EASITrain

EASISchool 2 on Cryogenics

30 September 2019 to 4 October 2019
CEA, France
Europe/Paris timezone

research instruments

Cryogenic projects at RI and Cryogenics for ESS

Michael Pekeler, RI Research Instruments GmbH

September 30th, 2019

RI Research Instruments

Facts and figures

- Founded in 2009
- Employees 220

  ca. 90 physicists, engineers
  ca. 100 manufacturing specialists
- Annual revenue: 35-40 million EUR
- Established with the core team of ACCEL Instruments GmbH (1994-2009) and of INTERATOM/Siemens
- Management holds significant equity stake in the company which is majority owned by Bruker EST, Inc.

Our site

***Technologiepark* of Bergisch-Gladbach, a city very close to Cologne, Germany**

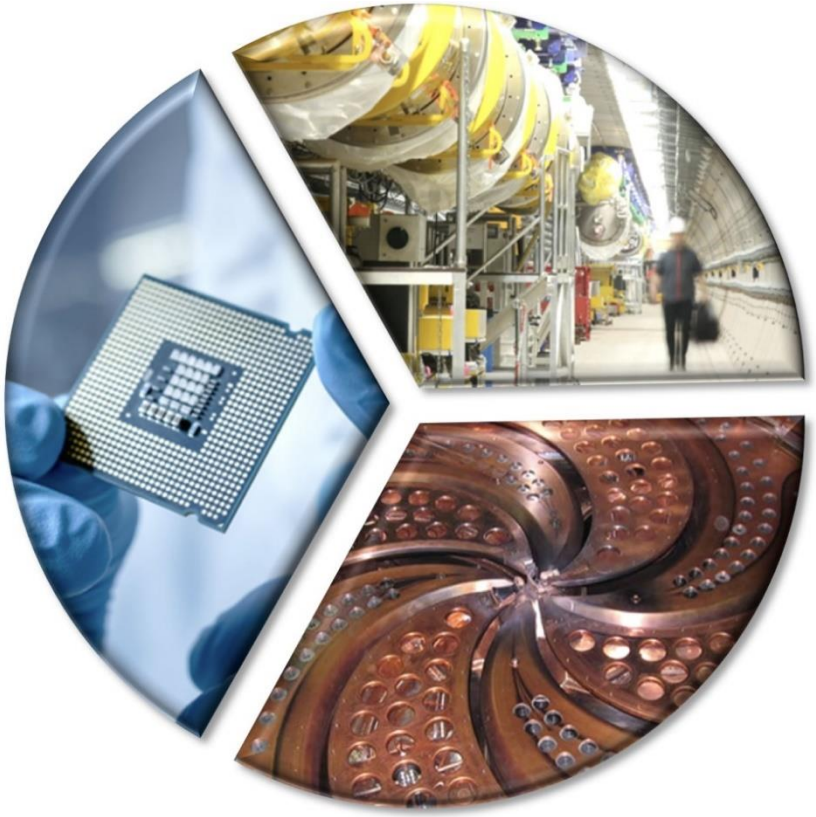
RI rents buildings (highlighted) of the Technologiepark

Our site is 20 km away from the cathedral of Cologne

Our customers

Industry (5 MEUR):

- EUV tools
- Components for EUV lithography machines



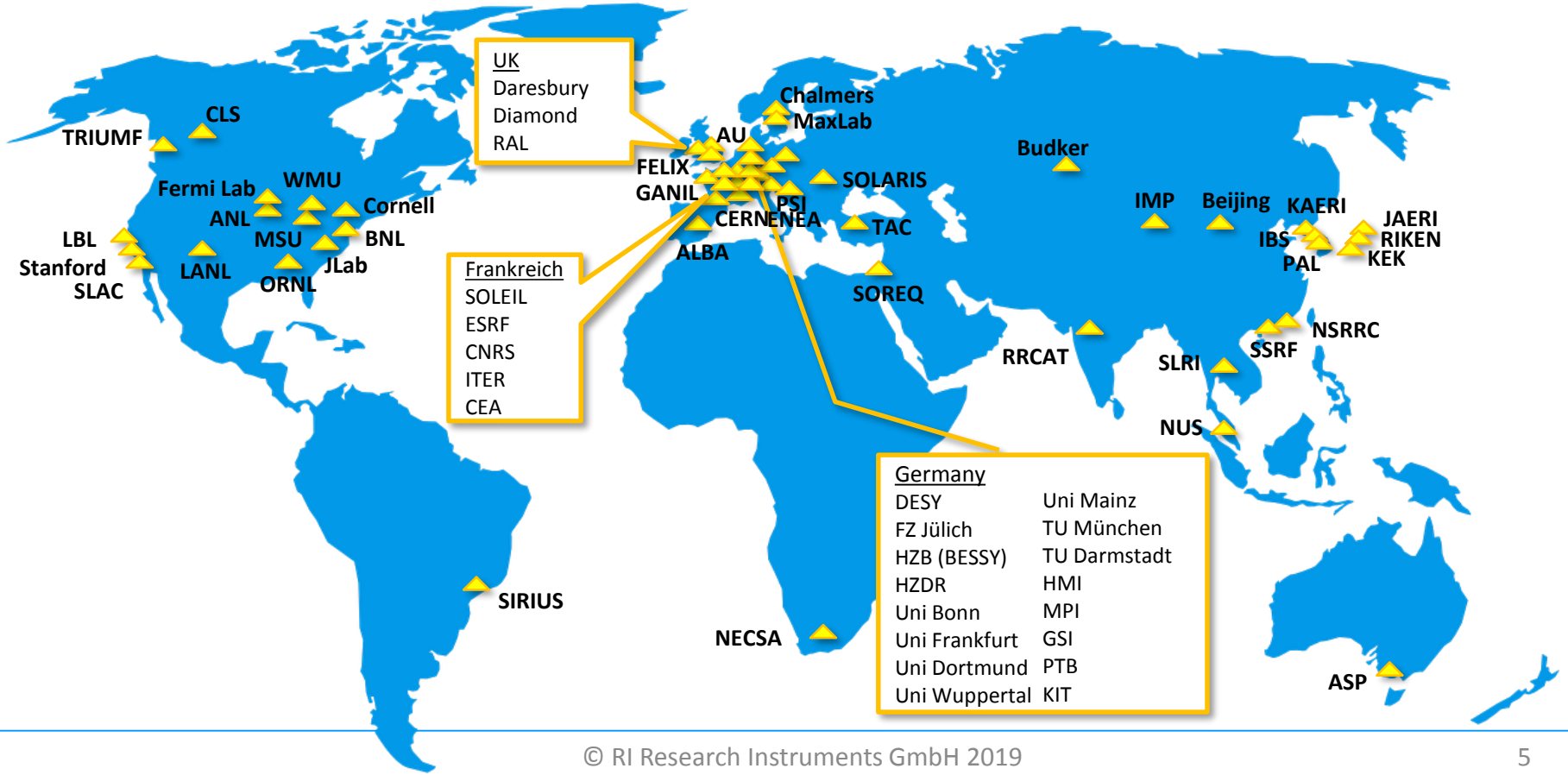
„Big Science“ (30 MEUR):

