5 K Shield Study of STF Cryomodule

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Heat loads scaled from TESLA TDR by Tom Peterson

Heat Load @ 2 K

	Static	Dynamic
RF load	NA	7.46
Supports	0.6	NA
Input Coupler	0.55	0.16
Current Leads	0.28	0.28
Others	0.27	1.76
Total	1.70	9.66

Total : 11.36 W

Heat Load @ 40 K

	Static	Dynamic
Radiation	32.5	NA
Supports	6.0	NA
Input Coupler	15.5	60.1
Others	5.2	28.2
Total	59.2	94.3

Total : 153.5 W

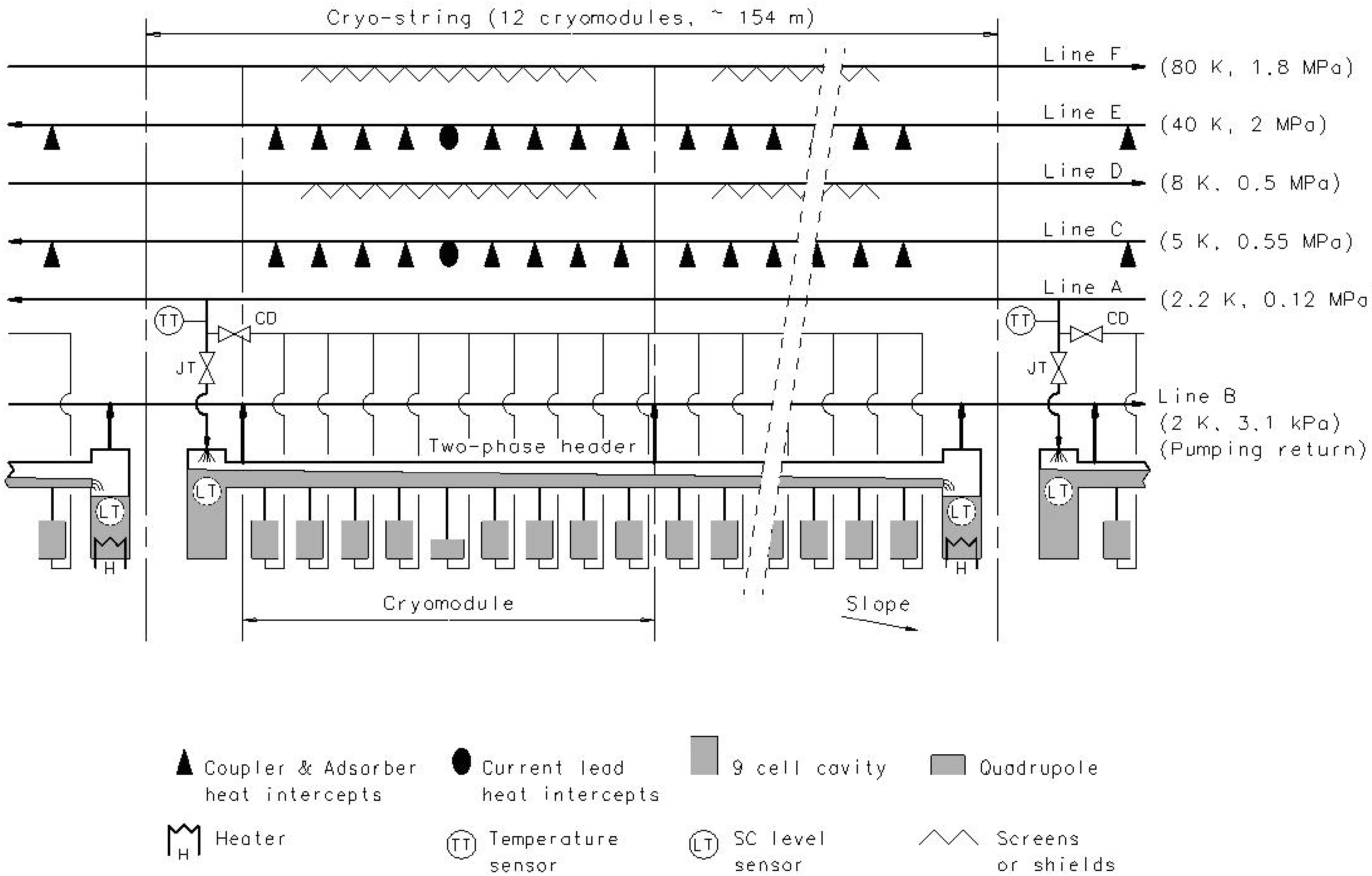
Heat Load @ 5 K

	Static	Dynamic
Radiation	1.41	NA
Supports	2.40	NA
Input Coupler	1.48	1.32
HOM Coupler (cable)	0.29	1.82
HOM Absorber	3.13	0.76
Current Leads	0.47	0.47
Diagnostic Cable	1.39	NA
Total	10.56	4.37

Total : 14.9 W

It is assumed that in the cryomodule without the 5 K shield, the heat load of 1.41 W at 5 K by radiation in the table goes into the 2 K region.

