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Cold Linac Head Load Estimate:
Hybrid vs. Segmented Cryomodule Design

13 February 2012

Cold Linac Heat Load estimate:
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SCOPE

The aims of this Technical Note are:

1) to compare heat loads of the segmented design with warm corrector magnets and the hybrid design;
2) to assess the cold linac heat load in order to estimate the necessary capacity of the linac cryoplant.

COLD LINAC HEAT LOAD CALCULATION

Introduction and Assumptions

The complete length of the cold linac is taken into account. The cold linac and cryomodule breakdown structures are following the baseline 2011_11_23, which is described in the Conceptual Design Report [1].

Both spoke resonator cryomodules and elliptical cavity cryomodules are taken into account in the calculations. The number of components is based on the CDR description [1].

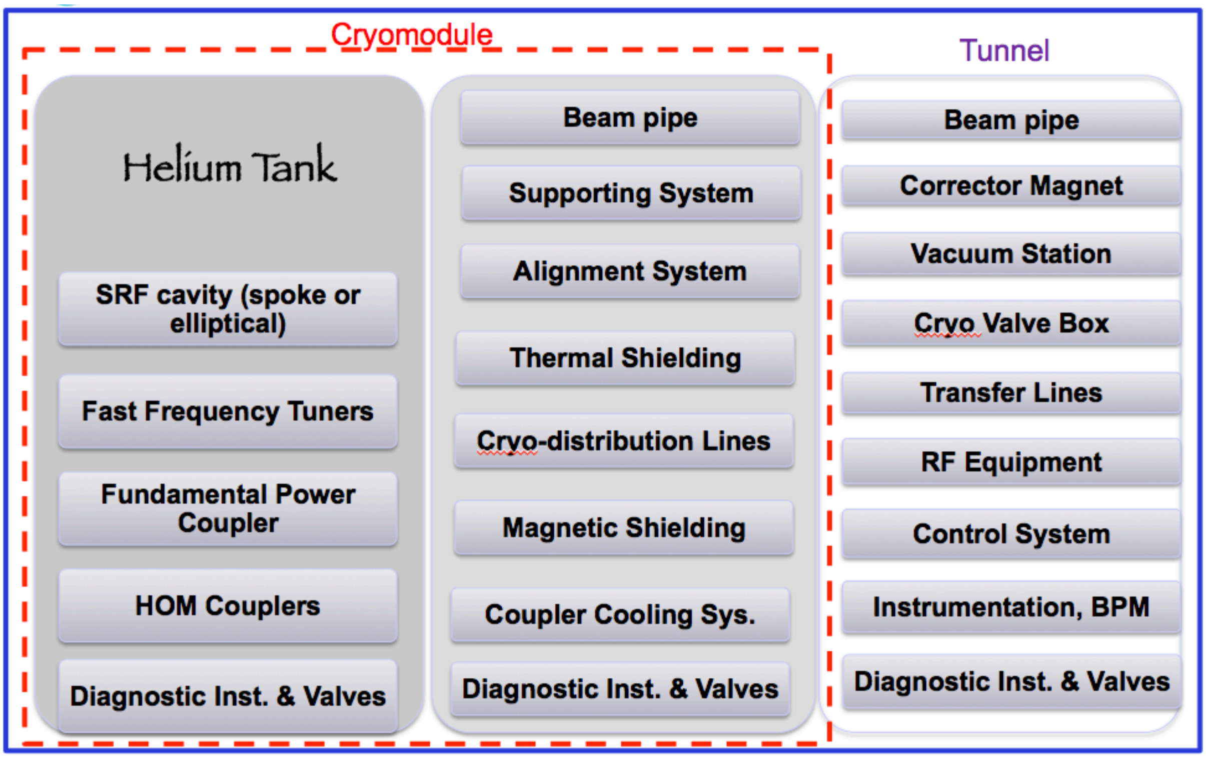


Figure 1: Cryomodule Breakdown Structure and Interfaces

Table 1 summarizes the active components and cryomodule environment, which are taken into account in our calculation.

