

# **ACD PMT 0046 Engineering Unit Failure Issue Summary and Status**

**Draft 3 12/08/03 – 1/20/04**

**Michael Amato**

## **CONTENTS –**

**Note : Other than THE LATEST section every thing is in chronological order as items happened or options considered**

- **Current Plan, plan flow, analysis case tables**
- **Actions and results log**
  - **Test summary for the test where failure occurred**
  - **December 8 action items**
  - **Results from December 8 action items**
  - **December 9 meeting with materials branch and Dec 10 additional action items**
  - **Results from Dec 9 and 10 action items**
  - **Dec 11 action items and results**
  - **Dec 16 actions**
  - **Dec 30 – Jan 30 - Actions from Tuesday PMT crack tiger team meetings in chronological order**
- **An now dated premature look at some options and decisions to consider**
- **The dated beginnings of a what we know list and top level draft Fault/Decision Tree on Dec 16**

**Note/disclaimer – This started as a way for me to track what we were doing and our thinking at the time and as a place to summarize preliminary results and options so is not as formal as one might expect**

## **Updated near term plan of attack summary.**

The following paths will be pursued in parallel.

1. Continue to push to make better technical contact with Hamamatsu. In addition to their initial response, suggestions, and their input on whether these glass flaws were normal in past flight and other parts, it was recommended we specifically ask if there is any testing or information they have that could help us more and that we forward to them as much as we know on the test results as possible. We should also try to attempt a telecon of some kind if language and communication issues can be worked out. If response from Hamamatsu is not forthcoming within the next day consider asking higher ups to help. Hamamatsu will obviously be even more critical if we eventually decide new PMTs with an altered process is our best route. It will take a great deal of cooperation to get such an option to work rapidly and effectively.

2A. Decide what it takes to determine if the PMTs we have are reliable enough to be flyable. This will probably require a set of tests and analysis that a team will have to craft. The help of the materials branch, particularly Mr. Leidecker and Mr He, will be of great importance (they have already been very helpful). It was suggested that some proposed initial tests be postponed briefly until we can get more people to help develop a more complete overall approach. This approach work is already underway with agreed to investigations into residual stress in the PMTs , flight PMT inspections and flaw measurement underway. When it is more developed, this path must be spelled out in a more communicable way.

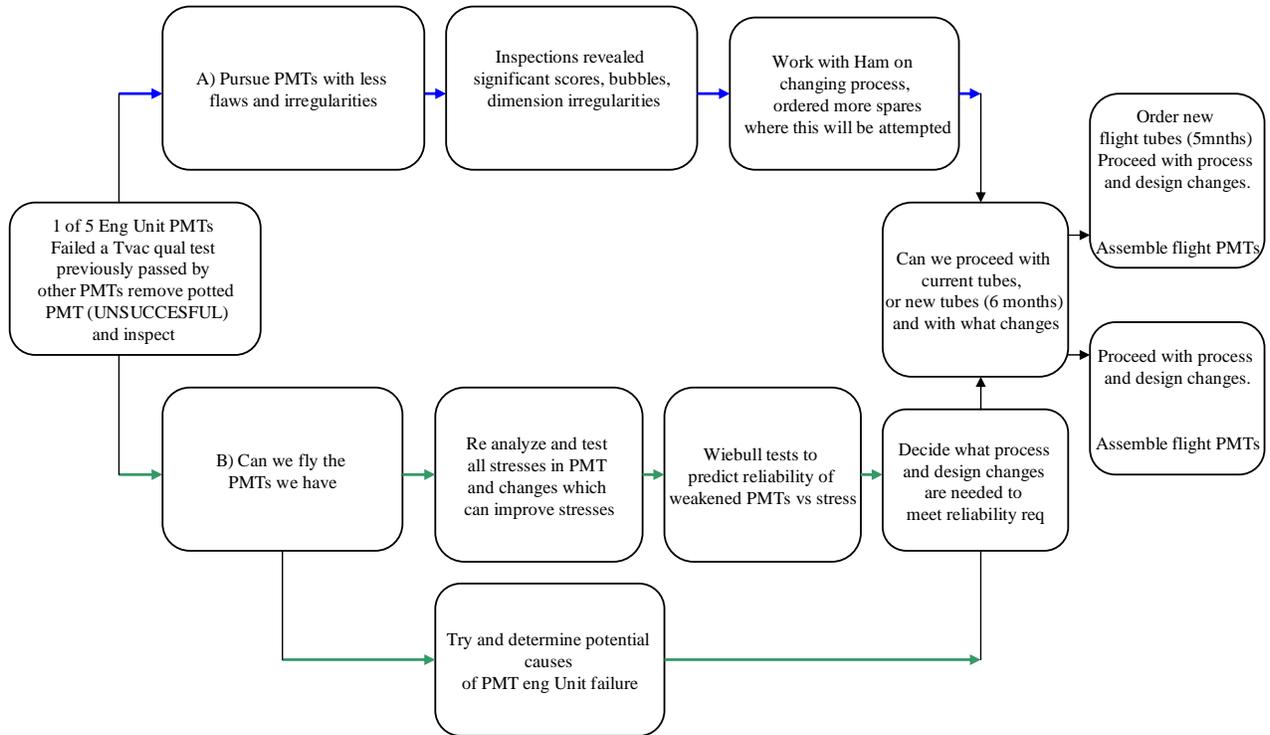
2B. Increase fidelity of PMT glass stress analysis and investigate PMT housing modifications that reduce or eliminate stress on the PMTs. The Path 2 solution will probably require this analysis and redesign and or process changes to reduce risk.

