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Thermal Qualification of ATLAS Pixel Detector Disk Sector Prototypes

Abstract

The thermal qualification tests for the ATLAS Pixel Detector disk sector prototypes are described. Recent measurements on prototypes are presented.

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Distribution List

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1 Introduction

This note summarizes recent thermal qualification tests of prototypes of the pixel detector disk sectors. The disk sectors support pixel modules in the disk (end) regions of the pixel detector. The components of a disk sector are shown in Figure 1.

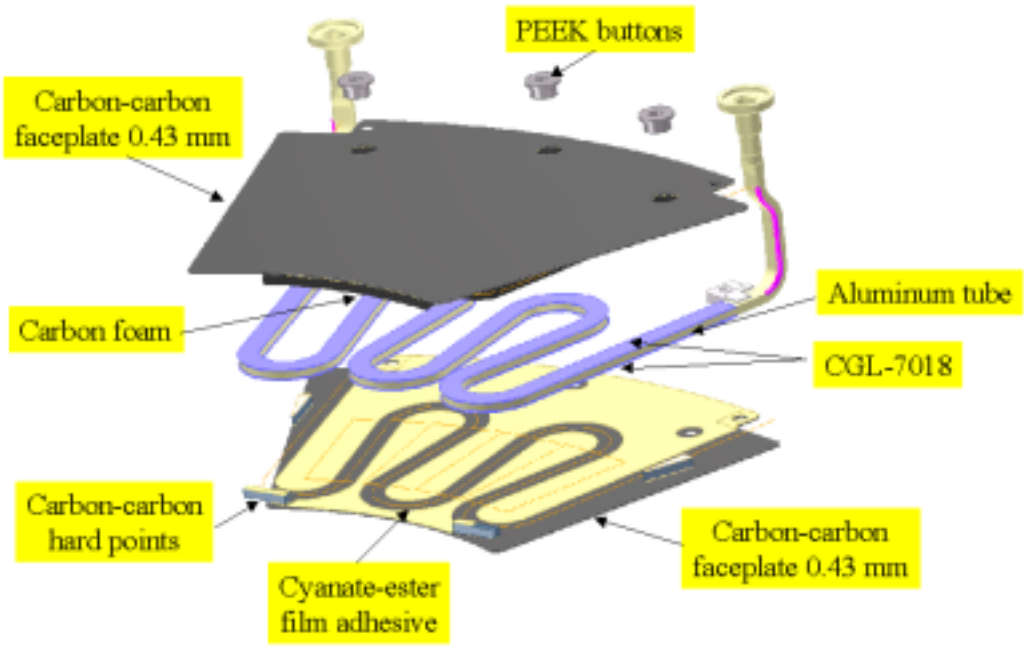

Figure 1. A disk sector without modules.

2 Thermal Qualification Criteria and Test Procedures

2.1 Thermal Qualification Criteria

The thermal requirements, including stress testing, are defined in the document on ATLAS Pixel Local Supports Requirements.[1] The series of thermal qualification tests used to qualify the sector design is summarized in Table 1.

1. 50 thermal cycles 20° C to -35° C
2. Thermal shock 20° C to -35° C in < 60 sec
3. Pressure to 8 bar absolute
4. 50 thermal cycles 20° C to -35° C
5. Irradiate to 50 MRad
6. 50 thermal cycles 20° C to -35° C
7. Thermal shock 20° C to -35° C in < 60 sec
8. Pressure to 8 bar absolute
9. 50 thermal cycles 20° C to -35° C
10. Loss of coolant (sector in air at 20° C)

Table 1. The thermal qualification test sequence.

2.2 Test Procedures

Dummy heaters were used in place of actual pixel modules. The dummy heaters are platinum-coated silicon. The thin platinum is deposited by evaporation on the silicon in a footprint that simulates the heat distribution expected for the pixel module electronics. Each of the heaters had a resistance of 6-7 ohms. The three on each side of a sector were connected in series to a power supply at around 20 V to provide about 25 W of power to each side of the sector. The coolant used in the test is water at around 21° C. The flow rate in all tests was close to 0.75 liters/minute. Prior to testing, the sectors and heaters were coated with black paint to ensure uniform surface emissivity. Thermal cycling damaged the paint in some small areas, but no important data were lost. Tests were done in air at room temperature. Unpainted heaters on a sector are shown in Figure 2.