Table 1: Assumptions used in the calculation of the heat load

Quantity	**Unit**	**Value**	**Reference**
Beam loss	W/m	1	[2]
Dynamic – Spoke Resonator	W/cavity	1	[3]
Dynamic – Medium Beta	W/cavity	7	[4]
Dynamic – High Beta	W/cavity	5.2	[4]

Static - Supporting system	W/m		[5]
80 K		0.8	
20 K		0.07	
2 K		0.02	
Static - Radiation	W/m^2		[5]
80 K		1.2	
20 K		0.1	
2 K		0.05	
Static- Warm to cold transition/End effects	W/end		[6]
80 K		0.7	
20 K		0.09	
2 K		1	
Static Coupler spoke	W/cavity	1.8	[3]
Static Coupler	W/cavity		[4]
High beta		3.6	
Medium beta		3	
Static Instrumentation Cable	W/CM		[6]
80 K		12.7	
20 K		5.9	
2 K		0.07	
HOM contribution	W/CM		[6]
80 K		69	
20 K		25	
2 K		0.35	
Carnot efficiency		0.3	

In the calculations, it is worth noting that:

- the segmented configuration using cold corrector magnets inside the cryomodules is not taken into account in this document;
- for the segmented configuration with warm corrector magnets, we have removed the heat deposited to the 2 K temperature level for the length of the magnets;
- the beam induced value of 1 W/m is a conservative value used by SNS and similar projects [2];
- since the design of the cryostat which is housing the helium tank and the cavity supporting system is not yet defined, the calculations have been based on best-guesses and empirical results from other installations [3-8]. We assume that even if no physical thermal shielding is used at the 20 K temperature level, a thermal sinking of the supporting system, the thermal shielding, the warm to cold transition and the instrumentation (diagnostic) will be available at the 20 K and 80 K temperature levels;
- the static heat load is composed of the contribution, of the thermal shielding system, the supporting system, the tuner, the power coupler, the warm to cold transitions and the instrumentation (for diagnostic) cables;
- the dynamic heat loads for the spoke resonators, medium beta and high beta elliptical cavities are based on IPNO and CEA input [3-4];
- the HOM heat loads used in the calculations are based on Project X HOM design [6]. These values can be very different from the future ESS HOM ones.

The heat transfers considered are thermal radiation, solid conduction and conduction in residual gas. Figure 2 shows the heat transfer flow scheme between cryomodule components.

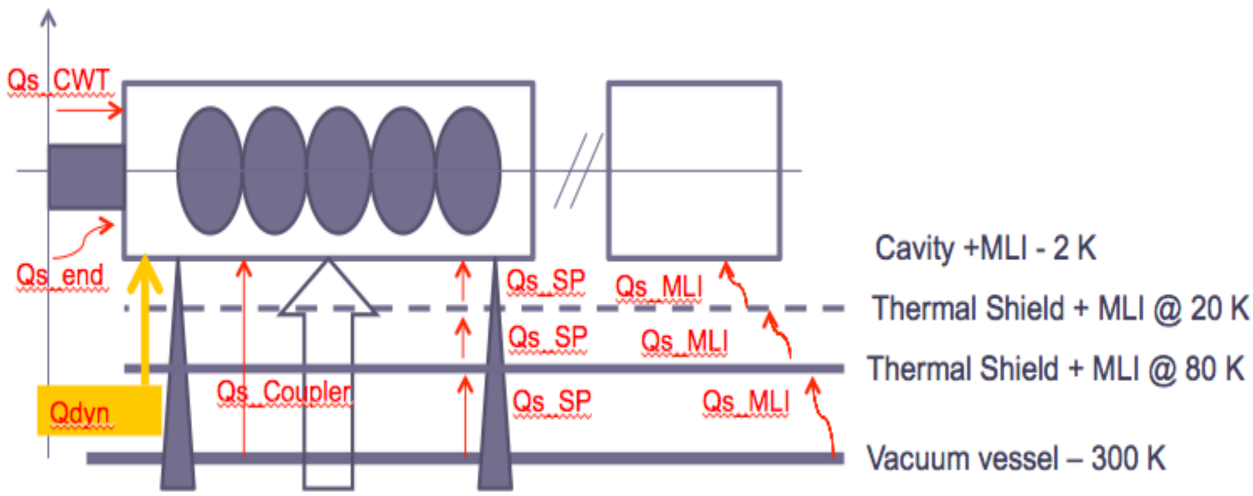


Figure 2: Main cryomodule heat transfer flow scheme of the heat transfer (HOM, tuner and instrumentation contributions are not shown)

Results

Using the heat transfer scheme shown in Figure 2 and the list of components listed in Table 1 and Figure 1, the heat load has been calculated at the different temperature levels. Results are listed in Table 2 and Table 3, for the Hybrid and Segmented design, respectively.

