High Temperature Cooling of Cryoplants and RF Systems at the European Spallation Source

EUROPEAN SPALLATION SOURCE

2nd Workshop Energy for Sustainable Science at Research Infrastructures
CERN, Geneva Switzerland
October 23-25, 2013

John Jurns
john.jurns@esss.se

EUROPEAN
SPALLATION
SOURCE

ESS Overview

- Spallation Neutron Source
- Being built in southern Sweden
- 482.5m long, 5MW, proton linear accelerator at 2.5 GeV, 5 mA
- 2.86 ms pulses, ≈14Hz (60 ms period)
- Solid tungsten metal target
- 22 neutron instruments
- To support a 5000-strong user community
- 450 staff
- First protons in 2019
- Full design specifications 2025

Photo - Henning Larson Architects

Energy Philosophy and Heat Recovery Strategy

ESS has committed to an energy management strategy* that minimizes cost, lowers environmental impact, and factors out variability in energy. The ESS energy management strategy is based on four pillars:

- Responsible – optimize energy efficiency and lower energy consumption to 270 GWh/yr from the original estimate of 310 GWh/yr
- Renewable – Invest in renewable energy production sufficient to cover ESS integrated annual electricity use
- Recyclable – Provide a cooling system that recycles waste heat to the city of *Lund district heating system* and/or other potential customers
- Reliable – Provide stable electricity and cooling supplies for ESS operations

* ESS-0002126 “Energy Policy”

Lund District Heat System

Lund District Heat system will be source for ESS cooling, and customer for ESS recycled heat

Lund population ~ 111,000

~80% of population served by Lund district heat system

LDH system description

- 300 km network
- 10,000 m^3 of water circulating
- 74% of heat from renewable & recycled sources
- Plan for towards zero carbon by 2020
- 1,087 GwH heat produced in 2012

Interface with ESS

- Supply temperature to ESS – 45 C
- Return temperature to LDH – 80 C

EUROPEAN SPALLATION SOURCE

Lunds Energi progress towards zero carbon

Direct emissions per unit of energy district heating (kg/MWh)

	2012	2011	2005
Koldioxid	35	44	110
Kväveoxider	0,15	0,16	0,13
Svaveloxider	0,019	0,019	0,009

Direkta utsläpp är de som uppstår inom våra egna anläggningar för fjärrvärmeproduktion.

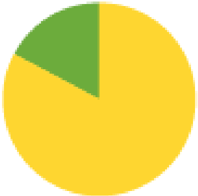
Fuel mix for district heat input fuel energy

	GWh
bio-oil	291
heat pumps (geothermal water heat from waste water, heat from the cooling output, heat from the aquifer)	222
Natural gas	187
electricity to heat pumps	110
waste heat nordic sugar	91
recycled wood	61
pellet	35
Bought heating wood chips and straw-based	35
woodchips	34
briquette	16
biogas	4
oil	0,6
electricity (electric boiler)	0,3

Share of renewable fuels and recycled heat in the consolidated district heating production