- SRF cavities and accelerator modules
- Fusion equipment
- Normal conducting cavities, RFQ’s, linacs
- Photon instrumentation

Medical & pharma (5 MEUR):

- Components for Varian proton therapy cylotrons
- Design of SRF accelerator for Mo99 production

Our map of the world



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RI manufactory

The RI manufactory

A one-stop-shop on 6000 m²

The RI manufactory

A one-stop-shop on 6000 m^2

- Forming, milling and turning
- Certified welding and brazing
  - Electron beam welding
  - Vacuum and induction brazing
  - TIG welding
- Electro-chemical and physical surface preparation and coating

- Heat treatments
- Clean room assembly
- State-of-the-art test facilities
  - RF measurements
  - Vacuum and cryogenics
  - Electromagnetic field measurements
  - Dimensional inspection, alignment and vibrational test

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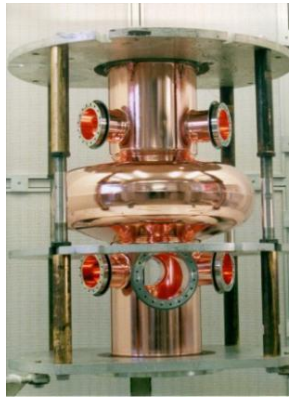
Selection of Accelerator projects for cryogenic application

Superconducting RF cavity production

1900 SRF cavities produced so far
Since 2013: delivering 100 cavities/year
World leader in SRF cavity manufacturing

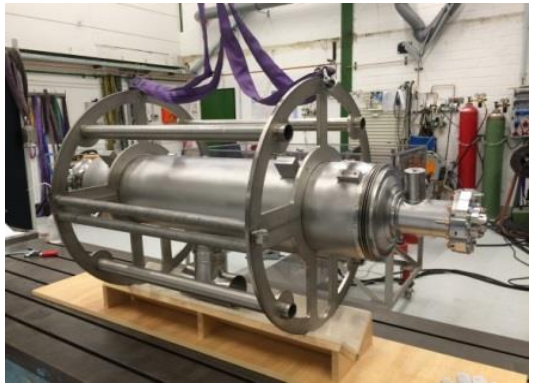


TESLA-type SRF cavity production

420 cavities for European XFEL project at DESY
from 2010 to 2015

210 cavities for LCLS-II project at SLAC
from 2015 to 2018

- Manufacturing of cavity, respecting the pressure vessel code
- Complete surface preparation and helium vessel welding
- Including N2 doping for LCLS-II



Cavities are shipped und vacuum ready for cold RF testing at customer

Delivery rate: 4 cavities per week, first cavity 6 months after material receipt

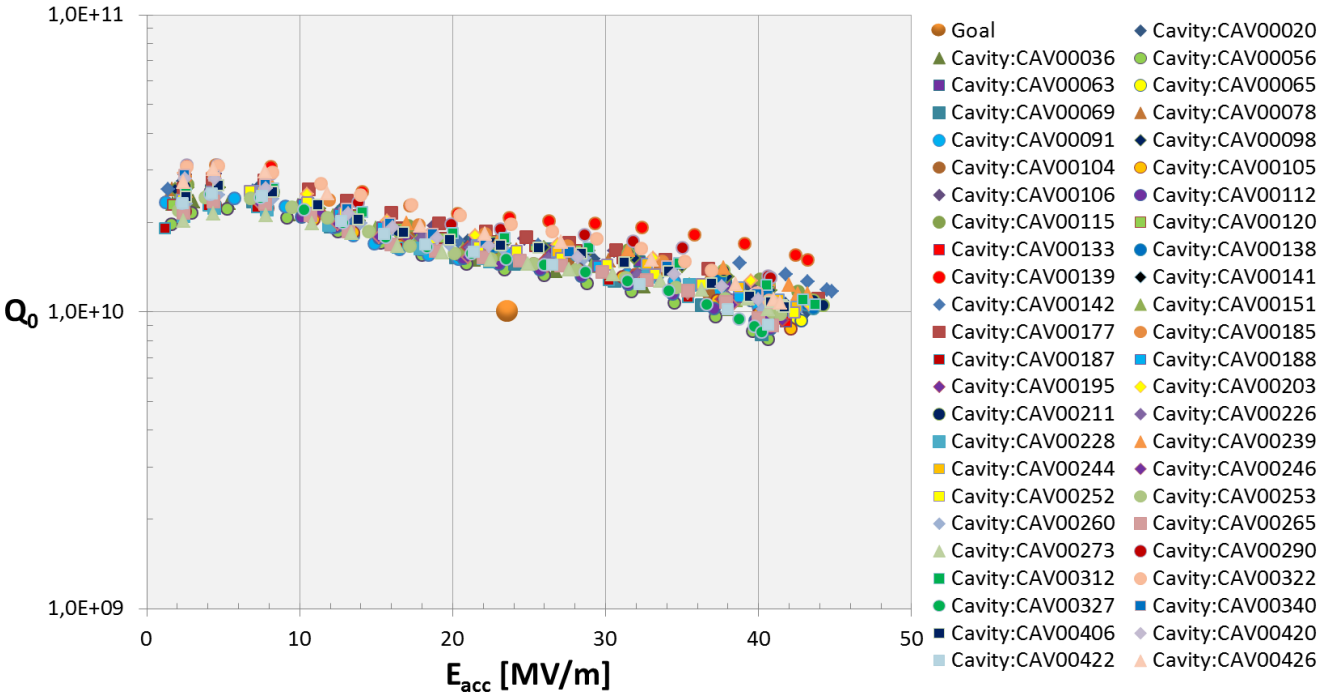
SRF cavity assembly in ISO 4 clean room

research instruments

RI XFEL cavity performance

Cavity cold test results:

- **47 of 420 cavities** of RI cavity production exceeded **40 MV/m**
- **More than half** of the 420 cavities exceeded **35 MV/m**
- **Average accelerating gradient** of all RI cavities was **33 MV/m (RMS 6.5 MV/m)**



Ongoing SRF cavity production at RI

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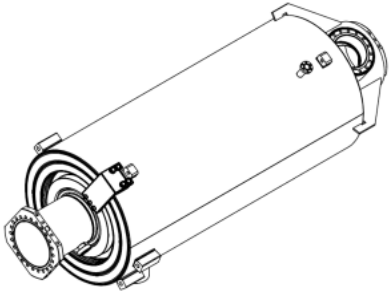
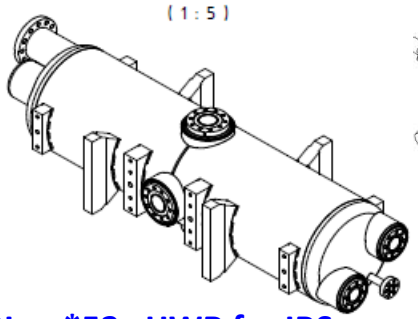
***Scope includes surface preparation (BCP/EP, HPR, clean room assembly)**
Only mechanical manufacturing