Cooling Scheme by T. P. (in RDR)



Thermal calculation of STF cryomodule model
Thermal Radiation-1

- Conditions of the calculation model (STF cryomodule)
  - 80 K thermal shield
    - The shield length: 5.732 m
    - The shield surface area: 14 m^2
    - Emissivity: 0.2 (as oxidized surface)
  - 2 K components
    - Gas return pipe, 4 helium vessels, beam pipes, LHe supply pipe
    - Surface area of the components : 9.75 m^2
    - Effective emissivity : 0.03

CERN data

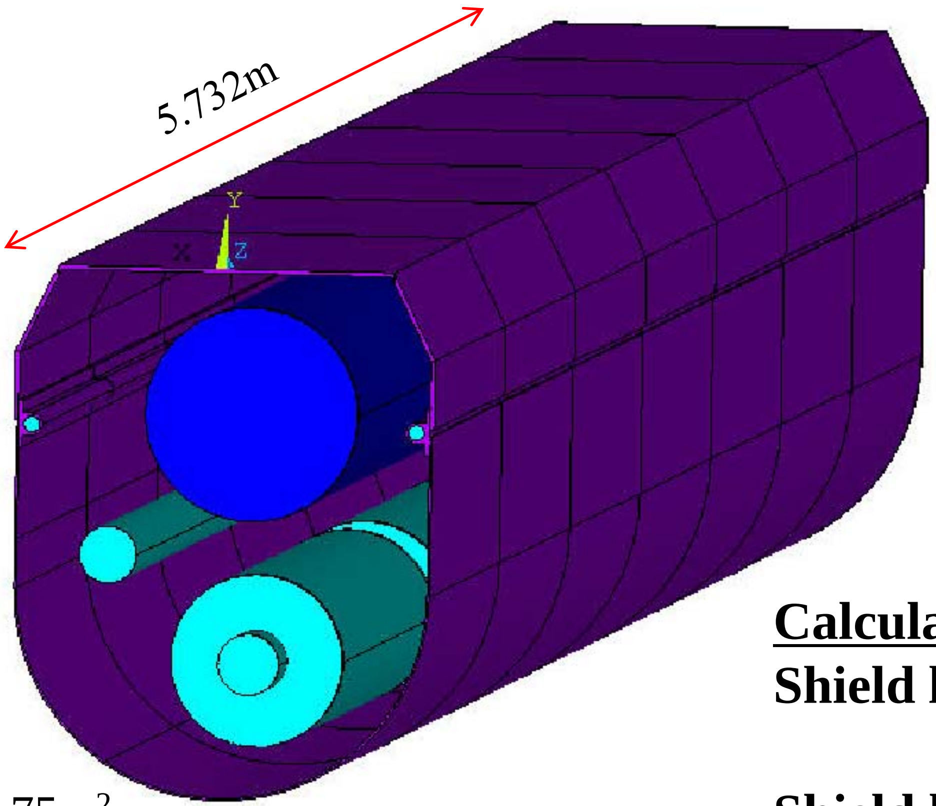
Heat flux by radiation from 80K -> 2K = 0.05 W/m^2

From the equation of heat flux between the parallel planes

$$q/A = \sigma (T_1^4 - T_2^4)/(1/\varepsilon_1 + 1/\varepsilon_2 - 1)$$

$$q/A = 0.05 W/m^2,\ T_1 = 77K,\ T_2 = 4K,\ \varepsilon_1 = 0.2 \Rightarrow \varepsilon_2 = 0.027$$

Thermal calculation of STF cryomodule model
Thermal Radiation-2



80 K shield surface=14m^2
Emissivity=0.2

2K surface=9.75m^2
Emissivity=0.03

<u>Calculation result;</u>
Shield length=5.732 m
q = 0.83 W at 2 K
Shield length for ILC = 12.653 m
q = 1.83 W at 2 K

Thermal calculation by ANSYS
(The effect of the surface shape was checked.)

Operation cost (10 years= 66000H)

Efficiency in Watts/Watt (by T. P. in RDR)

T_c	2 K	5 K ~ 8 K	40 K ~ 80 K
$W_{@300K}/W_{@Tc}$	702.98	197.94	16.45

Heat load of 1.41 W@2K =0.991 kW at 300K,
Total heat loads at three temp. levels = 13.46 kW at 300 K

Required power at 300 K for one cryomodule

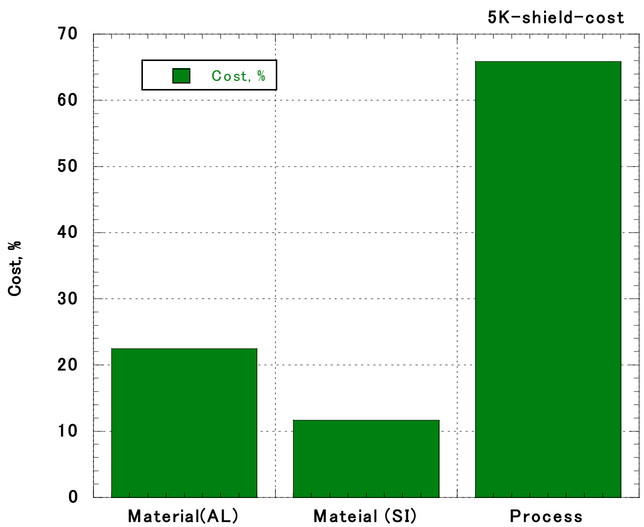
	T. P. model	STF cryomodule model
With 5 K shield, kW	13.489	13.570
Without 5 K shield, kW	14.202	14.484
Difference between two models, kW	0.713	0.914