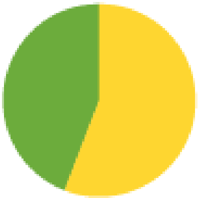
1985

- Renewable fuels & recycled heat 17%
- Other 83%



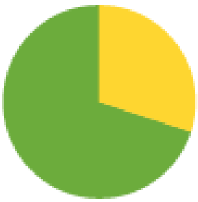
2005

- Renewable fuels & recycled heat 44%
- Other 56%



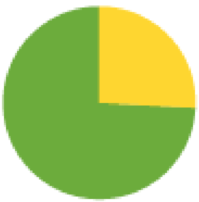
2011

- Renewable fuels & recycled heat 70%
- Other 30%



2012

- Renewable fuels & recycled heat 74%
- Other 26%



Lunds Energi Koncernen Hållbarhetsredovisning 2012

Other potential users of recycled heat

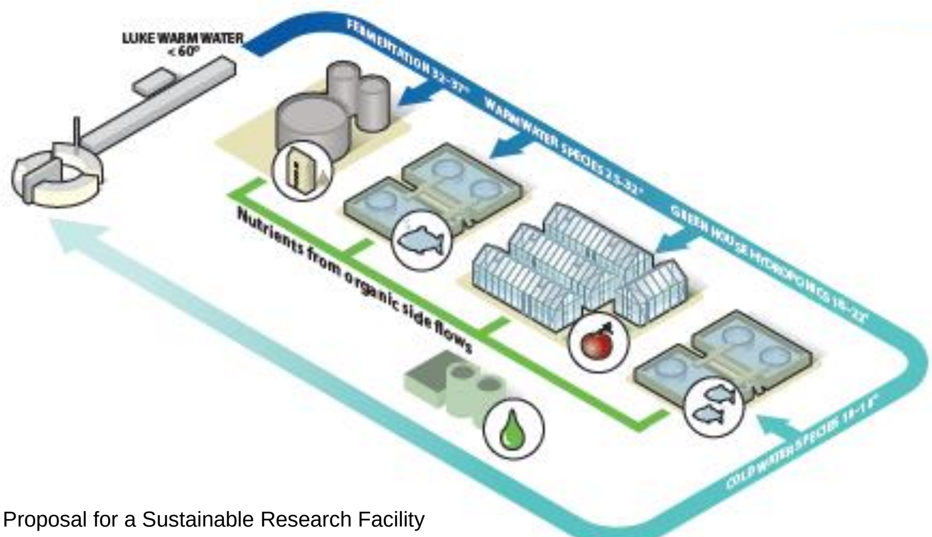
Unfortunately, not all heat recovered from ESS is at warm enough to send directly to LDH

Options to use this heat:

- Use heat pumps to increase temperature
- Find other uses for low grade heat

ESS is investigating use of low grade heat in a hybrid cooling chain to extract heat for things like the production of food, fodder and bio-fuels

More details are outlined in other ESS presentations.



Proposal for a Sustainable Research Facility
ESS Energy Concept Final Report January 2013

Cooling System Overview

ESS will ultimately consume over *40 MW of electrical power*, only a small portion of which ends up generating neutrons. Only 5 MW goes into the beam - most of the energy consumed is turned into waste heat.

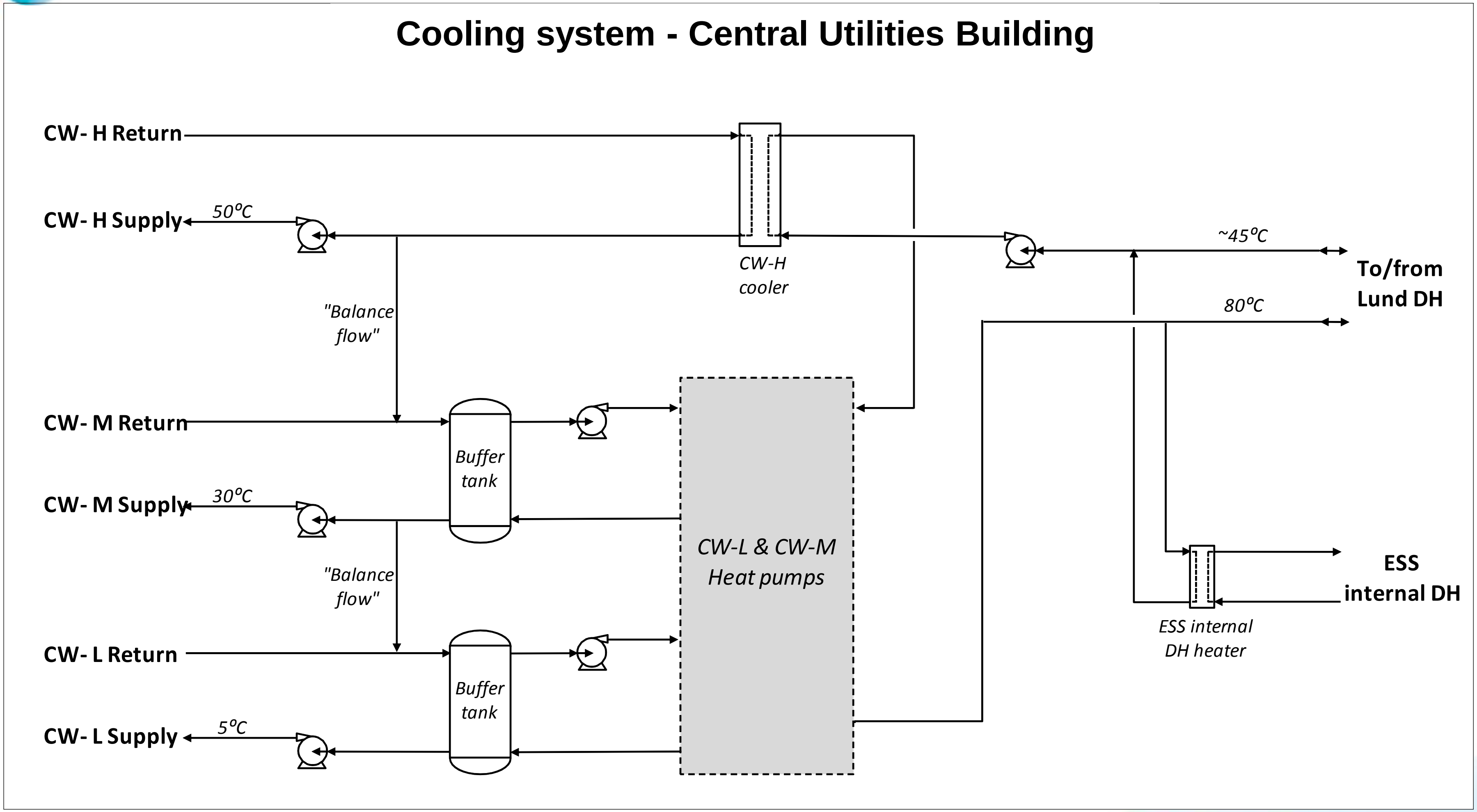
ESS plans to *recycle waste heat* to the Lund district heating network, ultimately supplying 20 percent of its total annual requirement.

