New DSSSD mount and cooling system

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1 Introduction

A new DSSSD mount has been installed at the end of DRAGON. The mount includes a liquid cooled cold plate which can cool DSSSDs to to temperatures as low as -10°C. This report describes motivation for the new DSSSD mount, and its design and operation with a recirculating liquid chiller. A thorough introduction to the DRAGON DSSSD system in general can be found in [1].

2 Motivation

2.1 Radiation Damage

Radiation damage can affect DSSSD performance [1]. There are two mechanisms for inducing radiation damage in a segmented silicon semiconductor detector [2, p. 387] [3].

1. Bulk damage may result from an incident charged particle undergoing a non-ionizing collision with a silicon atom, displacing it from its lattice site. Depending on the collision kinematics, the recoiling silicon atom may displace further atoms forming a cluster of defects in the lattice. Bulk damage leads to charge carrier trapping, and a build-up of space charge which changes the required operating voltage and increases the leakage current.

[1]The text of this section borrows from [1, ch. 6].

2. Surface damage leading to increased surface currents may result from charge build up on the surface of the DSSSD and affect the inter-strip isolation. Effects of charge build-up depend strongly on the structure and composition of the detector.

The reverse bias current increase per unit volume for a silicon detector, $\Delta\ I_R$, is a linear function of particle fluence, Φ, the time-integrated particle flux, when a DSSSD is used to detect transmitted particles.

$$\Delta\ I_R = \alpha\ \Phi, \tag{1}$$

where the damage coefficient $\alpha = 3 \text{ x } 10^{-17}$ A/cm for minimum ionizing protons, for example [3]. Equation 1 can be simplified for low energy heavy ions of the same energy: if the ions are all stopped in the detector then the detector volume is irrelevant and current is proportional to the total number of ions incident on the detector. Low energy heavy ions induce more damage per particle than minimum ionizing protons, but estimates vary with ion species and energy [2, p. 388], so equation 1 must be used as a guide. After enduring a sufficiently large fluence, a detector becomes inoperable due to the increase in leakage current. This situation may be rectified by cooling the detector since the leakage current is a strong function of the temperature of the detector.

$$\frac{I_R(T_2)}{I_R(T_1)} = \left(\frac{T_2}{T_1}\right)^2 \exp\left[-\frac{E}{2k}\left(\frac{T_1 - T_2}{T_1 T_2}\right)\right], \tag{2}$$

where I_R is the leakage current as a function of temperatures T_1 and T_2, k is the Boltzmann constant, and $E = 1.2$ eV is the ionization energy of crystalline Si. Equation 2 shows that cooling the detector from room temperature to 0 °C should yield a 6-fold reduction in leakage current.

2.2 Radiation Damage to the DRAGON DSSSDs

Several of the DRAGON DSSSDs have been subject to a sufficient fluence of heavy ions from ISAC beams to induce damage, due to errors made while tuning the magnetic and electrostatic elements of the separator. The DSSSDs subjected to the beam are no longer able to hold the full depletion bias without exceeding the maximum allowable leakage current of about 2 μA at room temperature.

Detector	Rad. Damage	Bias (V)	I_r (μA)	Macroscopic damage
DSSSD 1288-3	none	70	0.58	broken wires
SSSSD 1288-15	none	70	0.41	none
DSSSD 1288-18	none	70	1.45	broken wires
DSSSD 2069-5	beam 10/31/01	10	2.00	broken wires
DSSSD 2069-4A	beam 12/05/01	11	2.00	broken wires
DSSSD 2069-3	beam 07/30/02	16.5	2.00	none
DSSSD 2069-1				
DSSSD 1865-16	none	70	0.20	none
DSSSD 2239-3	none	50	0.17	none

Table 1: DRAGON silicon strip detector inventory.

