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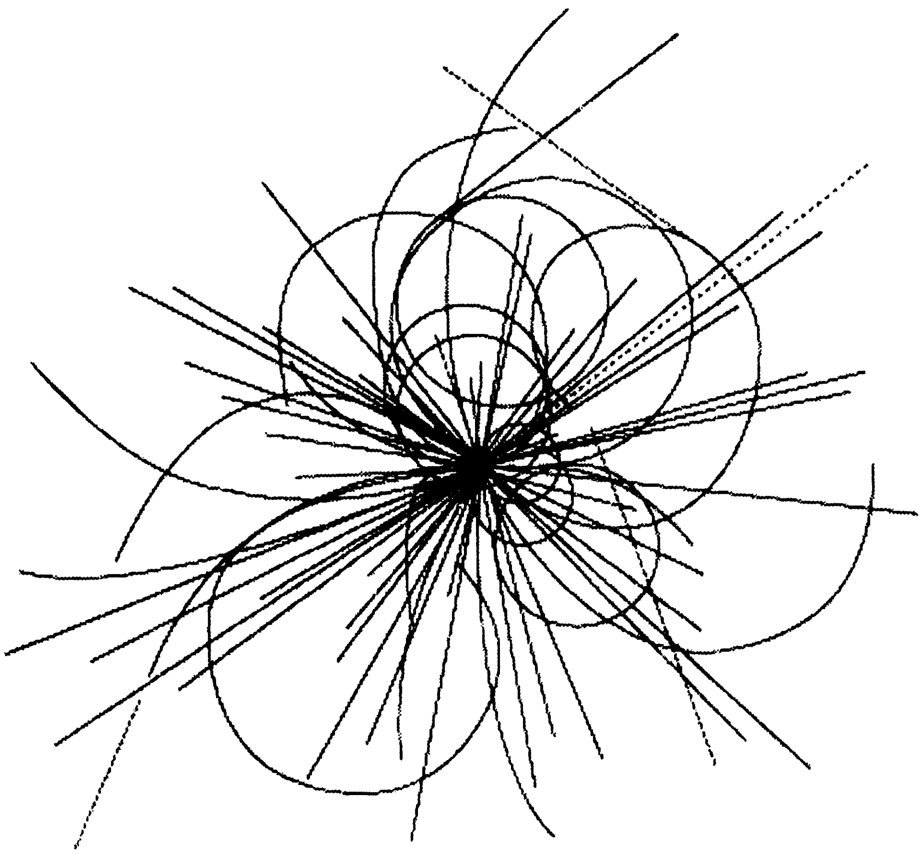

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OPERATING MODES OF THE SSC SECTOR STATION CRYOGENIC SYSTEM

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INTRODUCTION

The magnets in the Collider rings and in the HEB (High Energy Booster) ring are refrigerated by single phase helium flow controlled at a temperature of 4 K to maintain the magnet windings in the superconductive state. To minimize the heat load into the 4 K loop, the magnet cryostats are designed to provide high quality thermal insulation achieved by a high vacuum with multilayer insulation (MLI) and by two thermal shields at a nominal temperatures of 84 K and 20 K, respectively.

An extensive cryogenic system capable of normal operation of the superconducting magnets and handling transient conditions such as quenches, beam activation, ring filling, and beam ramping is required. The cryogenic system must also have the capability to perform other services such as cleanup, cooldown, and warmup, to allow for maintenance and repair of the superconductive components throughout the ring.

The refrigeration system is designed with a specific capacity to meet each of the various loads viz. 4 K refrigeration, 4 K liquefaction and 20 K shield cooling, to meet all the loads during normal and upset conditions and possess some extra capacity. The static heat leak and dynamic load to the 4 K components are the 4 K refrigeration load. It is handled by the latent heat of vaporization in the helium recoolers. The 4 K helium used for cooling the electrical leads returned at 300 K to the refrigerator, is the liquefaction load. The 20 K shield that absorbs part of the radiation and the static heat leak above 20 K is the 20 K refrigeration load. This load is handled by supplying 200 g/s, 3.0 bar helium at 14 K and returns the helium to the refrigerator at a temperature depending on the load. The refrigeration system has one spare compressor. It is capable of delivering 4 K and 20 K refrigeration and part of the liquefaction load in the nominal mode of operation given in Table 1 even when any one of the expanders fail.