Cooling system requirements

The cooling and heat recovery system of the ESS plant shall be designed to meet the following requirements:

- Provide reliable and efficient cooling of all parts of the ESS site that requires water cooling
- Transfer as much heat as possible from the cooling system to the city of Lund district heating system and/or other external waste heat recovery systems

ESS cooling system architecture overview



- 3 cooling water supply temperatures (5/30/50 deg C)
- 45 deg C supply from Lund district heat system
- Heat pumps to raise temperature of CW-L & CW-M return

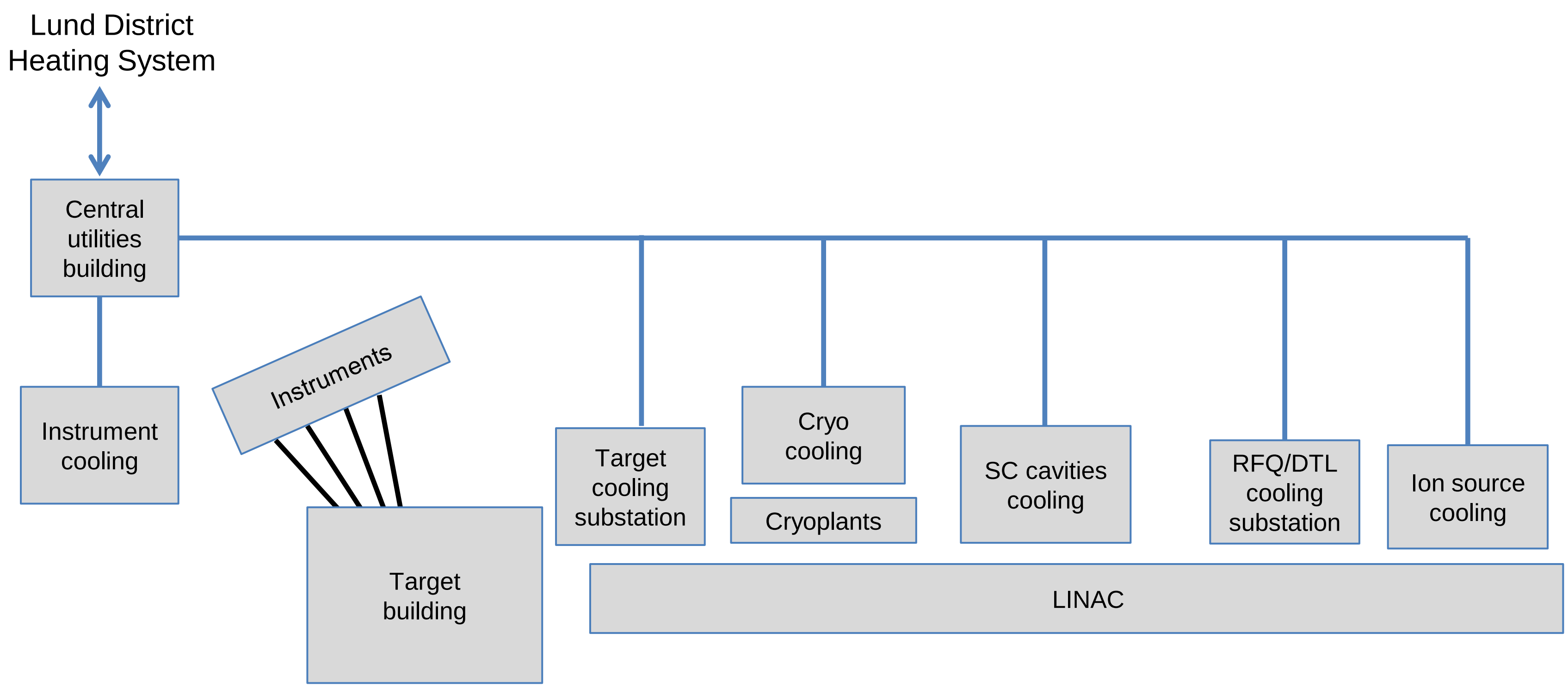
EUROPEAN SPALLATION SOURCE

ESS cooling system architecture (continued)

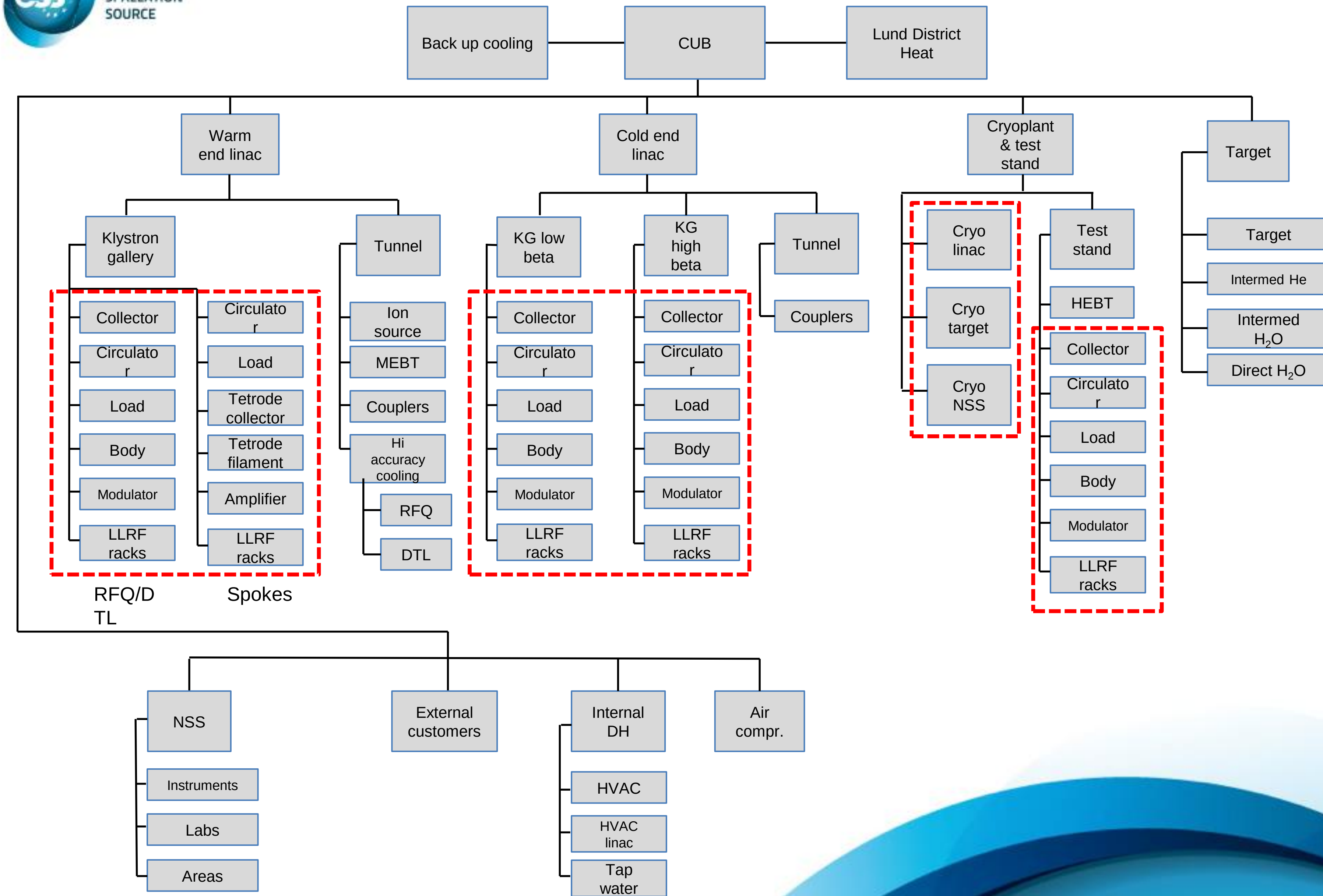
The scope of the cooling system design is primarily to manage the flow of heat in the technical infrastructure (i.e. – the “machine”). Cooling is accomplished primarily with water. Systems in scope include:

