Appendix B
Process Control Inspection
432mm Disk Support Ring

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Abstract

This document outlines the minimum inspection steps deemed necessary to ensure that the Disk Support Ring and ring components have been fabricated in accordance with the Procurement Plan for the ATLAS Pixel Detector Disk Support Rings, HTN-106210-0005, and other applicable specifications set forth by Lawrence Berkeley National Laboratory (LBNL). The controlling LBNL document is drawing 21F5224.

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1. Introduction

Specific process control techniques are necessary to produce a "per print" 432mm Disk Support Ring. HYTEC has outlined key inspection steps, techniques, and nominal dimensions (based upon individual part tolerances and fabrication tolerance stack-up) expected for a deliverable product.

The first half of this document details inspection steps required for Phase 1 (fabrication of the ring's inner and outer C-Channels), and steps that complement those outlined for Phase 2, contained in the Procurement Plan for the Atlas Pixel Detector Disk Support Ring [1]. It is believed that adopting and enacting an inspection process control along the lines outlined here, or an equivalent procedure, will provide the necessary structure to successfully produce high quality in the 6 production rings planned in Phase 3.

2. Phase 1 – Inspection of Ring's Inner/Outer C-Channels

HYTEC and Allcomp have produced C-Channels for two rings in a past SBIR program. The C-Channels were produced using a different process than currently planned. It is believed that improved C-Channels will result from the revised compression molding process. Qualification of the new channels will use inspection steps based upon this prior experience. Achieving high dimensional quality in the C-Channels is essential to the production of a quality composite ring. In this regard, it is important not to produce a set of channels (inner and outer), which have different widths, or that possess an in-grained twist. It is expected that either of these conditions will lead to ring twisting. The unfortunate result will be that all of the Pixel Detector Sector mounting bushings would be twisted out of position. This condition, if sufficiently severe, would result in the final product being rejected.

The “per print” specifications for the ring’s inner and outer C-Channels are shown on LBNL drawings 21F524, and 21F525. The critical features of the C-Channels are (1) the major physical radius (the web profile of the C-Channel that defines the outer and inner physical dimensions of the ring), (2) the width of the C-Channel, (3) toe in/out condition channel legs, and (4) the perpendicularity of the channels.

There are other potential non-conformities that may be fabricated into the molded channel, which are not cited. It is important to realize that not all non-conformities, when found, will necessarily result in a particular C-Channel being rejected. This document attempts to focus on key potential non-conformities prior to fabrication, to establish an awareness mindset, in the hopes of producing a “near-perfect” C-Channel.

2.1 C-Channel Specifications (defined by drawings 21F524, and 21F525)

An acceptable C-Channel should have these features:

- Web of the C-Channel must be perpendicular to its legs better than 0.5°.
- Outside radius to outside radius width to be within 0.548-0.546in.
- No toe out of C-Channel face. Toe in of 1° across the face (6 mils) is acceptable (as described in note 7 of the drawings).
- The major physical radius of C-Channel must be “per print.”
- In-grained twist of .002” per inch/.008” max per arc length is acceptable.
- Aesthetics is important; the C-Channel must be smooth and continuous in appearance. Devoid of cracks, frays, and major non-conformities.

2.2 Determination of Potential Nonconformities

This section presents acceptable C-Channel “parameters”. We attempt to explain why specific non-conformities are unacceptable, and identify techniques for inspecting the critical dimensions, and possible corrections to identified problems.

2.2.1 Channel Web Not Perpendicular to Side Face

The desire to have a C-Channel web perpendicular to its face(s) is to facilitate assembly. The vertical web is pulled to an aluminum half-ring, which positions the C-Channel during bonding. Out-of-perpendicularity, as accentuated in Figure 1, will likely result in built-in stress at bonding, leading to ring twist in the free state. Figure 1 shows an example of the channel web not being perpendicular to the channel legs even though both of the channel legs and width are within tolerance. Drawing 21F524 and 21F525 define that the channel web must be perpendicular to the channel’s legs within 0.5° or 5 mils.