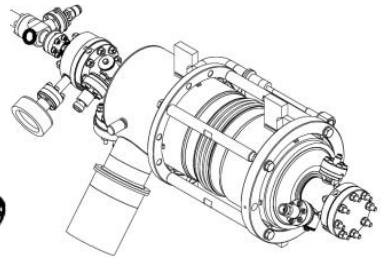
In total **250 cavities** currently under production



***88x ESS prototypes for UKRI**

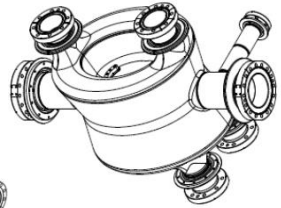


***52x HWR for IBS project**

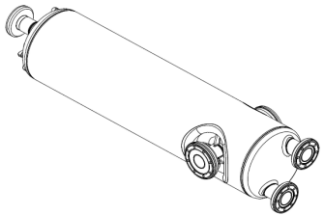


***24x 3rd harmonic 3.9 GHz for LCLS-II**

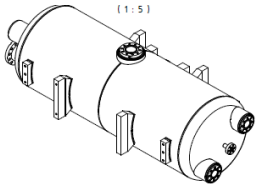
***30x PPU cavities for ORNL**



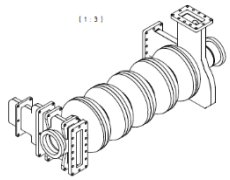
***11x crab cavities for CERN**



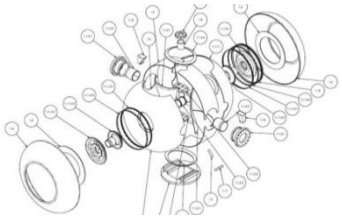
9x QWR for IBS



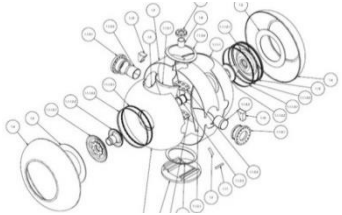
21x HWR for CEA/SARAF



8x C75 cavities for JLAB



1 SSR1 spoke for IBS

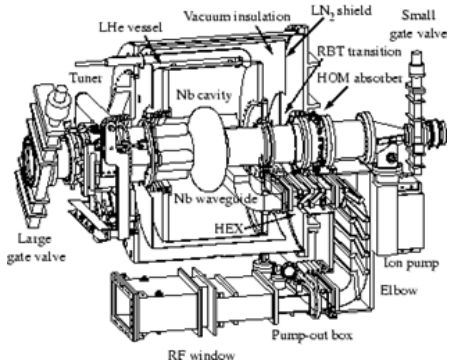


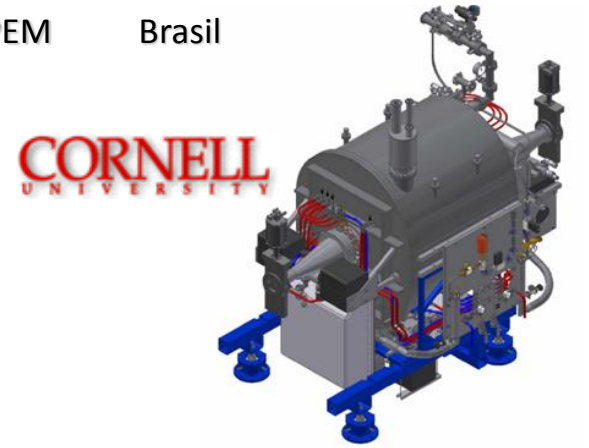
***2 SSR2 spoke for IBS**

500 MHz SRF accelerator modules

Technology transfer from Cornell University, USA

2 SRF modules	for NSRRC,	Taiwan
2 SRF modules	for CORNELL,	USA
3 SRF modules	for CLS,	Canada
4 SRF modules	for DLS,	Great Britain
3 SRF modules	for SSRF,	PR China
4 SRF modules	for PAL,	Korea
2 SRF modules	for CNPEM	Brasil





Turn key SRF modules:

- Cavity production, surface preparation and test
- Coupler production and conditioning
- Ferrite style HOM loads
- Module assembly,
- **Installation on customer site**
- Commissioning, performance guarantee on cavity voltage and Q0
- **Valve boxes and transfer lines lines**
- **SRF Electronics, interlock and data acquisition system**

Factory testing, shipping, installation

We do it all






research instruments

Fusion projects - focus on components for cryogenic application

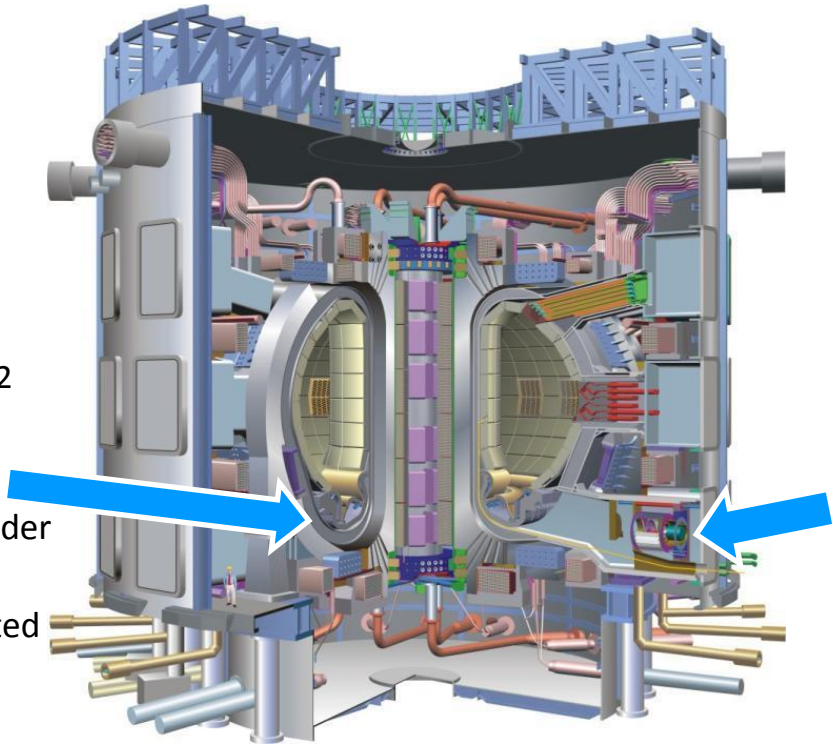
ITER components by RI

Grids for beam sources

- Spider grids done, DNB grids ongoing
- MITICA grids under production since 2019
- tender of grids for ITER sources expected in 2022