- Accelerator – klystron gallery and linac tunnel
- Target – interface at target internal cooling systems boundary
- Cryoplants – compressor and helium cooling
- NSS – cooling as required for instruments and support equipment
- Test stand – cooling for test stand klystrons, power supplies, etc.

ESS cooling distribution



Cooling water block flow



Waste heat summary

Our current estimate of cooling loads and cooling water supply temperature is shown in the table below.

ESS total cooling requirements by system & supply temperature

System	Low temp. 5 C (MW)	Med temp. 30 C (MW)	Hi temp. 50 C (MW)	Total
Linear accelerator	4,2	2,3	8,4	14,9
Target Station	7,5	-	-	7,5
Instruments	1,6	-	-	1,6
Cryogenic systems	1,4	5,5	-	6,9
Miscellaneous	0	0,5	-	0,5
Buildings		-1,8		-1,8
Total	14,7	6,5	8,4	29,6
Heat pumps to raise temp.	4,2	6,0	-	10,2

~71% of all heat comes from RF equipment and Cryoplants

Waste heat summary

Our current estimate of heat available from the return flows for each of the temperature ranges is shown in the table below.

ESS total heat returned by temperature range

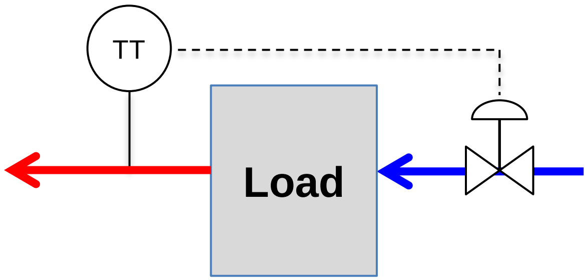
Return flows	(MW)	From RF, cryo (MW)
Low (25 C)	10,1	1,3
Med (40 C)	5,0	3,0
Intermed. (65 C)	1,4	
High (85 C)	13,1	13,1
High (heat pumps) (85 C)	10,2	
Total	39,8	21,8