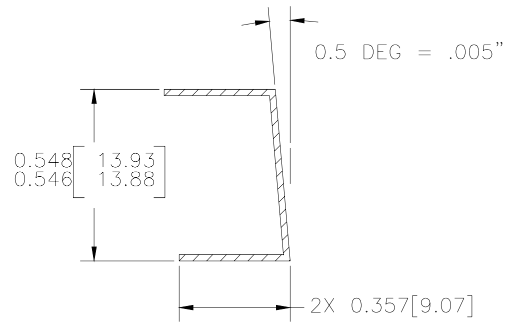

Figure 1. C-Channel web not perpendicular to its face.

2.2.1.1 Inspection for Channel Web Perpendicularity

A molded C-Channel (pre-machined) can be set (unrestrained) on a granite table. A machinist's square or gauge block is placed against the web of the channel. If a gap is exhibited between the parts, feeler gauges may be used to determine the extent. Sweep the gauge block around the entire radius of the part (90° active arc length). Flip the C-Channel over and repeat this process for the other side. If a feeler gauge of greater than .005" can be placed between the two parts, the C-Channel is rejected.

2.2.2 Channel Width

All C-Channels must have a closely controlled specific height (see drawing 21F524, 21F525 and Figure 2) to create a flat co-planar surface for face sheet #2. Another reason is that all of the individual bushing parts are machined to a specific width to match the correct C-Channel width. The acceptable channel width is shown in Figure 2; a channel outside of these limits may be rejected.

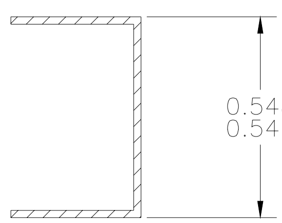

Figure 2. C-Channel width specification.

2.2.2.1 Channel Width Inspection

The width of the C-Channel may be measured using a caliper. No fewer than 10 measurements should be taken across the arc length of the channel. Alternately, the channel can be restrained on a granite table and measurements can be recorded using a height gauge.

2.2.3 Channel Leg Toe In/Out

The C-Channel legs in their as-molded condition are very rigid. It takes a lot of force to push a channel face inward. Any attempt to force a C-Channel to a perfect shape during bonding would result in a strain in the finished composite ring. Therefore C-Channel toe out is unacceptable and will result in rejection. In contrast, C-Channels may have a slight toe in condition. Any slight gap produced by the "toe-in" condition may be filled with adhesive (when bonding to a face sheet), which should not result in a residual strained. LBNL drawings 21F524 and 21F525 specify a leg toe in of 1° or 6 mils is acceptable (note 7).

2.2.3.1 <u>Channel Face Toe Inspection</u>

Each side of the C-Channel toe-in can be measured using a feeler gauge (C-Channel restrained flat on a granite table). It may be cause for rejection of a C-Channel, if a feeler gauge of greater than 6 mils can be inserted between the C-Channel and granite table. Any condition greater than 6mils requires approval.

A toe in/toe out condition can be corrected by adjusting the female mold spring-back angle. This condition will be experimentally corrected during Phase 1 of the project.

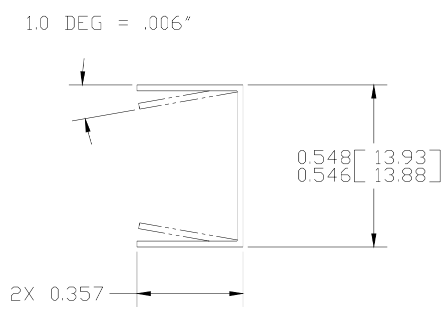

Figure 3. C-Channel toe in/out specifications.

2.2.4 Channel Web Radius

The C-Channel is inherently stiff in a direction normal to its outer radius. It takes considerable force to bend it to a different than as-molded radius. Therefore, it is extremely important for its major physical radius to be per specification (see drawings 21F524 and 21F525). Any attempt in constraining the C-Channel outer radius for bonding into the assembly will result in an as-bonded assembly that has serious strain.

2.2.4.1 <u>Channel Web Radius Inspection</u>

The physical radius of the C-Channel will have to be measured (unrestrained) using a go/no go template or equivalent. Any deviation from the correct radius may be corrected by adjusting the mold. All deviations should be adjusted in Phase 1.

