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PFIS Camera and Collimator
CDR Conceptual Design Report

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Contents

I. Summary of Design Features

Figures 1a and 1b show the concept layout of the PFIS camera and collimator. The layouts are shown without the eventual turning flat. Referring to figure 1a, the main elements are:

--The right-most barrel containing the camera elements.
--The left-most subassembly containing the first group of the collimator.
--The second-to left subassembly comprising the main collimator barrel.
--The remaining subassembly consisting of the last collimator group on its own stand.

(N.B. Figures 1 through 4 show various 3D and 2D views of the Collimator and Camera conceptual designs. In those views, the 3D models are more representative of the final configuration with regard to overall sizes and envelopes. The 2D views are more accurate with regard to the particular details of the assemblies and subassemblies. Since the designs are largely axisymmetric, often only one half of the components is shown.)

The main features of the design are as follows.

Elastomeric Bonding: All of the optical elements are bonded into their cells with and elastomer. For this design, the elastomer is Dow-Corning Sylgard 184. For the close–coupled groups, a bezel is bonded to subsequent elements, and the bezel is then bolted to the cell. This is shown in Figure 3 where the orange ring is a bezel around element 8. This ring is bolted to the turquoise cell in which element 9 is bonded.

Fluid-Coupled Multiplets: For this design, the multiplets are optically coupled with Cargille LL5610. Each fluid-containing cell is sealed with single Viton o-ring in face-flange configuration. The change of fluid volume with temperature is accommodated by a bladder external to the cell. An example bladder is shown in Figure 5.

Most Element Spacing Set By Shims and Spacers: In all of the multiplets, the spacing for the elements is set when the elements are bonded in place. This is done by placing appropriate polyester shims between the elements to maintain the proper separation until the elastomeric bond is in place. The cell is then disassembled and the shims are removed before the cell's final assembly.

For the groups assembled in the camera and collimator barrels, the separations are set by means of spacer rings that are cut to length during assembly. This permits compensation of the manufacturing tolerances in the cells by measuring the as-assembled position of the optics within their cells. The spacer is then cut to account for the measured positions.

The separation between the first collimator group and the main barrel is set by means of a gage bar that is cut to length at assembly. Due to the presence of the waveplates, a permanent spacer cannot be used. Rather, by inserting a gage bar between datum surfaces on the first and second cells, the position of the first cell can be properly adjusted.

Deflections of Elastomeric Bonds Managed by Means of Engineered Bond Sizes: It is possible to limit the deflection of the elastomeric bonds that retain the optics to acceptably small values. These deflections are due to the weight of the elements and in the case of the multiplets, the hydrostatic pressure of the coupling fluid.

In the radial direction, the deflections can be limited to 1.7 microns for any orientation. In the axial direction, the deflections are 14 ±2.5 microns, with the exception of elements 1 and 10. For these elements, weight-induced axial motions are 6.2 and 6.5 microns respectively. The tilt of an element caused by the gradient in the hydrostatic pressure is no more than 0.01 degrees (0.6 arcminutes).

Adjustable Groups: In the collimator, the first and last groups (groups 1 and 5) each have adjustments in 5 degrees of freedom. Figures 2b and 3b schematically indicate these adjustments with adjusting screws. The tip, tilt, and piston adjustments are accomplished with three screws that bear kinematically in the axial direction. The centering adjustments are accomplished with two screws that bear in the radial direction and cells that are flexured for motion in that direction. The layout of such a cell is shown in Figure 7.

Flexured Focus Suspension: The system is focused by moving elements 14 through 17 in the camera as a group. To achieve this, these elements are supported by a diaphragm flexure at each end of the subassembly. This is best seen in Figures 4a and 4b.

Low Element Stresses: The maximum stress in an optical element over the operating range of –5 to 20 °C is under 50 psi. Over the survival range of –20 to 40 °C, the maximum stress is under 100 psi. To achieve these levels, the elements must be assembled at 10 °C (50 °F).

Passive Thermal Compensation: The design includes thermal compensation in the axial direction for elements in the collimator barrel, and for focus in the camera. For the collimator, this can be seen in Figure 2a as the two black rings that form parts of the barrel structure. These rings are made of Delrin and are the length necessary to compensate for other changes with temperature within the collimator.

Focus Mechanism: Figure 9 shows the focus mechanism. It consists of a passive Delrin thermal compensator, a Physik Instrumente M230 stepper micrometer, a lever reducing mechanism, and a Schaevitz LVDT model 100DCSE. The arrangement is suitable for positioning and measurement with a resolution of less than 1 micron.

Active Thermal Management: To work properly, the Delrin thermal compensators in the collimator barrel must be within about 2 °C of each other. As an inexpensive precaution to insure that this is the case, the design provides thermocouple sensors and low-wattage foil heaters at each of the collimator's Delrin compensators. Should one compensator be significantly cooler than the other, the cooler one could be warmed.

Primary Materials:

Black anodized aluminum structure.
Delrin thermal compensators.
Delrin optics seats.
Stainless steel focus flexure.
¼-80 adjustment screws.
Cargille LL5610 optical coupling fluid.
Dow-Corning Sylgard 184 bonding elastomer.

Ether-based polyurethane bladders.
Stainless hardware.

II. Summary of Quantitative Results

Mounting Tolerances: In general, the allowable tolerance for the tilt of an element is ±0.032° (2 arcminutes), and for the positioning, ±0.075 mm (0.003") relative to the preceding element. In two exceptional cases, the tolerances are tighter. In the first case, lens 3 must be constrained to a tilt and decenter of less than ±0.016° and ±0.050 mm. In the second case, group 4 (lenses 5 through 7) must be centered to within ±0.050 mm.

Element Stresses:

The thermally induced stresses are tabulated below.

Element No.	**Stress For 15 °C Excursion (psi) (Operating Range)**	**Stress For 30 °C Excursion (psi) (Survival Range)**
1	6.1	12.6
2	44	88
3	4.2	8.4
4	3.4	6.8
5	45	90
6	43	86
7	34	68
8	0.1	0.2
9	44	88
10	-20	-40
11	44	88
12	-20	-40
13	49	98
14	47	94
15	-41	-82
16	46	92
17	-11	-22

Note: Negative values indicate a tensile stress with rising temperature.

Optical Element Gravity and Hydrostatic Deflections

The optical elements will move in their elastomeric mounting depending on the forces exerted by gravity and the hydrostatic pressure of the coupling fluid within the cells.