In the large particle fluence environments of high energy particle physics experiments, a DSSSD can maintain operation up to a minimum ionizing proton fluence larger than 10^{15} cm^{-2} provided that it is cooled to between -10 °C and 0 °C [4]. A typical stable beam intensity for DRAGON experiments is 15 pnA (particle nano-Amperes) which is about 10^{11} ions/s. If the DRAGON DSSSDs were exposed to this full beam for less than 100 s, then the DSSSDs were exposed to less than 10^{13} ions. Assuming that the increase in leakage current induced by a given number of low energy heavy ions is less than 100 times that for the same number of minimum ionizing protons (this is a reasonable assumption [2, p. 388]), the damaged DSSSDs should function when cooled. A preliminary design of the cooling system was used to test the effects of cooling on the radiation damaged DRAGON DSSSDs.

2.3 Inventory of the DRAGON Silicon Strip Detectors

In the summer of 2002, an inventory was taken of the DRAGON silicon strip detectors, including one single sided silicon strip detector (SSSSD). Recorded were their serial number, apparent macroscopic damage, and the extent of radiation damage gauged by the bias they could hold at 2 μA leakage current and room temperature. Shown in table 1 is an update of this inventory on 02/25/03.

Detector	Damage	I_r (μA)	Counts	Time (s)	Rate (c/s)	Efficiency
SSSSD 1288-15	none	0.35	789 885	1936	408.0	0.929
DSSSD 1288-3	none	0.47	266 020	606	439.0	1.000
DSSSD 2239-3	none	0.12	260 330	606	429.6	0.979
DSSSD 2069-1	beam	0.55	269 500	607	444.0	1.011
DSSSD 2069-3	beam	0.15	272 770	610	447.2	1.019
DSSSD 2069-5	beam	0.19	263 950	605	436.3	0.994

Table 2: Good SSDs vs. cooled radiation damaged DSSSDs.

2.4 Cooling Radiation Damaged DSSSDs

The effect of cooling on efficiency and resolution of the radiation damaged DSSSDs was tested and compared to undamaged silicon strip detectors (SSDs). Each detector was exposed to a 2 μCi ^{241}Am α-particle source at a distance of 10 cm. Radiation damaged DSSSDs were each cooled to -3.8 °C while undamaged SSDs were run at room temperature. In all cases the source geometry and electronics were identical. This gave a reliable comparison between new SSDs run at room temperature and cooled damaged DSSSDs.

As shown in table 2, there is no significant difference in the efficiency of the full energy peak of undamaged SSDs and radiation damaged DSSSDs. The number of counts in the full energy peaks of strips 1 through 12 were summed to produce the column labelled "counts", and a rate was determined from run time. Efficiency data were normalized to DSSSD 1288-3, a DSSSD without radiation damage. The only anomalous efficiency is in SSSSD 1288-15 which is an old SSSSD. The small differences in efficiency between the detectors can be attributed to statistics ($\pm$0.2 %), and subtle variations in manufacturing between detectors, particularly in the surface area of strips and gaps ($\pm$2.0 %) [5].

The energy resolution of damaged DSSSDs is of interest if they are to be used in place of new DSSSDs on DRAGON. Energy resolution data were analyzed by fitting a Gaussian curve to the Gaussian portion of the peak in the energy spectrum of each strip in each SSD. Shown in figure 1 is the FWHM energy resolution as a percentage of full pulse height across the front strips of 6 detectors, taken from the same runs as the efficiency data. In general, the undamaged detectors show uniform resolution across the surface of the detector with the exception of strip 11 in SSSSD 1288-15, an anomaly which