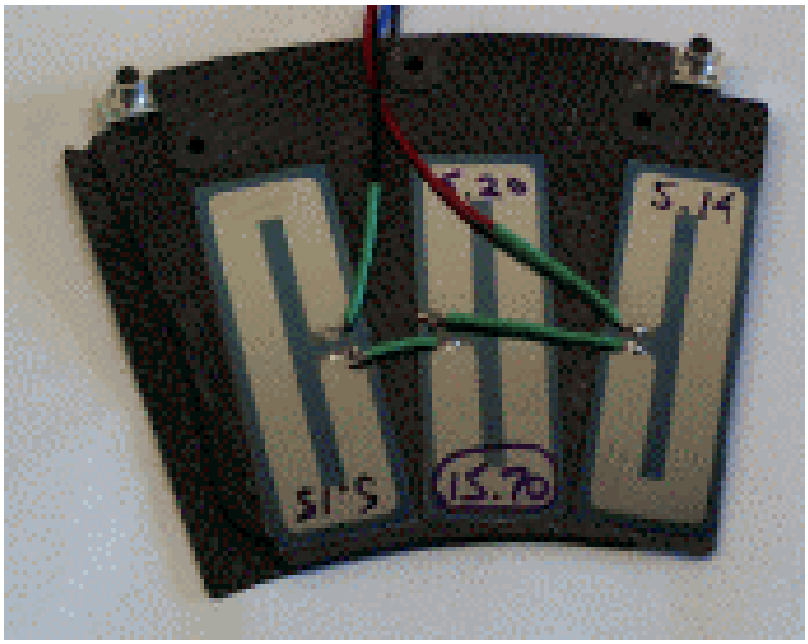

Figure 2. Unpainted dummy heaters on a disk sector.

Temperature data were taken with an Inframetrics model 600L Infrared Imaging Radiometer at a distance of about 25 cm. This gives a temperature map of the surface, with resolution to within a fraction of a degree. Data from one side only of the sectors are given in this paper, but the results are typical of measurements on the other sides of both sectors.

The temperature difference between the incoming coolant and the hottest point on the sector is an important measure of sector performance. These values, along with the thermograms after each test, are given in the subsequent sections.

3 Prototypes

The test results on two prototypes are described in this note. The two prototypes differ only in the thermal compound used to connect the aluminum tube to the sector facings. Prototype 11 used CGL-7018, a thermally conductive paste adhesive, between the aluminum tube and the sector facings.[2] Prototype 12 used an epoxy-based, thermally conducting adhesive.[3]

4 Test Results

4.1 Baseline Testing

The baseline heat pattern for sector 11 is shown in Figure 3, and the heat pattern for sector 12 is shown in Figure 4. The test results are summarized in Table 2.

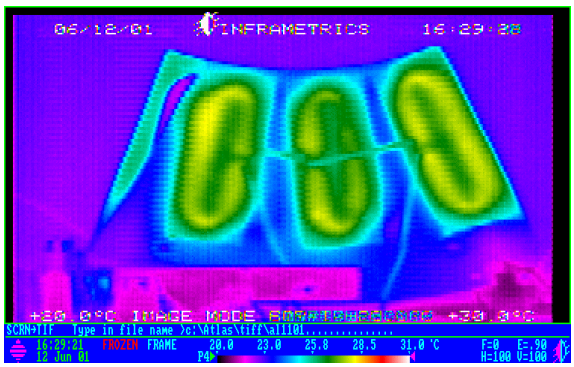

Figure 3. Sector 11 baseline.