The motions due to gravity are an axial piston or a radial decenter, depending on the orientation of the element. The motions due to hydrostatic pressure are an axial piston and a tilt induced by the gradient in the pressure. Note that the hydrostatic deflections occur only when the element is vertical.

The table below lists the various deflections. For the elements up to and through the corrector barrel (elements 1 through 7), axial sag due to gravity is the dominant deflection during operation since the gravity orientation is confined to a small range. For the remaining elements, gravity may range over practically any direction during operation. For testing, all of the elements will be oriented vertically so that the hydrostatic motions and the radial decenter will be the relevant deflections.

Element No.	**Axial Sag, Gravity (μm)**	**Radial Sag, Gravity (μm)**	**Axial Motion, Hydrostatic (μm)**	**Element Tilt, Hydrostatic (degrees)**
1	6.2	0.3	9.7	0.009
2	16.1	0.9	-8.8	-0.007
3	13.0	1.0		
4	11.6	1.1		
5	14.2	0.3	11.8	0.007
6	11.7	0.6		
7	12.7	0.4	-16.1	-0.009
8	10.7	0.3	16.7	0.010
9	13.6	0.3	-12.7	-0.007
10	6.5	0.1	15.4	0.007
11	14.7	0.2		
12	12.2	0.2		
13	15.3	0.3	-17.3	-0.008
14	16.1	0.3		
15	15.5	0.2	12.4	0.007
16	15.9	0.8		
17	12.6	0.1	-6.3	-0.004

<u>Thermal Behavior</u>

Estimates of various thermal time constants follow. The time constants assume an ambient temperature of 295 K, and a component temperature of 305 K.

Collimator Barrel
- Aluminum Portion
  - Convective Time Constant
    - Horizontal ....1 h
    - Vertical...0.9 h
  - Radiative Time Constant...................................0.4 h
  - Internal Conduction

Circumferential ....260 s
Longitudinal... 14 s

Delrin Portion

Convective Time constant

Horizontal ....2.3 h
Vertical..1.9 h

Radiative Time Constant..................................0.32 h

Internal Conduction

Circumferential ....31 h
Longitudinal..1.4 h
Through thickness................................113 s

Camera Barrel (Aluminum)

Convective Time Constant

Horizontal ....2.6 h
Vertical..2.1 h

Radiative Time Constant...4.4 h

Internal Conduction

Circumferential ....342 s
Longitudinal...433 s

Camera Focus Compensator (Delrin)

Convective Time Constant

Horizontal ....1.3 h
Vertical..1.3 h

Radiative Time Constant...0.1 h

Internal Conduction

Circumferential ....2.7 h
Longitudinal..1.4 h
Through thickness..113 s

Calcium Fluoride Slab (example optical element, 20 mm thickness, 300 mm diameter)

Internal conduction, through thickness........................... 11 s
Convection, vertical ....5.0 h

With the exception of the internal conduction values, all of these time constants are rough approximations. The radiative time constants will be considerably longer since as the temperatures equilibrate, the heat transfer decreases. The convective time constants will effectively be shorter since the values above are for truly free convection in otherwise still air. The slightest breeze can easily reduce a time constant by a factor of 2.

The important features are:

--Every component has an internal conduction time constant that is short compared to any convective or radiative time constant. This means the component will have only small internal gradients as temperatures equilibrate.

--The convective and radiative time constants of the structural components are of similar scale. This means the temperatures of the components will equilibrate at similar rates.

--The time constant for an optical element can be considerably longer than that for the structural components. This means that the temperature of the optics can be considerably different from that of the structure if exposed to a sudden temperature change. Fortunately, even if we assume a rather extreme case in which the time constant for the structure is 1/2 hour and that for the optic is 5 hours, the effect is benign. For a 20 °C mismatch between an unfavorable element (element 13) and the structure, the induced stresses are still below 300 psi. This is due the relatively soft bonding material that largely isolates the element from its cell. The temperature behavior resulting from a 1 degree step change in ambient is shown in Figure 8.

Masses

All masses in kilograms.

Collimator:

Front Cell 3.8
Lens 1 ....0.55
Lens 2 ....1.38
Subtotal ....5.73 kg

Main Barrel 10.5
Lens 3 ....0.99
Lens 4 ....0.86
Lens 5 ....3.0
Lens 6 ....1.55
Lens 7 ....2.9
Subtotal ....19.8 kg

Last Cell, incl. support 8.1
Lens 8 ....2.1
Lens 9 ....3.5
Subtotal ....5.5 kg

Camera

Structure 19.2
Lens 10 ....2.3

Lens 11..6.1
Lens 12..4.2
Lens 13..5.0
Lens 14..4.6
Lens 15..2.6
Lens 16..2.3
Lens 17..3.8
Subtotal..50.1 kg

Total..81.1 kg

Fluid Volumes

(Fluid volumes will be calculated when cell details are finalized.)

Structural Deflections

The largest bending and shear deflections occur in the outer Delrin compensator in the collimator. For this element the total deflection is less than 5 microns, and the resulting angle is less than 5 arcseconds.

III. Alignment and Positioning

The general approach to alignment of the optics is to first accurately mount the elements in their cells, and then taking into account the measured cell dimensions, align the cells in their respective assemblies. The details are as follows:

1. Alignment of Elements in Cells:

a). Fabricate accurate cells. "Accurate" means that there is a Delrin seat in the cell that is concentric to a datum diameter on the outer surface of the cell to within +/-10 µm, and parallel to datum face to +/-10 µm.

b). Fixture the cell on a rotary table so that the Delrin seat is concentric to the axis of the table.

c). Place the optical element on seat. Since the seat is centered, the optical surface resting on the seat is also centered.

d). Tilt the element to align the upper vertex with the axis of the rotary table. This is done by observing a reflection from the upper surface with a long-working distance microscope. (Sensitive to about 0.2 arcseconds).

e). Bond the element in place.

f). For multiplets, repeat the procedure by setting next element in place on spacing shims, aligning as above, and then bonding the element into its bezel.

2. Alignment of Cells in Assemblies:

For the camera barrel:

Spacings are set with spacers that are cut to length at assembly. The as-built dimensions of the cell are measured on a milling machine with suitable metrology. Contact measurements can be made on hard-coated elements. Measurements with a video camera and microscope objective are made on surfaces with sol-gel coatings. (Accurate to about ±4 microns over 10", repeatable to ±2 microns.)

Axial alignment of the cells in the assembly is again done on a rotary table with long working distance microscope, similar to the alignment of the optics in their cells.

