D0 ENGINEERING NOTE

No. 3823.112-EN-456

D0 SILICON UPGRADE

HEAT TRANSFER AND THERMAL BOWING CALCULATIONS OF THE D0 F-DISK

August 26, 1996

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Shown in Figure 1 is a side view of the D0 F-disk assembly. SVX II chips are mounted to a flex copper/kapton circuit, which is glued to a beryllium substrate. Figure 1 shows the top and bottom disk assemblies mounted on the cooling channel. However, the disks are not mounted directly opposite one another as shown, but alternately rotated through 30° wedges mounted on either side of the cooling channel.

The assumed channel temperature for these calculations is 0°C, as in the cases of the ladder cooling calculations, ref. [1] and [2]. The assumed SVX II chip power is 0.400 W. The finite difference method is used to calculate the temperature profiles of the various components. It is described in Ref. [1].

Each disk is read out using SVX II chips on both sides of the silicon. The silicon is 59.2 mm wide at its widest location. The SVX II chip location opposite the cooling channel has 8 chips mounted on the hybrid, and there are 6 SVX II chips mounted outboard of the cooling channel on the same side as the cooling channel.

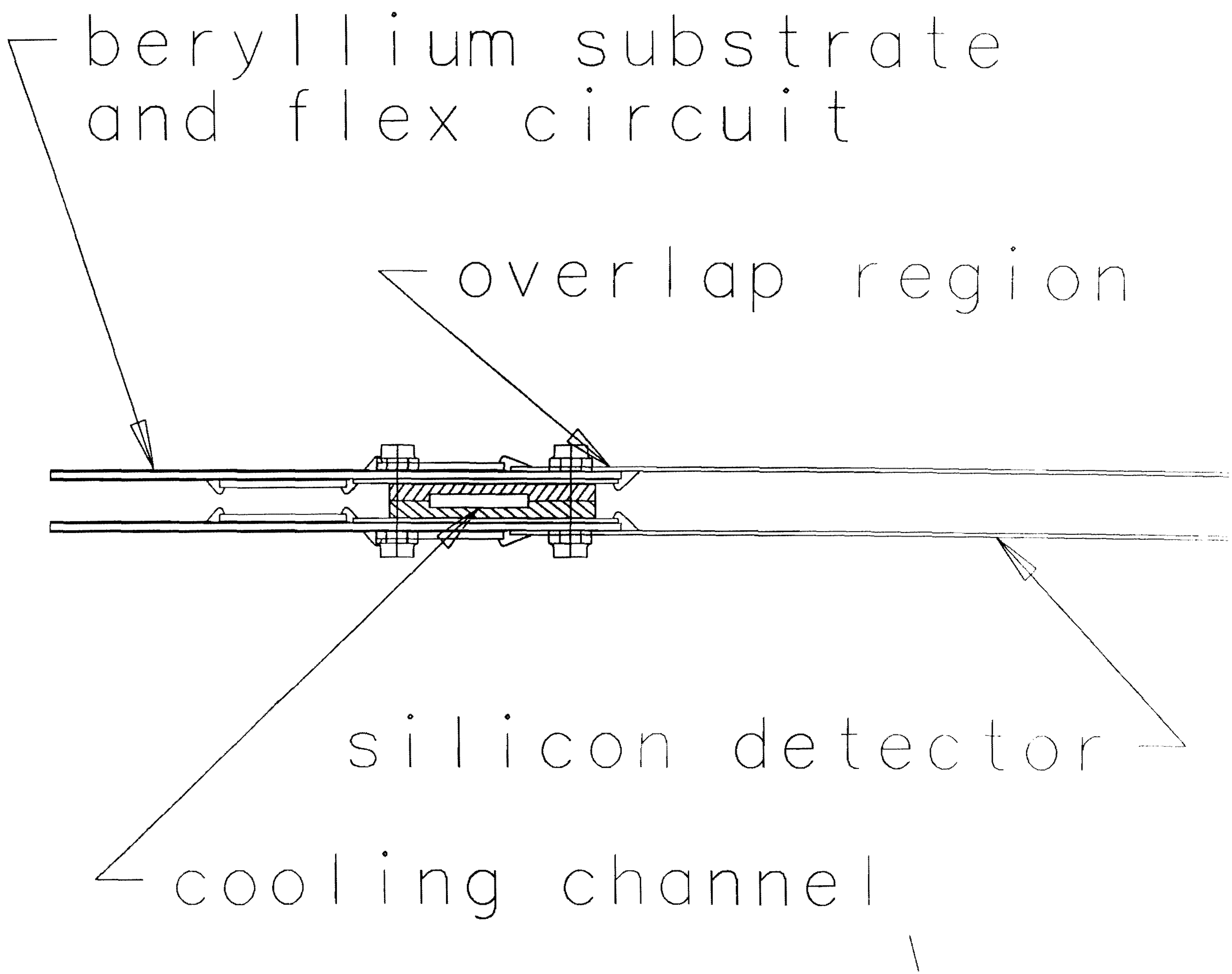
The SVX II chips mounted on the same side as the cooling channel read out the silicon via a jumper which passes between the beryllium substrate and the cooling channel. Currently there are two substrate materials under consideration for the jumper; kapton/copper and silicon/aluminum. The two materials have different thermal properties, so both will be considered in this note in order to compare their performance in the two different assemblies.