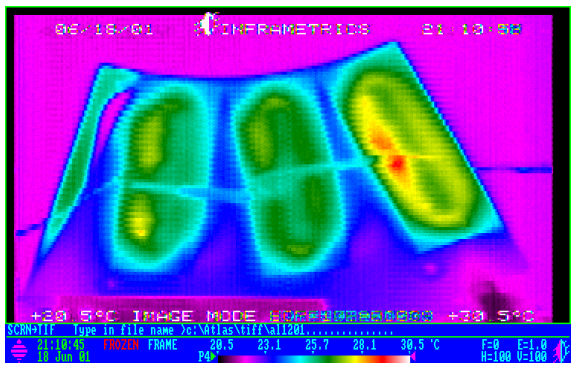

Figure 4. Sector 12 baseline.

Conditions (average)	*Sector 11*	*Sector 12*
Coolant temperature (° C)	*21.0*	*21.0*
Coolant flow (liters/min)	*0.77*	*0.75*
Power to heaters (W)	*48.4*	*49.1*
Maximum ΔT (° C)	*6.9*	*7.8*

Table 2. *Baseline test results.*

4.2 First temperature cycling test

The sectors were cycled 50 times between 20° C and -35° C. The results are shown in the figures below.

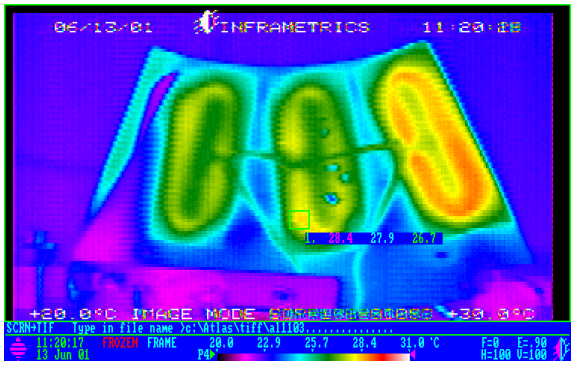

Figure 5. Sector 11 after thermal cycling.

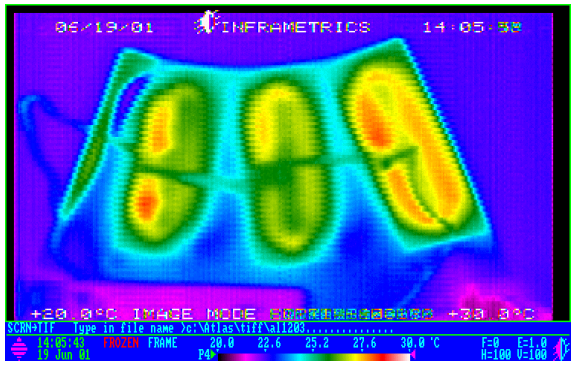

Figure 6. Sector 12 after thermal cycling.

Conditions (average)	Sector 11	Sector 12
Coolant temperature (° C)	21.0	21.0
Coolant flow (liters/min)	0.77	0.75
Power to heaters (W)	48.4	49.1
ΔT (° C)	7.7	7.4

Table 3. *Results after first temperature cycling.*

4.3 Cold Shock

Sector 11 was brought from room temperature at 17.3° C to –37° C in 45 seconds by pumping liquid nitrogen vapor into the coolant tube. The average cooling rate was 1.2° C/sec. The flow of nitrogen was then shut off, and the sample was allowed to warm to room temperature. Sector 12 underwent similar treatment, being cooled from 20° C to -40° C in 50 seconds. The average ramp rate was 1.2° C/sec. The sectors were then tested in normal operation. Thermal images are given below in Figure 7 and Figure 8. Damage to the paint on the middle heater of sector 11 caused some minor loss of data. Results are summarized in Table 4.

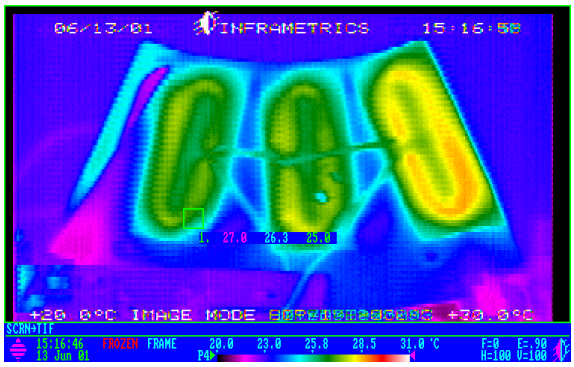

Figure 7. Sector 11, after cold shock.