100% of high grade heat comes from RF equipment and Cryoplants

Plans to optimize heat recovery

Overall design philosophy

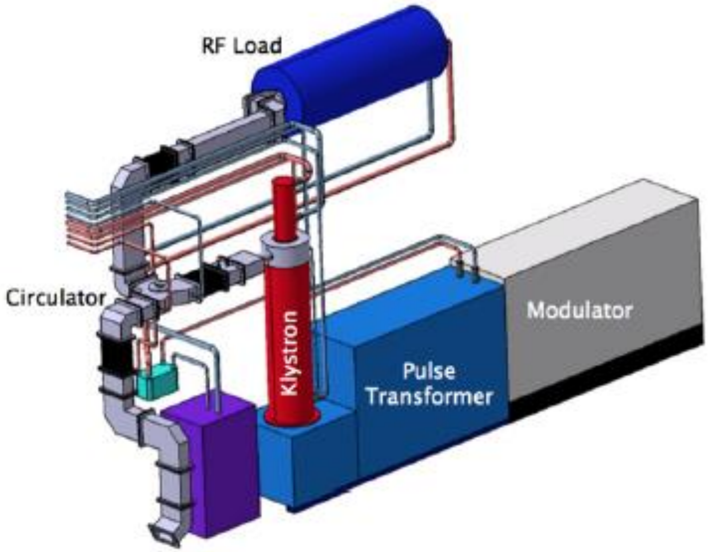
- Use highest reasonable temperature for cooling equipment
- Maintain outlet temperature, control flow



Plans to optimize heat recovery

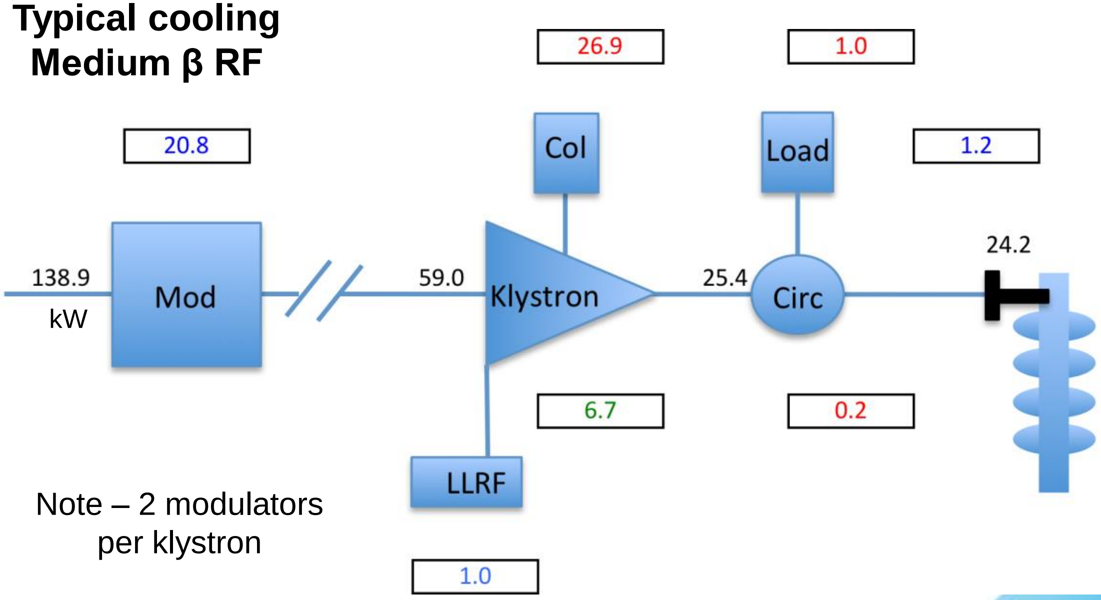
Klystron gallery equipment

- Klystrons
  - Collector – CW-High supply
  - Body – CW-Medium supply
- Circulators – CW-High supply
- Loads – CW-High supply
- Modulators – CW-Low supply
- LLRF – CW-Low supply



