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Heat Load Estimation of the Cryomodule for 200 MeV Energy Upgrade at KOMAC

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양 성 자 가 속 기 연 구 센 터

양성자가속기 기반 반도체 대기 / 우주 방사선 영향평가

- **우주 / 대기 방사선 환경**
  - ❑ 우주 방사선 환경
    - Proton: 1~500 MeV, 10^3 ~ 10^9 p/cm^2/s, SEE
    - Heavy ion: (He~Fe), multi GeV/n, 10^5 ions/cm^2/s
  - ❑ 대기 방사선 환경 (Neutron flux at atmosphere with energy >10 MeV)
    - 6000 n/cm^2/hr (@ 12 km high)
    - 20 n/cm^2/hr (@ sea level)

- **최근 반도체의 고 집적화로 인해 위의 대기 / 우주 방사선에 의한 반도체 영향평가가 중요해짐**
  - ❑ 반도체에의 영향
    - Single Event Effect, Total Ionizing Dose, Displacement Damage
  - ❑ 반도체의 우주 / 대기 방사선 영향시험 국제기준
    - JEDEC JESD 89A: 14 MeV neutron, 50~60MeV proton, 90~100MeV proton, min. 200 MeV proton
    - ESA ESCC 25100: 20~200 MeV proton
    - 200 MeV 양성자를 이용하여 중성자를 발생시키는 경우 대기 방사선 스펙트럼의 90%이상을 구현할 수 있음

• 200 MeV 양성자가속기 - 반도체 영향평가 전용시설로 적합

200-MeV Energy Upgrade

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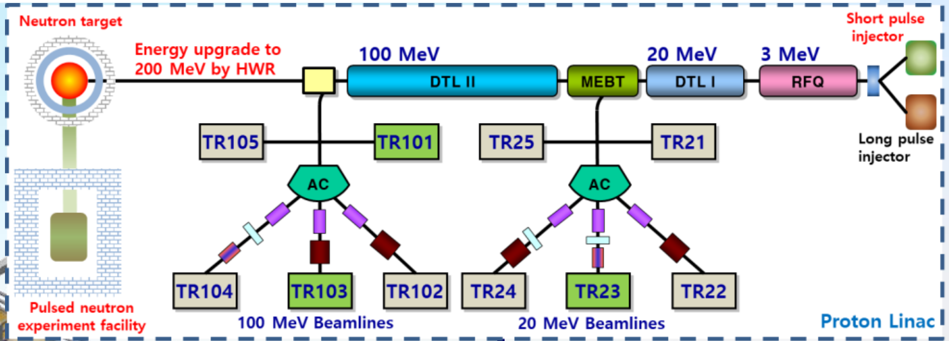
200-MeV 에너지

- 대기 방사선의 90% 이상을 cover 할 수 있음
- 국제 시험 기준을 만족하는 전용 시설로 구축 가능
- 단일 구조의 초전도 가속기 사용 가능 (200-MeV 이상에서는 elliptical cavity + klystron 이 유리함)
- 기존 100-MeV 가속기 터널을 대규모 증축하지 않고 가속기를 설치할 수 있음