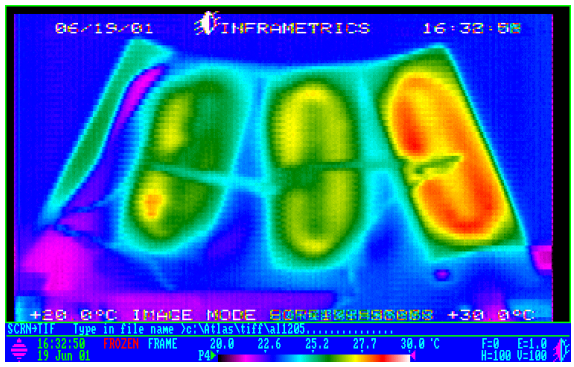

Figure 8. Sector 12, after cold shock.

Conditions (average)	Sector 11	Sector 12
Coolant temperature (° C)	21.0	21.0
Coolant flow (liters/min)	0.77	0.75
Power to heaters (W)	48.4	49.1
Maximum ΔT (° C)	7.6	7.5

Table 4. Results after thermal shock.

4.4 Pressure Testing

The coolant tube was attached to a compressed gas cylinder and subjected to 8 bar for 1 hour. The results are given below.

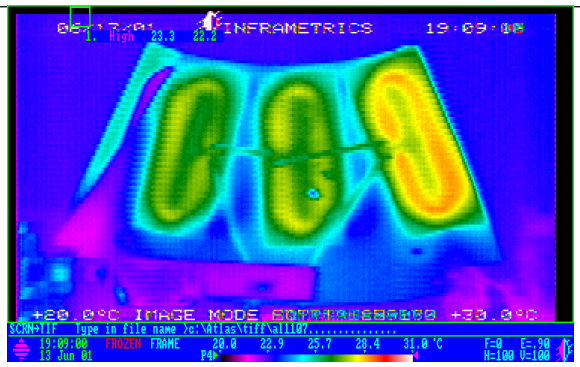

Figure 9. Sector 11, after pressure test.

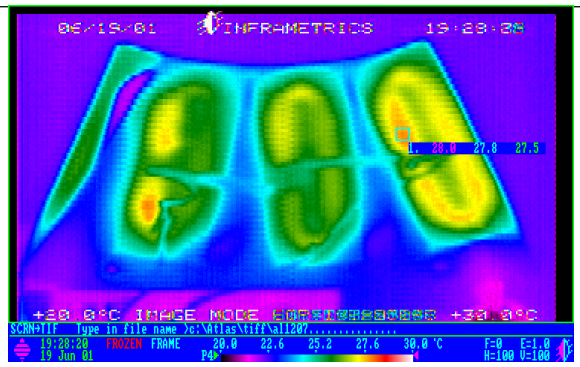

Figure 10. Sector 12, after pressure test.

Conditions (average)	*Sector 11*	*Sector 12*
Coolant temperature (° C)	*21.0*	*20.8*
Coolant flow (liters/min)	*0.76*	*0.76*
Power to heaters (W)	*48.4*	*49.1*
Maximum ΔT (° C)	*7.6*	*7.0*

Table 5. *Results after pressure test.*

4.5 Second thermal cycling test

The sectors were exposed to an additional 50 cycles from 20° C to -35° C, for a total of 100 cycles. The cycling damaged paint on sector 12. However, most of the sector was unaffected, and accurate temperature readings were possible.

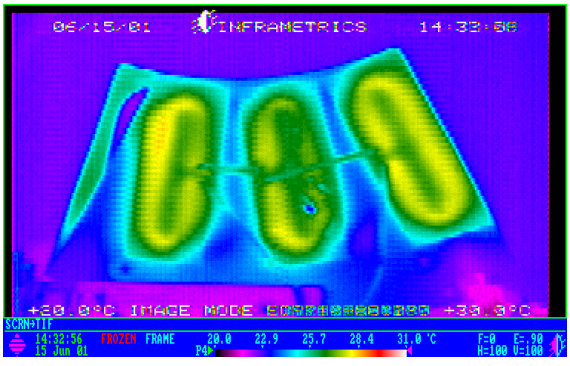

Figure 11. Sector 11, after second thermal cycling.