Top level flow shown below

## PMT Weakness Issue Testing and Modification Flow - proposed

R3 - Michael Amato 1/8/04

Note : Blue, Red and Green arrows are parallel paths



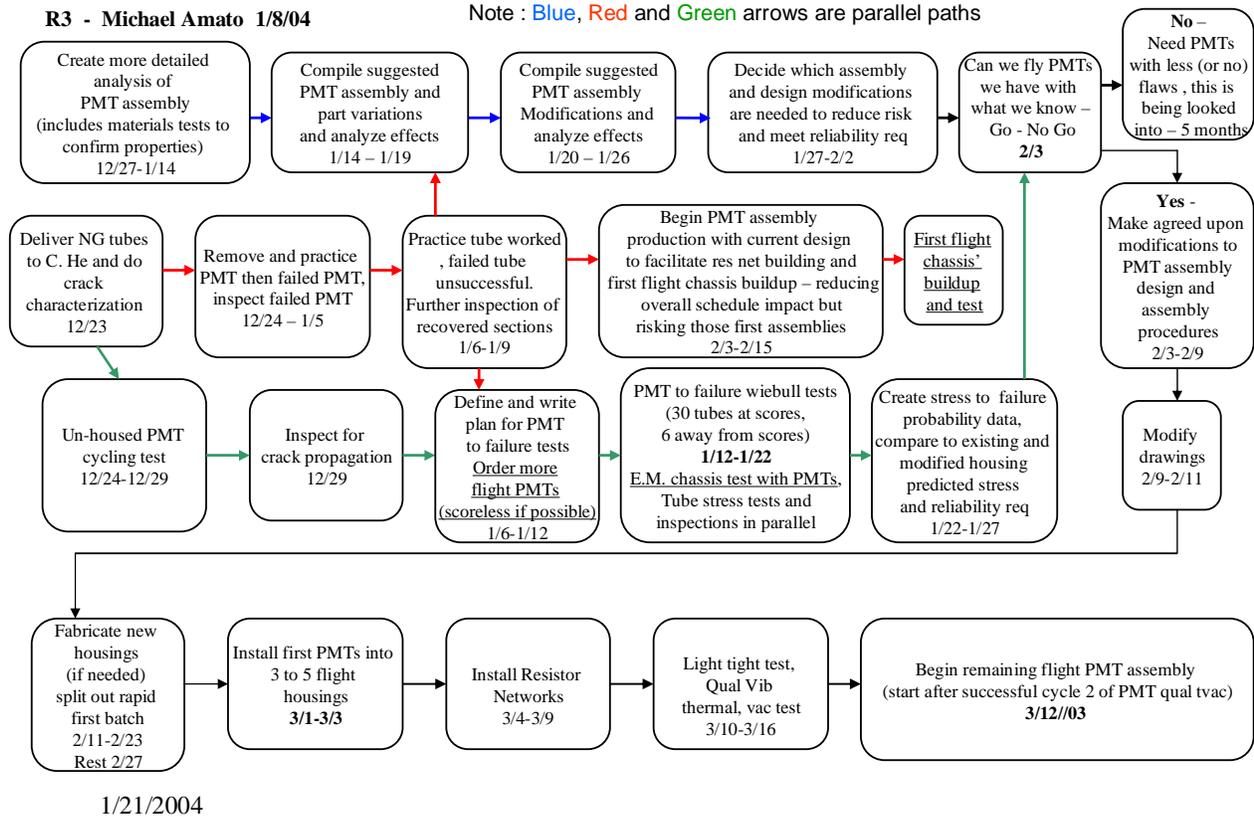
1/21/2004

Below - A more detailed flow and dates

## PMT Weakness Issue Basic Top Level Paths

**R3 - Michael Amato 1/8/04**

Note : Blue, Red and Green arrows are parallel paths



See separate test matrix for Plan 2A current design and process analysis case matrix and for Plan 2B redesign analysis matrix

## TEST SUMMARY

### Summary of events in Thermal Vac test where failure occurred on Friday December 5

The following is a summary of the thermal vacuum testing up to the time of the failure:

\* 5 PMT assemblies were mounted face-up in a mounting of flight design. A small button of plastic scintillator with an embedded Am-241 source was placed on the face of each PMT (to provide a simple calibration signal), and a light-tight cap was placed over each tube face.

\* All 5 PMTs were tested and found to be operating normally at room temperature (~22C) before the vacuum chamber was closed.

\* The high voltage was turned off during the initial pump-down; it remained off during a vacuum warm soak (40C), and during the subsequent cool-down to ~25C.

\* With the temperature at ~25C and the chamber pressure <1E-5 torr, the high voltage was turned on at 500 V, and each PMT output was examined for evidence of sparking or corona. No sparking or corona was found.

\* The high voltage was increased in steps of 100 V, checking each PMT signal at each step.