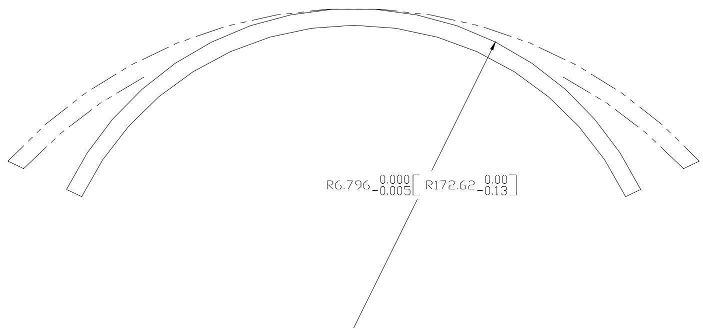

Figure 4. C-Channel major radius

2.2.5 Channel In-grained Twist

In an unrestrained condition, a C-Channel may have the correct width and acceptable toe specifications, but it may exhibit an in-grained twist. Ingrained twist is most likely produced by a slight irregularity in the lay-up of the prepreg layers. If the channel passes other specifications, it can be constrained (it is not inherently stiff to twisting) during the bonding process. There should be little bonded stress as a result of constraining a twisted C-Channel.

2.2.5.1 <u>Channel In-grained Twist Inspection</u>

In-grained twist may be measured with the C-Channel lying unrestrained on a granite table. Insert feeler gauges at one end of the C-Channel. In-grained twist of less than .002"/in and not more than 0.008" per total arc length is acceptable.

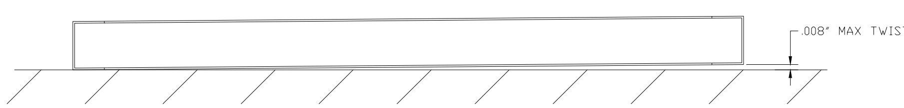

Figure 5. C-Channel with in-grained twist

2.2.6 Other Nonconformities

2.2.6.1 <u>Thickness Variations</u>

Material thickness variations may be present in the C-Channel. Channel side face thickness measurements should be taken at various angular positions around the C-Channel for both legs. C-Channel drawings specify 0.5 mm as the C-Channel material thickness. The material thickness tolerances are dependent up the fiber content specified in the C-Channel material callout. A variation in thickness may be due to uneven silicone rubber pressure on the prepreg material during curing. Some random thickness variations are acceptable; if considerable thickness variations are found during Phase 1, the condition should be investigated for correction. Thickness variations in the excess of 20% of thickness will require approval before proceeding.

2.2.6.2 Cracking or Fraying at Channel Edges

Cracking or fraying at machined edges is due to the improper tools (carbide or tungsten tips are necessary) used during the machining process. In most cases, machining thin molded or sheet carbon material should be sandwiched between aluminum plates (the part should be constrained). Cracking or fraying is not acceptable, but is avoidable with proper machining practices.

2.2.6.3 C-Channel Aesthetics

The C-Channel should be free of major non-conformities and be visually "perfect."

2.2.7 Summary of C-Channel Inspection

The cause of most of these problems can be identified and corrected. Some problems will be a result of improper mold dimensions, but this will be corrected in Phase 1. Other problems exhibited, may be a result of the silicone plug not applying enough pressure to the prepreg during curing, or being misaligned during molding.

C-Channel wall thickness measurements will be recorded and this information will be used to ensure that the fiber volume fraction is correct.

3. Phase 2 – Bonding of the Composite Disk Support Ring

All of the individual parts for the disk support ring including: face sheets, mount tab, bushings and washers must be inspected and certified by the appropriate machine shop prior to delivering the components to the ring assembly area. All recorded dimensions for the piece parts must be supplied with the parts in a "traveler" package. A fully assembled and inspected disk support ring will include a similar traveler, unique to each ring, and this traveler will provide traceability to the piece part travelers.

A bond fabrication procedure (as a part of the Procurement Plan Document [1]) has been submitted by HYTEC to LBNL for their review. Once released, it is a binding document that must be followed step by step. The procedure will be reviewed and revised prior to Phase 3 of the ring fabrication effort. There should be no need for revision during the Phase 3 fabrication of the 6 production rings. As a part of the procedure, inspection documents (notations in the traveler document) will be processed for each inspection step.

Discrete inspection steps have been inserted through the ring assembly task to better understand what deviation or tolerance stack-up may have led to an out of specification condition. Common quality control practices should be implemented, such as always using the same inspector throughout a ring's fabrication (or even throughout the entire project) to maintain repeatable inspection readings. Any problems or questions should be immediately reported to HYTEC for review.