For the collimator:

Alignment of the collimator is complicated by the fact that it mounts in three sections on the optical bench: field lens, main barrel, and last group. The following is one possible alignment procedure:

a). The main barrel is first assembled in a manner similar to camera barrel, as outlined above.
b). Mount the main barrel in a fixed (nominally final) position on the optical bench.
c). Mount the alignment telescope (K&E 2202) ahead of field lens and cell.
d). Align the telescope with the axis formed by front and rear vertices of main barrel.
e). Install the last group and align the front and rear vertices with the telescope axis (tilt and decenter).
f). Install field lens and align front and rear vertices with telescope
g). Set field lens spacing with gage bar.
h). Set last group spacing in autocollimation: Place a mirrored flat behind last group and align with the telescope. Place pinhole and camera (or camera with microscope objective) at the focal surface. Move the last group axially until return spot is in sharp focus at the focal plane.

IV. Shop Tests

We propose that acceptance testing consist of verification of the correct back focal distance and spot size using two colors for the camera and collimator. Testing will be accomplished by introducing a collimated beam and measuring the spot size and location with a measuring microscope. The camera will be tested in the forward direction; the collimator will be tested in reverse.

V. Technical Risks

Compared to other systems we have produced, the primary technical risk in the PFIS system is damage to the sol-gel coatings and damage to the NaCl optical elements. These risks are addressed in section VI below.

VI. Environmental Risk Mitigation

The PFIS system will be assembled in an environmentally controlled pseudo-clean room. This in not intended to be a true clean room by industrial standards. Rather, it is a room where dust is kept to a practical minimum through use of smooth surfaces, air filters, and good personal practice. The room will also be dehumidified and temperature controlled.

Additionally, the system design includes features to minimize the risk of damage during handling and operation. This includes guards on the cells—either integral or removable—that prevent the optical element from making contact when the cell is set on a flat surface. Covers will also be provided for all exposed surfaces when not in use.

The camera and collimator barrels will include ports for the introduction of a filtered dry-air purge.

VII. Open Issues

The selection of the coupling fluid, bonding compound, and bladder material has not been finalized. The materials assumed for the conceptual design (Cargille LL5610, Sylgard 184, and ether-based polyurethane) are know to be compatible. We do not know if LL5610 is acceptable optically. Should another coupling fluid be selected, it may be necessary to change other materials.

Figure 1a
3D PFIS Camera and Collimator General Layout

From left to right, the subassemblies are: Collimator Group 1, Collimator Main Barrel, Collimator Group 5, Camera Barrel