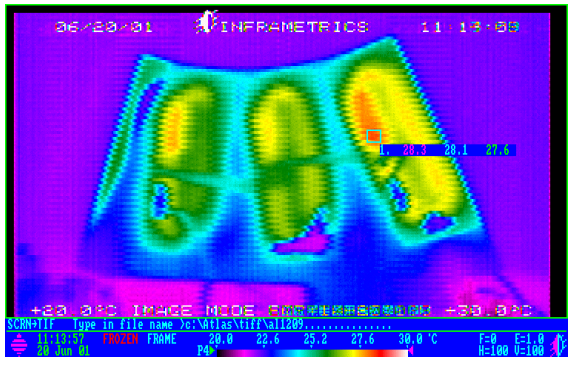

Figure 12. Sector 12, after second thermal cycling.

Conditions (average)	*Sector 11*	*Sector 12*
Coolant temperature (° C)	*21.0*	*20.8*
Coolant flow (liters/min)	*0.76*	*0.75*
Power to heaters (W)	*48.4*	*49.1*
Maximum ΔT (° C)	*7.6*	*7.2*

Table 6. *Results after additional thermal cycling.*

4.6 Radiation Testing

Both sectors were exposed to about 50 MRad(SiO_2) over about 16 hours. After testing, the sectors were repainted, and thermal images were taken. Both sectors showed a slight degradation in thermal performance. ΔT for both sectors grew to 8.4° C, compared to previous highs of 7.7° C for sector 11 and 7.8° C for sector 12.

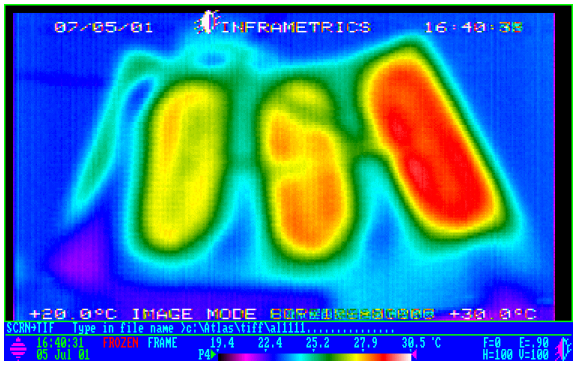

Figure 13. Sector 11 after irradiation.

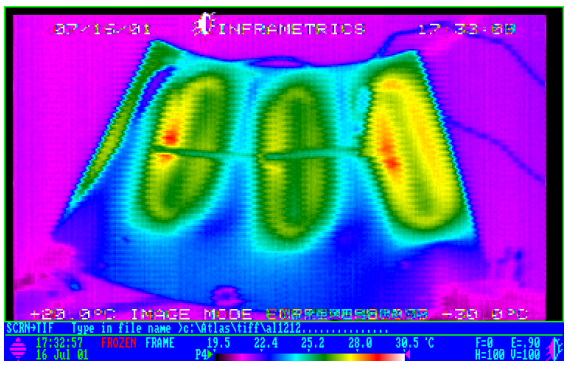

Figure 14. Sector 12 after irradiation.

Conditions (average)	*Sector 11*	*Sector 12*
Coolant temperature (° C)	*21.0*	*21.0*
Coolant flow (liters/min)	*0.75*	*0.75*
Power to heaters (W)	*50.3*	*50.1*
Maximum ΔT (° C)	*8.4*	*8.4*

Table 7. Results after irradiation to 50 MRad.

4.7 Third thermal cycling test

The sectors were each cycled 50 times from 20° C to 35° C. Sector 11 showed very little change after cycling. Sector 12 developed a small, hot spot near a solder joint on a heater (shown below). Note the change of scale on sector 12, to a maximum of 31° C.