Required extra operation cost for 10 years

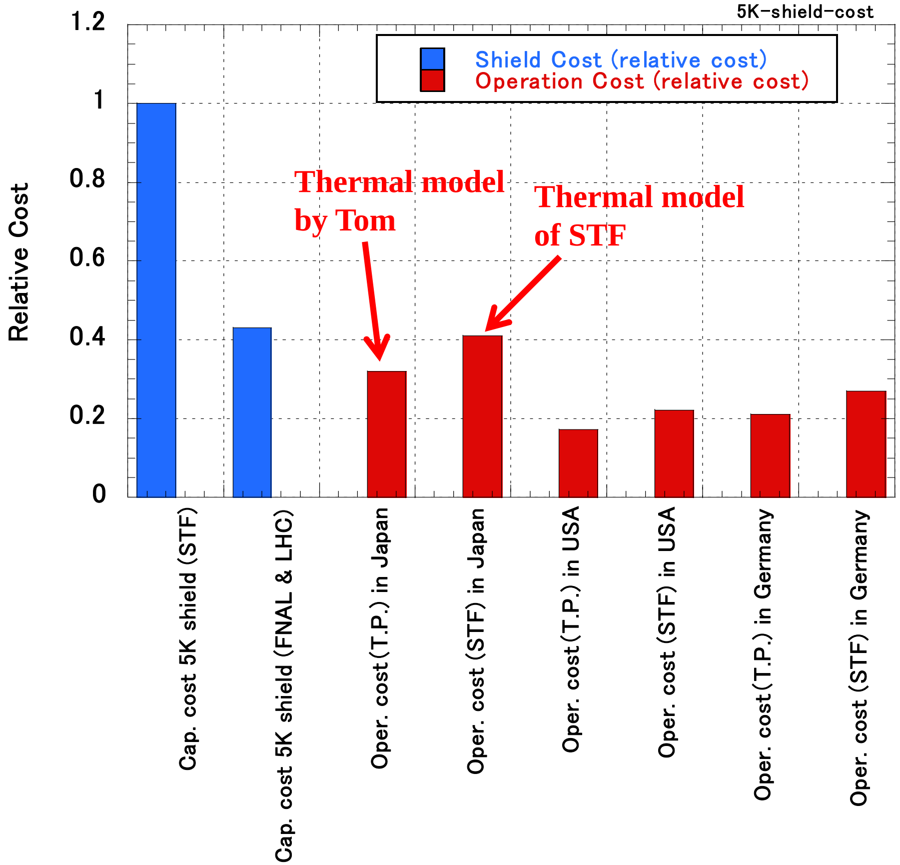
	$/kWh @2006	T.P. model, k$	STF model, k$
Japan	0.117	5.50	7.06
USA	0.063	2.96	3.80
Germany	0.077	3.62	4.65

5 K shield cost of STF cryomodule

- **The cost estimation of 5 K shield is based on the RDR study by the Japanese company.**
- **For the cost estimation of 5 K shield of the STF cryomodule, the learning ratio of the man-hours of processing and discount of the material cost for 2100 cryomodules (for 8 cavities) are considered.**
- **The estimated cost of 5 K shield does not include the company profit.**