Included in the National R&D roadmap



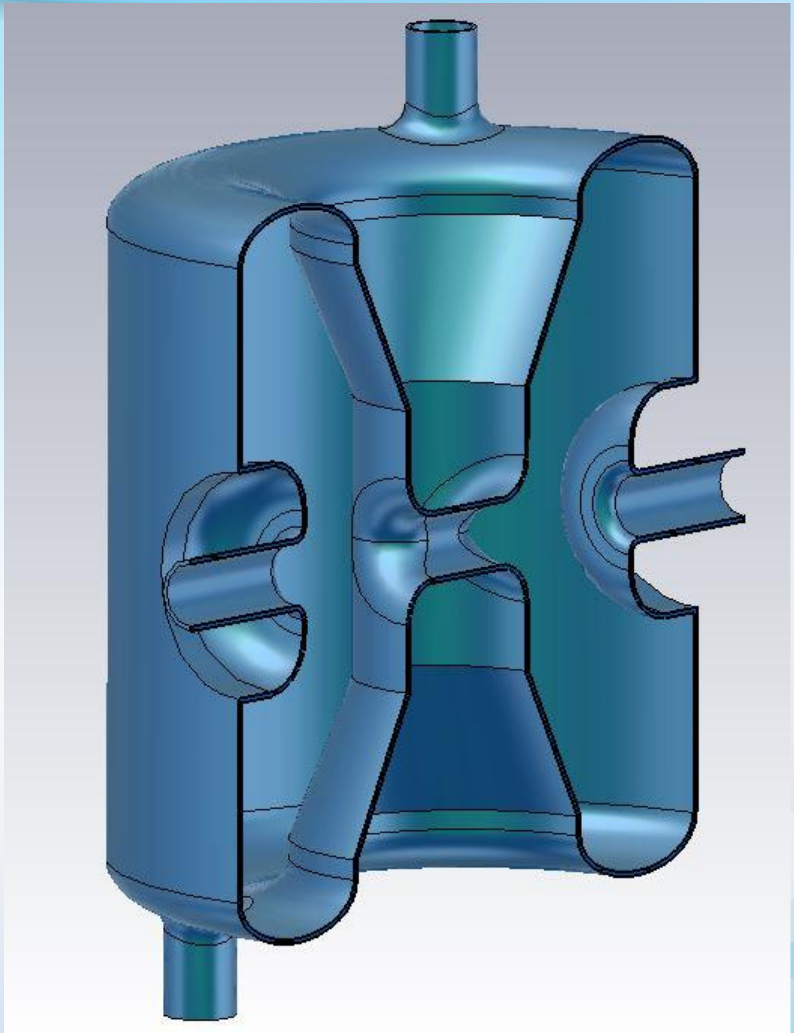
Facility site plan

HWR Design Parameters

- Frequency: 350 MHz
- Beam energy: 100 MeV ~ 200 MeV
- Peak current: 20 mA
- RF duty: 10%
- Length: ~45 m
- Optimum beta: 0.56
- Eacc: 7.5 MV/m (Ep< 35 MV/m, Bp < 70mT)
- Operation temperature: 2 K
- HWR per CM: 4 HWRs / cryomodule
- Total no. of CM: 9 sets
- Total no. of HWR: 36 sets
- Focusing: Normal conducting doublet

HWR Cavity Design

Parameter	Unit	Value
Optimum beta (β_{opt})	-	0.56
V_{acc} (@β_{opt})	MV	3.61
E_{acc} (@β_{opt})	MV/m	7.53
E_{pk}	MV/m	29.08
B_{pk}	mT	61.66
E_{pk} / E_{acc}	-	3.86
B_{pk} / E_{acc}	mT/(MV/m)	8.19
V_0	MV	4.14
E_0	MV/m	8.63
R/Q (@β_{opt})	Ohm	256.6
G	Ohm	116.1
Q_0 (@Rs=20 nΩ)	-	5.81E+9
Cavity loss (@R_S=20 nΩ)	W	8.75
Stored energy	J	23.1
Cavity diameter	m	0.45