ESS CDR reference

Typical cooling Medium β RF



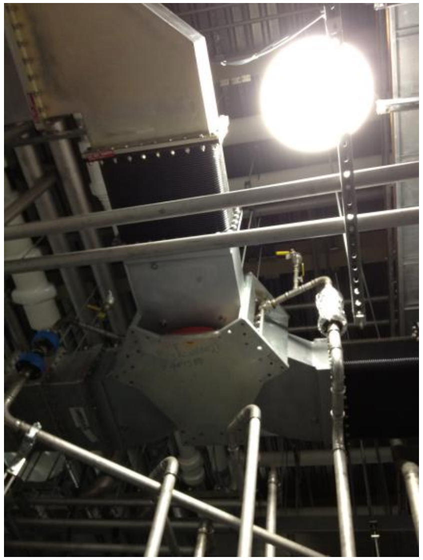
Note – 2 modulators per klystron

Klystron gallery equipment

Modulator

Klystron

Circulator



Load

ORNL/SNS site visit photos August 2012

Total RF equipment cooling loads, supply & return temperatures

Equipment	*Supply temp*	*Return temp*	*Cooling load (kW)*			
	(°C)	*(°C)*	High Beta	Med beta	Spoke	DTL+RFQ
Modulator	27	42	2,121	625	123	148
LLRF Racks	22	26	120	60	3	96
Klystron body	35	40	1,370	404	14	383
Collector	50	80	5,481	1,615	31	3
Circulator	50	80	49	15	27	14
Dummy load	50	90	197	58	28	196
Linac tunnel	20	25	246	73	17	5

Plans to optimize heat recovery

ESS cryoplants

- Cooling for the cryomodules (2 K, 4.5 – 8 K and 40 K)
- Cooling for the Target LH_2 Moderator (16 K)
- Liquid Helium for the Neutron Instruments
- Cooling for the cryomodule test stands (2 K, 4.5 – 8 K and 40 K)
- This is accomplished via 3 separate cryoplants

Cryoplant equipment requiring cooling water

- Oil coolers
- Helium coolers
- Motor cooling

Cryoplant Equipment

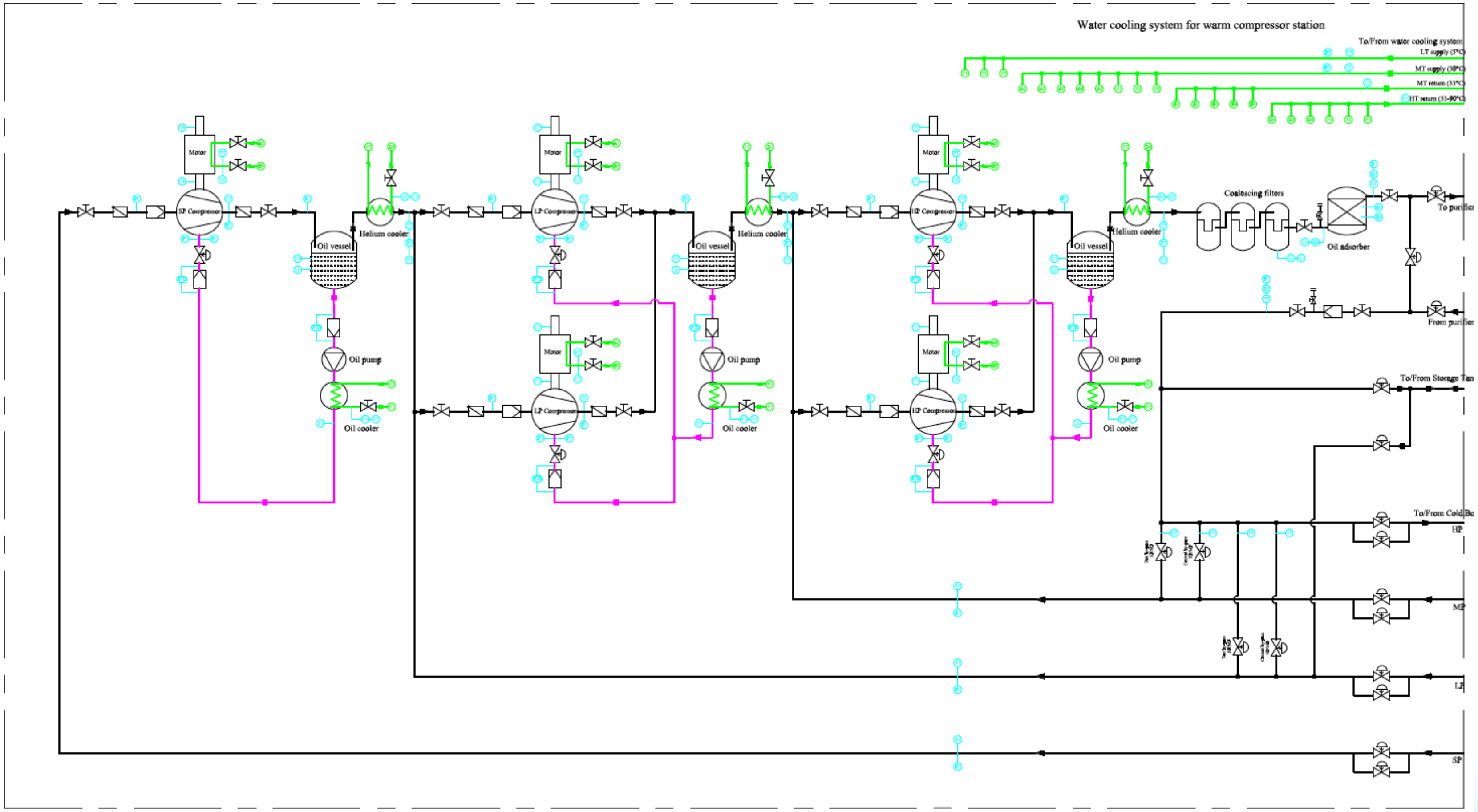
<u>Cryoplant water cooling requirements</u>