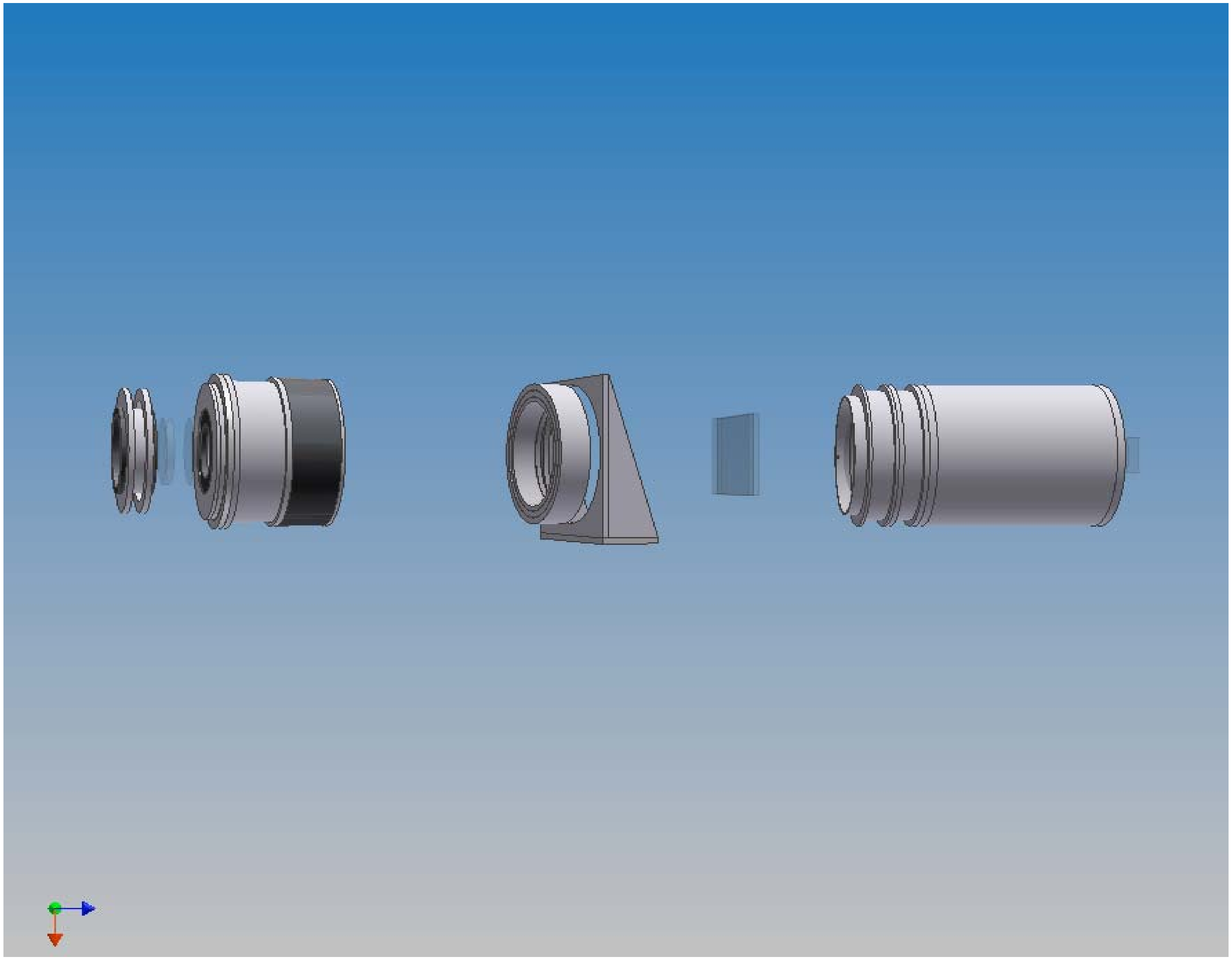

Figure 1b
2D PFIS Camera and Collimator General Layout

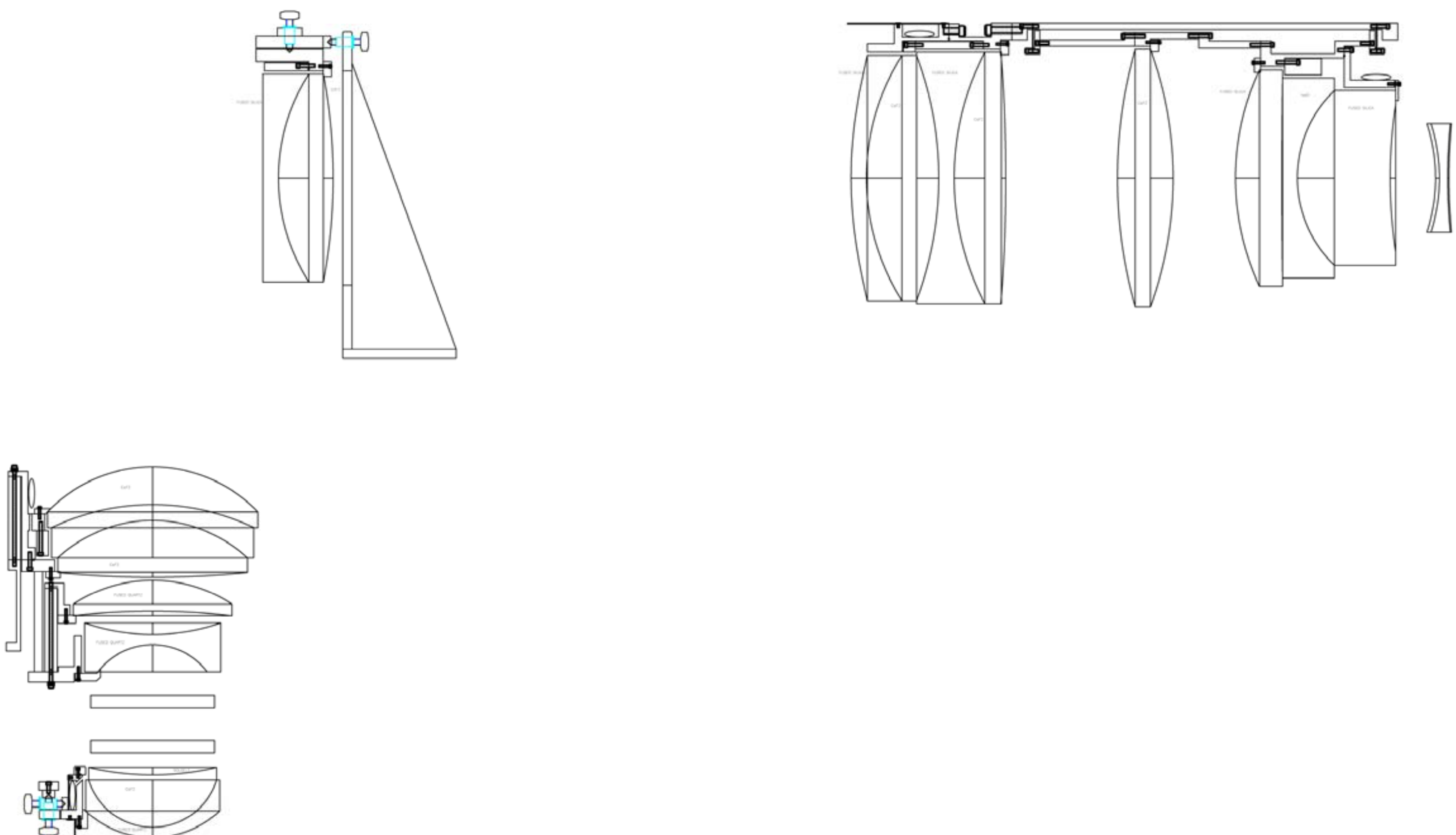

Figure 2a
3D Sectioned Layout of Collimator Group 1 and Main Barrel

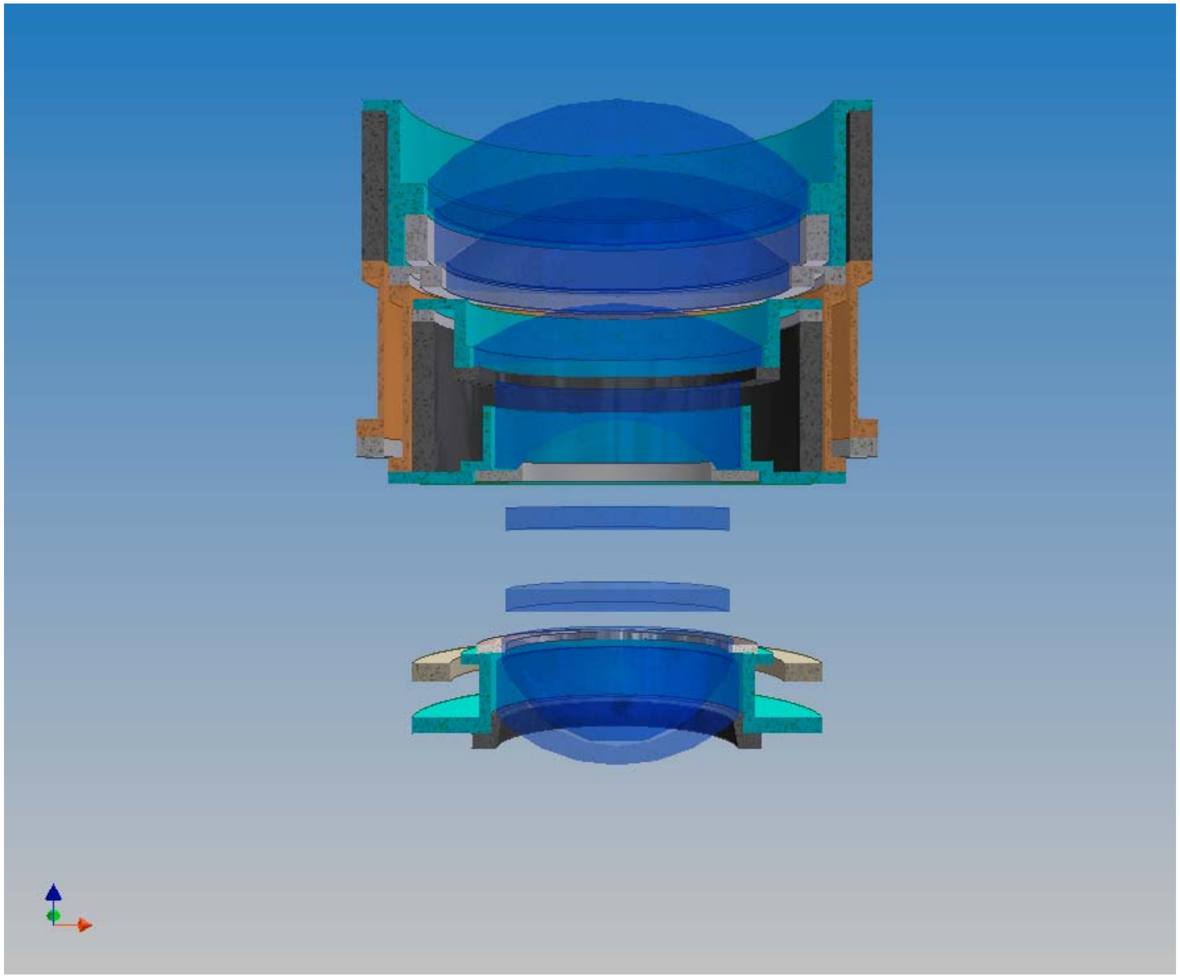