This document does not address all procedural steps as a whole, but rather reference the step as part of the Procurement Plan Document - PPD. We stress specific inspection points throughout the assembly task, and identify the anticipated fabrication dimensions at said points.

3.1 432mm Sector Mount Ring Assembly Specifications (defined in drawing 21F522)

The following is a written translation of the dimensions and tolerances shown on LBNL drawing 21F522:

- The 3 bushings for mounting each sector are a pattern. It is important to critically position them to each other within ∅0.001. This will be done with a critical pattern machined into a mistress gauge supplied by LBNL. A secondary task is to less critically position each 3-bushing pattern relative to the entire bushing pattern within ∅0.005”.
- All bushing heads are to be coplanar within 0.002” when the ring is unrestrained.
- All four of the mount tab ∅3.50 mm holes are to be coplanar within 0.005”.
- The composite disk support ring width is to be less than 15 mm (to provide clearance for sector tube services).
- The ring shell should be bonded together in the most strain free condition possible.

3.2 Mistress Gauge

A mistress gauge will be supplied by LBNL for the purpose of critically positioning and bonding the brass bushings into the back of the graphite plate.

The mistress gauge has two discrete 2-hole patterns in it. The first 2-hole pattern is used to critically position and hold three brass bushings relative to themselves within 0.001” during bonding. The second 2-hole pattern is used to position the mistress gauge on the graphite fixture during the bonding process. Gauge pins are used to transfer the tight positioning of the 3-hole pattern in the mistress gauge to the position of the brass bushings in the graphite fixture plate.

After bonding, the graphite fixture plate with the brass bushings bonded in place will be inspected using a CMM by LBNL.

3.3 Inspection Steps During Bond Fabrication

The following inspection steps are derived from the Procurement Plan for the Atlas Pixel Detector Disk Support Ring

3.3.1 Facesheet #1 on Graphite Bond Plate

Any time anything is placed on the graphite plate, it should be visually and physically inspected. Small bumps of adhesive may have temporarily adhered to its flat surface. By running a hand over important flat “zones” (area where the face sheet lies flat on the plate), bumps may be felt. Air should be blown over the entire surface to remove grit, lint, hair, and dirt that may have collected on its surface. A hair (hair is 0.003” thick) is thick enough to prevent the bushings from being coplanar during bonding).

The face sheet material has a specified thickness (see LBNL drawing 21F523) of 0.483-0.432 mm. After a face sheet has been positioned using no less than 3 pins in the mount tab holes (∅7.50 mm), it should be tapped (with a finger) to see if it is lying flat on the plate, especially in the areas immediately surrounding the pins.

Inspection to prove the face sheet is seated flat shall be done using a height gauge (see step 6 in PPD). The height gauge base should be sitting in the center of the graphite plate. It’s gauge point, after being zeroed on the graphite plate, should read .483-.432 mm (see Figure 6).

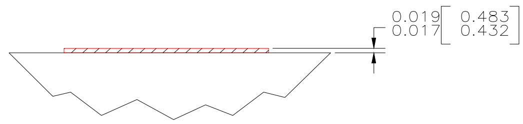

Figure 6. Face sheet flat on graphite plate

Note: Drawings and notes MUST be prepared showing the position of each serialized part in the assembly (face sheets, C-Channels, and mount tabs). Therefore if deviations are noted, one can trace back through the serialized inspection reports to determine if the problem is a result of the bond procedure or a part tolerance. This process MUST be carried out for each bonding step in the fabrication process (with the exception of the location of individual bushings and washers).

3.3.2 C-Channels Bonded to Facesheet #1

The face sheet has been inspected, and is lying flat on the graphite plate. Each C-Channel has been individually inspected and approved (per LBNL drawing 21F524 and 21F525). Knowing the limit dimensions for each we can determine (see Table 1):

	MAX	mm		MIN	mm
C-CHANNEL WIDTH	0.548	13.93		0.546	13.88
ADHESIVE BOND WIDTH	0.003	0.08		0.003	0.08
FACESHEET THICKNESS	0.019	0.48		0.017	0.43
TOTAL DIMENSION	0.570	14.49		0.566	14.39