HWR Cryomodule

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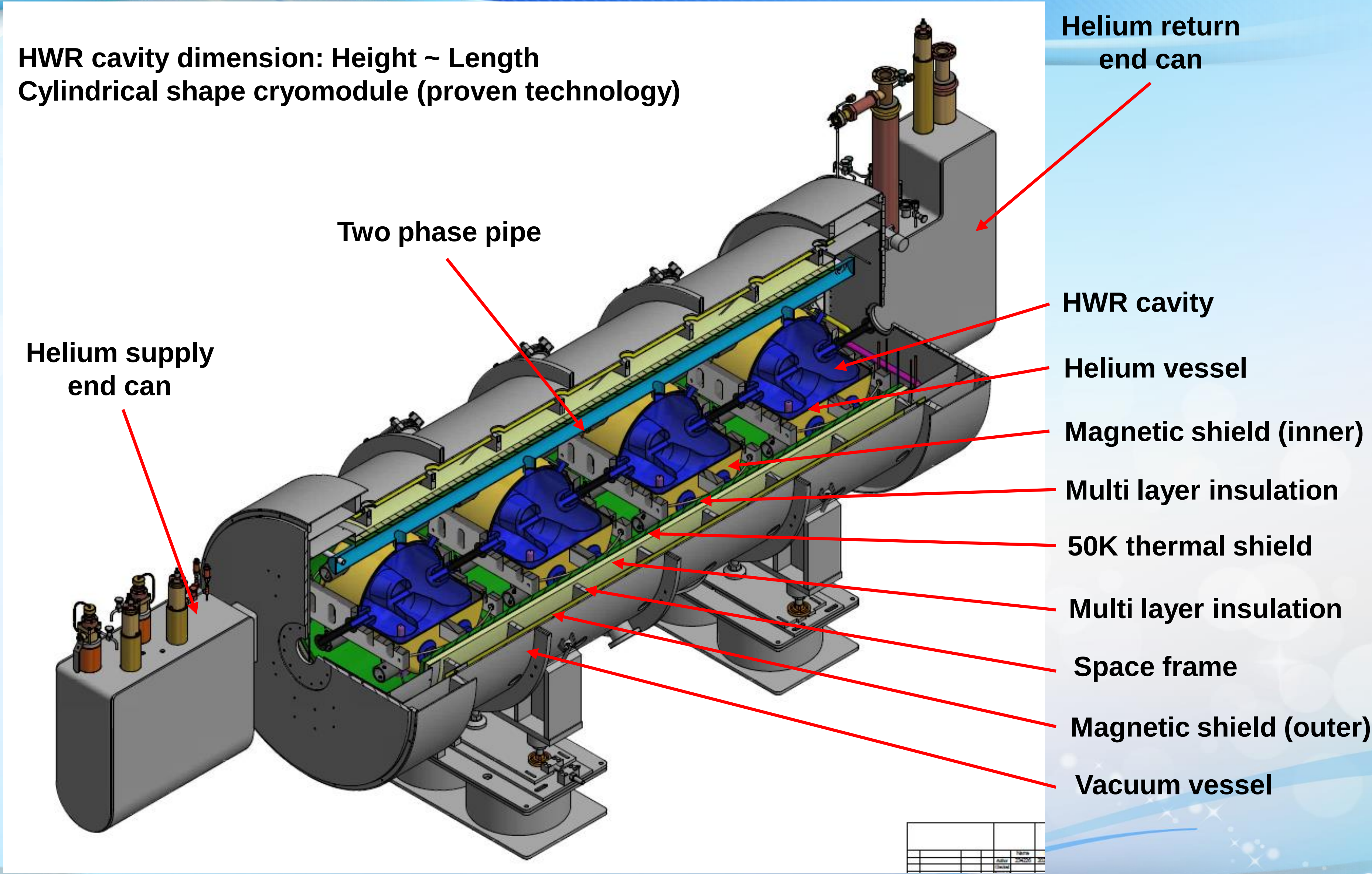
- Concept: Use well proven technology
- Cylindrical cryomodule (based on SNS CM)
    - Cavity dimension: height ~ diameter
    - Focusing: External normal conducting doublet
    - Widely used in large facilities (ex. CEBAF, SNS, ESS and so on)
- HWR operating temperature: 2 K
- HWR cavities / cryomodule: 4
- HWR fixing and alignment: Space frame