Figure (1) is a block diagram showing the major components and their relative locations in the Sector Station Cryogenics System (SCS) which are the Sector Refrigeration Surface System (SRS), Sector Refrigeration Tunnel System (SRT) and the Sector Refrigeration Control System (SRC). There are many operating modes for the SCS and for each mode of operation there is a different scheme for the cryogen flows. The SCS is reconfigured each time by switching and by activation/deactivation of specific sets of equipment that allow for adjusting the process conditions, capacity and the throughput. The line numbers shown in Figure 1 as well as a detailed description of the plant operation is given in Reference.[1]

This paper summarizes the operating modes of the SCS, the various states and processes.

THE OPERATING MODES OF THE SCS

The various modes of operation are defined as follows: Design Mode, Nominal Mode, Standby Mode, Assist Mode, and Utility Modes. Figure 2 shows the various system states and plant operational modes.

The refrigeration capacity required for a sector in four different modes of operation is given in Table 1. The design mode loads have a design margin of 25% for the 4 K loads and 50% margin for the 20 K load compared to the nominal mode. These margins account for the variation in the loads from sector to sector due to the difference in the lengths of the actual sectors and provide extra capacity required in the Assist Mode. The SCS is operated in the Nominal Mode when the collider is at full normal operation. This means the system is cold and the beam is on. The dynamic heat load on the system depends on the beam intensity. The 20 K shield cooling load remains unchanged in the Nominal, Standby and Assist modes of operation. The heat load budgets for each individual sector in the collider as well as the HEB sectors are given in Reference.[1]

The SCS is operated in the Standby Mode when the collider is cold at nominal temperatures, with no beam operating. Hence the refrigeration and liquefaction loads are lower than in the nominal mode. In this mode of operation the refrigeration load depends only on the "static load." The liquefaction load used for the electrical leads may be reduced since there is no electrical current. The excess liquid produced in the assist mode is transferred to a neighboring sector where the refrigeration plant is operating below nominal capacity.

During a quench, a large amount of energy (~7 MJ) is transformed into heat and deposited in the cold mass. The magnets are protected by quickly aborting the beam and ramping down the electric curren . The quench valves are opened and helium is vented from the cold mass into the 20 K line. The cold mass is then gradually brought back to nominal operating temperature. Operations such as cleanup, cooldown, warmup and maintenance are part of utility mode operations. The heat capacity of a sector is highly dependent on the temperature. The process times for each of these utility modes depends on the temperature level and the changes in the fluid inventory. Table 2 shows the fluid inventory in each of the cryogenic lines and the process times for each of the utility mode operations in a sector.