Figure 2b
2D Sectioned Layout of Collimator Group 1 and Main Barrel

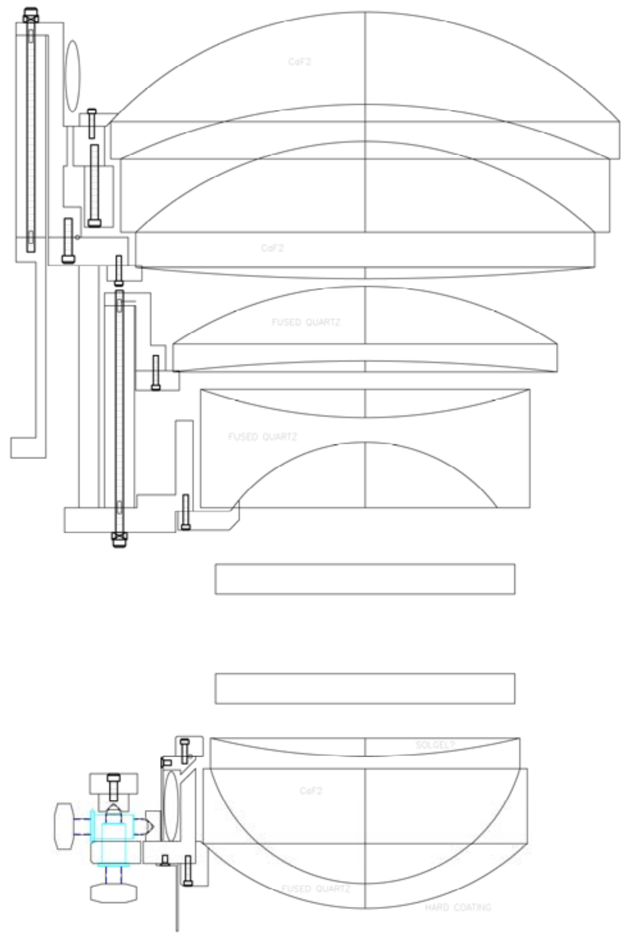

Figure 3a
3D Sectioned Layout of Collimator Group 5

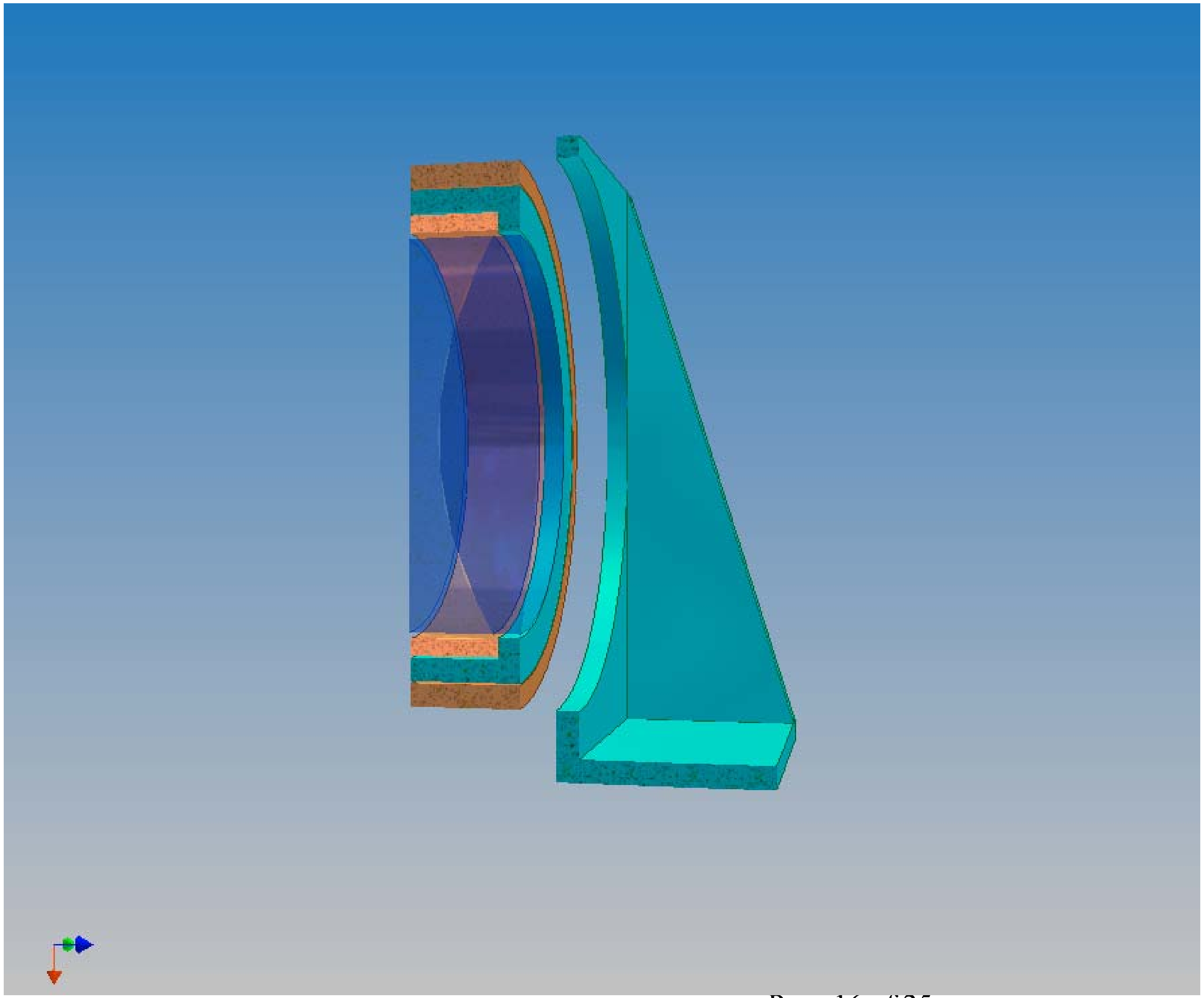

Figure 3b
2D Sectioned Layout of Collimator Group 5