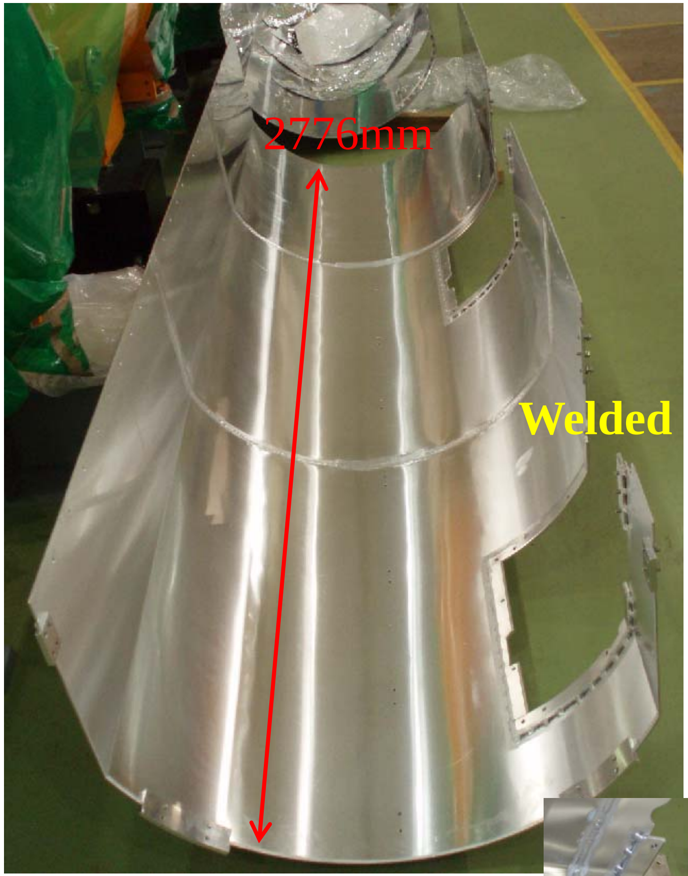


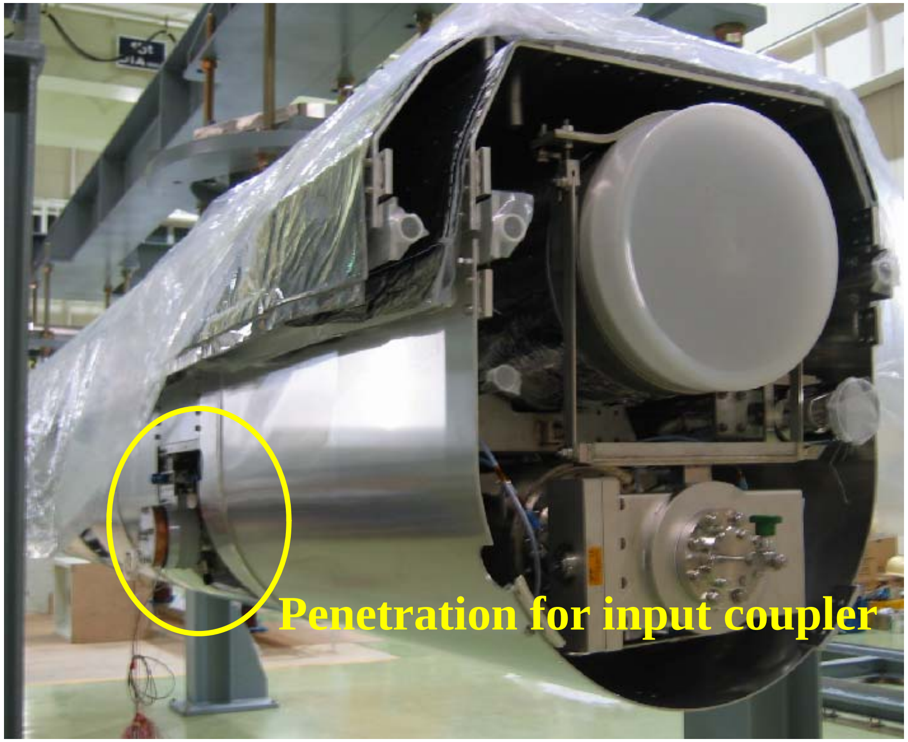
Cost for material and process of the STF 5 K shield
(The material cost includes Al plate and 10 layers SI.)

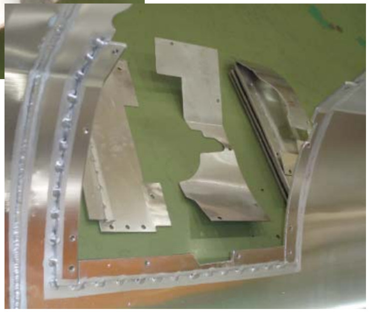


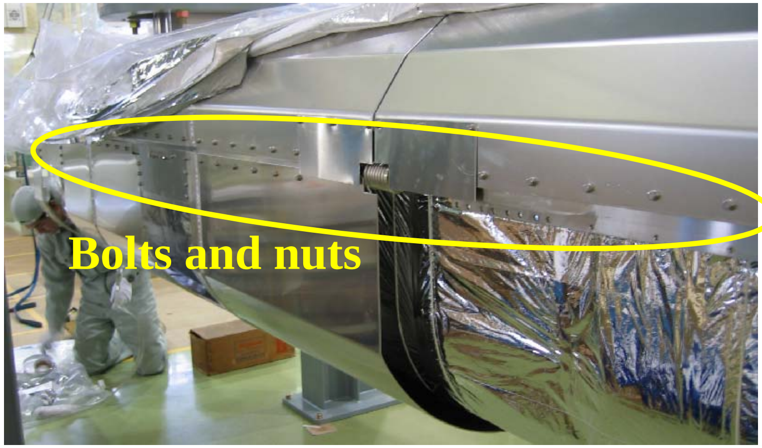
Comparison between the capital cost of 5 K shield and the operation costs
(The 5 K shield cost by FNAL and LHC are estimated for the magnet cryostat. This shield does not have penetrations for the input couplers.)

STF-cryomodule thermal shield









1. The length of one piece is 2776 mm.
2. The three plates are welded for this one piece.
3. Connections between upper-side, lower side and cooling pipes are done by bolts and nuts.

Capital cost of cryogenic system from T.P. study

Cryogenic system cost

- Cost impact is calculated for cryoplants and their installation but not for distribution system
  - Installed plant power increases from 4.28 to 4.49 MW for each of the large cryoplants
  - Assume capital cost increases by installed power ^0.6
  - $7.59 M total cryogenic plants capital cost increase
  - 1815 standard 1.3 GHz cryomodules including sources (not including multi-magnet cryomodules)
- Cryosystem additional M&S is $4200 per cryomodule
- Cryogenic plant operating power
  - Increases from 3.34 MW to 3.50 MW for each of the 10 large plants
  - Total of 1.6 MW added for ILC cryogenic system
- Added operating cost at $0.10/kW-hr is $1.38M/yr ($770 per cryomodule per year

Estimation for 1.41 W at 2K
1.83/1.41=1.30 for KEK cal.

To get the same operation margin, the cryogenic system should be enlarged.
4.2k$ × 1.30=5.5 k$