\* All five PMTs operated normally up to high voltage of 1200 V, at which point the higher-gain tubes began to show clear evidence for limiting. A rough computation of the average anode current indicated that the anode current was comparable to that in the resistive divider (~1 microamp), so the limiting was to be expected.

\* At high voltage of 1300 V (~1210 V on the PMTs), all PMTs were limiting, but there was still no evidence for sparking or corona.

\* The high voltage was reduced to 900 V, and an overnight transition to -30C was initiated. Based on previous (and also subsequent) experience, the transition to -30C took ~10 hours.

\* The following morning, with the temperature stabilized at -30C and chamber pressure still <1E-5 torr, four of the five PMTs showed normal operation, but AA0046 gave no output signal at any voltage up to 1300 V.

\* We assumed that the failure of AA0046 was in its coax connection through the chamber wall. Therefore we continued the test to see if it recovered when the temperature was raised. With the high voltage set to 900 V (and chamber pressure still <1E-5 torr), the temperature was raised to 40 C over a time interval of ~6 hours.

\* At 40C, the other four PMTs were still operating normally, but AA0046 had not recovered.

\* The temperature was reduced to ~25C. The other four PMTs were still operating normally, but AA0046 had not recovered.

The high voltage was turned off, and the vacuum chamber was back-filled with room air. The AA0046 assembly was removed from its mounting and examined. It was determined that the cathode was gone. Upon viewing with a microscope, it was found that there was a crack in its face, with length roughly 1/4 of the diameter.

At the present time, we do not know the reason for the crack in the face of AA0046. It is being examined for possible visible glass faults.