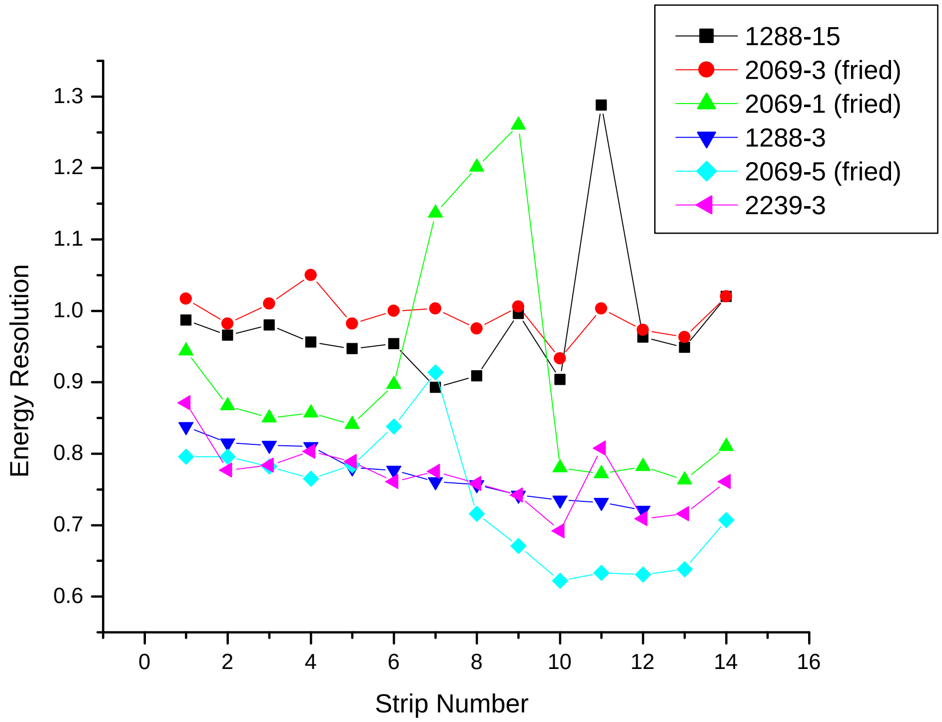


Figure 1: Energy resolution of undamaged DSSSDs compared with that of radiation damaged, "fried", DSSSDs.

cannot be due to radiation damage since this detector has not been subject to a large fluence of charged particles. DSSSDs 2069-1 and 2069-5 show good energy resolution in general but show degraded energy resolution near their center which is likely where the beam was incident. In DSSSD 2069-1, which exhibits the largest degradation, the worst resolution is 1.3 % FWHM which is useable. The localization of the resolution degradation could allow the undamaged portions of these DSSSDs to be used without sacrificing optimum energy resolution by localizing the beam and recoil spots. DSSSD 2069-3, a radiation damaged DSSSD, did not show a localized degradation in energy resolution but rather exhibited a poorer overall energy resolution which may be due to damage by a diffuse beam spot.

2.5 Cooling New DSSSDs

Because of the strong dependance of leakage current on DSSSD temperature, cooling new DSSSDs while running can best benefit DRAGON as a damage control measure. If a DRAGON operator impinges the full beam or a large part of it on the DSSSD accidentally then the leakage current rises quickly. Cooling a DSSSD reduces this spike in leakage current which could otherwise lead to the breakdown of the diode by avalanche ionization. The cooling mount also allows running to continue using the newly radiation damaged DSSSD without significant downtime to replace the DSSSD.

Cooling a DSSSD from room temperature to 0 °C can effectively eliminate the 15 keV contribution to the energy width in new DSSSDs [6]. Temperature fluctuations and inhomogeneities contribute about 1 $\frac{\text{keV}}{^\circ\text{C}}$ to the energy width [6], and this can be reduced with accurate temperature control. However, in DRAGON experiments other larger contributors to the energy spread render the improvement from cooling and temperature stability and homogeneity negligible [1, ch. 6].

3 The DSSSD Cooling System

The DSSSD cooling system installed on DRAGON consists of a cold plate mount and a recirculating liquid chiller to regulate the temperature of the cold plate.

3.1 DSSSD Cooling Mount

The DSSSD cooling mount is fixed on one vacuum plate which is compatible with the standard $24.1 \times 24.1 \times 24.1$ cm^3 "TISOL" vacuum boxes. The plate is mounted on the top of the TISOL box at the end of DRAGON. Fed through the plate are the 32 DSSSD signals, two copper liquid lines, and two K-type thermocouples. The liquid lines enter and exit a copper chamber to which a cold plate is fastened. The copper chamber is supported mechanically by an aluminum bracket which is fastened to the top of the vacuum box and is thermally insulated by nylon washers. The DSSSD is positioned on the cold plate by two mounting holes on two pins, and fastened to the cold plate by 3 electrically insulated clamps (one on the bottom and two on the sides). The cooling mount situates the DSSSD 3 cm upstream of its old position,