Cryomodule

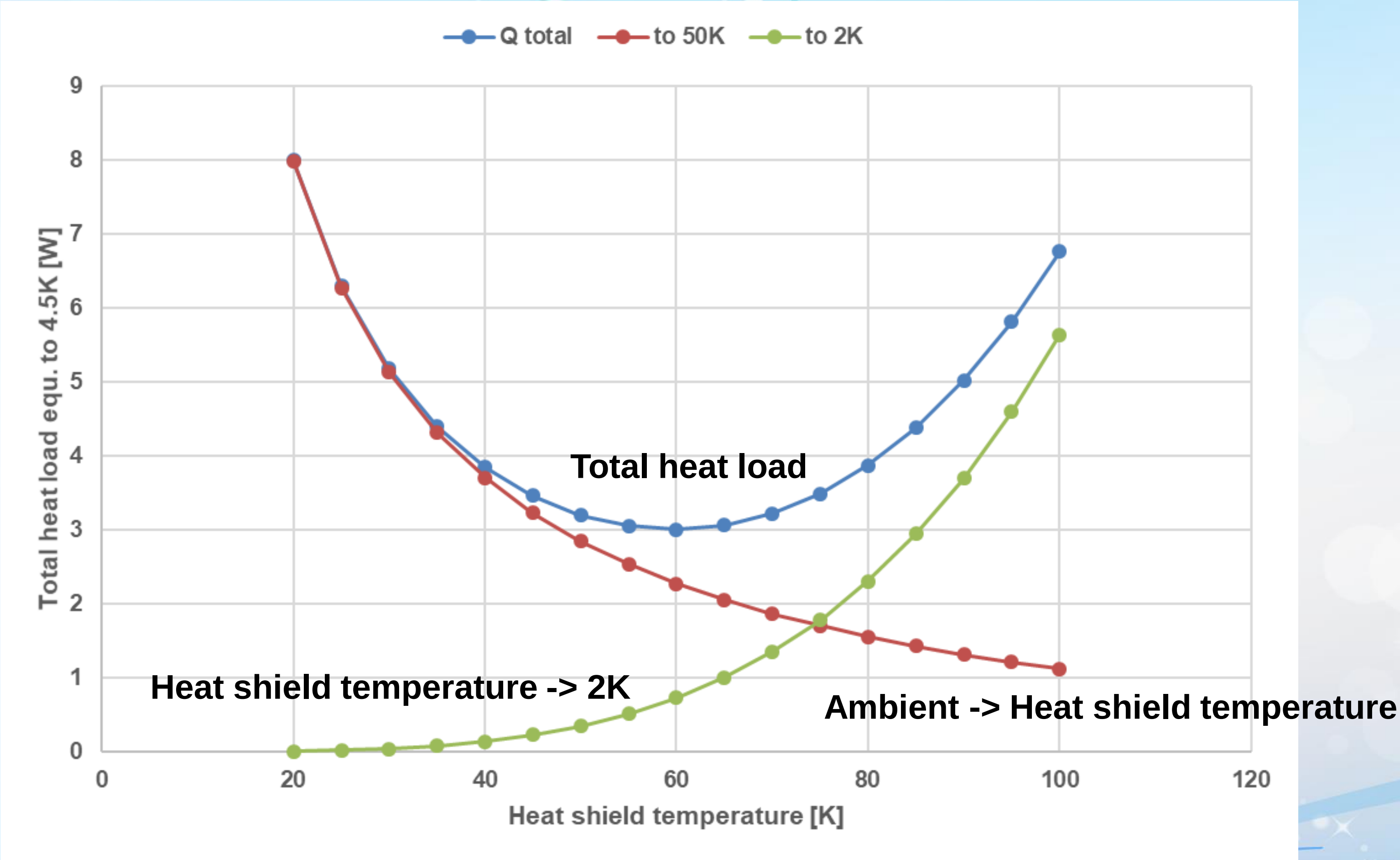
HWR cavity dimension: Height ~ Length
Cylindrical shape cryomodule (proven technology)