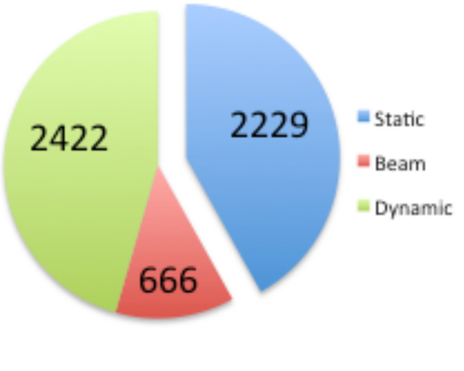
Table 2: Heat load distribution for the cold linac - Hybrid Design

Hybrid Heat Load (W)	Radiation	Supp. system	Coupler	End effect	Inst. Cable	HOM	Qstatic	Qbeam	Qdyn	Total
80 K	1157	880		0	610	3313	5960			
20 K	83	77		0	283	288	731			
2 K	24	10	660	0	3.4	17	714.4	368	1067	
Eq. 4.5 K							2024	835	2422	**5281**

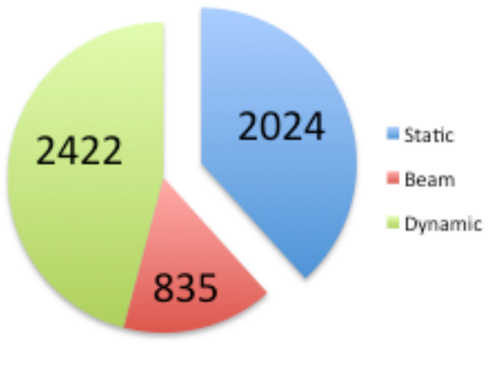
Table 3: Heat load distribution for the cold linac - Segmented Design

Segmented Heat Load (W)	Radiation	Supp. system	Coupler	End effect	Inst.Cable	HOM	Qstatic	Qbeam	Qdyn	Total
80 K	926	880		70	610	3313	5799			
20 K		77		90	283	288	738			
2 K	14	10	660	96	3.4	17	800.4	293	1067	
Eq. 4.5 K							2229	666	2422	**5316**

Figures 2a and 2b are showing the distribution of the heat load for the Segmented and Hybrid designs, respectively.



2a: Segmented configuration



2b: Hybrid configuration

Figure 2: Cold linac heat load distribution (W)

OBSERVATIONS

Summary of the calculations

This Technical Note lists the bottom up calculations of the heat loads at the different operational temperatures of the cryomodules.

Relative heat load comparisons clearly show that there is no advantage in choosing a hybrid design, especially since choosing the segmented design results in a reduced length of the cold section. The overall capacity difference is less than 7%.

The resulting heat load of 5.3 kW at 4.5 K could be used if we assess an adequate capacity margin for the cryoplant. Useful examples of the overcapacity and uncertainly coefficient can be found at [7]. At this early stage of the ESS project, we recommend a safety margin of 2 to cope with unknowns in the cryomodule conceptual design and machine configuration.

Load distribution:

If we are considering the thermal budget distribution for a given layout [1], we notice that more than 42 % is due to static heat load contribution, which is largely dominated by the power coupler (approximately 1.5 kWatt at 4.5 K).

→ We suggest confirming the assumptions of the power coupler's static heat load using experimental data (value may be closer to 1 Watt/coupler).

Load due to beam losses

Using the given assumptions (distances and layout from the CDR), the heat load from the beam represents more than 13 % of the total.

→ The beam loss assumption of 1 W/m needs to be refined by a detailed neutronic calculation.

CONCLUSIONS

Those calculations need to be completed when a conceptual design of the cryomodules and the cold linac will be available. In the meantime, this report permits to refine the initial heat load analysis [9].

This note is used to complete ESS AD Technical Note 0029 [10].

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As side conclusions, since the static heat load due to the fundamental power coupler is not negligible in the total heat load distribution, we suggest to perform additional measurements. Furthermore, as the heat deposited by the beam is significant, more precise neutronic calculations are needed.

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[1] "ESS Conceptual Design Report", edited by Steve Peggs, 2012-02-13.

[2] "Estimation of Residual Dose Rate and Beam Loss Limits in the ESS Linac", by L. Tchelidze and J. Stovall, ESS/AD/0026.

[3] Private conversation with Sebastien Bousson, WP4 leader.

[4] Private conversation with Guillaume Devanz, WP5 leader.

[5] "Thermal PerformanceMeasurements on a 10-meter long Dipole Prototype Cryostat (CTM2), by C. Darve et al., CERN-LHC Project Note 112.

[6] "Cryomodules Heat Load Estimates Converted to 4.5 K Equivalent Cooling Power" by Tom Peterson, TTC meeting, Beijing, 2011-12-6.

[7] "Cryogenic Heat Load and Refrigeration Capacity Managements at the LHC", by S. Claudet et al.,CERN-LHC Project Report 1171.

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[9] "First Considerations for the Design of the ESS Cryo-Modules", by A. Ponton, ESS/AD/001.

[10] "The ESS Cryomodule Design: Change towards a Segmented Linac", by W. Hees and C. Darve ESS/AD/0029.

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