Inner vertical target (IVT)

- Full scale prototype under production at RI
- tender of series expected in 2022



IFMIF cryomodule assembly

- Assembly at QST, Japan of an SRF module (8 HWR cavities) for proton acceleration
- Project should be finished in 2020

Front end cryopump distribution system

- Design and manufacturing of 8 cryogenic valve boxes
- contract received in June 2018

Torus and vacuum vessel cryopump

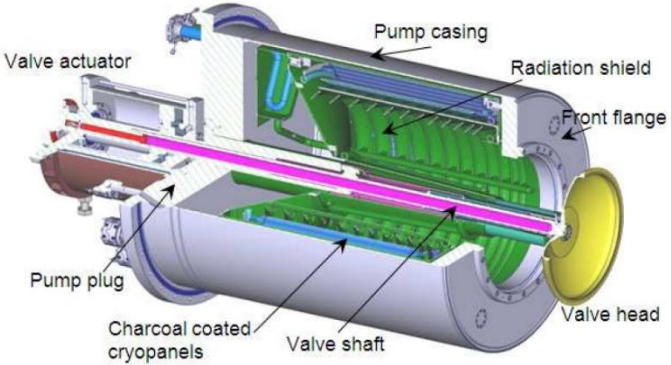
- Pre-production pump finished
- Now producing 8 pumps for torus and vacuum vessel

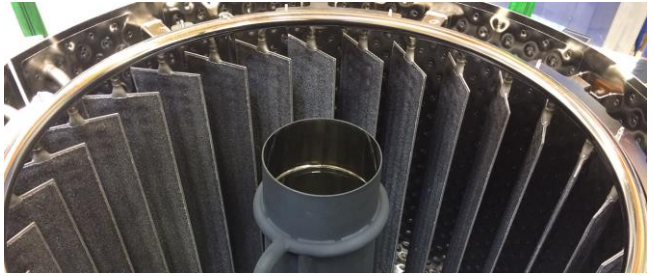
Torus and vacuum vessel cryopump

Consortium RI - Alsyom built Pre-Production Cryopump and is now producing 8 Series Cryopumps

Pump size:
diameter 1.5 m, length 3 m length

Redesign of the valve bearings and alignment strategy of the valve (with Alsyom, F4E, and IO)





Special manufacturing and assembly

WGTS (Windowless gaseous tritium source)
for KATRIN (KArlsruhe TRItium Neutrino) experiment at KIT, Germany

Weight 25 t, length 16 m, height 5 m, width 2 m

- Technologies: superconducting magnets, ultra high vacuum, cryogenics, alignment, welding, assembly, leak testing, QA, documentation
- 5 different cryogens used:
  Liquid neon, **liquid argon**, **liquid nitrogen**, **liquid helium** and **gaseous helium**
- Delivered in September 2015, WGTS in full operation at KIT since 2017

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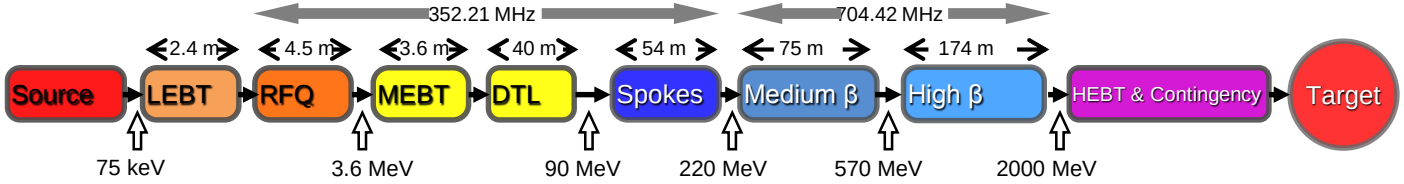
ESS cryoplant

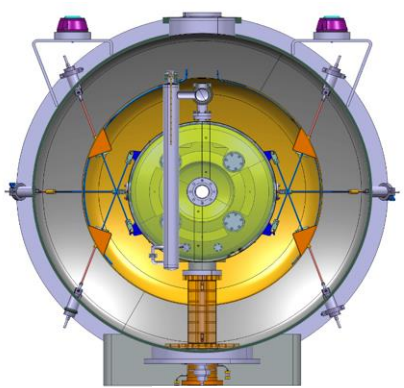
ESS Linac - layout

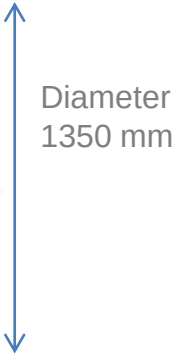


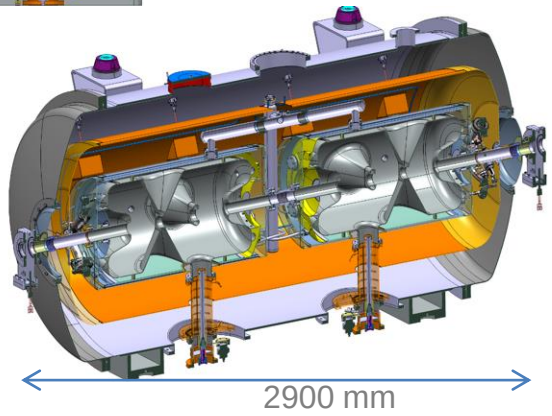
	Energy (MeV)	No. of Modules	No. of Cavities	βg	Temp (K)	Cryo Length (m)
Source	0.075	1	0	–	~300	–
LEBT	0.075	–	0	–	~300	–
RFQ	3.6	1	1	–	~300	–
MEBT	3.6	–	3	–	~300	–
DTL	90	5	5	–	~300	–
Spoke	220	13	2 × 13	0.5 β_{opt}	~2	4.14
Medium β	570	9	4 × 9	0.67	~2	8.28
High β	2000	21	4 × 21	0.86	~2	8.28
HEBT	2000	–	0	–	~300	–