Table 1. C-Channel and Face Sheet #1 Limit Dimension

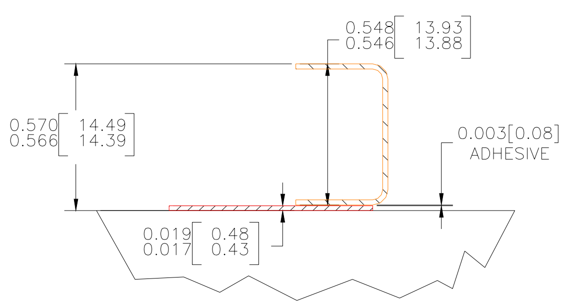

Figure 7. C-Channel bonded to face sheet

Therefore, the limit dimension for step 11 in the PPD document is 14.48-14.38 mm (see Figure 7). If the face sheet and C-Channels have been inspected and approved, any deviation from this limit dimension will be a result of a varying adhesive thickness or an unbalanced applied load from the Caul plate.

3.3.3 Face Sheet #2 Bonded to C-Channels

Table 2 shows the tolerance stack up for the bonding of face sheet #2 to the C-Channels. Figure 8 shows the sketch of the assembly.

Approximately 6 inspection measurements should be taken on each C-Channel unless a deviation is determined, then at least 10 measurements should be recorded. These measurements can be used to map elevation deviations that will later help in forecasting problems.

This corresponds with inspection step 17 of the PPD document. Because each part has a tolerance associated with it, the tolerance as the assembly is put together increases. The limit dimension measured from the graphite plate to the top of face sheet #2 is 15.04-14.88 mm.

Once again, a height gauge is used for making measurements. The base of the height gauge is placed in the center of the graphite plate.

	MAX	mm		MIN	mm
C-CHANNEL WIDTH	0.548	13.93		0.546	13.88
ADHESIVE BOND WIDTH	0.006	0.152		0.006	0.15
FACESHEET THICKNESS	0.038	0.97		0.034	0.86
TOTAL DIMENSION	0.592	15.05		0.5864	14.89

Table 2. C-Channel and Face Sheets Limit Dimension

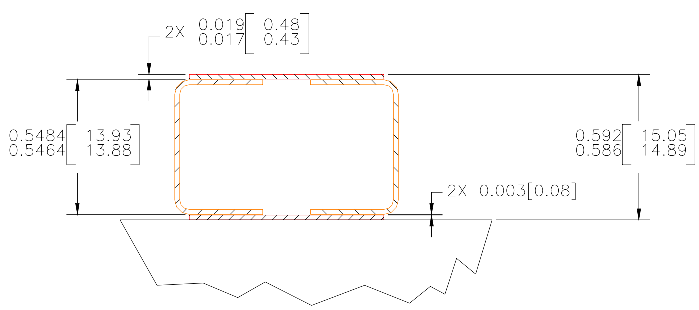

Figure 8. Face sheet #2 bonded to C-Channels.

3.3.4 Installing the Mount Tabs

Before installing the mount tabs, a visual inspection should be done to determine if adhesive has flowed out and will interfere with the installation of the mount tab. Some light scraping with a “hot knife” may be necessary to remove unwanted adhesive on the face sheet material. The assembly should not be removed from the graphite plate unless absolutely necessary; if necessary, retain the original angular orientation of the ring, and re-inspect the ring to determine that it is flat on the graphite plate (see inspection step 3.3 for correct limit dimension).

After the mount tabs have been bonded in position, insert a ∅3.5 mm pin into the ends of each mount tab. Is there enough room for the height gauge in the corner of the graphite fixture? Place the height gauge on the granite table. Re-zero the gauge so that the top of the graphite plate is zero. Using that new zero reference, measure to the top of the pin. The point being that they should all be coplanar.

Figure 9 shows the limit dimension for the mount tab being 9.29-9.21 mm.

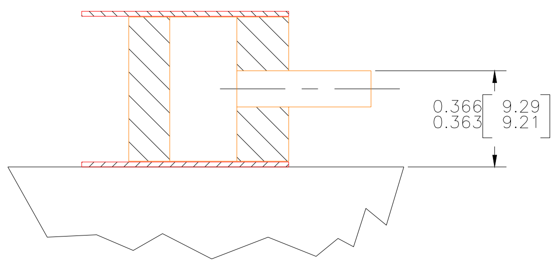

Figure 9. Mount tab measurement.