Static Heat Load - Radiation

- Worst case in radiation heat transfer*

300 K -> 50 K: 2.5 W/m², 50 K -> 2 K: 94 mW/m²



* J. G. Weisend II, Cryostat Design, Springer, 2016

Static Heat Load - Conduction

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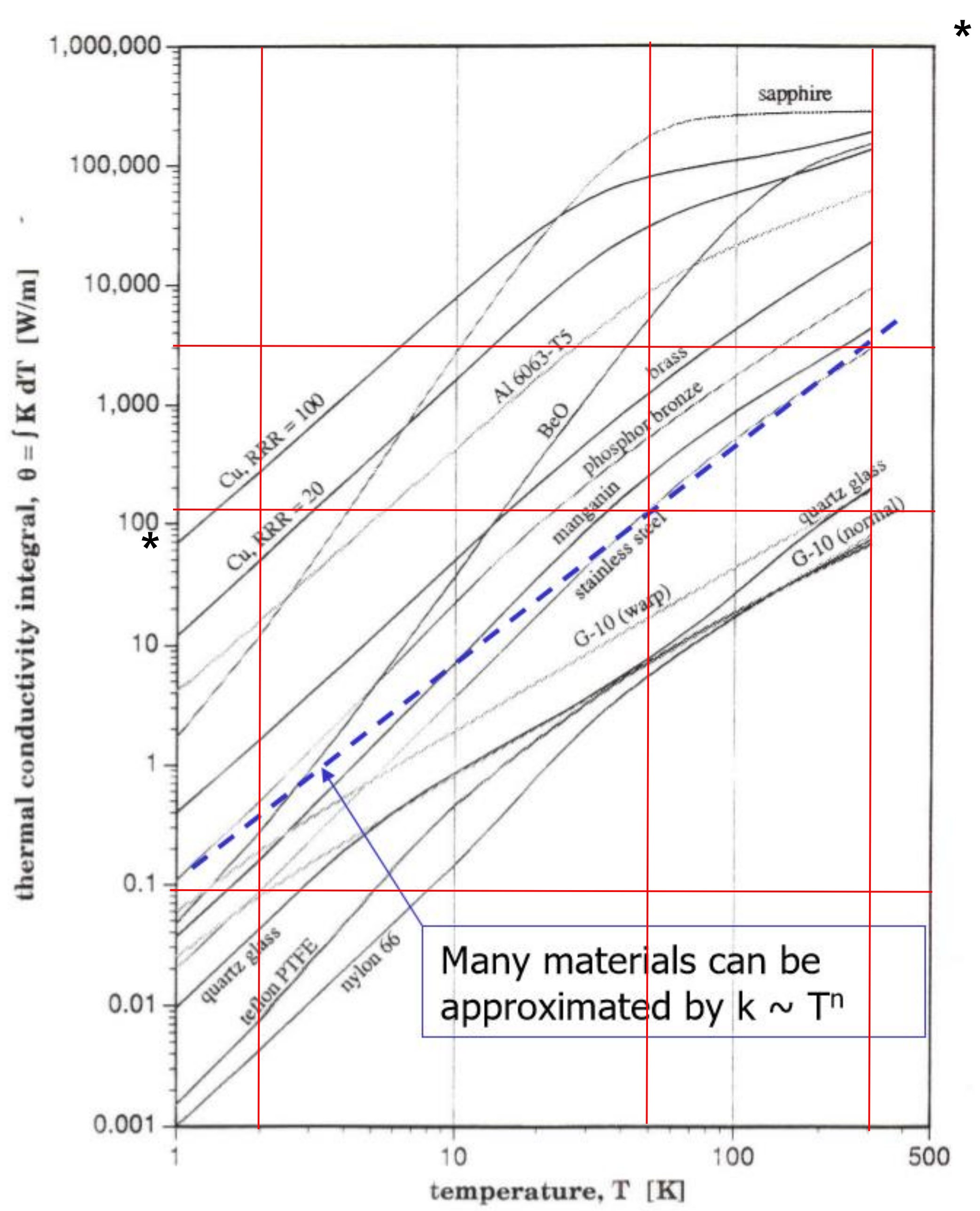
$$\bar{k}\,(T1, T2) = \bar{k}\,(0, T2) - \bar{k}\,(0, T1)$$

For example, stainless steel

$\bar{k}\,(2, 300)$ = 3,000 – 0.09 = 3,000 [W/m]
$\bar{k}\,(2, 50)$ = 120 – 0.09 = 120 [W/m]
$\bar{k}\,(50, 300)$ = 3,000 – 120 = 2,880 [W/m]

- **In general, a pressure of 10^{-6} mbar or less is sufficient vacuum to eliminate all convective heat transfer**
  - **- The cold wall of the vacuum space acts as a cryopump for residual gas**
  - **- But need another pump to reduce the pressure near 10^{-6} mbar prior to cool down the cryostat**



* J. G. Weisend II, Cryostat Design, Springer, 2016

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Dynamic Heat Load at Cavity

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$$P_c = \frac{E_{acc}^2\, d^2}{Q_0}\frac{1}{R/Q}DF = \frac{V_{acc}^2}{Q_0\ R/Q}\ DF$$