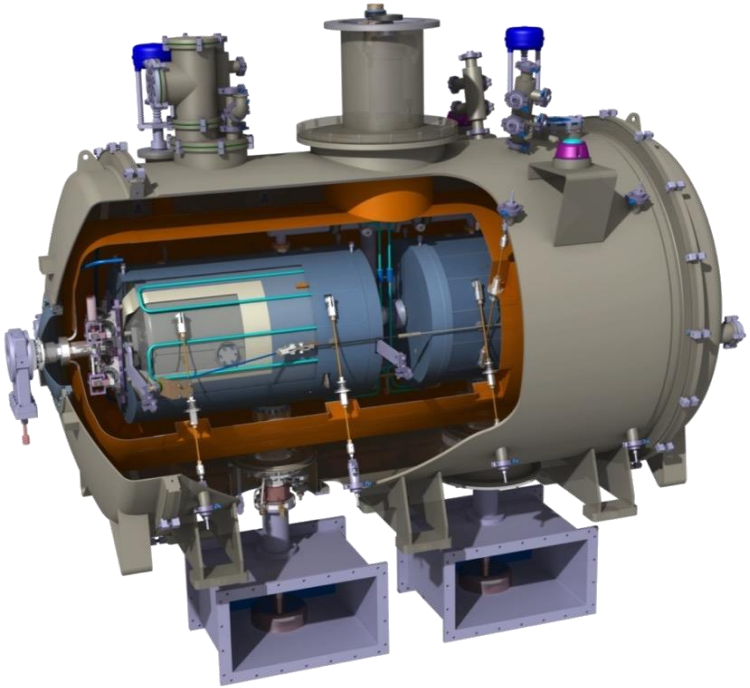
Upgrade with additional 14 high β cryomodules possible

Double spoke cavity cryomodule





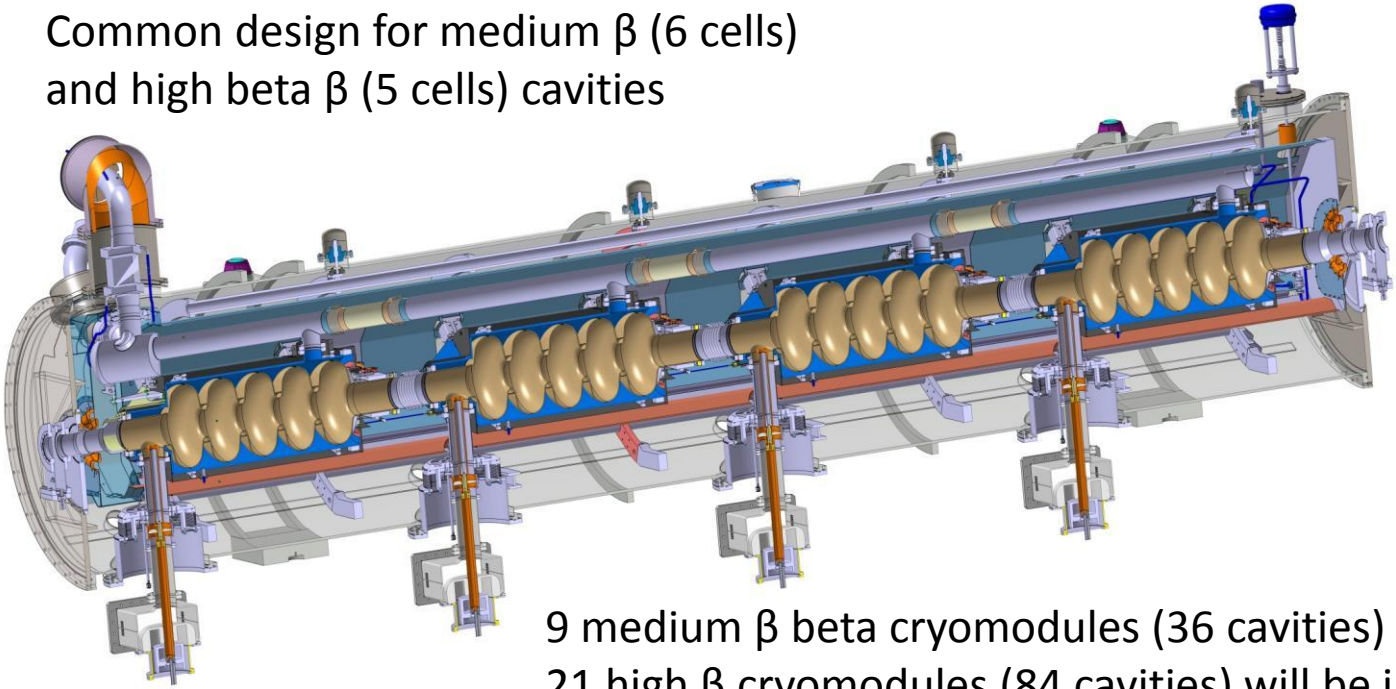




13 cryomodules, 26 cavities will be installed in ESS
Design by CNRS, France , 352 MHz

Medium / high β beta cavity cryomodule

- Similar to CEBAF/SNS cryomodule concept with 4 cavities per cryomodule
- Common design for medium β (6 cells)
  and high beta β (5 cells) cavities



9 medium β beta cryomodules (36 cavities) and
21 high β cryomodules (84 cavities) will be installed in ESS
Design by CEA, France, 704 MHz

Accelerator cryoplant at ESS

Accelerator and cryo distribution cryoplant includes capacity for upgrade with 14 add. high beta SRF modules	2K [W]	Thermal shields 50 K [W]	Coupler cooling 4-300 K [g/s]
Spoke, medium beta and high beta SRF modules	3 060	11 300	9.0

- Supercritical helium at 4.5 K is transported to the SRF modules and 2 K helium is generated in the SRF modules by a JT valve
- Duty cycle of linac is 4%, for cw operation plant (2 K capacity) must be factor 15 larger (static losses ≈ dynamic losses)
- Safety factor to calculate the cryogenic load was 1.5
- No liquid nitrogen pre-cooling for accelerator cryoplant to avoid large amount liquid nitrogen inventory/usage

- 2 K operating temperature was chosen for more stable operation of the cavities, no pressure fluctuations, no excessive tuning at operating temperature