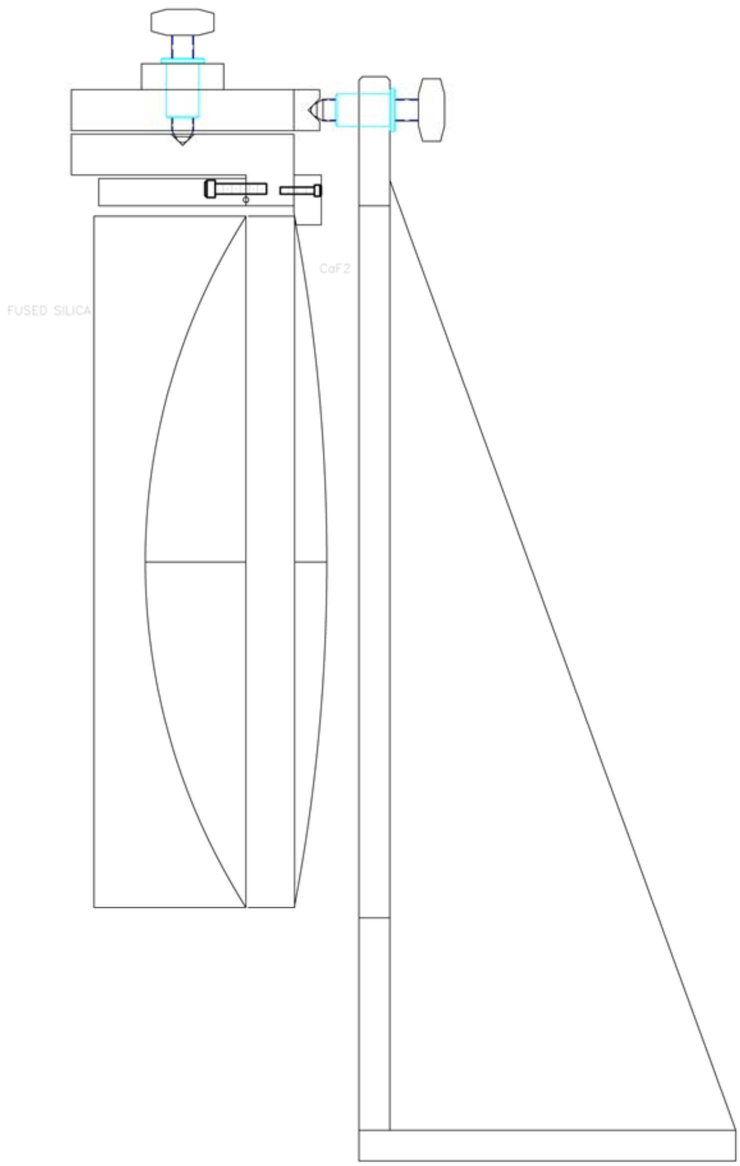

Figure 4a
3D Sectioned View of Camera Layout

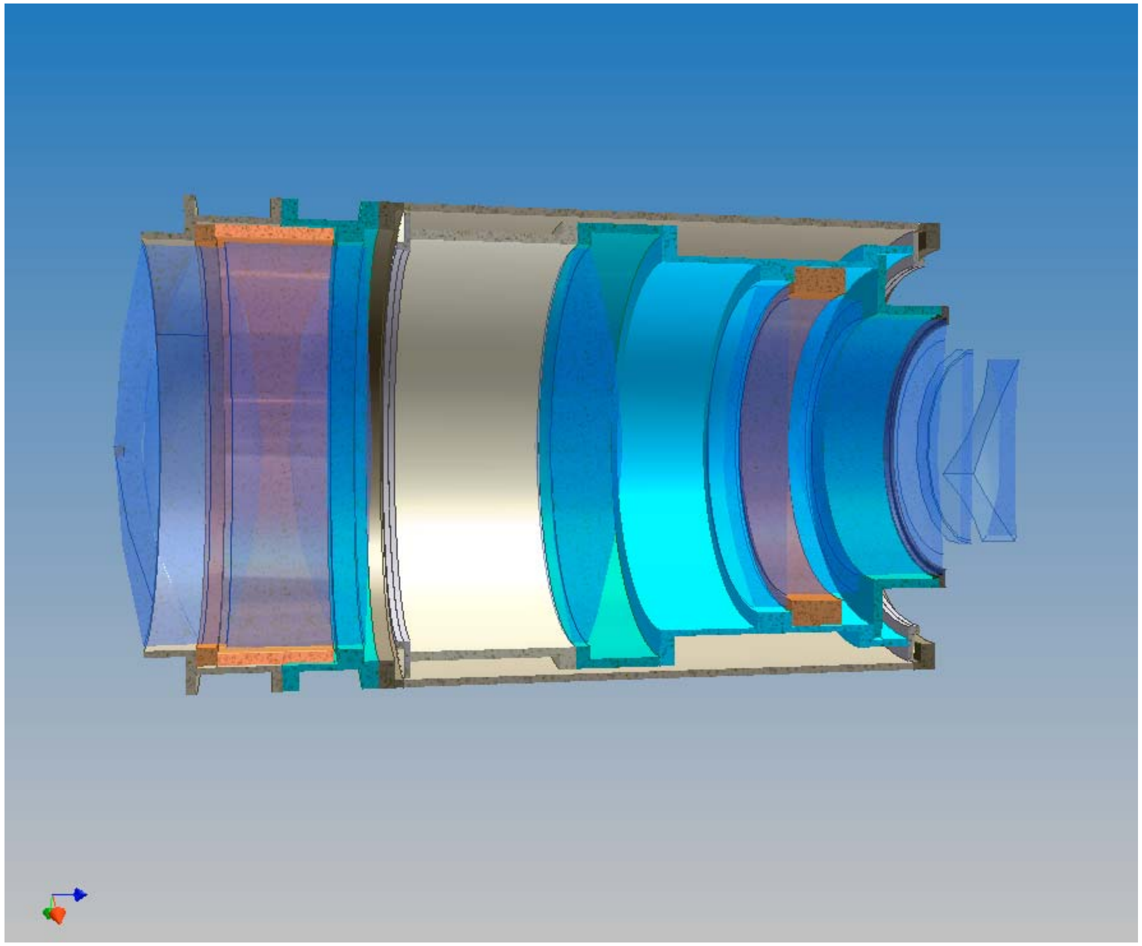

Figure 4b
2D Sectioned View of Camera Layout

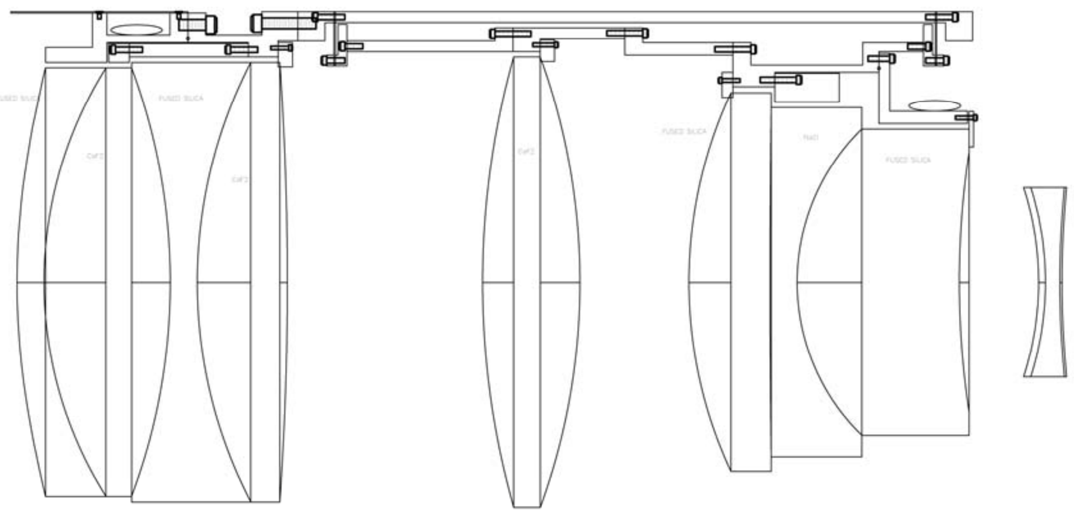

Figure 5