The silicon jumper is assumed to be 0.3 mm thick with a thermal conductivity of 0.15 W/mm-K. The kapton/copper flex circuit is assumed to be 0.075 mm in thickness, with 1/2 oz copper traces (a thickness of 0.017 mm copper with 0.4 W/m-K thermal conductivity) along the length. The thermal conductivity of kapton is 0.12E-3 W/mm-K [3].

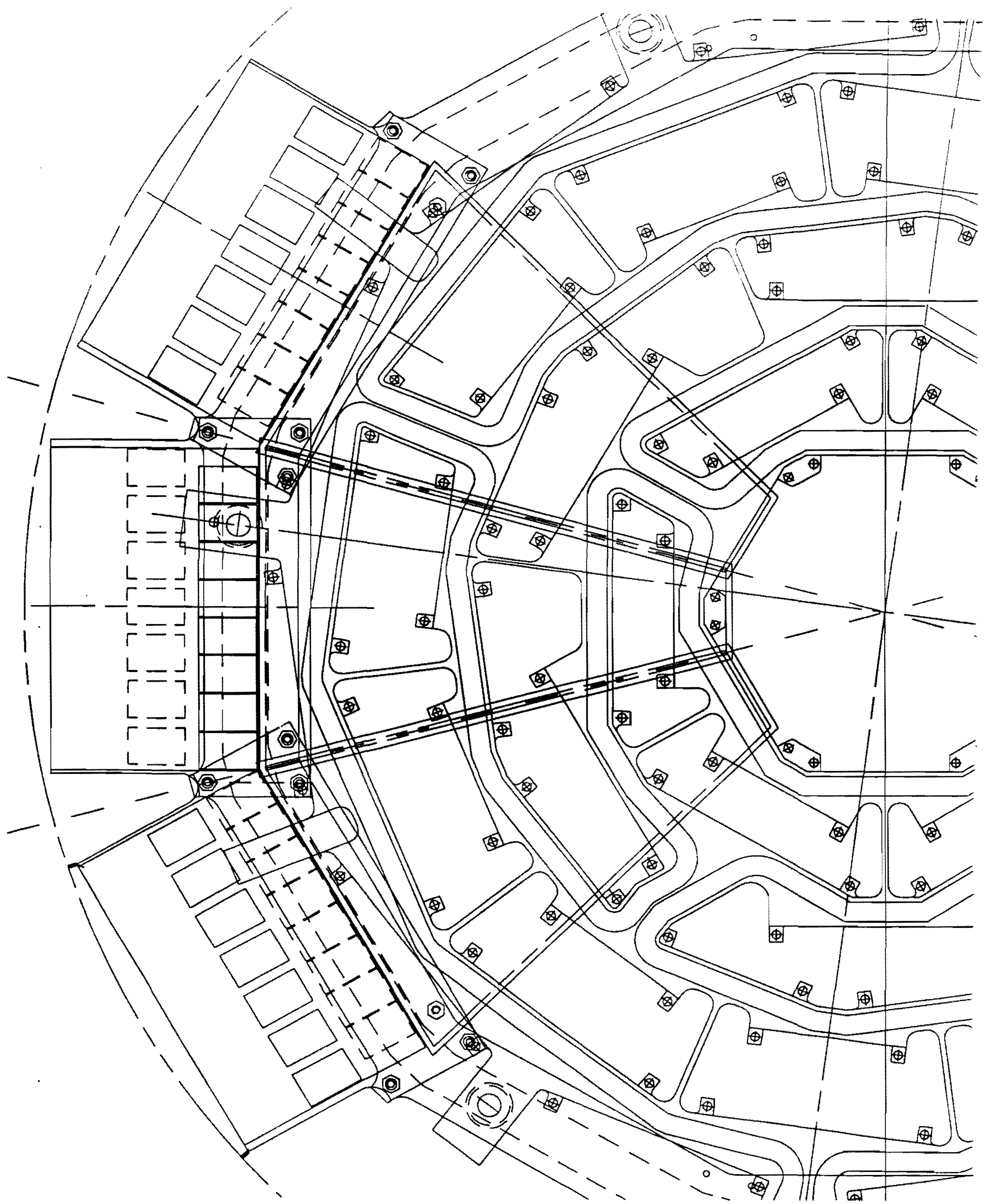
The F-Disk region is occupied by cables which extend from the barrel ladders. The cables dissipate power [4] and will contribute to warming the gas. The SVX II chips on both the disks and the ladders will also contribute to warming the gas. In addition, this region will not be perfectly insulated from the surrounding gas, which is considerably warmer than the cooling channel.