### **Proposed actions on December 8**

1. Materials has taken the PMT and WOA to building 30 and will perform a non-destructive inspection analysis.

2. Materials will contact Unger when the analysis is complete
3. Contact QA
4. Get Modified the WOA
5. QA (Fowler) was originally asked to inspect in building 2 but was not available. Therefore, QA should go to building 30 to inspect the PMT
6. A follow-up meeting will be held to review the Materials analysis
7. ACD wants to revisit the thermal and mechanical analysis that the mechanical subsystem created. Ken, can we meet to revisit and discuss the analysis tomorrow AM?
8. Enter a PFR
9. Contact Hartman and then Hammamatsu to discuss them inspecting the PMT. If so , we'll resolve all logistical issue.
10. The remaining PMTs in TVAC will complete the testing as planned. However, on the last cold cycle, the PMTs will be taken as cold as possible (the chamber can't go much colder than -30 C)
11. Amato has suggested that we consider doing mechanical (i.e. glass) inspections on the PMT prior to assembly
12. Review thermal stress analysis report. Determine if more detailed analysis is possible and useful
13. From Johnson, Amato - Seriously consider put all remaining PMT's through Thermal Testing (ideally in TVAC but may not have to be, do we man all remaining PMTs which are in housings or do we mean ALL?). Additionally a group of these (say 5 plus a few tubes not in a housing) should be subjected to more extreme temperatures (as cold as -50C for housed tubes colder for bare tubes) to determine how much (if any) temperature margin exists.

## **December 8 Action Results**

*Actions 1. thru 3 and 6* - All items complete. Initial inspection reveals a crack half way across the face around the PMT window and tube interface and some distance down the tube (can't tell how far). Crack appears to breach the surface at the window to tube interface. Inspection also reveals the following concerns about this PMTs glass. Thousands of bubbles in glass at window to tube interface. Likely due to water vapor in imperfections on tube edge when window is sealed on. Contamination just below the window tube interface. A few orange foreign objects in the glass at the window tube interface. A sharp transition at the top of the chamfer in the window tube interface that is susceptible to damage. It was also noted by material branch that soldering heat was an unlikely source of any damage at the lead glass interface (metal is long thin and does not conduct well). However movement of the leads, which we do, can cause micro cracking. We have not been able to inspect this region yet. Materials glued old failed PMT back together and concluded crack started from middle of tube just above vice marks in glass.

*Actions 4 and 5* - Complete

*Action 7* - Requested from Sheila. Ken has asked that we wait before asking her to recommend how the analysis might be done in more detail. Summary Received on December 11. The simplified 2-D model shows a safety factor of 1.87 which is probably actually higher. Analysis does not attempt to determine stresses in window or transition to window.

*Actions 8 and 9* - complete no feed back from Ham. yet as of COB December 10

*Action 10* - Complete, chamber went done to -40c on last cycle. Remaining PMTs passed aliveness test, even in atmosphere. Recommend visual and more detailed functional to confirm they are in perfect working order

*Action 11 thru 13* - still under consideration

## **December 9 and 10 additional action items**

14. Recommend visual and more detailed functional of 4 remaining PMTs from TVAC test to confirm they are in perfect working order
15. Get failed PMT bonding assembly to materials to test Dremel cutting and Acetone PMT removal technique
16. Get final agreement to cut out PMT 46 from housing and further inspection. This may prevent us from sending ti to Ham for further testing which might tell us more on why it died even with a crack in vac.
17. Get materials a flight PMT to inspect for flaws seen in PMT 0046 and for any damage around leads. This was done in Wednesday night but He levels in bldg 30 complicating effort. PMT may be removed over night and brought back.
18. Find out why PMT might have failed even in vac
19. Expand item 11 from Dec 8 action list to include inspection of all lead glass interfaces for damage. We already have handled all flight PMTs to remove commercial base and test
20. Consider Re writing handling procedure to prevent any contact with hard surfaces and assembly procedure to prevent lead motion at base.

## **Results from December 9 and 10 actions**

Action 14. - PMTs still in chamber because of potential very low level source contamination from sources used in test

Action 15 - Started but stopped in favor of TOLUENE soak at no more than 40C (we know the PMT is failed but this wil test this approach for future use where 40C would be limit). Soak has less risk of further damage to PMT we decided.

Action 16 - Decided to remove PMT here probably using TOLUENE soak if it is successful in removing test unit. May start over the weekend if test is finished by Friday. Check with Material Friday afternoon to decide to soak over weekend.