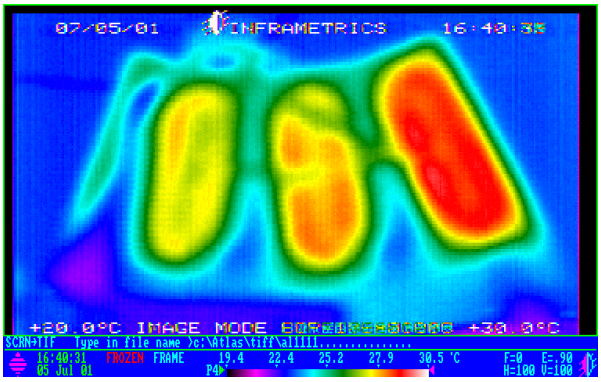

Figure 15. Sector 11 after thermal cycling.

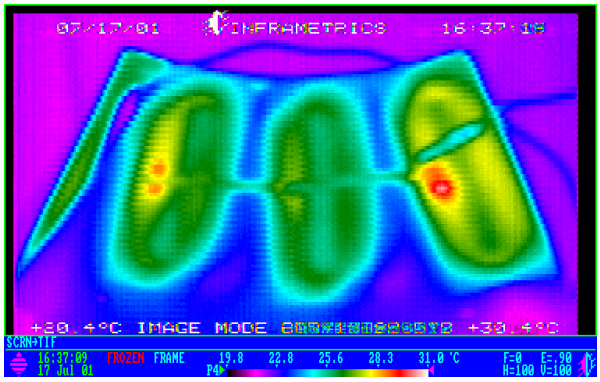

Figure 16. Sector 12 after thermal cycling.

Conditions (average)	Sector 11	Sector 12
Coolant temperature (° C)	21.0	21.0
Coolant flow (liters/min)	0.75	0.75
Power to heaters (W)	50.3	51.3
Maximum ΔT (° C)	8.3	8.9

Table 8. Results after additional thermal cycling.

4.8 Second thermal shock

Sector 11 was cooled from 20° C to -35° C within 40 seconds by pumping very cold nitrogren gas through the coolant pipe. The average ramp rate was 1.4° C/second. Sector 11 was unaffected by the test.

Sector 12 was also cooled from 20° C to –35° C in 40 seconds, with a ramp rate of 1.4° C/second. Thermal maging revealed that ΔT at the hot point on sector 12 grew worse, to a maximum temperature of 9.4° C.

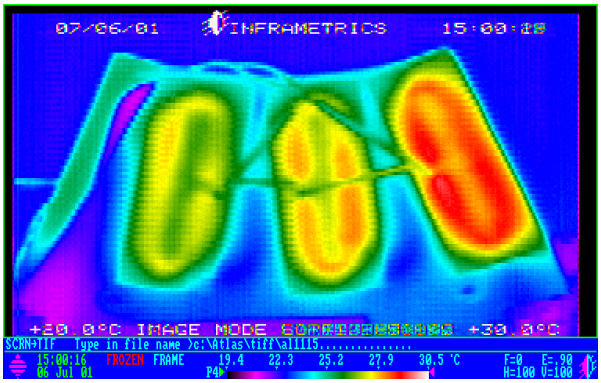

Figure 17. Sector 11 after thermal shock.

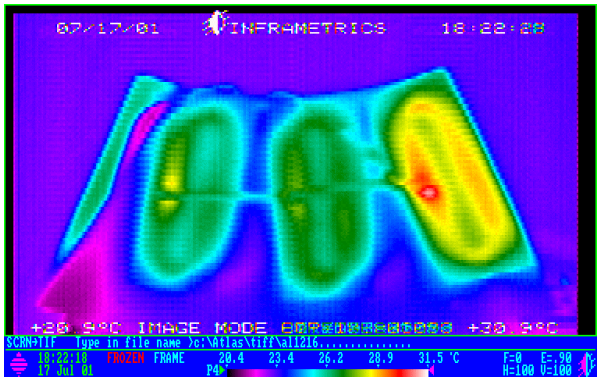

Figure 18. Sector 12 after thermal shock.