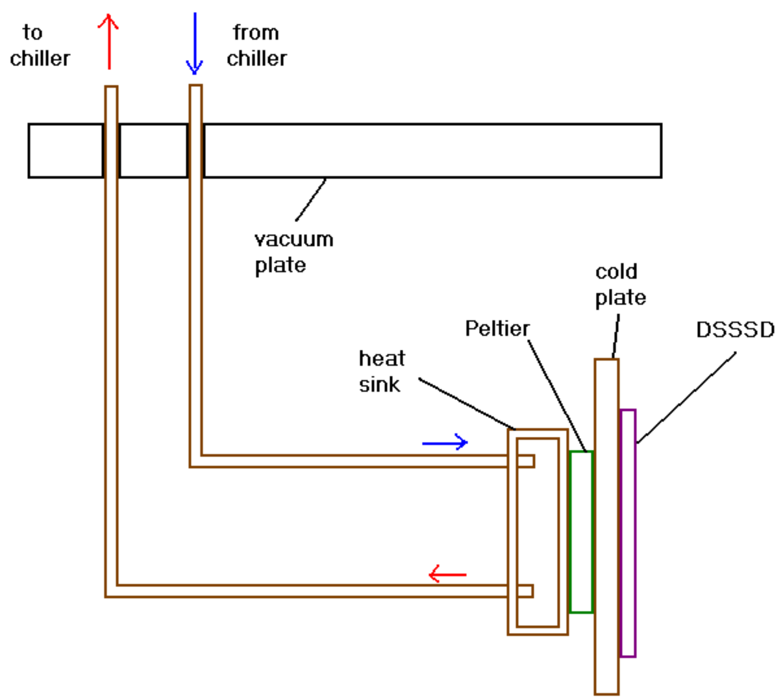


Figure 2: Schematic of DSSSD cooling system design.

3 cm nearer the optical design final focus of DRAGON. A schematic of the cooling mount is shown in figure 2.

3.1.1 Installing a DSSSD

The procedure for installing a DSSSD is:

1. Rest the vacuum plate on a horizontal surface in a stable position, with the cold plate facing upwards.
2. Clean the O-ring and relevant vacuum surfaces. Grease the O-ring with vacuum grease and put it in place.
3. Remove the DSSSD from its storage box by touching only the edges of the G-10 DSSSD frame and take care to avoid touching the fragile bond wires at the edges of either active surface of the DSSSD or the

surfaces themselves. If the wires are touched then they will break, rendering certain strips useless. Wearing gloves will ensure that the DSSSD surface is not contaminated but gloves may hamper dexterity.

4. Place the DSSSD mounting holes over the two pins at the top of the cold plate and slowly lower the DSSSD onto the surface of the cold plate until it rests there.

5. Place the bottom clamp (the one with two screws) over the bottom edge of the DSSSD frame, with the insulation contacting the DSSSD frame, and screw it to the plate.

6. Do the same with the side clamps (the ones with three screws). They are interchangeable.

7. Connect the ribbon cable to the pin headers at the top of the DSSSD.

8. Mount the vacuum plate to the top of the TISOL box at the end of DRAGON, with the DSSSD facing upstream.

9. Connect the liquid lines and start the chiller if necessary (see section 3.2).

10. Connect the ribbon cable from the preamplifier motherboard to the vacuum feed-through.

11. Ground all cable shields (green wires).

12. Pump the chamber down. Never pump or vent through the 100 mtorr range with bias on.

13. Set the recirculating chiller to -15 °C (see section 3.2).

14. Turn the bias to 50 V for 250 μm thick DSSSDs or 70 V for 300 μm thick DSSSDs slowly enough to avoid exceeding 2 μA leakage current at any time (this should take $\approx$ 30 s).

3.1.2 Removing a DSSSD

To remove the DSSSD:

1. Turn down the DSSSD bias to 0 V.

2. Set the recirculating cooler to ambient temperature and wait until the DSSSD temperature is above the dew point (see section 3.2).