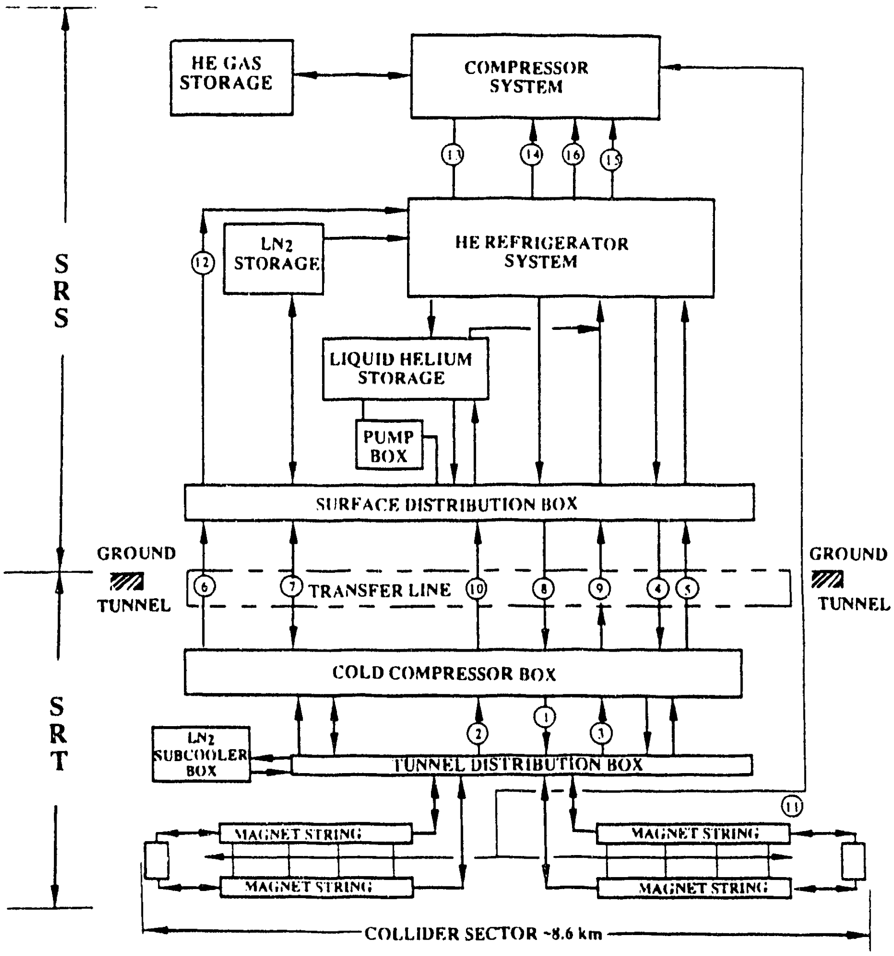

Figure 1. Sector Station Cryogenic System Block Diagram.

Table 1. SCS Capacity for Different Modes of Operation.

	DESIGN MODE							NOMINAL MODE						
	PI	TI	PO	TO	Flow	Load	W(Car)	PI	TI	PO	TO	Flow	Load	W(Car)
	MPa	K	MPa	K	g/s	Watts	KW	MPa	K	MPa	K	g/s	Watts	KW
Refrigeration	0.400	4.0	0.077	3.95	330	6750	574	0.400	4.0	0.077	3.95	264	5400	461
Liquefaction	0.400	4.0	1.05	305	45		320	0.400	4.0	1.05	305	36		256
20 K system	0.400	14.0	0.2	27.8	200	15000	302	0.300	14.0	0.2	23.2	200	10000	208
Cold Compressor	0.075	4.3	0.145	6.07	330	2745	48	0.075	4.3	0.14	6.06	264	2235	45
Total Capacity							1244							970
	STANDBY MODE							ASSIST MODE						
Refrigeration	0.400	4.0	0.077	3.95	138	2800	238	0.400	4.0	0.077	3.95	264	5400	461
Liquefaction	0.400	4.0	1.05	305	25		178	0.400	4.0	1.05	305	54		384
20 K system	0.300	14.0	0.2	27.8	200	10000	208	0.300	14.0	0.2	23.2	200	10000	208
Cold Compressor	0.075	4.3	0.135	6.05	138	1191	27	0.075	4.3	0.14	6.06	264	2235	45
Total Capacity							651							1098

The plant is operated in special modes for other types of collider configurations such as single ring cryogenic operation. The plant is said to operate in maximum capacity mode when the sector loads are high, or when assisting a neighboring sector, or when handling additional liquefaction load. It is operated in minimum capacity mode when the sector heat loads are low such as in a standby condition of the ring.