Conditions (average)	Sector 11	Sector 12
Coolant temperature (° C)	21.0	21.0
Coolant flow (liters/min)	0.75	0.75
Power to heaters (W)	50.3	50.3
Maximum ΔT (° C)	8.3	9.4

Table 9. Results after thermal shock.

4.9 Second pressure test

The coolant tube for each sector was attached to a compressed gas cylinder and pressurized to 8 bar for 1 hour.

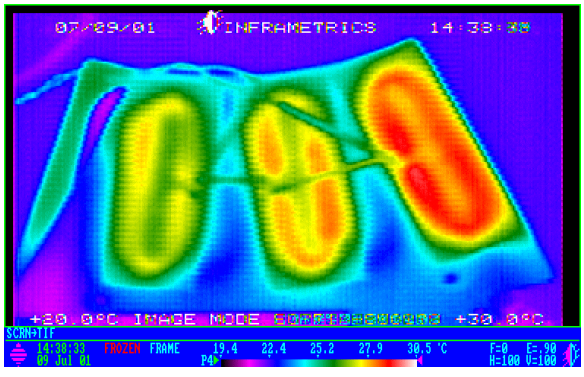

Figure 19. Sector 11 after pressure test.

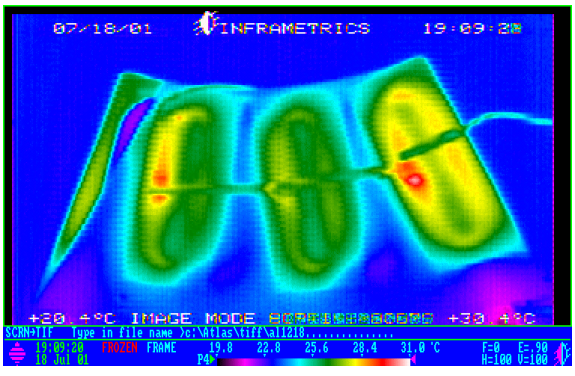

Figure 20. Sector 12 after pressure test.

Conditions (average)	Sector 11	Sector 12
Coolant temperature (° C)	21.0	21.1
Coolant flow (liters/min)	0.75	0.75
Power to heaters (W)	50.3	47.7
Maximum ΔT (° C)	8.3	8.6

Table 10. Results after pressure test.

4.10 Fourth thermal cycling test

Each sector was cycled an additional 50 times from 20° C to -35° C, for a total of 200 temperature cycles.

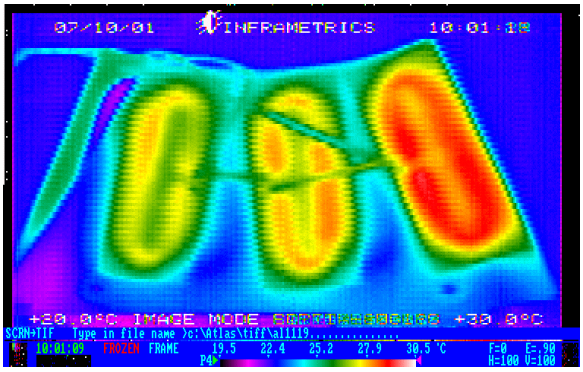

Figure 21. Sector 11 after thermal cycling.

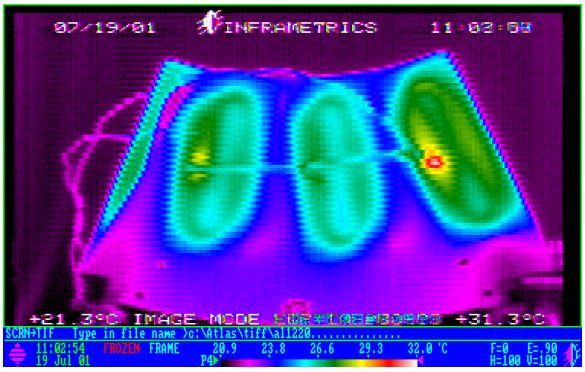

Figure 22. Sector 11 after thermal cycling.