3. Vent the vacuum box.

4. Disconnect the ribbon cable from the top of the vacuum box.

5. Disconnect the liquid lines if necessary (see section 3.2).

6. Carefully remove the vacuum plate from the top of the TISOL box at the end of DRAGON, along with the DSSSD.

7. Rest the vacuum plate on a horizontal surface in a stable position, with the DSSSD facing upwards.

8. Remove and store the DSSSD (steps 3 through 7 in section 3.1.1 in reverse order). Be careful to rest the DSSSD in its storage box in such a way that the fragile bond-wires are clear of any surface.

9. Store the DSSSD in the desk at the end of DRAGON (short term) or in the DRAGON cabinet in the detector facility (long term).

If a longer local time-of-flight is required, then the vacuum plate can be mounted on the back of the TISOL box, and the cold plate fastened to an alternate copper chamber with alternate liquid lines, as shown in figure 3.

3.2 Recirculating Chiller

A Julabo FE500 recirculating cooler [7] is used to cool a 1:2 mixture of ethylene glycol ($HOCH_2CH_2OH$), and water, and pump it through the cold chamber. The manufacturer advises the use of these liquids only. The chiller is operational in the temperature range -20 °C to 40 °C with temperature stability ± 0.5 °C. An abridged manual for the cooler is shown in figure 4 and a summary of operating controls and functional elements in figure 5. More information can be found in the full operating manual.

The chiller reservoir is connected to Tygon tubing which is, in turn, connected to copper feed-through lines which protrude from the vacuum box by about 25 cm. All tubing is thermally insulated. Cooling lines should be connected or disconnected at the junction between the copper and Tygon tubing, and care should be taken not to spill the cooling liquid.