Photo of Example Bladder

Figure 6
Example Flexure Model and Photograph

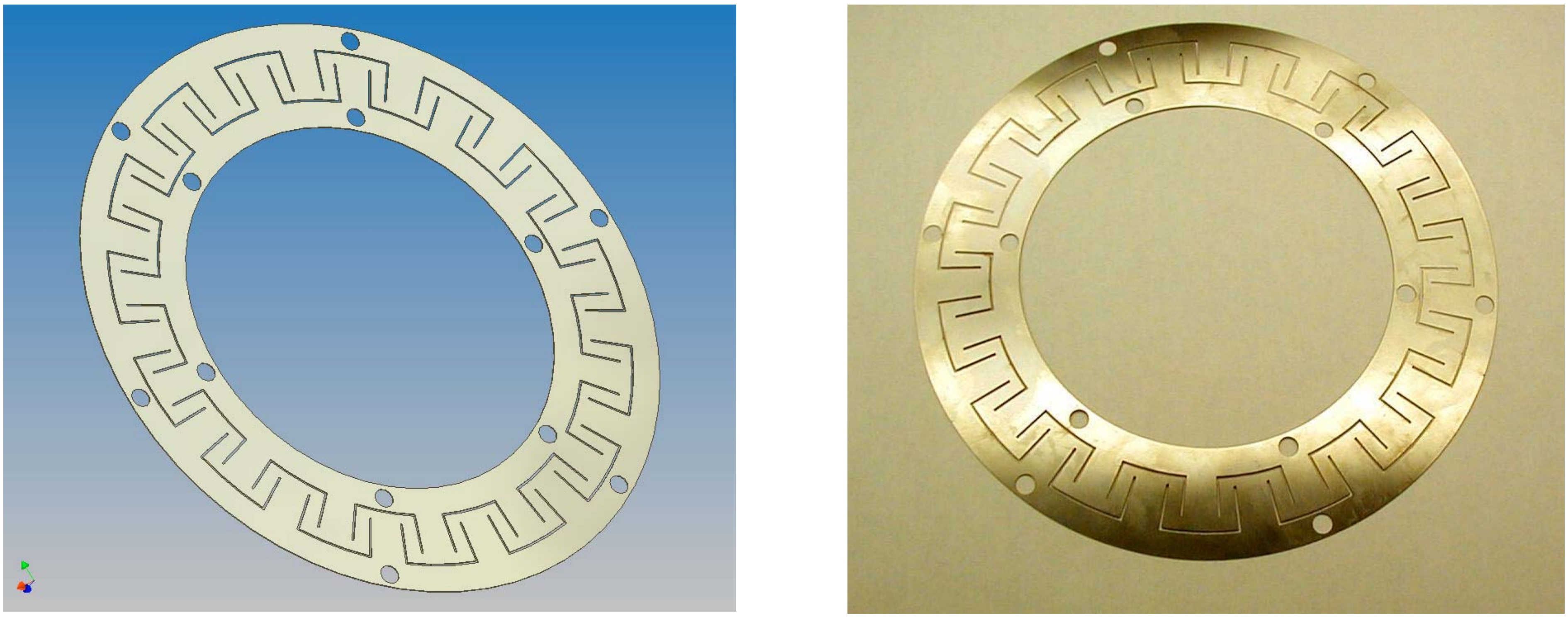

Figure 7

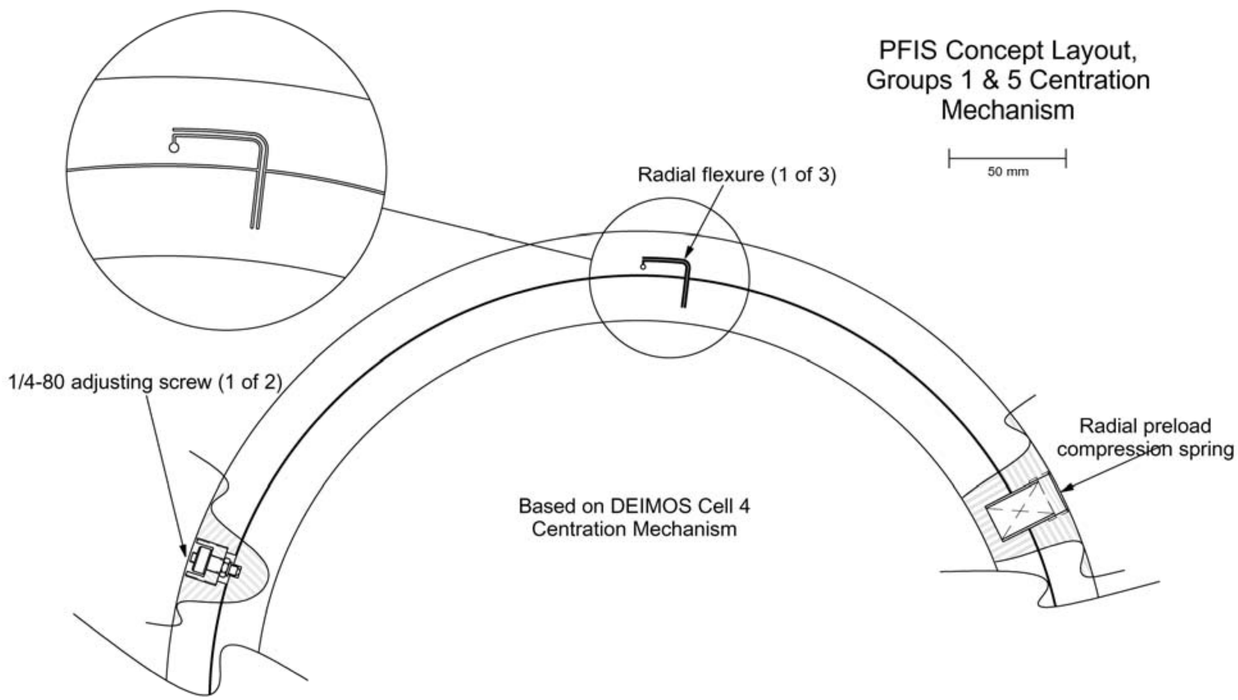
PFIS Concept Layout,
Groups 1 & 5 Centration
Mechanism
50 mm
Radial flexure (1 of 3)