Two more cryoplants installed at ESS

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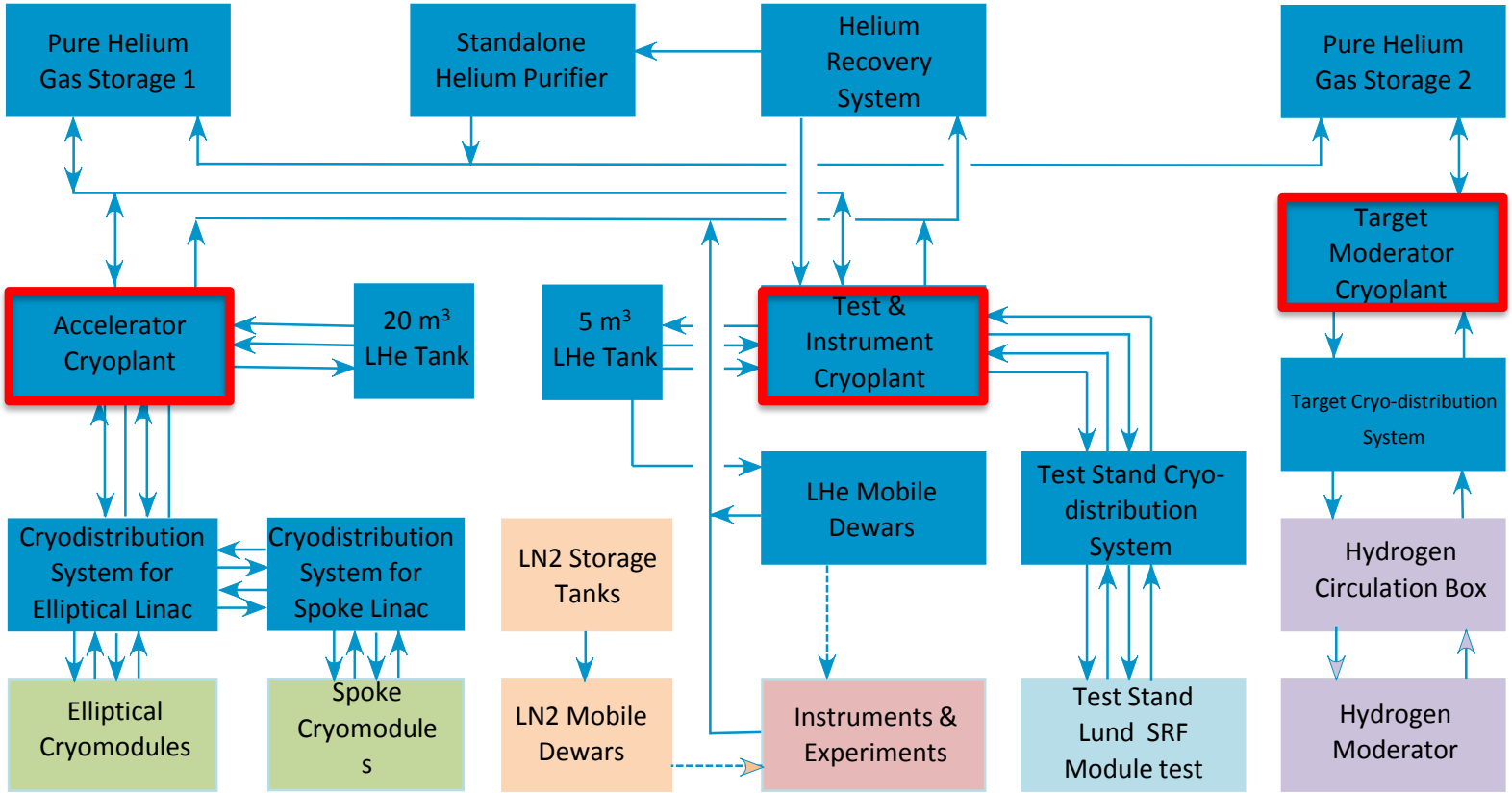
Target moderator cell cryoplant	15-20K [W]	LN2 pre-cooling
The target moderator cell is operated with liquid hydrogen. The hydrogen is cooled by means of an heat-exchanger with 15 K helium gas	32 000	No

Test and instruments cryoplant	Liquefaction [g/s]	50 K [W] Thermal shields	LN2 pre-cooling
Cryoplant for SRF cryomodule test and for supply of experiments with liquid helium	4	390	Yes