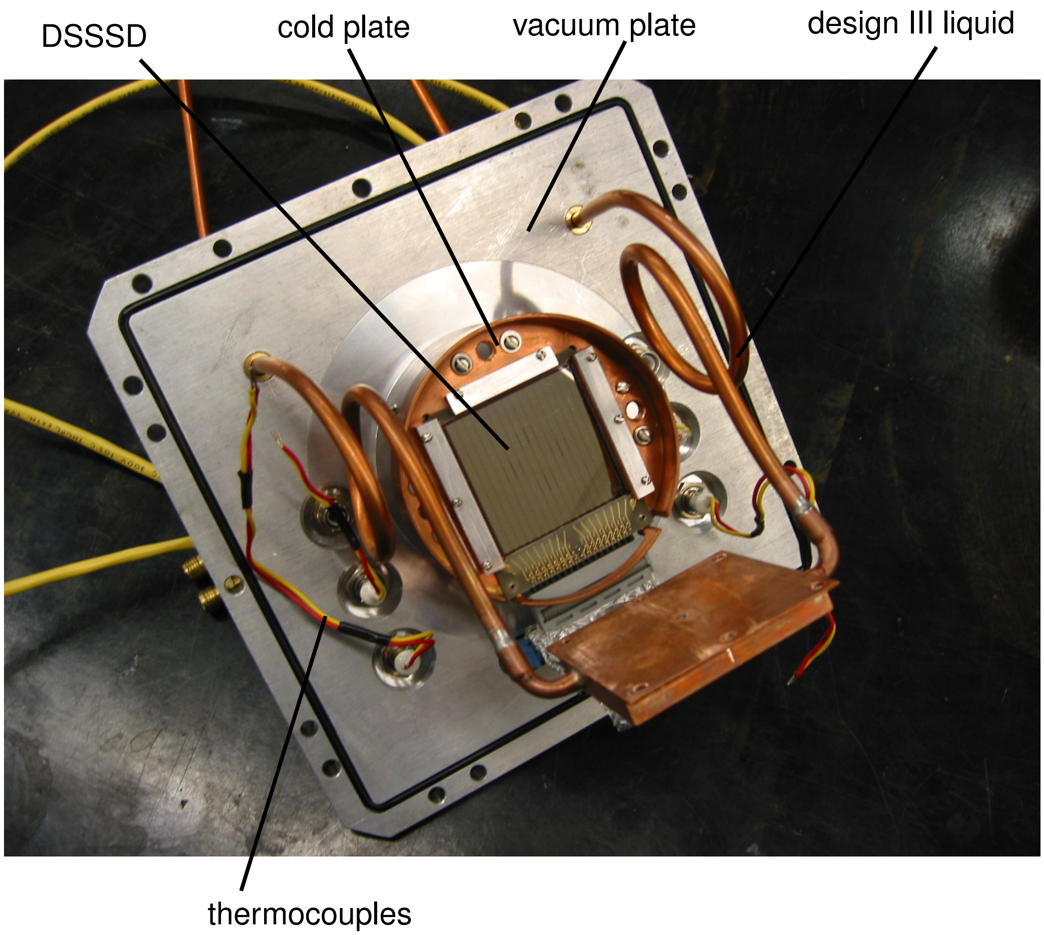
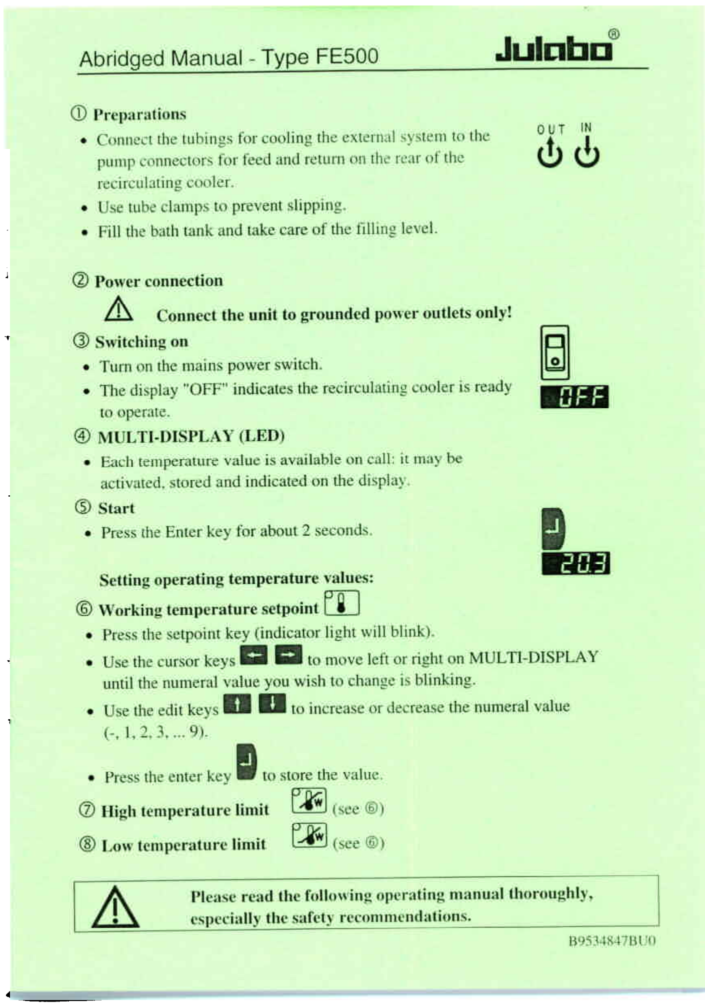


Figure 3: Inside of the DSSSD cooling system vacuum plate, with the DSSSD mounted in its alternate position. Also shown are the liquid lines and copper chamber for the conventional top-mounted configuration, labelled design III liquid.



Abridged Manual - Type FE500 Julabo®

① **Preparations**

- Connect the tubings for cooling the external system to the pump connectors for feed and return on the rear of the recirculating cooler.
- Use tube clamps to prevent slipping.
- Fill the bath tank and take care of the filling level.

OUT IN

② **Power connection**

⚠ **Connect the unit to grounded power outlets only!**

③ **Switching on**

- Turn on the mains power switch.
- The display "OFF" indicates the recirculating cooler is ready to operate.

OFF

④ **MULTI-DISPLAY (LED)**

- Each temperature value is available on call: it may be activated, stored and indicated on the display.

⑤ **Start**

- Press the Enter key for about 2 seconds.