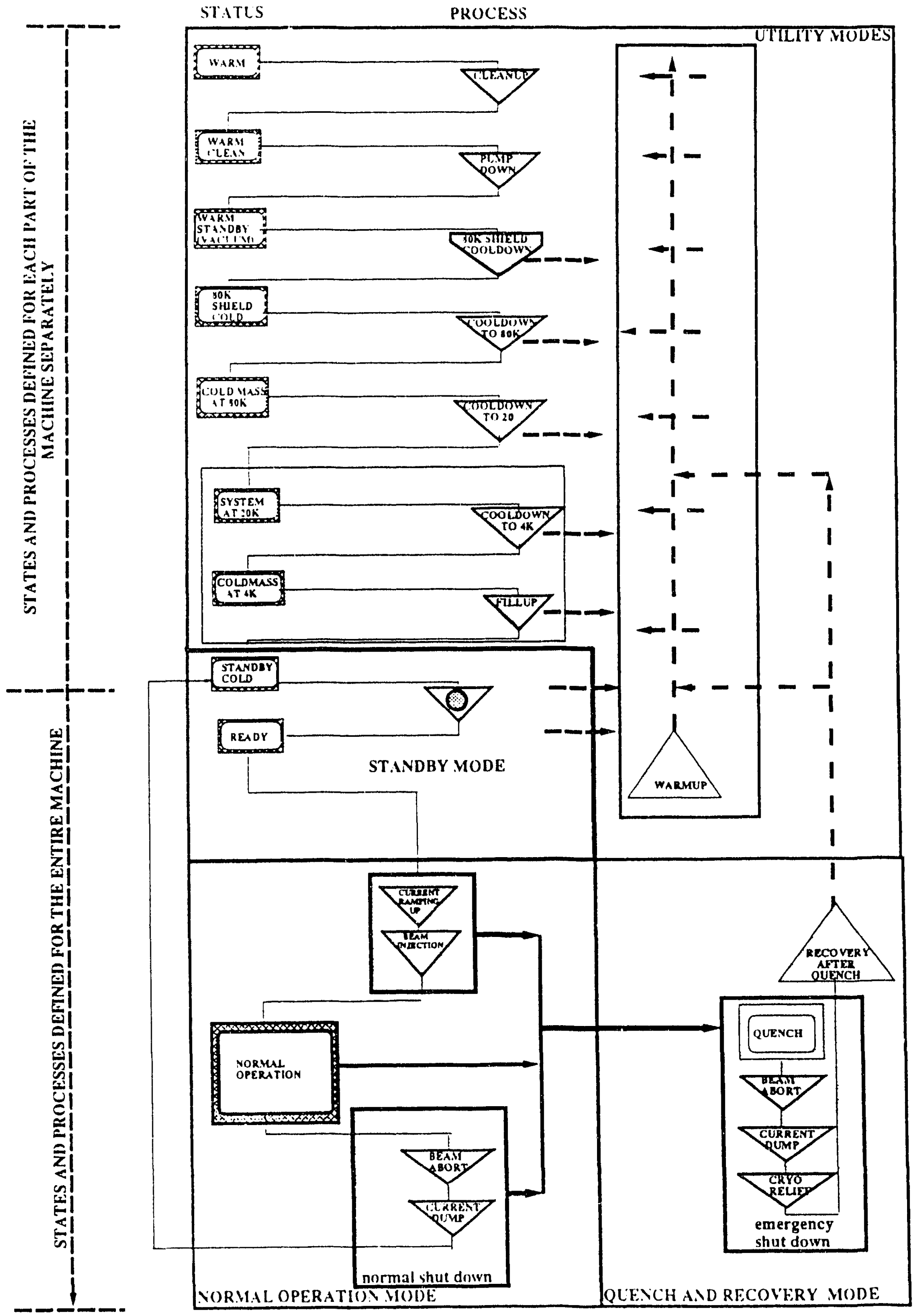

Figure 2. The System States and the Operational Modes.