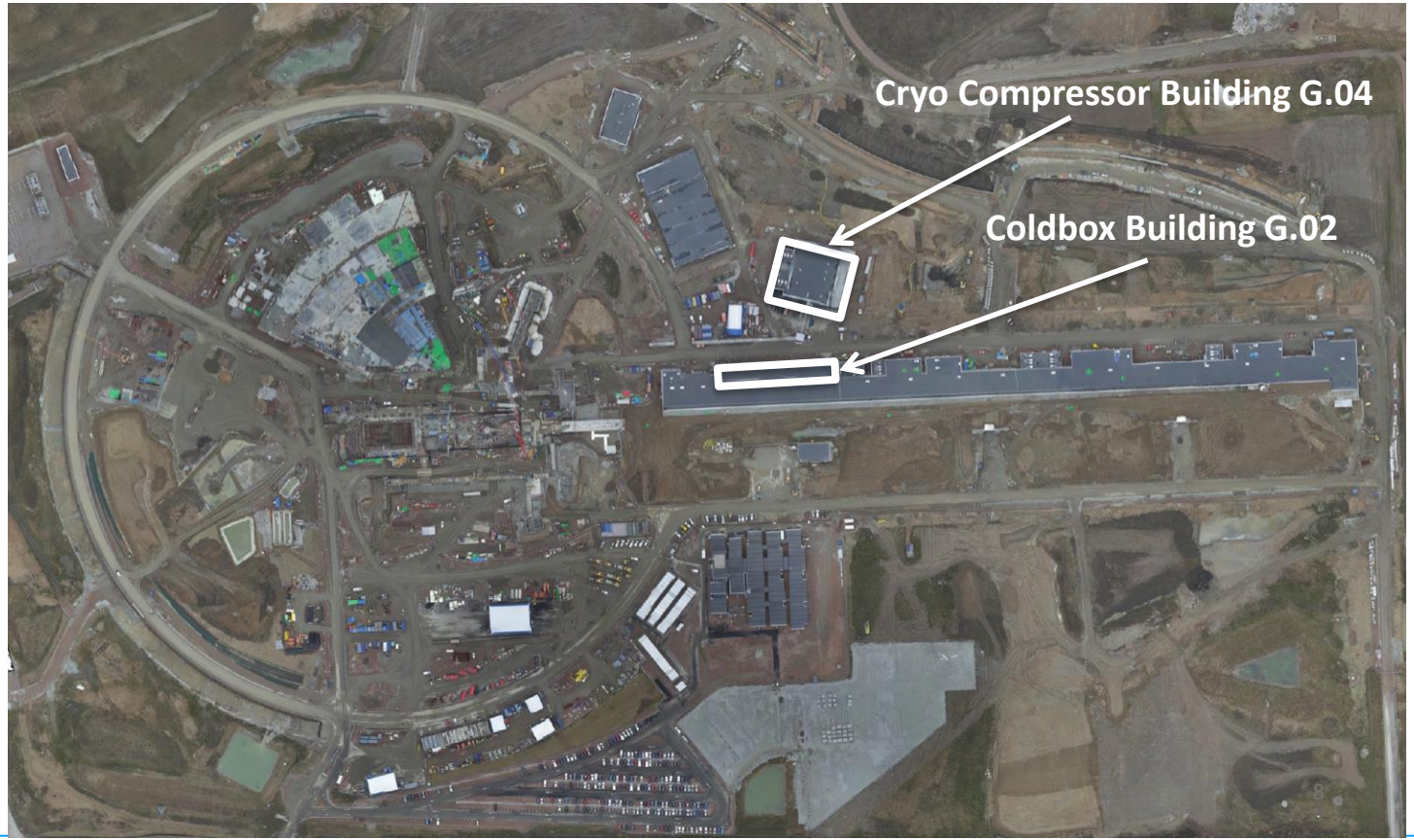
Overview, three cryoplants for ESS



Major Components and Status

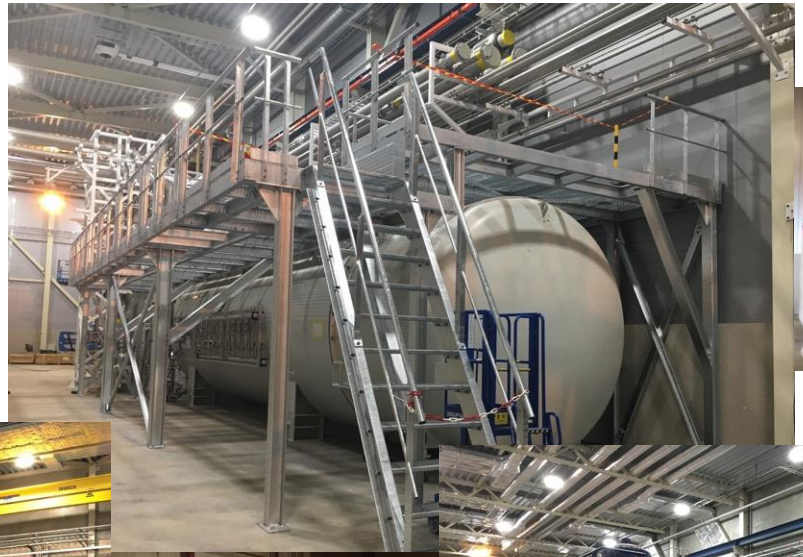
Work Unit and Name	Supplier	Status
Accelerator cryoplant	Linde Kryotechnik, CH	Commissioning
Test and Instruments cryoplant	Air Liquide Advanced Technologies, FR	In Operation
Target moderator cell cryoplant	Linde Kryotechnik, CH	Commissioning
Moderator cryolines	Kriosystem, PL	Finished
Linac cryolines	Wroclaw University of Science and Technology, PL	Finished Turned over to ESS
Valve boxes elliptical cavities In-kind		Installation
Valve boxes spoke cavities In-kind	IPNO, FR	Manufacturing
CMS (Target, WP3) In-kind	Forschungszentrum Jülich, DE	Manufacturing
Warm Interconnecting Piping In-kind	Powerheat AB, SE	In Operation
LN2 tanks and supply	Air Liquide Gas AB, SE	In Operation
Helium supply	Strandmöllen AB, SE	In Operation

Cryogenics at the site - aerial view



Aerial View of Compressor Facility Showing Pure Helium Storage Tanks & LN_2 Dewar

Accelerator cryoplant



Target moderator cryoplant

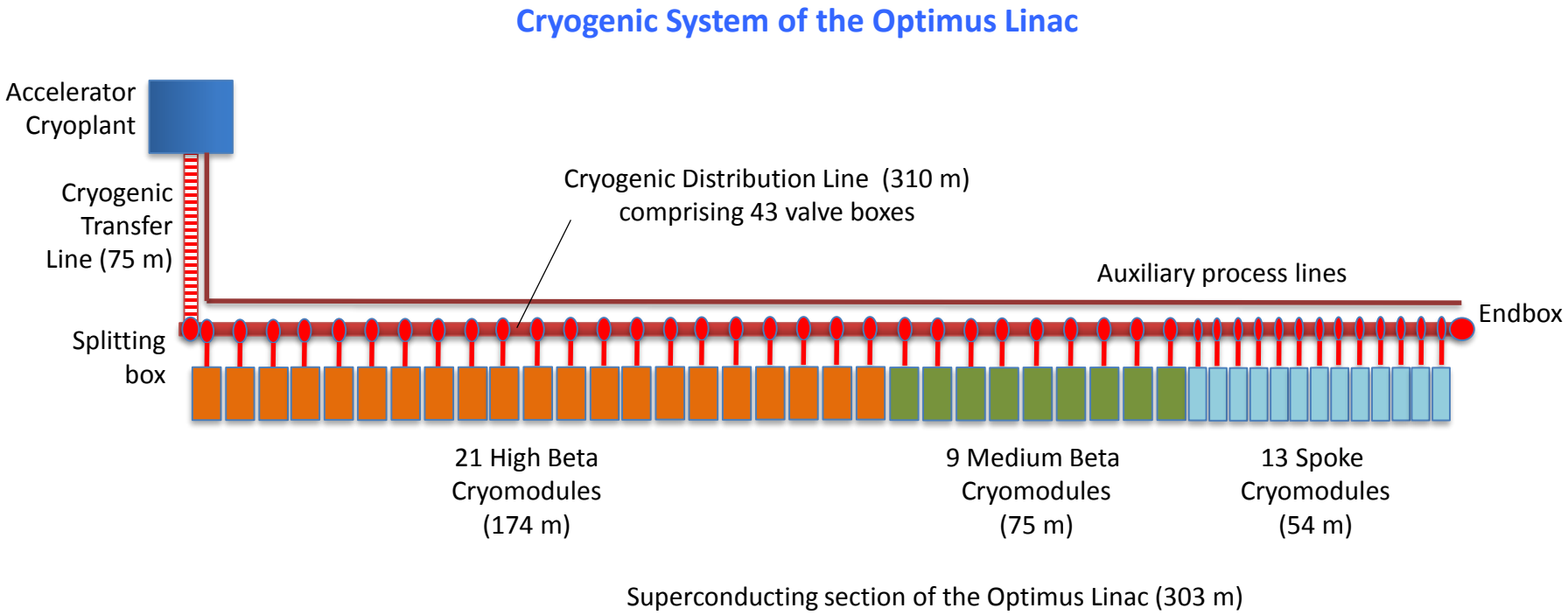
Cold Box installed
30.3 kW @ 16 K

Test and instruments cryoplant

Liquid Helium for Lund University

Test and instrument cryogenic plant in operation and delivering helium to Lund University

Linac Cryogenic distribution system



Cryogenic distribution system

Valve boxes multichannel transfer lines of elliptical linac components - installation in tunnel