Vacc = 3.61 MV
R/Q = 256.6 ohm
Q0 = 5.81E9

Pc = 8.74 W / cavity @ 100% duty
Pc = 0.874 W / cavity @ 10% duty

Pc = 3.5 W / cryomodule @ 10% duty

* H. Padamsee, et al., RF Superconductivity for Accelerators, Wiley-VCH Verlag GmbH, 2008

Heat Load per Cryomodule

KOMAC HWR Cryomodule heat load (200708)

	SNS Medium			SNS High			KOMAC		
Slot length [m]	5.839			7.891					
CM length [m]	4.239			6.291			3.582		
CM diameter (OD) [m]	1.22			1.22			1.154		
CM outer surface are [m2]	18.585			26.450			15.078		
Conversion factor from SNS to KOMAC							0.811		
Calculated heat load									
	Qty	2.1K	50K	Qty	2.1K	50K	Qty	2.1K	50K
Static [W]	1	9.7	131.0	1	11.5	161.0	1	11.0	143.6
U tube & Allotment [W]	1	10.0	24.0	1	10.0	30.0	1	10.0	24.0
Dynamic [W]	1	8.3	0.0	1	17.1	0.0	1	8.1	0.0
Total heat load per CM [W]		28.0	155.0		38.6	191.0		29.1	167.6
Budget per CM		39.0	170.0		48.0	200.0		36.2	175.5
Dynamic contribution									
Cavity	3	6.0		4	14.0		4	7	
Power coupler	3	0.6		4	0.8		4	0.8	
Bellows	2	0.2		3	0.3		3	0.3	
HOM	3	1.5		4	2.0		0	0	
Total dynamic		8.3			17.1			8.1	
Static contributions									
Radiation - HV & Bellows	3	1.1	41.7	4	1.8	65.3	4	1.00	37.75
Power coupler (radiation)	3	2.1		4	2.8		4	2.80	
Tuner	3	0.75		4	1		4	1.00	
He vessel Supports	3	0.2	18	4	0.3	24	4	0.27	24.00
Warm Beam Tube Conduction	2	0.1	2	2	0.1	2.5	2	0.54	12.97
Warm Beam Tube Radiation	2	0.9	0.9	2	0.9	0.9	2	0.90	0.90
Cables (3 per cavity)	1	0.5	1.8	1	0.5	1.8	1	0.50	1.80
Sub total CM		5.65	64.4		7.4	94.5		7.01	77.42
Supply Bayonets	2	1	12	2	1	12		1	12
Radiaton	1	0.04	9	1	0.04	9		0.04	9
PC JT Valve	1	0.25	2	1	0.25	2		0.25	2
Subcooler JT Valve	1	0.25	2	1	0.25	2		0.25	2
Shield Relief	2	0	4	2	0	4		0	4
5K Transfer Line	1	0.1	0	1	0.1	0		0.1	0
50K Transfer Line	1	0	3	1	0	3		0	3
Sub total Supply Bayonets		1.64	32		1.64	32		1.64	32
Return Bayonets	2	1.5	6	2	1.5	6		1.5	6
Radiation	1	0.1	11.2	1	0.1	11.2		0.1	11.2
Cooldown / PC Return	1	0.25	10	1	0.25	10		0.25	10
Shield Relief	1	0.3	2	1	0.3	2		0.3	2
Cooldown Valve	1	0.25	2	1	0.25	2		0.25	2
5K Transfer Line	1	0	0	1	0	0		0	0
50K Transfer Line	1	0	3	1	0	3		0	3
Sub total Return Bayonets		2.4	34.2		2.4	34.2		2.4	34.2
Total static		9.69	130.6		11.44	160.7		11.0	143.6

130 W / CM @ 4.5 K equivalent

Summary

- Energy upgrade of existing 100 MeV proton linac
  - Space / Atmospheric radiation test facility on semiconductor with 200 MeV proton linac
  - HWR based superconducting linac

- Cryomodule heat load estimation
  - Static: radiation, conduction
  - Dynamic: cavity
  - Total heat load: 130 W / CM @ 4.5 K equivalent