Action 17 - Flight PMT revealed some bubbles in glass. Not known if as many as Cal units because a more serious flaw was discovered. This flaw is a score along the inside of the tube all the way up almost certainly due to flex lead riding up tube during PMT internal electronics insertion. The broken PMT (46) was inspected and the visible part of the crack is at the same orientation as the score would be on that tube. The first failed tube that underwent excess clamping force was also inspected to check

for the score. It was there and the crack in that PMT originated from the score. Removal of the housing will tell if PMT 46 failed at the score or not.

Action 18 – No info from Hamamatsu yet on this or in general from actions 8 and 9. Reluctant to bypass US sales subsidiary but have no response of any kind yet. Our best guess is that vac in tvac chamber is just enough higher than perfect vac that it caused failure. Open question is if this kind of failure is immediate calling into question whether we really know what temp the crack breached the surface

Action 19 - This and item 11 (glass flaw inspection of all flight PMTs is still under consideration) We would have to define what size flaw could be detected under microscope and , how much manpower this would take and if this was a good enough inspection.

Action 20 - Under consideration but increased handling concern was verbally mentioned to C. H. and R.R. for their input

Figures of 'score' flaws below

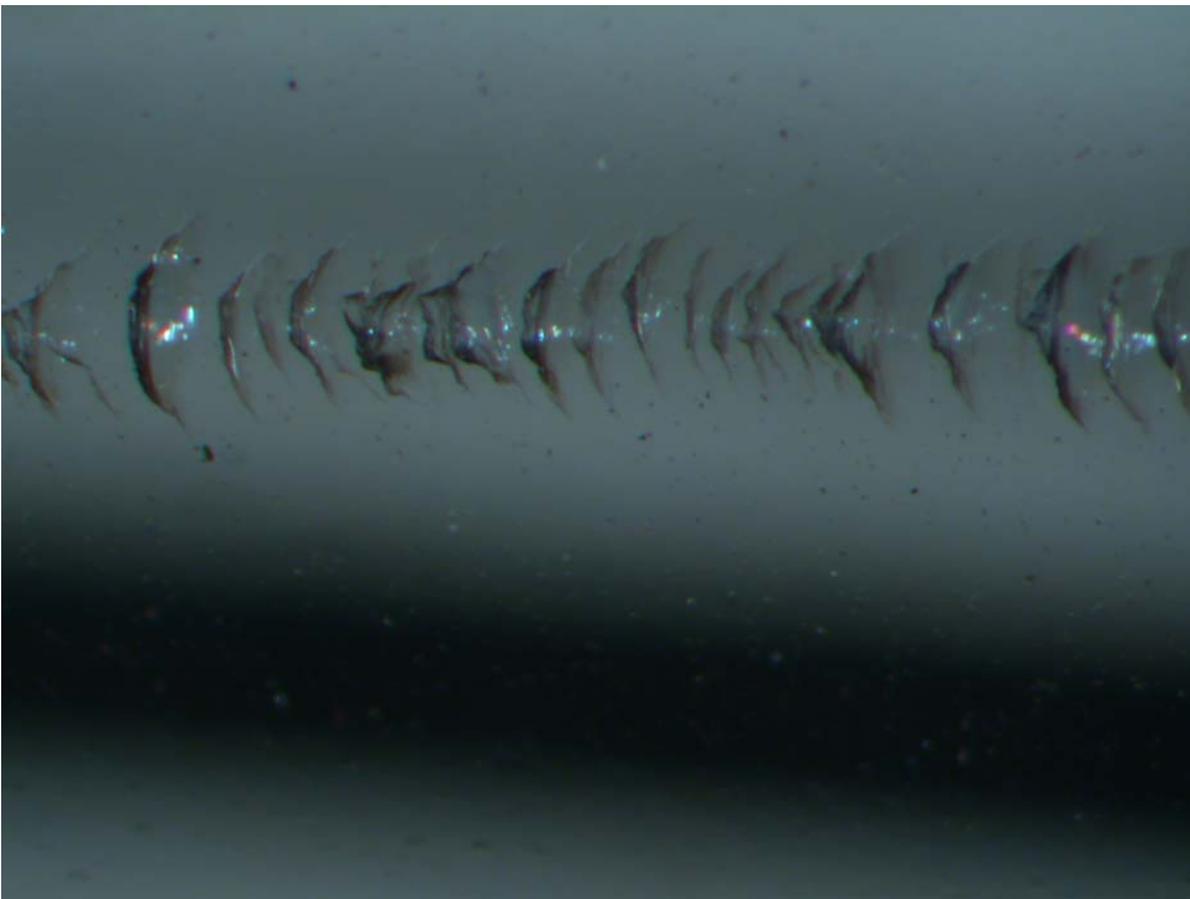




Figure of less serious 'bubble field' at tube to window interface



### **Action items from December 11, 2003**

21. Bring 5 additional flight PMTs to materials to see if those also have the tube 'score'. Possibly measure average or select few score dimensions so they can possibly be re-measured after some proposed thermal tests.
22. Run additional 5 flight PMT tubes not in housing and a few non-flight PMTs already in a housing (possibly the 4 surviving TVAC PMTs if radiation issue gets us access to them) through many thermal cycles (10-20?). Inspect flight PMTs. The idea here is that if we can visibly measure crack or flaw growth after these cycles for the PMTs not in a mount and therefore not under additional stress from housing then the current batch of 240 PMTs is not flyable. The tubes in a housing can be removed after test with TOLUENE soak and the flaws measured for growth compared to average numbers in precycled inspected units assuming a good average can be obtained. If they show growth, then at a minimum current housings can not be flown with these PMTs and new housing design could be considered (quasi-kinematic mount or matched CTE material) if that risk was even deemed acceptable.