The exposed cooling channels (bulkhead and disk mount channels), on the other hand, will contribute to cooling the gas in this region. The gas temperature in which the disks reside is not known due to all these uncertainties. The range of gas temperatures considered for this thermal analysis is 10-15°C [5].

Figures 3 and 4 show the expected temperature profile in the various disk assembly components during operation of the SVX II chips.



beryllium substrate
and flex circuit
overlap region
silicon detector
cooling channel



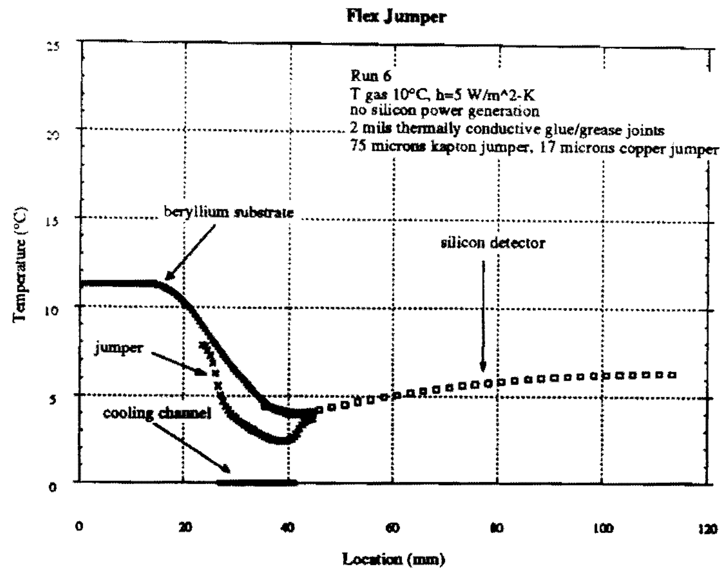


Figure 3
Disk assembly temperature profile with flex jumper and 10°C gas.