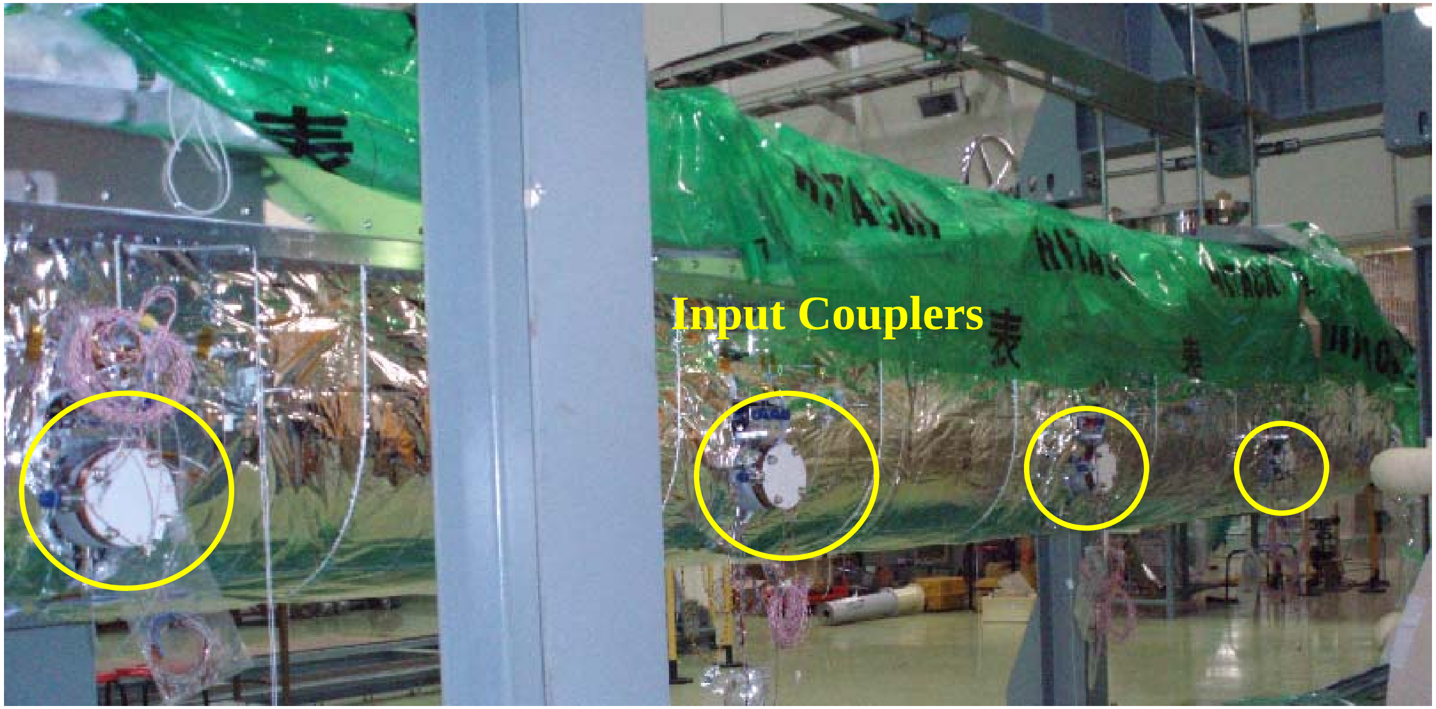
For one cryomodule, 0.882 kW.
For 10 year operation,
0.882 × 66000 × 0.117 × 1.30 = 8.9 k$ in Japan.

28 Sep 2007 Tom Peterson Cryosystem cost tr

In total, 5.5 k$ + 8.9 k$=14.4 k$ for one cryomodule

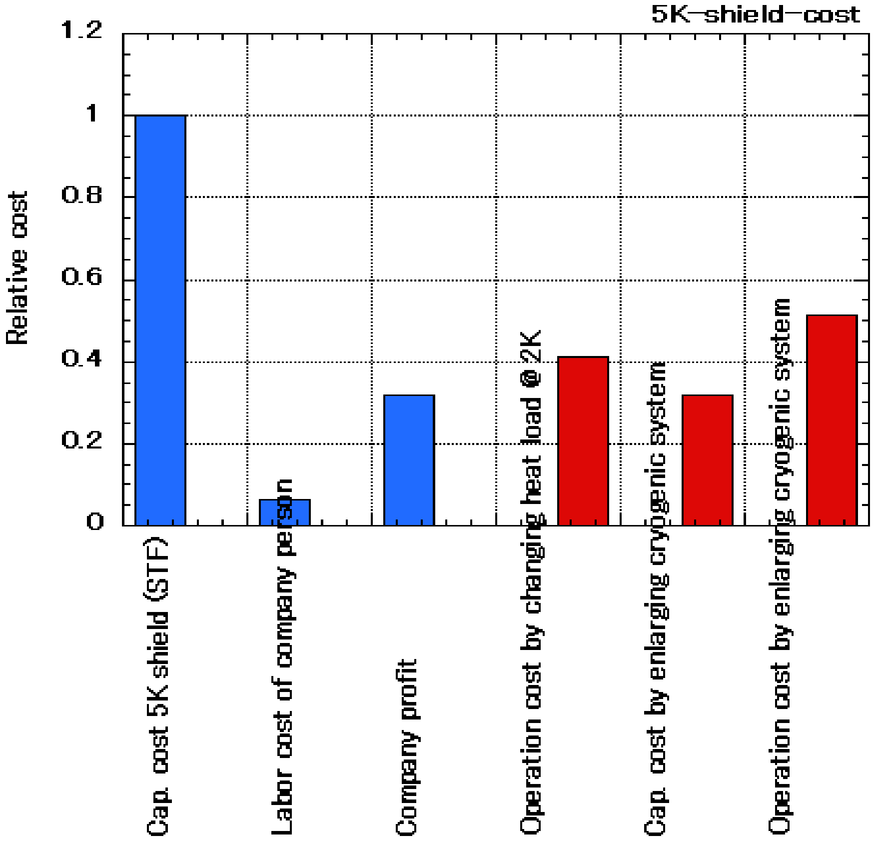
Assembly cost of the shield and SI

- **Assembling and welding the upper and down shields**
  - **Assembling shields: two persons × 0.5 day**
- **Assembling SI on the 5 K shield and around the input couplers**
  - **4 persons × 0.5 day**
- **In total, 3 person × 1 day**