### **December 11 action results**

*Action 21* – All 5 flight PMT tubes brought to materials have 4 scores along the inside of the tube almost certainly caused by the pressure tabs during insertion of the tube inside components. The scores might average ~80? microns in length and ~50? microns in apart. The depth into the glass is not measurable but past experience might suggest they could be approximately half the length or ~40? Microns. Some additional minor features were noticed on one of the tubes. Some particulate metallic contamination was noticed inside the tube. Hamamatsu specs do allow some metallic contamination if they are under a certain size. The inspection specs also allow for the ‘bubbles’ that are observed in the window to tube interface as long as they are under a certain size. There is some question on how they inspected the thousands of bubbles in each tube. Materials speculated that these tubes could well have very humid air in them which greatly accelerates crack propagation. However the bubbles are still thought to be a much smaller risk when compared to the scores. It appears from testing of an earlier PMT fragment that the PMTs do have built in internal stress fields, but another test may be necessary to get more information.

*Action 22* – This un-housed accelerated thermal cycle test to check for visible flaw or crack propagation growth has been delayed until we know it will give useful data.

## **Dec 16 Initial Hamamatsu response summary**

More here soon but initial response says the scores are part of the process, the high pressure is needed to hold the inside of the tubes in place and these tubes handle excessive conditions in their old rig form. They are confident that the design and process is Ok. They seem willing to help us and asked for drawings and a mount.

## **December 16 actions**

*Action 23* – Provide materials with a sacrificial Cal or NG PMT to allow a cross section test looking for internal stresses.

*Action 24* – Materials to provide ACD with a list of questions they would like to ask Hamamatsu so we can have a complete list.

*Action 25* – Materials will define a set of tests to help us answer the central question to attack plan 2. Can we fly the PMTs we have? With the flaws in the glass it is possible for PMTs to fail over a wide range of stresses, stress cycles and time after stress. It was determined that to really answer this question the best approach so far is to create our own Weibull distribution curve for failures of our PMTs. This would involve testing a statistically significant number of our PMTs (~30) through a simulated I&T and total flight stress exposure. Two tests might be required one for instant failures and one to predict failures over time after stress. These tests would tell us the probability of failure for our remaining PMTs. This would sacrifice up to 60 PMTs many of which would be flight tubes. We could then compare that to our requirement over the 5 year min lifetime. It was suggested we explore pushing that requirement to its extreme for getting useful science in case we get probability answers which don't meet our current requirement. This would be similar to the exercise we went through after CDR when our micrometeoroid shield did not appear to be able to meet the detector protection requirement within its other constraints. Still curious if the PMTs can survive in space if it cracks in space once the surrounding vacuum is good enough. This might enable us to test through less lifetime.