SRF Module test stand

Valve box & cryogenic distribution line inside bunker

Medium beta cryomodule test area

First medium beta cryomodule arrived at ESS SRF module test facility

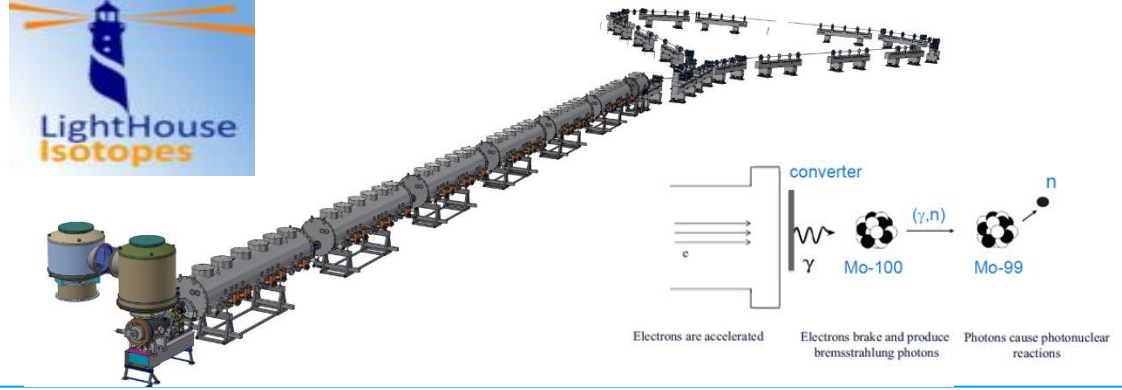
research instruments

The LightHouse accelerator for Mo99 production

The LightHouse SRF electron accelerator

RI contribution to the production of radiopharmaceuticals

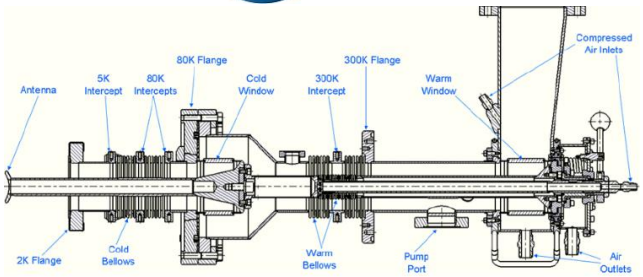
Schedule	Task	Remarks
02 - 10/2018	Risk mitigation study	study successfully completed in 10/2018
10/18 - 09/19	Design	Intermediate design phase
10/19 - end 2021	Detailed design and prototyping	Manufacturing design, prototyping of critical components, preparation to start manufacturing by 2022

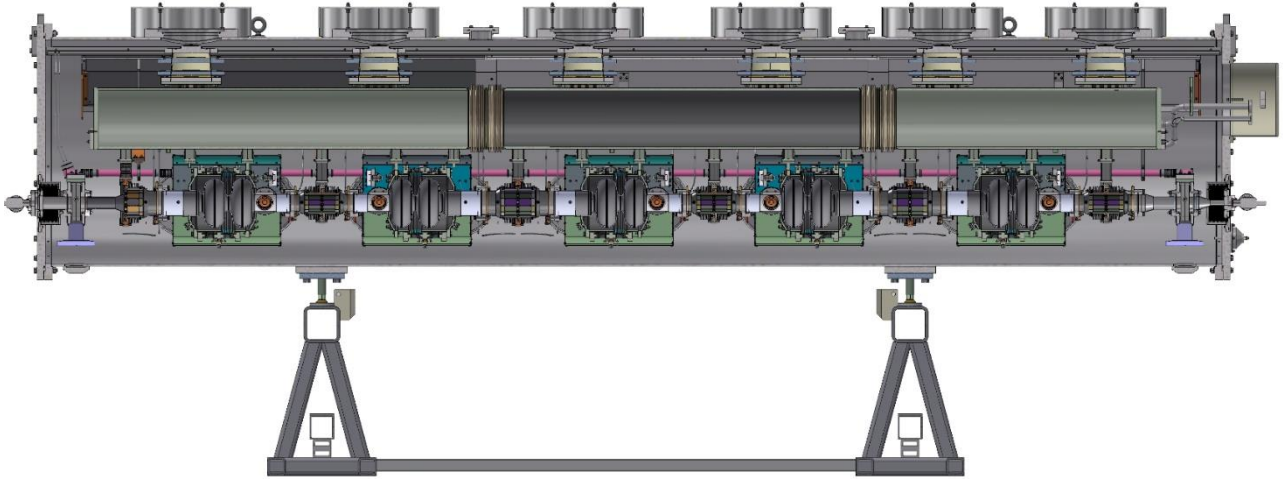


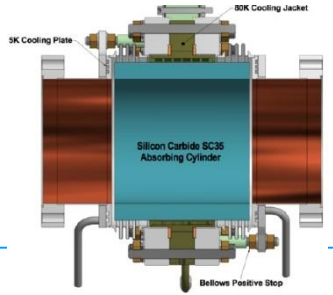
- Company **IRE/Belgium** plans Mo99 production using SRF electron accelerator with 3 MW beam power (75 MeV, 40 mA)
- Accelerator based on Cornell 400 kV ERL photon injector and 6 Cornell SRF injector modules
- RI is partner for design and building the accelerator (beam on target)
- IRE will decide on accelerator fabrication after successful detailed design and prototyping phase and evaluation of business plan
- Design of the 3 MW target **not** within RI's scope

Cornell ERL injector cryomodule

- 5 x 1.3 GHz 2-cell cavities operated at 2 K, Vacc = 2.5 MV, Eacc = 11.4 MV/m
- 10 x RF input couplers (2 for each cavity) operated at nominell 50 kW
- Each cavity increases the power of the beam by 100 kW
- 6 HOM loads, HOM power per module is below 50 W
- Module length: 5 m







LightHouse cryogenic plant parameters

Source	2K [W]	5K [W]	80K [W]
Heat Load per 1.3 GHz SRF module (2.5 MV, 40 mA), static and dynamic	45	90	900
Heat load for 6 x 1.3 GHz SRF modules (75 MV, 40 mA)	270	540	5.400
Heat load cryodistribution (estimated)	40	50	800
Total heat load	310	590	6.200

Intense discussion with cryoplant suppliers started

Cryogenic plant shall provide and distribute cooling for 6 Cornell 1.3 GHz SRF-Modules:

- 2K liquid Helium for cooling Cavities
- 5 K gaseous Helium for thermalizing intercepts on HOM loads and RF power couplers
- 80 K gaseous Helium for cooling of HOM-coupler, RF power coupler and thermal shield
- High reliability (simple design)
- Cost efficient and low energy consumption
- Cold compressors

We are now **hiring physicists/engineers** for design, detailed specification and production overview of the LightHouse cryopland and cryo-distribution

Acknowledgements

Many thanks to **John G. Weisend II**, ESS group leader/deputy head of accelerator projects for providing details and photographs of the ESS cryogenic plant

John recommends for further reading:

- J.G. Weisend II, P. Arnold, J. Fydrych, W. Hees, J.M. Jurns, X.L. Wang, **"Cryogenics at the European Spallation Source"**, Physics Procedia 67 (2015)27-34
- W. Hees, P. Arnold, J. Fydrych, J.M. Jurns, X.L. Wang, J.G. Weisend II, **"The evolution of the Cryogenic System for the European Spallation Source"**, Materials Science and Engineering 101 (2015) 012074
- P. Arnold, W. Hees, J. Jurns, X.T. Su, X.L. Wang, J.G. Weisend II, **"ESS Cryogenic System Process Design"**, Materials Science and Engineering **101** (2015) 012011
- P. Arnold, H. Gous, D. Phan, Ciaotao Su, J.G. Weisend II, **"Challenges of parallel ESS cryoplants installation and commissioning activities"**, Materials Science and Engineering **502** (2019) 012108

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