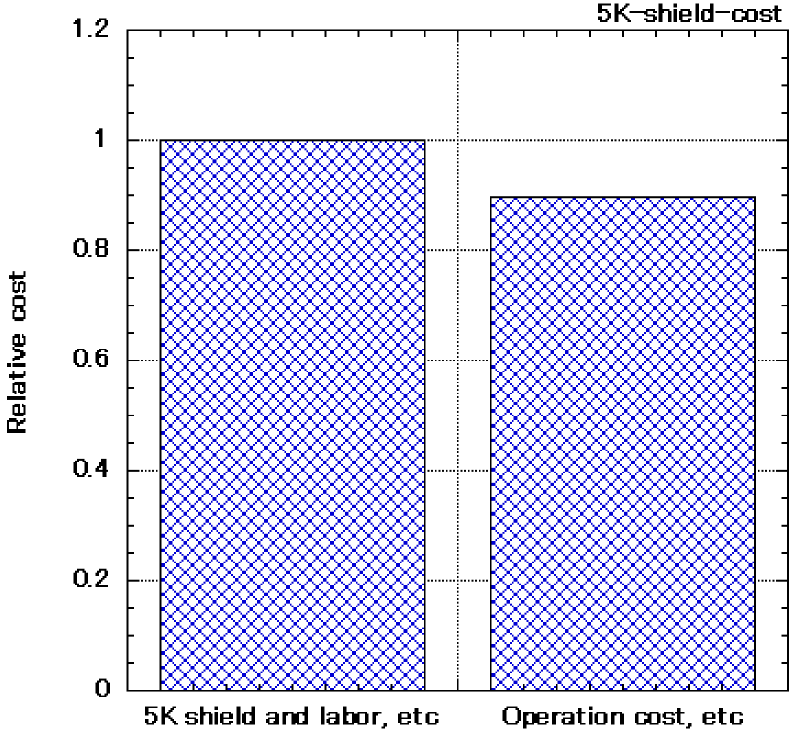


Super Insulations on the 5 K shield

Comparison of the costs including all items for the 5K shield of STF cryomodule



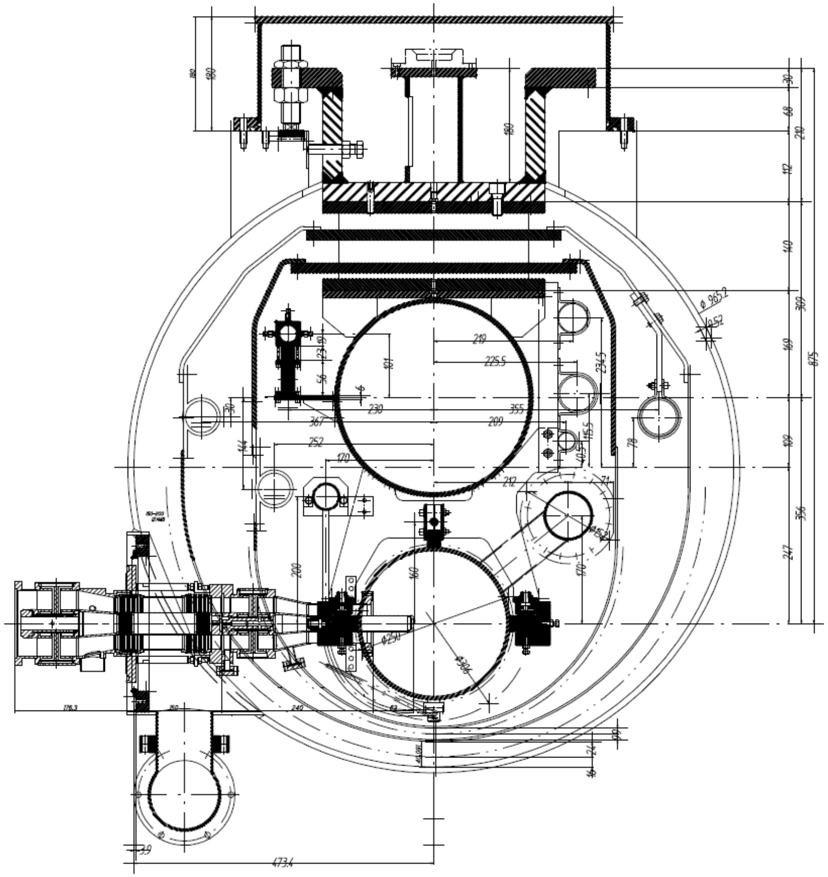
The company profit is included for costs of components and labors of company people.