Action 26 - Consider initializing a procurement of additional PMTs under the assumption that either A. Ham can change their process and get us 'scoreless' PMTs but we have to pay for all or some of them or B. we have to find a way to fly the PMTs we have but that many get sacrificed in testing to determine reliability necessitating more to be purchased. The procurement could be canceled late in the game if things change but these are 6 to 9 month lead time items and procurement has not exactly been rapid lately

## **Dec 30 – Jan 30 - Actions from Tuesday PMT crack tiger team meetings in chronological order**

**1/6/04**

\* The thermal shock test run on 5 unhooused tubes (30 cycles) resulted in no measurable crack growth. This may give us some evidence that internal stresses combined with worst case thermal cycles do not propagate existing cracks rapidly.

\* The failed engineering model tube did not make it out of the removal process in tact despite the fact the practice tube did. The surprise is that it does not appear the crack initiated at one of the main score lines. Charles will inspect further to see if any initiation points can be discovered or other flaws outside the main scores could have been the cause, but direct evidence of cause will be difficult. It was proposed uneven stresses from the tube diameter variances, centering errors etc could be contributing.

\* What tests to run to gain failure probability data from the score and now away from the score were discussed and deferred to a splinter meeting (which occurred thursday, its rather complicated but I think we now have a reasonable plan on this)

\* A basic analysis of Hamamatsu pressure test (1 of 5 failed at 50 atm) shows the one tube may have failed at lower pressure than expected. Materials branch theorized thickness variance could have cause local tension.

\* Temper and annealing questions were forwarded to Hamamatsu with ambiguous results. In house investigation into tube internal stresses will continue. A tube was provided for this.

\* A much more detailed analysis of stresses on the existing mount and design were initiated (Kevin and Len). We must understand these stresses and the effects on these stresses due to tube and assembly variances.

\* We could not accurately determine if the failed tube was off center in any way but there is some evidence that the 'practice tube was. There may also be evidence the Mu metal was not always staying perfectly flush to the tube.

\* Steve and materials branch will get more accurate materials properties (uralane, Mu metal, Mu metal tape, tube glass etc..) for analysis. The potting material is of particular interest. tube glass thickness and diameter variances will be measured.

\* Charles will inspect windows of already installed electronics chassis engineering unit to double check for evidence of any cracks. The chassis will go into env testing next week.

\* Chuck, Paul, Russ Steve and Ken will look into proposed process and handling changes to reduce damage risk and to improve possible unsymmetries in stress (centering, eliminate Mu metal overlap or move Mu metal to inside of tube, PMT coating to replace Mu metal and coating to reduce He etc..).

\* A very initial list of initial design and process modification ideas to address some of the potential risks was generated and will be included in a future email.

## 1/13/04

So far no additional information from the broken PMT. Charles will do additional continue inspections. (Charles)

Wiebull testing set up designed, a few needed parts being fabbed, Charles to write a brief test plan. 7 NG tubes were delivered to Charles. We have 5 more, 50 more have been ordered but may not be in until Jan 26. (Charles, Len)

Analysis initial model complete, starting to run and to tweek materials properties in preparation for investigating variables in the matrix (Kevin, Steve, Len)

Materials testing and investigation to confirm material properties for above analysis not complete yet, will continue

Tests will be conducted on cross sections and a tube with ends cut off in indexing fluid to try and determine internal stresses in tubes as delivered. Tempering question never answered really by Hamamatsu (Henning, Walt etc..)

Decided we will need to inspect all flight tubes for additional glass flaws we may have caused (or Ham) since production. Need to write a brief inspection process. (charles)  
Continue to pursue tube, tube mount and failure data on SOHO and IMP (Dave, Pilar)

We will try and jumpstart implementation and practice runs of proposed assembly process changes.

We have ordered 30 more flight tubes with an option of more, Ham has changed course and agreed to try and make them with less scoring via a sleeve process. 5 mnths min

Some flight tubes assembly will resume feb 3 to allow testing of the first flight chassis. Some process and handling changes might be used in that production. There is no guarantee those will flyable.