3.3.5 Bushing

Bonding the bushings heads coplanar is one of the primary objectives of the disk support ring design. Prior to installing any bushing be sure to inspect each counterbore for sand, hair, or lint. The planarity of these bushings is affected by the variations in the counterbores in the graphite plate. The graphite plate will be inspected by HYTEC to verify that the individual 24-counterbores are machined to the correct depth. Of equal importance is to determine that each bushing is completely seated against the counterbore shoulder.

3.3.6 Installing the Bushings

Table 3 and Figure 10 show the limit dimension for a bushing seated in its counterbore. This dimension is measured by a height gauge (height gauge base on the graphite plate). The height gauge knife-edge should be re-zeroed for calibration on the graphite plate (not the granite table as done in step 3.4). The dimension measured from the top of the bushing to the face of the graphite plate should be 16.18-16.03 mm.

		mm			mm
BUSHING	0.717	18.21		0.712	18.08
COUNTERBORE DEPTH	0.082	2.08		0.081	2.05
TOTAL DIMENSION	0.635	16.13		0.6311	16.03

Table 3. Bushing Installed on Pin and Located in Counterbore

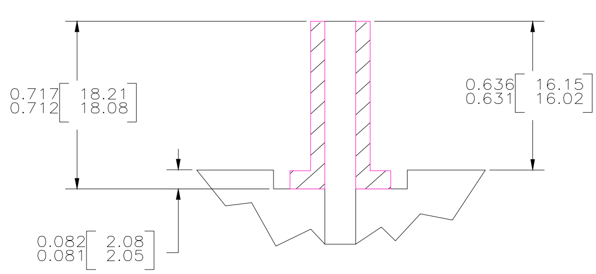

Figure 10. Bushing located in counterbore.

3.3.6.1 <u>Bonding the Bushings to Ring Shell</u>

After the 24 bushings are in place and have been inspected to make sure they are correctly seated in place. After adhesive has been applied to each surface, and the ring has been re-positioned, re-check to see that the ring is correctly seated on the graphite plate. The measured values should closely correspond with the inspection measurements recorded in step 3.3.

3.3.7 Bond Washers to Face Sheet #2

After the washers have been bonded in place, an inspection (see step 35 PPD document) is done to determine planarity of the washers. Table 4 and Figure 11 show the calculations and the final limit dimension.

Any variation outside of the limit dimension may be a result of the adhesive bondline being greater than 0.003”. The dimension recorded should be within 16.23-15.95 mm.

		mm			mm
SHELL WIDTH	0.592	15.05		0.586	14.89
ADHESIVE WIDTH	0.003	0.08		0.003	0.08
WASHER WIDTH	0.044	1.13		0.039	1.00
TOTAL DIMENSION	0.640	16.25		0.6287	15.97

Table 4. Washer installed in Place

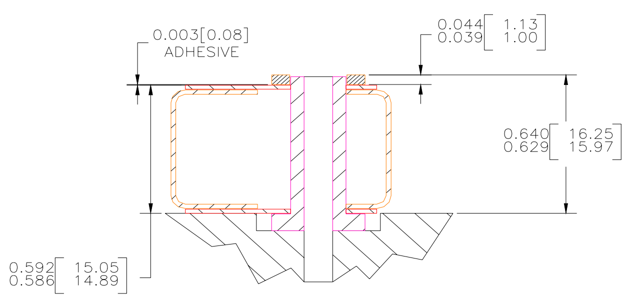

Figure 11. Final dimension when washer is bonded in place

4. Inspection Summary

These inspection steps are an indicator as to how well the ring bonding operation is proceeding. Naturally, if excess adhesive is used in the initial stages of the bonding, the measured dimension will increase accordingly. Any time a predicted inspection measurement is not within limits, immediately investigate to determine what caused the deviation. Determine if a change in the process control is needed to correct such a future deviation. This type of investigation is the key to understanding the necessary processes to produce a “deliverable article.”

After Phase 2 is complete - a procedure, design, and inspection review meeting will be conducted. The meeting will serve to summarize, make recommendations and consider improvements or any necessary changes to be implemented prior to initiating Phase 3. The appropriate changes will be made to the procedure and inspection processes. After these changes are made we do not anticipate any deviations from the approved procedure will be necessary. At this point final production approval will be granted.

5. References

[1] Procurement Plan for the ATLAS Pixel Detector Disk Support Rings, HYTEC HTN-106210-0005