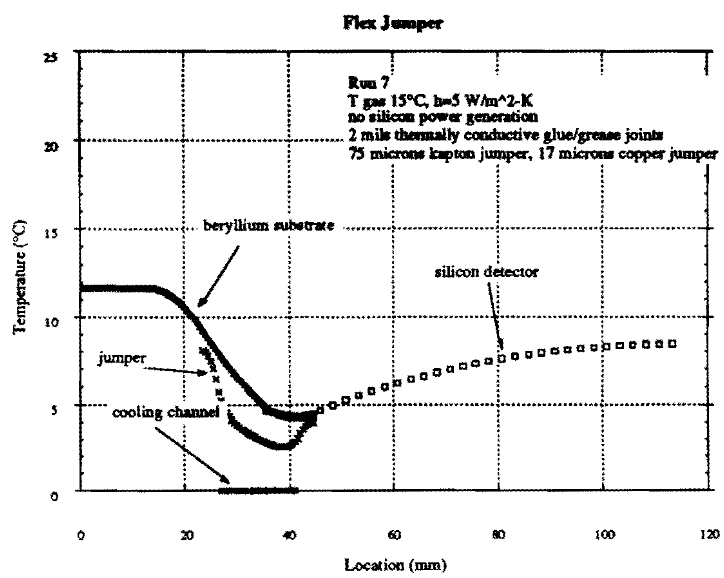


Figure 4
Disk assembly temperature profile with flex jumper and 15°C gas.

Figures 3 and 4 indicate that the maximum silicon temperature is not heavily dependent on the assumed gas temperature. The maximum temperature of ~6-9°C occurs at the disk center point (nearest the beam line) for the flex design.

Next is considered the silicon jumper. With a higher thermal conductivity in the jumper the resultant temperatures are somewhat lower, under the same assumptions, than in the flex jumper design.

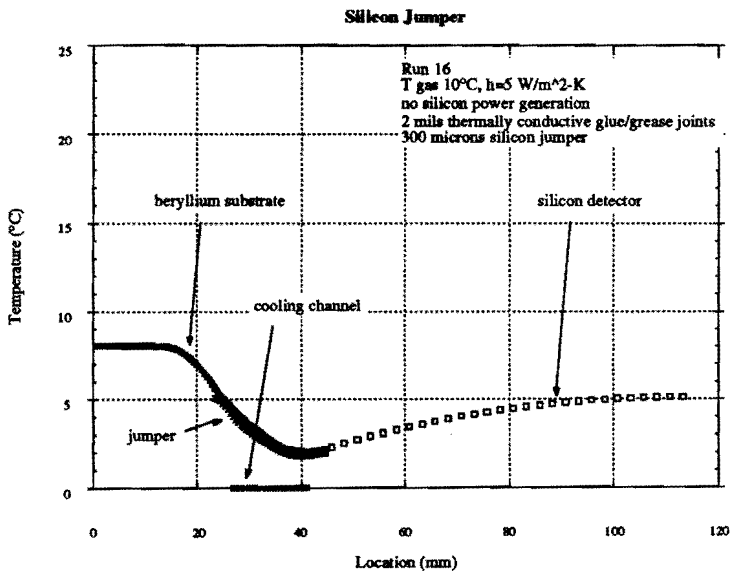


Figure 5
Disk assembly temperature profile with silicon jumper and 10°C gas.

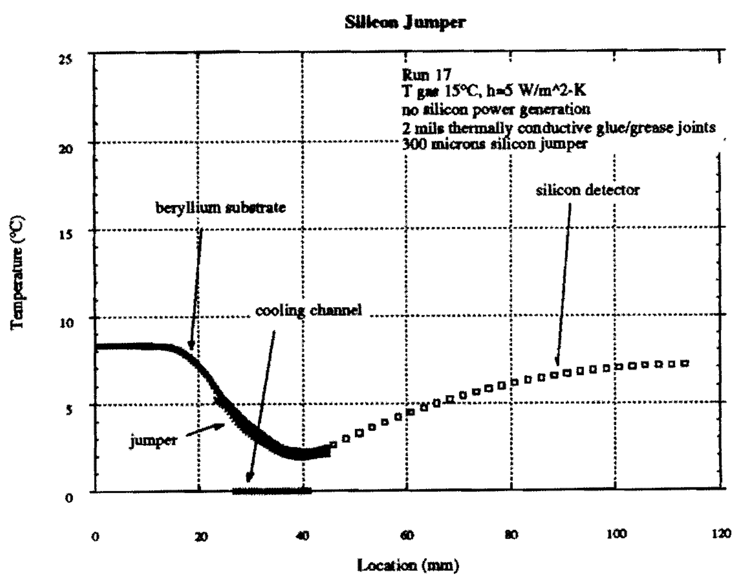


Figure 6
Disk assembly temperature profile with silicon jumper and 15°C gas.