Table 2. Collider Sector Fluid Inventory.

	I.D.	Pressure	Temperature	Volume	Warm clean	Warm standby	80K shield cold	20K shield at 80 K	Coldmass at 80 K	Coldmass at 20 K	Nominal mode	Quench and recovery	Gas desorption
	mm	MPa	K	liters	kg	kg	kg	kg	kg	kg	kg	kg	kg
LINE1-4K He feed		0.4	4.05	133702	21.73	21.73	21.73	21.73	240.13	966.40	18758	-100	966.40
LINE2-4K He Return	45.2	0.35	4.3	27720	4.50	4.50	4.50	4.50	49.79	200.36	3690		200.36
LINE3-GHe return	86.5	0.08	4.05	101500	16.49	16.49	16.49	16.49	182.29	733.64	1260		733.64
Recooler (shell)		0.08	4.05	2592	0.42	0.42	0.42	0.42	4.66	18.73	365		18.73
LINE4-20 K shield	82.6	0.3	14.28	92549	44.52	44.52	44.52	167	167	669	669	100	669
LINE5-80K LN2	57.2	0.7	84	44380	49.84	49.84	34620	34620	34620	34620	34620		34620
LINE6-80K GN2	57.2	0.14	84	44380	49.84	49.84	245	245	245	245	245		245
Warm He gas return	127	0.11	300	218787	35.55	35.55	35.55	35.55	35.55	35.55	35.55		35.55
				total helium	**123.22**	**123.22**	**123.22**	**245.70**	**679.41**	**2623.63**	**24778**		**2623.63**
				total nitrogen	99.68	99.68	34865	34865	34865	34865	34865		34865
HELIUM PLANT AND VERTICAL TRANSFER LINES NOT INCLUDED													
Pumpout 192 half cells 22,000 liters each to rough vacuum													
insulating vacuum after pumpdown ~0.013 Pa. Expected pump down time including leak check ~48 hours.													
Cooldown the 80 K shield from 300 to 80 K (LN2 flow=20 g/s up to nominal flow), 3-4 days/km minimum.													
44,530 MJ (2,577kJ/m) to be removed from the shield : 197,760kg LN2/sector (12,360 kg LN2/section , 16 sections/sector)													
Cooldown the 20 K shield from 300 to 20 K (20 g/s up to nominal flow).													
27,270 MJ (1,578 kJ/m) to be removed from the shield : First cooldown is performed together with the cooldown of the cold mass , approximately 22 days to cooldown to 80 K. Additional 24 hours to cooldown to 20 K.													
Cold mass cooldown from 300 to 80 K (400 g/s divided into 4 strings), 22 to 23 days													
8.55 E08 KJ to be removed from the cold mass :													
Coldmass cooldown from 80 to 20 K (140 g/s divided into 4 strings) 3 to 4 days													
4.46 E07 KJ to be removed from the cold mass:													
Coldmass cooldown from 20 to 4 K (400 g/s divided into 4 strings) 1 to 2 days													
4. E05 KJ to be removed from the cold mass:													
Up to 7 MJ transferred into heat. 100 kg, 4 K helium vented into the 20 K shield line. Half cell warmed up to 7 to 10 K. Time ~20 minutes.													
Cooldown 1/2 cell to 4 K: 4.5MJoules(heat)+ 45 minutes static load /sector(3.2MJ) . Refill 100kg with 100 g/s ~20 minutes. Control loop activation (the whole sector) 15-20 minutes													
Warmup the sector to 20 K by pumping 100g/s 20 K helium (total heat = 4. E05 MJ). 10-15 hours.													
Cooldown the sector to 4 K (total heat = 4. E05MJ) increase inventory by 22,000 kg , fillup with 400 g/s ~15 hours.													

REFERENCES

1. R. Than, S. Abramovich, V. Ganni. "The SSC Cryogenic System Design and Operating Modes."

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