Conditions (average)	Sector 11	Sector 12
Coolant temperature (° C)	21.0	21.0
Coolant flow (liters/min)	0.75	0.75
Power to heaters (W)	50.3	50.0
Maximum ΔT (° C)	8.4	9.5

Table 11. Results after additional thermal cycling.

4.11 Loss of coolant test

A loss of coolant fault was simulated by shutting off the flow of water to the sectors during operation. Sector 11 warmed from 20° C to 100° C within 1 minute. After 5 minutes, sector temperature levelled off at about 135° C. After equilibrium at 135° C was established, coolant flow was restored, cooling the sector to 30° C within 1 minute and close to equilibrium within 2 minutes.

After loss of coolant, sector 12 warmed from 25° C to 90° C within 1 minute and to an equilibrium temperature of 142° C after 5 minutes. The restoration of coolant flow brought the sector to about 30° C within 20 seconds.

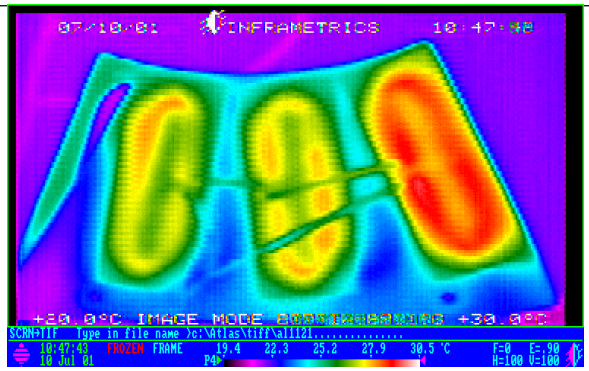

Figure 23. Sector 11 after loss of coolant test.

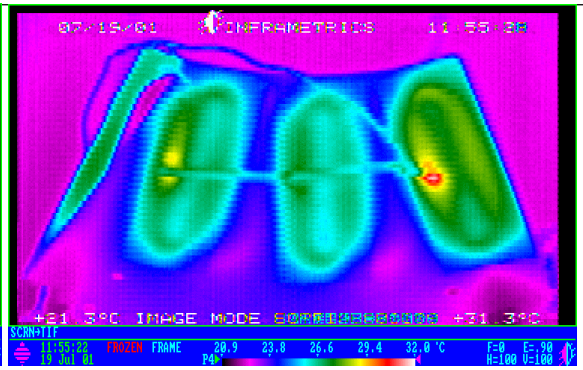

Figure 24. Sector 12 after loss of coolant test.

Conditions (average)	*Sector 11*	*Sector 12*
Coolant temperature (° C)	*21.0*	*21.0*
Coolant flow (liters/min)	*0.77*	*0.75*
Power to heaters (W)	*50.3*	*49.1*
Maximum ΔT (° C)	*8.3*	*9.5*

Table 12. Results after loss of coolant test.

5 Conclusions

All results are summarized in Table 13. Both sectors easily meet the requirement of a maximum $\Delta T < 15^{o}$ C.

	Maximum Δ T for sector 11 (° C)	*Maximum Δ T for sector 12 (° C)*
Baseline	*6.9*	*7.8*
50 T cycles 20° C to -35° C	*7.7*	*7.4*
Thermal shock	*7.6*	*7.5*
Pressure	*7.6*	*7.0*
50 more T cycles 20° C to -35° C	*7.1*	*7.3*
Irradiation to 50 MRad	*8.4*	*8.4*
50 more T cycles 20° C to -35° C	*8.3*	*8.9*
Thermal shock	*8.3*	*9.4*
Pressure	*8.3*	*8.7*
50 more T cycles 20° C to -35° C	*8.4*	*9.5*
Loss of coolant	*8.3*	*9.5*

Table 13. Summary of all results on thermal qualification.

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[1] *ATL-IP-EP-0005. "ATLAS Pixel Local Supports Requirements." June 2001.*

[2] *AI Technologies CGL-7018-LV-XF.*

[3] *AI Technologies E67658.*