Radiation damage in silicon detectors results in an increase in the leakage current, hence the power generation in the silicon due to the applied bias voltage on it. When the heat dissipation within the silicon exceeds the ability to conduct and convect away this heat, a condition of thermal runaway occurs. The temperature in the silicon increases until catastrophic failure occurs. This phenomenon has been observed [6] and simulated (references [6], [7], and others).

Approximately 1 MRad of radiation damage will occur at the innermost disk location at ~26 mm from the beam, at z = 0 [7]. This translates to 5.11E-8 A/mm^2 leakage current at 0°C. The worst case disk cooling scenario occurs with the assumptions shown in Figure 4. In order to determine if thermal runway has the potential to occur in the disk assembly during any stage of operation during Run II, the thermal simulation was re-run with the simplifying assumption that the radiation damage is uniform over the entire length of the silicon (it will actually decrease ~1/r^2 moving away from the beam). The assumed bias voltage on the silicon is 150 V.

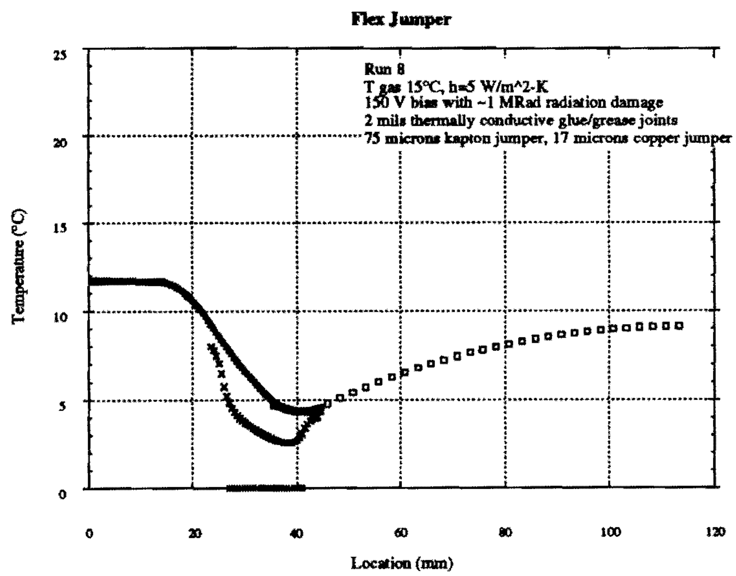


Figure 7
Disk assembly temperature profile with flex jumper and 15°C gas.

As is plainly indicated, the worst case temperature profile exhibits almost no propensity toward thermal runaway, with 1 MRad uniform radiation damage in the silicon. The maximum temperature of ~9°C is only ~0.5°C warmer than the case where there is no power generation within the silicon.

In addition to the cooling calculations, a portion of the F-Disk analysis has focused on thermally induced bow. In the region labeled "overlap region" in Figure 1, (ignoring the jumper) there are two materials in contact with different expansion coefficients.

Extending in-board of the cooling channel is a bi-material combination of beryllium and silicon. This region will be cooled from the assembly temperature (where it is assumed to be constructed in a stress-free state) to the operating temperature of, perhaps, 0°C. The change in temperature, for this set of assumptions, is -22°C.

By applying equations described in Ref. [8] for bi-material, thermally induced bow, the end deflection of the silicon can be calculated for the operating temperature. The assumed elastic modulus for silicon is 131 GPa, and that of beryllium is assumed to be 290 GPa. The expansion coefficient of silicon is assumed 2.6 ppm/°C, and that of beryllium is 11.0 ppm/°C.