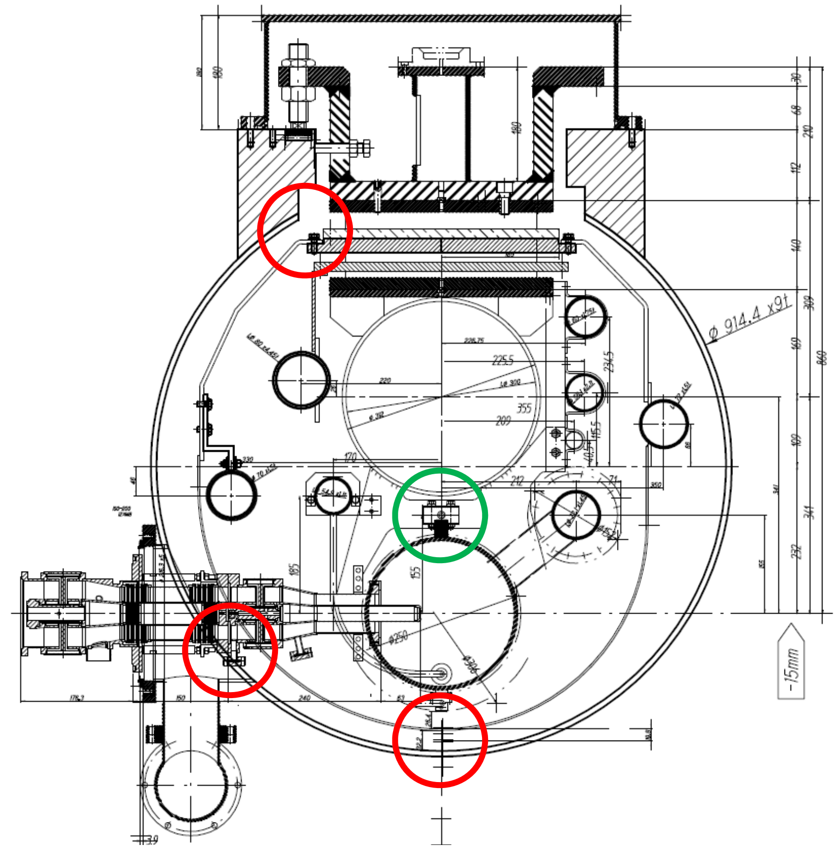


With the model of STF cryomodule, the capital cost of the 5K shield is 10 % higher than the sum of increments of the operation cost and the capital cost of the cryogenic system.

Study of the cryomodule cross-section

with keeping the same temperature profile (1)





Two shields model based on TTF-III

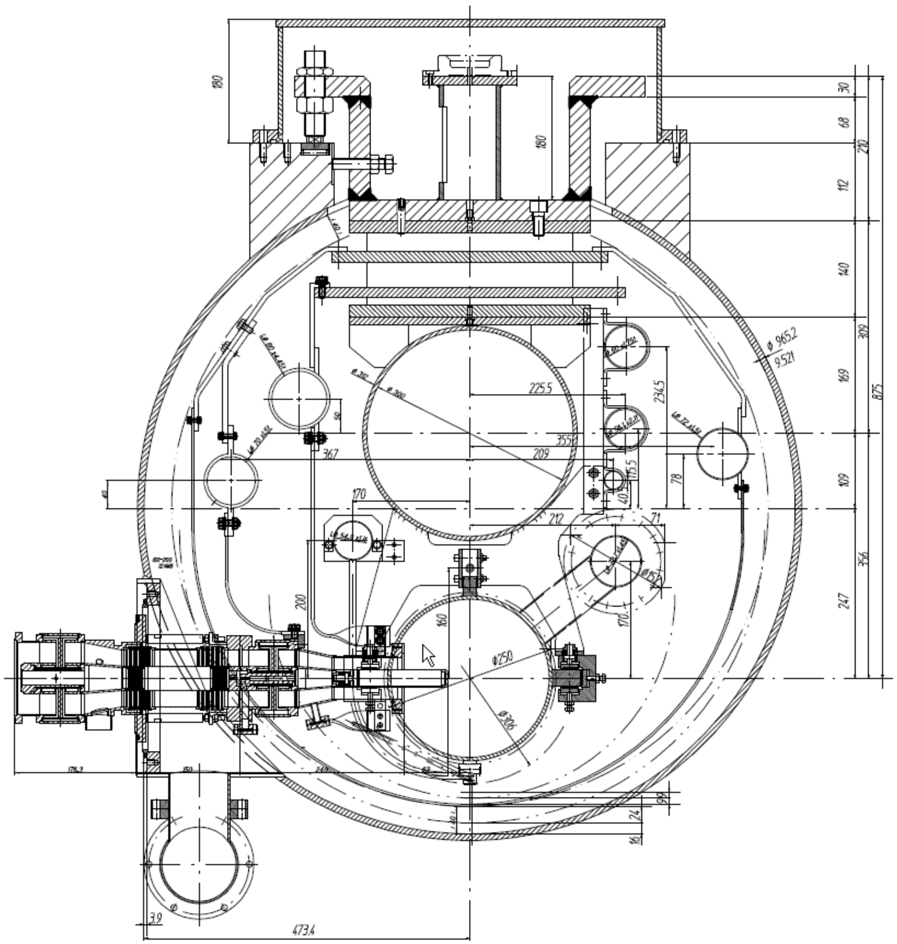
1. The vacuum vessel diameter is 965.2 mm.
2. The space for the SI on 80 K shield is 40 mm.
    - The design space for 30-layer-SI is 24 mm.

One shields model

1. The vacuum vessel diameter is 914.4 mm (commercial size).
2. Input couplers have sever interferences with the inner surface of the vacuum vessel.
3. The spaces for the SI on 80 K shield is 32 mm.
4. The material cost cut is 1 k$ for one cryomodule.