- Will likely use a combination cold & warm compression
- Turn down capacity & ability to recover from trips quickly are key issues
- Turning down cryoplants will result in lower cooling requirements

Cryoplant	Minimum cooling required (kW)	Maximum cooling required (kW)
Linac	1720	4300
Target	530	2200
NSS & Test Stand	400	400
Total	**2650**	**6900**

EUROPEAN SPALLATION SOURCE

Cryoplant equipment (typical)



- Helium coolers low temp supply
- Oil coolers, motor medium temp supply
- Consider control loop to regulate return temperature for varying cryoplant operation

Klystron operating temperature issues

Can we collect heat from klystrons at a high temperature?

- Collector temperature rise typically 20-30 C
- Maximum CW outlet temperature must remain below 80-90 C
- Depending on klystron operating mode, cooling flow rate can vary 2X
- Manufacturers typically specify a flow rate for cooling
- Literature review* indicates that failures do not appear to originate primarily at collector, but at the other end of the klystron. Note the electron gun portion of klystron is cooled at a much lower temperature (~40 C).

*Argonne Nat'l Lab 2008 – "The Linac Klystrons Aging & Associated Problems"
SLAC klystrons 1996 – "Advanced RF Power Sources for Linacs"

Based on the above:

- Reasonable plan to cool the klystron collectors at 80-90 C
- Arrange several klystrons in series to maximize outlet temperature
- Confirm plan to vary CW flow with klystron manufacturers

Cryoplant operating temperature issues

Can we collect heat from cryoplants at a high temperature?

- Oil cooler temperature should not exceed ~90 C
- Cool helium from CW-Low supply to optimize cryoplant performance
- Cryoplant operation at reduced capacity may be a candidate for flow control of cooling water to maximize CW return temperature
- Standard shell & tube heat exchangers not the most efficient – consider using plate heat exchangers instead to increase CW return temperature

Based on the above:

- Maximize CW return temperature
- Confirm high temperature CW return with manufacturers
- See if PHX are a possibility

Risks and challenges

Risks & Challenges

- Reliability – assess impact of cooling temperature on equipment performance
    - Lower operating temperatures – increased equipment reliability
- Balance equipment *technical requirements* with ESS *energy goals*
    - Higher operating temperatures – increased heat recovery
- Minimize cost of recovering heat
    - More equipment operating at higher temperatures means less energy required for heat pumps
- Design system to effectively recover heat under all operating regimes

Summary

- ESS has committed to an energy policy that *will influence system design*
- Energy recovery comes at a *cost*, but also provides *benefits*
  - Energy management innovation in large research facilities
  - Better stewards of our environment
  - Income! Recovered energy has cash value
- Innovation will require close cooperation with system designers, equipment manufacturers, and customers for our recycled energy
- Concentrate on areas of greatest return for energy recovery:
  - RF systems
  - Cryoplants
- Stay tuned!