The bi-metal region is constrained in the plane along the right edge of the cooling channel. For zero mm beryllium extension the theoretical end deflection of the silicon is zero. As the beryllium substrate grows in length, the bi-material region does as well, resulting in greater end deflection. The beryllium was considered to extend over a range from zero to 4 mm. The temperature changes were considered in increments of -10°C, to -30°C.

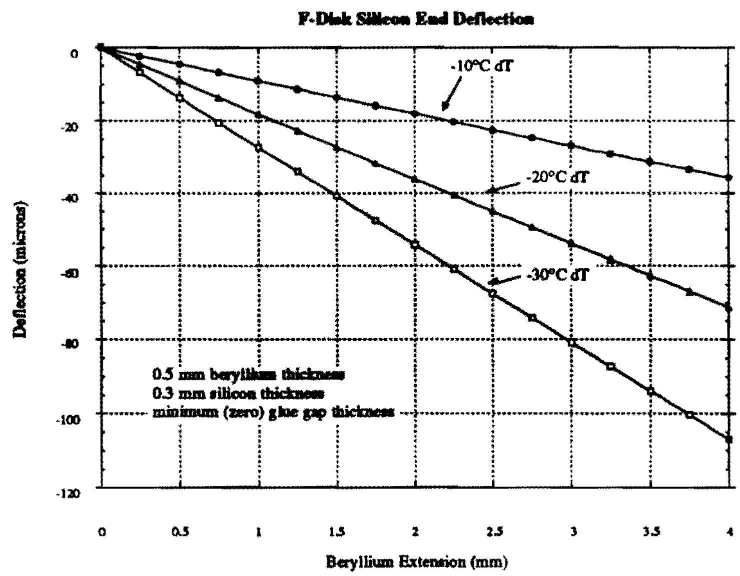


Figure 8
Theoretical Silicon End Deflection During Disk Operation

The design of the disk calls for a 3 mm beryllium extension beyond the cooling channel. With a temperature change of ~-20°C (-22°C stated above), the theoretical end deflection of the silicon nearest the beam line is ~-55 microns.

The length of the exposed silicon is 70.825 mm. It is unclear if this exposed disk length will be supported externally or not. In order to understand the amount of support required to restore this 55 microns to its theoretical starting position, an analytical solution was worked out for a non-uniform cross-section cantilever beam [9]. This analysis determined that less than 1 gram of force is required to restore the silicon to its starting position*.

[1] P. Ratzmann, Thermal Analysis of the D0 3 Chip Single Sided Ladder, June 18, 1996, D0EN 3823.112-EN-447.

[2] P. Ratzmann, Thermal Analysis of the D0 Double Sided Ladders, July 22, 1996, D0EN 3823.112-EN-455.

[3] From the Du Pont Summary of Properties of Kapton Polyimide Film.

[4] P. Ratzmann, Cable Power Dissipation in the D0 Silicon Tracker, July 8, 1996, D0EN 3823.112-EN-448.

[5] From a conversation with Bill Cooper.

[6] Kohriki, et. al., First Observation of Thermal Runaway in the Radiation Damaged Silicon Detector, submitted to the IEEE Trans. on Nucl. Sci., IEEE Nuclear Symposium, San Francisco, October, 1995 and KEK Preprint 95-157, November, 1995.

[7] Ratzmann, P., Thermal Analysis of the CDF SVX II Silicon Vertex Detector, accepted for publication in Nuclear Istruments and Methods, July, 1996 and preprint FERMILAB-Pub-96/031-E.

[8] Young, Warren C., Roark's Formulas for Stress and Strain, Sixth Edition, pp. 111 and 118-119.

[9] Analysis of non-uniform cross-section cantilever beam with end load provided by Joe Howell.

* Deflection of uniform cross-sectional cantilever beam is described by equation 4*P*L^3/E*b*t^3, and that of non-uniform cross-sectional beam is described by equation 6*P*L^3/E*b*t^3, as determined by Howell [9].