Study of the cryomodule cross-section

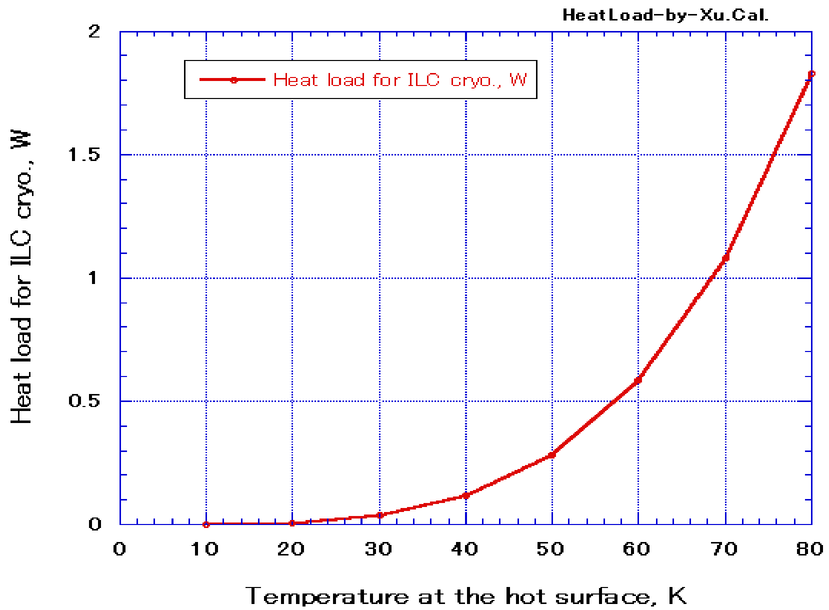
with keeping the same temperature profile (2)

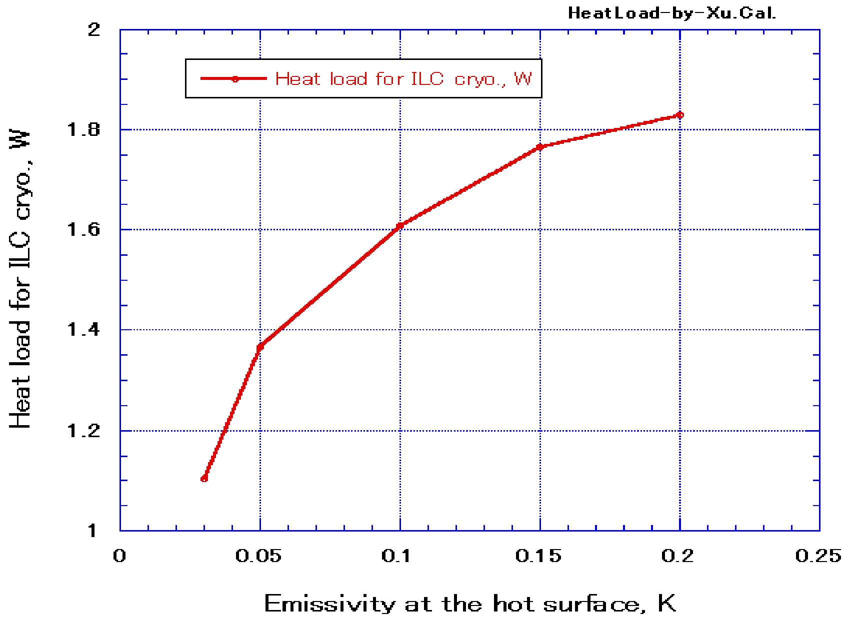


- **The reduction of the vacuum vessel diameter is difficult due to the interference with the other components.**
  - **Input coupler size when inserting the cold mass with cavities and cold couplers into the vacuum vessel.**
  - **Required space for SI and the space defined by the support posts, GRP and cavity vessels.**
- **Thermal interceptors**
  - **The modification of the design in the thermal interceptors**
    - **The interceptors for input couplers and the RF cables are connected to the terminals which are fabricated on the forward cooling Al pipe.**
  - **The interceptor size is not influenced.**
  - **By this modification, the thermal shields and the assembly process will be simple.**

Thermal radiation study by ANSYS

- **In the above calculation, the thermal condition is based on the CERN data.**
  - **$Q = 0.05\ W/m^2$, $\varepsilon_{80K}=0.2$, $\varepsilon_{2K}=0.03$ for 10-layer-SI and from 80K to 2K.**
- **The dependences of the temperature and the emissivity coefficient at the hot surface in the heat load at 2K are calculated.**





The lower temperature of the thermal shield is effective for reducing the heat load at 2K by radiation;

The heat load is reduced at 40 % by decreasing the temperature from 80 K to 70 K.

The reduction of emissivity by putting SI inside the hot surface is effective, too;

The heat load is reduced at 40 % by putting 10-layer-SI on the inside surface.

Conclusion

- **The sum of capital and assembly labor costs of the 5K shield is 10 % higher than the sum of increments of the operation cost and the capital cost of the cryogenic system.**
  - **Heat load from 80 K to 2 K : 1.83 W**
  - **Assumption of the heat intensity by radiation : 0.05 W/m2**
    - **Emissivity coefficient at 80 K = 0.2, coefficient at 2 K (10-layer-SI)=0.03**
- **It was expected to reduce the vacuum vessel diameter, however, it has turned out to be difficult for the interference between the inner surface of the vacuum vessel and the module components, mainly input couplers.**
- **The cross section of the cryomodule should be modified with the thermal interceptors.**
- **By the thermal calculation by ANSYS;**
  - **The temperature of the shield has a strong influence on the heat load by radiation.**
    - **The shield temperature should be optimized for the cryomodule without the 5K shield.**
  - **The emissivity coefficient of the 80 K shield is important factor.**
  - **These factor can be measured by the STF cryomodule.**