1/4-80 adjusting screw (1 of 2)
Radial preload
compression spring
Based on DEIMOS Cell 4
Centration Mechanism

Figure 8
Thermal Behavior for A Step Change in Ambient Temperature

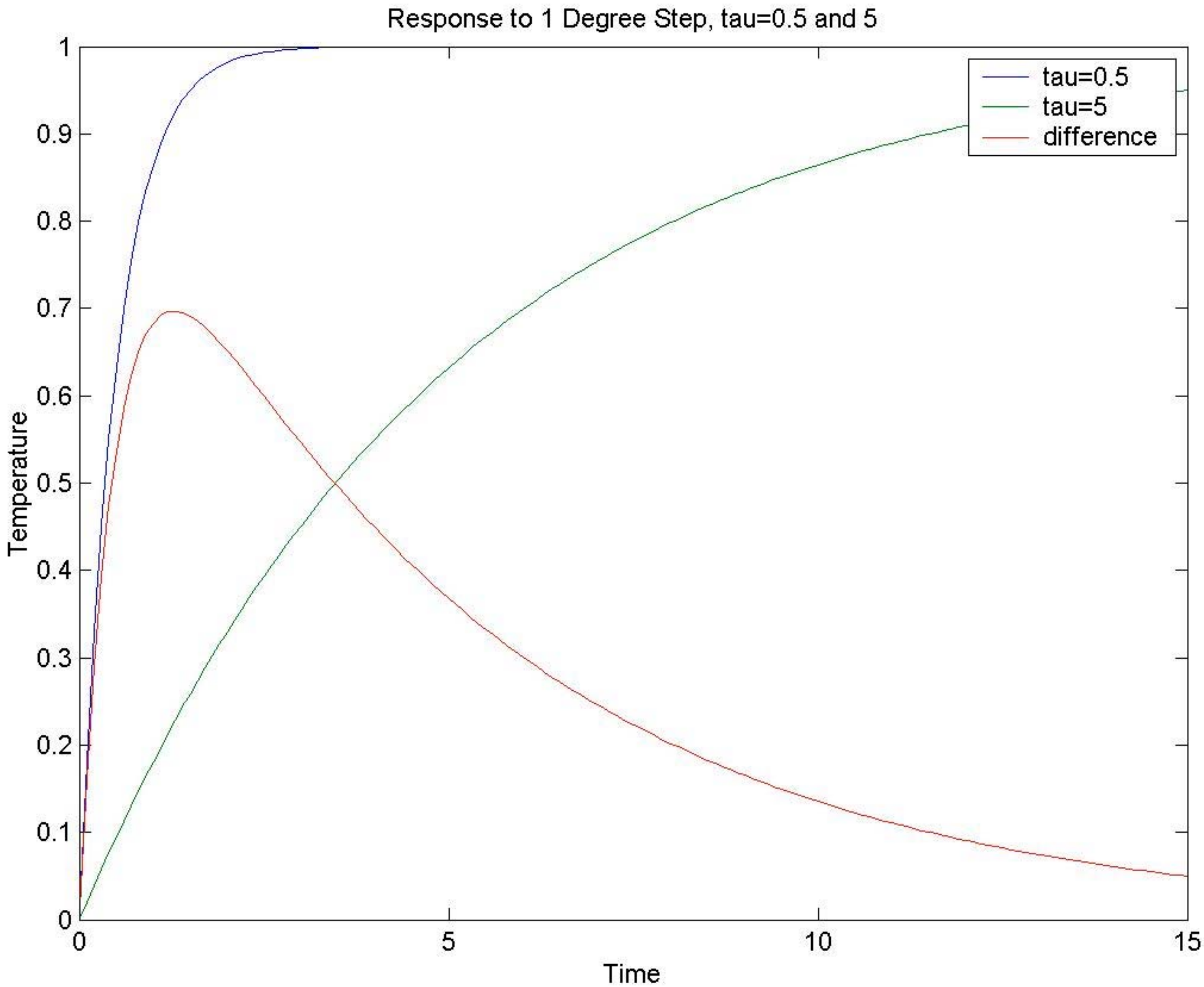

Figure 9
Focus Mechanism