20.3

Setting operating temperature values:

⑥ **Working temperature setpoint**

- Press the setpoint key (indicator light will blink).
- Use the cursor keys to move left or right on MULTI-DISPLAY until the numeral value you wish to change is blinking.
- Use the edit keys to increase or decrease the numeral value (-, 1, 2, 3, ... 9).
- Press the enter key to store the value.

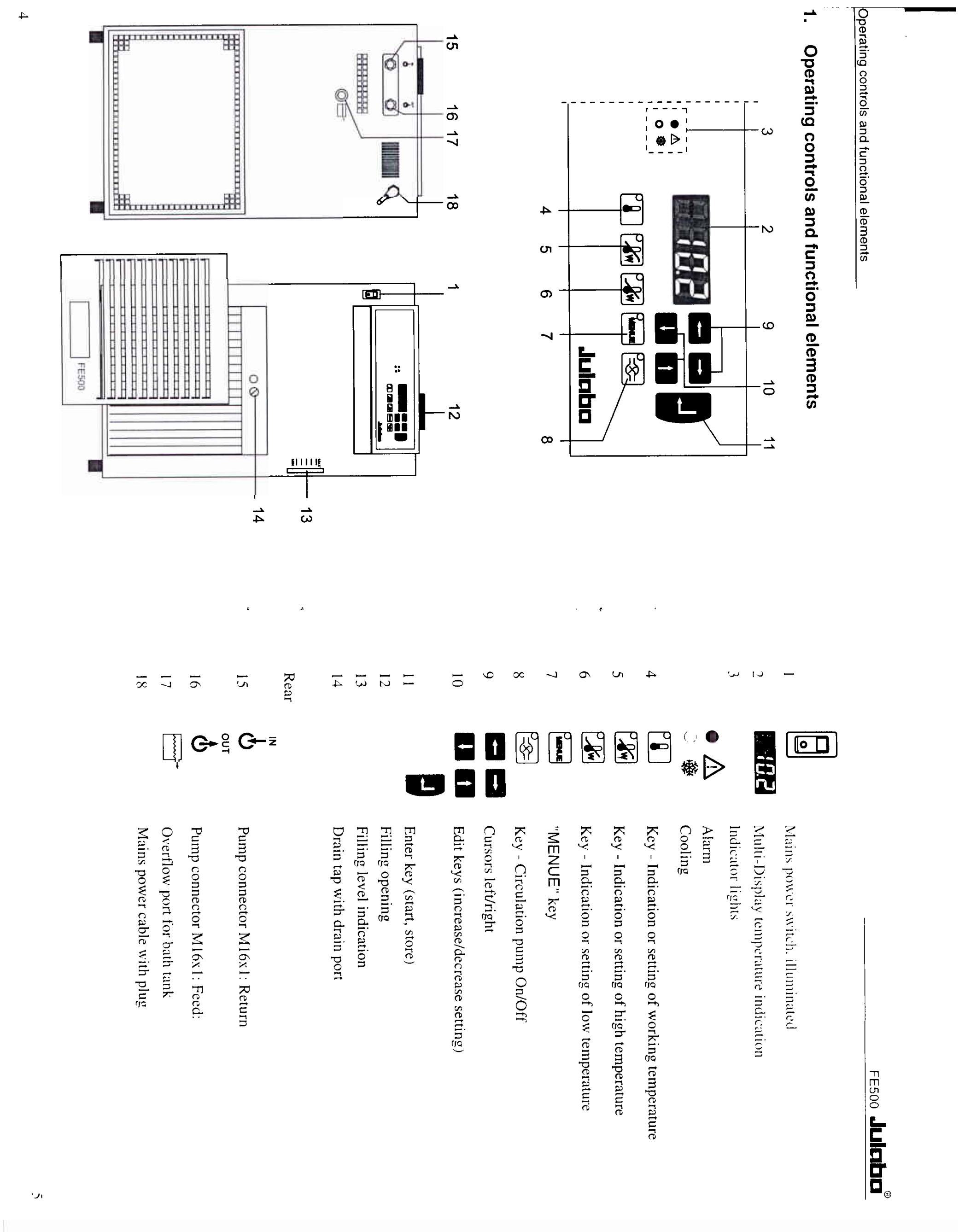
⑦ **High temperature limit** (see ⑥)

⑧ **Low temperature limit** (see ⑥)

⚠ **Please read the following operating manual thoroughly, especially the safety recommendations.**

B9534847BU0

Figure 4: Abridged manual for Julabo FE500 recirculating cooler.