An draft flow chart and a draft update of our main paths was handed out

A table was created that lists the assembly process and design issues and mods we will analyze for stress sensitivity.

## 1/20/04

Further inspection of failed tube did not reveal additional information on crack initiation or cause. Charles wants Henning and/or Walt to also inspect.

The Wiebull testing set up parts were not yet back in from the shop. When they are Charles will test the set up on some blank glass tubes, write up a test plan with set up specifics this week. If all is well with the test plan, he will commence testing on the 7 NG tubes we have. We expect additional NG tubes Tuesday from Japan.

Material tests nearly complete. Some questions on ability to test for Poisons ration or whether we will run with our assumptions and analyze for sensitivity to changes.

Henning and Pilar will ask the Materials branch to try and set up and run a strain test on a tube. They will need a potted tube for this. can we pot a tube, do we have any we dont need?

Kevin discussed preliminary results on the stress cases he could get to so far. Interesting PRELIMINARY results that, if they hold up, may show higher stresses than anticipated at the Mu metal overlap. Separate meeting reviewed Kevins model and analysis details and added some actions regarding the model.

**Some options to consider** 12/03 (even thought its to soon to draw any firm conclusions ) - So far there are three main paths one could take depending on what we learn in the next week.

A. Have Hammamatsu redesign the process if they are willing and order a new batch which will not arrive before 6 or more months

B. Inspect all flight PMTs to ascertain frequency of score, bubble, contamination, handling damage and lead handling damage. Try to mitigate the some of the additional risk on our current PMTs if that's even feasible, make those changes and move forward with the remaining increased risk. This might really be a project issue. The level of redesign depends on the risk mitigation we eventually deem necessary, at a minimum it requires redesign of the PMT housings but it is not clear if this is enough.

C. Redesign to use another manufacturers PMT. Most other PMt options are much larger and can introduce new risks like faster degradation rates.

Thinking ahead - Since it now seems possible we might have to order new PMTs, consider if we can assemble current instrument with one rail of current PMTs (so we only use that many flight resistor networks) to test all chassis and detectors. Redesign resistor network housings for quicker removal from chassis. With a minimum 6 month lead time plus process redesign time at Hamamatsu this might allow us to install the new PMTs just before ACD calibration and environmental testing at proto flight levels. Is this a possible path if its deemed necessary.

The other main option is to try and mitigate the risk with a redesign of the PMT housing with a quasi-kinematic PMT mount or out of a material with the CTE almost the same as glass. At this point the current flight PMTs seem to pose additional risk. This would require redesign work and would require us to at least try and quantify the additional risk and reliability hit by further testing.

By the way going to other more reliable PMTs that are larger or adding more spare PMTs to mitigate the risk requires the kind of redesign that would delay us longer than six months and seems to be only the option of last resort.

### **The beginnings of a top level draft Fault/Decision Tree - 12/03**

*What we know on Dec 12*

December 8

One of 5 Eng Unit PMTs in latest TVAC test failed to function on the first cold cycle at -30C . We know it functioned at -25C

December 9

Eng Unit PMTs have 3 or 4 imperfections in the glass

PMTs could be susceptible to lead glass damage due to motion at leads and to easy damage at the sharp edge at top of window tube transition based on past materials group experience

4 PMTs a year ago survived 3 cycles to -30C and a final cold cycle to -38 C

December 10

The remaining PMTs in this thermal vac survived 3 cycles to -30C and a final cold cycle to -40C

December 11

Flight PMTs have at least some bubbles in glass in window transition, a more serious flaw has been discovered upon inspection. This flaw is a score along the inside of the tube all the way up almost certainly due to flex lead riding up tube during PMT internal electronics insertion. The broken PMT (46) was inspected and the visible part of the crack is at the same orientation as the score would be on that tube. The first failed tube that underwent excess clamping force was also inspected to check for the score. It was there and the crack in that PMT originated from the score. This does not prove the failure originated at the score, we will need to remove the PMT successfully possibly prove that

**Very early draft top level Fault/DecisionTree – next page**

