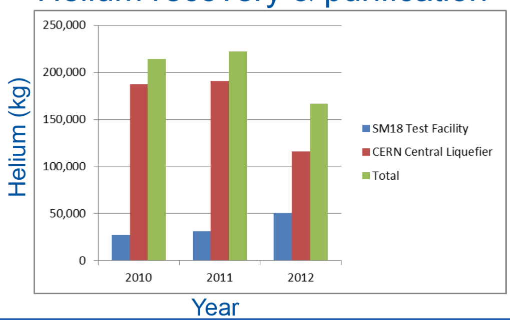
[Completing the existing CERN helium recovery system: high grade, 20 MPa, 5 km long and low grade, 3 kPa & 20 MPa, 3 km long each]



Helium Supply at CERN



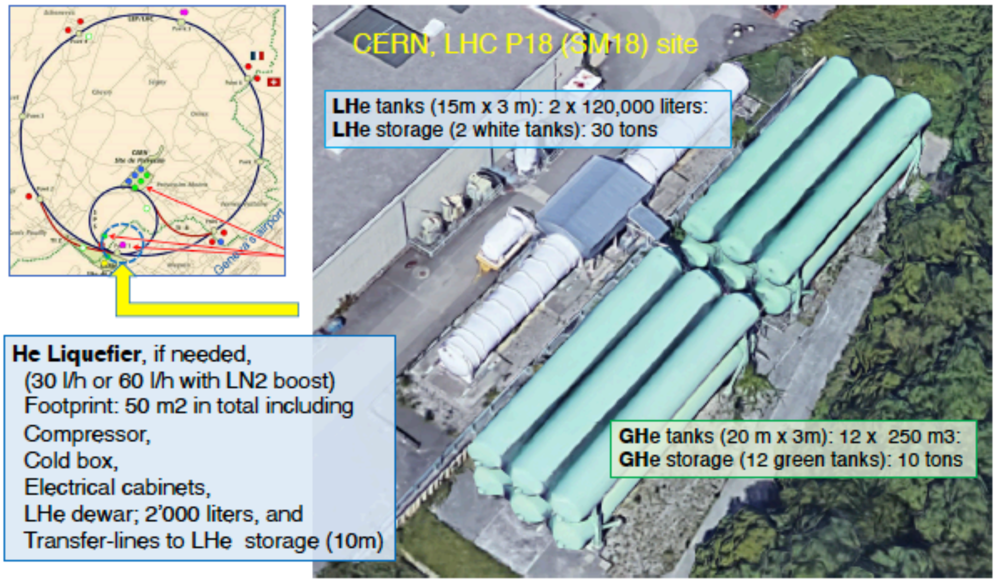
Helium recovery & purification



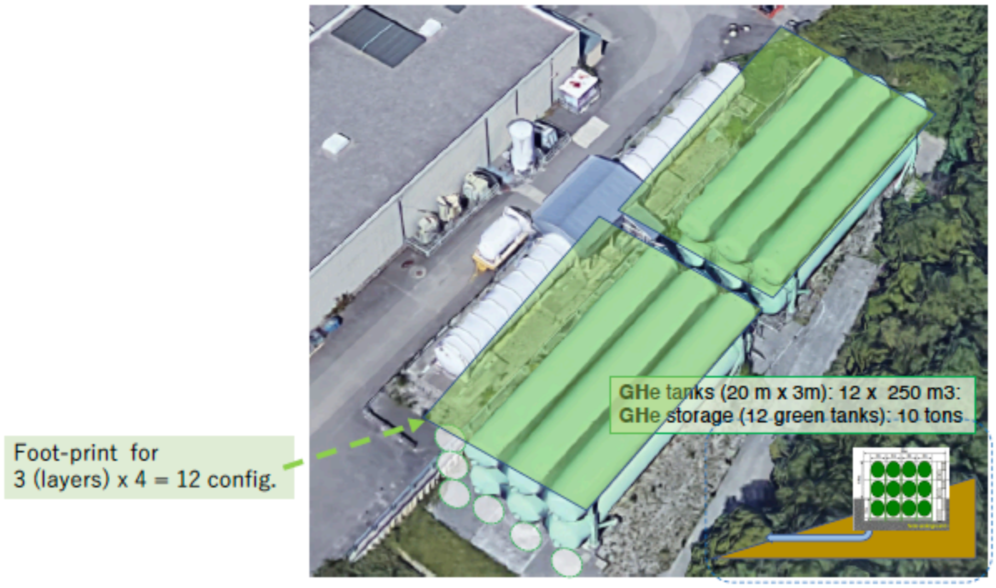
Summary

- Cryogenics at CERN: since 1960's for cooling components on accelerators, physics detectors & test facilities
- Very large spectrum of cryogenic engineering & working conditions (applications and refrigeration capacity @ T K)
- Implementation & successful operation of "state of the art" industrial cryogenic equipment at the edge of the present technology: The LHC cryogenic system (26.7 km, cooling @1.8 K, 80 ton of He II)
- Procurement and management of very important cryogen inventory (helium and nitrogen)
- Cryogenic operation availability to the users:
  - Before the LHC era: nearly 590'000 running hours have been cumulated over 15 years with a mean availability rate of 99%
  - The present LHC mean availability is already situated around 95%; progress is very impressive! Peaks at 99% are observed for several week periods!

Attachment 5: He Inventory Configuration at CERN LHC P18 (SM18)



Current Foot-Print: LHe (2) and GHe (2 x 2 x 3) Configuration



Image, Foot-Print: GHe (2 x 3 x 4) Tanks Configuration.