Operating controls and functional elements

FE500 Julabo

1. Operating controls and functional elements

1 Mains power switch, illuminated
2 Multi-Display temperature indication
3 Indicator lights
Alarm
Cooling
4 Key - Indication or setting of working temperature
5 Key - Indication or setting of high temperature
6 Key - Indication or setting of low temperature
7 "MENUE" key
8 Key - Circulation pump On/Off
9 Cursors left/right
10 Edit keys (increase/decrease setting)
11 Enter key (start, store)
12 Filling opening
13 Filling level indication
14 Drain tap with drain port

Rear

15 Pump connector M16x1: Return
16 Pump connector M16x1: Feed:
17 Overflow port for bath tank
18 Mains power cable with plug

4 5

Figure 5: Summary of operating controls and functional elements for Julabo FE500 recirculating cooler.

3.3 Temperature Calibration

A previous version of the cooling system was used to obtain a relationship between the cold plate temperature and the temperature of the center of the DSSSD using K-type thermocouples and a Fluke 54 II [8] thermometer [2]. The cold plate temperature was then calibrated against the recirculating liquid temperature, as read out by the chiller. Table 3 summarizes the calibration. The cold plate temperature and the liquid temperature are equal within experimental error. The DSSSD is warmer than the cold plate because of the competition between thermal radiative heating of the DSSSD and the poor thermal conductivity of the G-10 frame [1, ch. 6]. Since the measurement of the DSSSD temperature employed a thermal radiation shield and the cooling system does not, the actual DSSSD temperatures can be expected to be higher than those listed by as much as 5 °C for the lowest temperatures. Readings were only taken with the chiller down to an equivalent DSSSD temperature of -9.5 °C because lower DSSSD temperatures increase the risk of damage to a DSSSD from the different amounts of thermal contraction in the different detector materials, without significant benefit. For consistency, it is recommended to run with the chiller set to -15 °C at all times; this should correspond to a DSSSD temperature of about -5 °C when the lack of a radiation shield is taken into account.

3.4 Temperature Readout

Mike Leross will add the temperature readout of the cold plate from a thermocouple or of the liquid from the chiller to the EPICS control system. The chiller will be controlled manually.

References

[1] C. Wrede, M.Sc. thesis, *A Double Sided Silicon Strip Detector as an End Detector for the DRAGON Recoil Mass Separator*, Simon Fraser University (2003).

[2] G. F. Knoll, *Radiation Detection and Measurement* (John Wiley and Sons, New York; 3rd Ed., 2000).

[2] Borrowed from TRIUMF beam-lines group: Alan Richardson.

T_{liquid} ± 0.5°C	$T_{coldplate}$ ± 0.5°C	T_{DSSSD} ± 0.5°C
20.0	20.2	N/A
N/A	17.7	18.4
15.0	15.5	N/A
10.0	10.6	N/A
6.8	7.7	9.9
0.6	1.5	4.8
-4.8	-3.9	0.2
-9.8	-8.5	-3.8
-13.5	-12.3	-6.8
-16.4	-15.5	-9.5
N/A	-17.7	-11.2
N/A	-19.3	-12.5
N/A	-20.2	-13.3
N/A	-20.6	-13.5

Table 3: DSSSD cooling system temperature calibration.

[3] Particle Data Group, *Review of Particle Properties*, Phys. Rev. D66 (2002) 213.

[4] G. Lindstrom, M. Moll and E. Fretwurst, Nucl. Instr. and Meth. A426 (1999) 1.

[5] Micron Semiconductor, www.micronsemiconductor.co.uk.

[6] F. Calligaris, P. Ciuti, I. Gabrielli and R. Giacomich, Nucl. Instr. and Meth. 112 (1973) 591.

[7] Julabo Constant Temperature Circulators, www.julabo.com.

[8] Fluke Electronics, www.fluke.com.