ACD Phototube Breakage Issue

Summary of the Problem

Following a series of phototube failures (breakage at low temperature) in January, 2004, the mounting for the tubes was changed, reducing stress on the tube by nearly a factor of 10. The new mounting design was qualified with a set of 9 tubes down to temperatures of -40 C (-60 C for some) with no breakage. All tubes were visually inspected and graded. The new design was put into production. 100 of our 240 phototubes were potted into mechanical mounts (194 are needed for flight).

On July 2, 2004, two out of five tubes subjected to a single thermal cycle down to -30 C broke. Both tubes were “fair” quality. A “good” tube and a “worst” tube in the same test survived.

On that same day, a 12-cycle test (to -30 C) of 11 “worst” tubes had 2 break. After 30 cycles, no additional tubes had broken.

On July 9, a set of 25 “worst” tubes was carefully temperature cycled with checks at different temperatures for breakage. Four tubes broke at -15 C; one tube broke at -30 C.

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Outline of How We Attack the Problem

Three parallel paths:

1. Find the root cause. What went wrong? Why did our qualification program miss the problem?
2. Find a better mounting approach. Correct or avoid whatever went wrong and apply this method to the remaining tubes.
3. Find a way to use the flawed tubes we have. Mitigate or repair the problem for the tubes that are already in housings.

Find the Root Cause

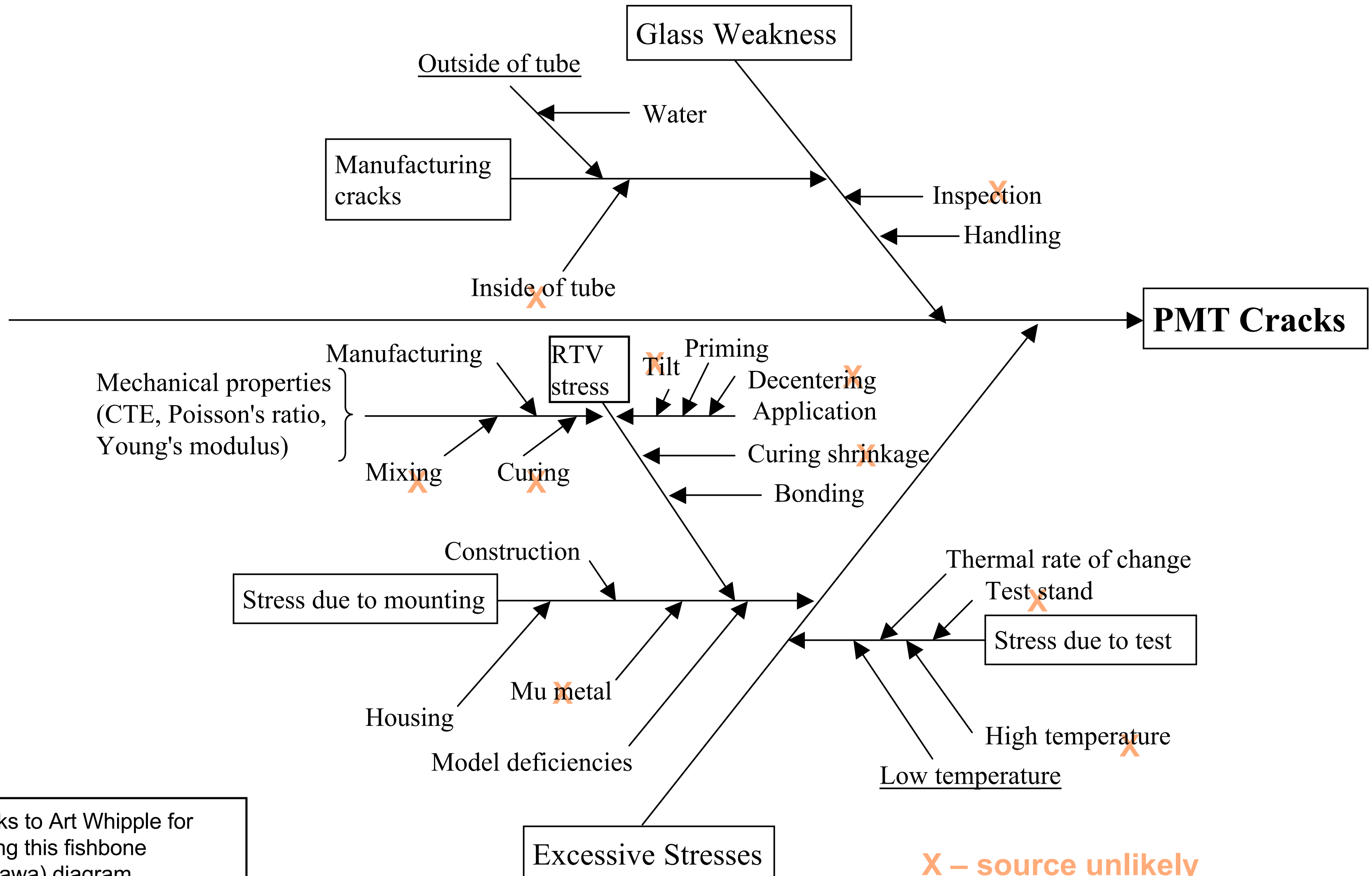
Cause outline – how did we pass the original qualification of the new design but fail the follow-on tests? Summary of possibilities:

- **A. The Stresses Increased –**
  - –RTV material properties changed
    - •Test new batches for CTE, modulus, Poisson's ration
    - •Develop new test to more accurately confirm early poisons ratio tests and data sources
    - •Retest old batch if possible for CTE, Poisson's ratio, modulus
    - •Compare test results with old test results, data sources and assumptions
    - •Use strain gauge tests to test for strain differences between old and new PMT batches and to correlate stress model
  - –PMTs that failed were unusual – diameter and glass thickness vary between tubes
    - •Look at new centering step data for diameters
  - –Less likely causes we must still disprove – large bubbles in RTV causing stress concentrations, Thermal vac chambers in error and we actually went much colder, etc

- **B. The photo-multiplier tubes became weaker over time –**
  - –Exposure to moisture over time has propagated glass flaws or made flaws much easier to propagate at lower stresses
  - –Handling - very unlikely with new handling procedure
  - –Is there any test of bare PMTs that could help see a weakening?

- **C. The stress analysis and /or assumptions were flawed AND we were lucky on what were demanding qualification tests**
  - –RTV properties and property tests were wrong to begin with – compare results of first bullet of A above
  - –Hard to understand how 5 tubes could go to multiple cycles at -60C and 4 tubes could go to -40C without failure. Used as controls but none have failed yet. Retest with very low temperature test. Test 7 PMTs potted with old RTV batches but never cycled.
  - –Review stress model again. Devise and use strain gauge tests mentioned in bullet 1 of A above to correlate model. Add non-linear ability to model.

Fishbone Diagram – Possible Sources of the Problem



Thanks to Art Whipple for starting this fishbone (Ishikawa) diagram.

X – source unlikely

Known contributors <u>underlined</u>.

PMT Solution Paths – Potted and New Tubes

- **Modified Potting Solution** – ***understand the new variables and stresses in the potting materials***
  - –RTV or more likely an alternate
  - –Must understand exactly how the latest PMTs failed
  - –Slit-potted design. May even be able to do this to already potted PMTs
  - –Removal methods for already potted PMTs

- **Thermal control solution** – ***don't let the PMTs see the stress of lower temperatures.***
  - –Heaters to -5 or 0C, Must determine via test what is warm enough
  - –Allows us to fly PMTs that have already been potted

- **Mechanical solution** – ***get out of the potting business since it looks like the material properties vary too much for these flawed tubes.***
  - –Partial CTE compensation design. Uses modified existing housings with inserts, does still add some stress but mostly compressive
  - –Quasi kinematic mounts. Various forms. Simple versions may be able to use existing housings with inserts
  - –Bonding release designs. Releases bonding on one side, grooved housings keep PMT from slipping

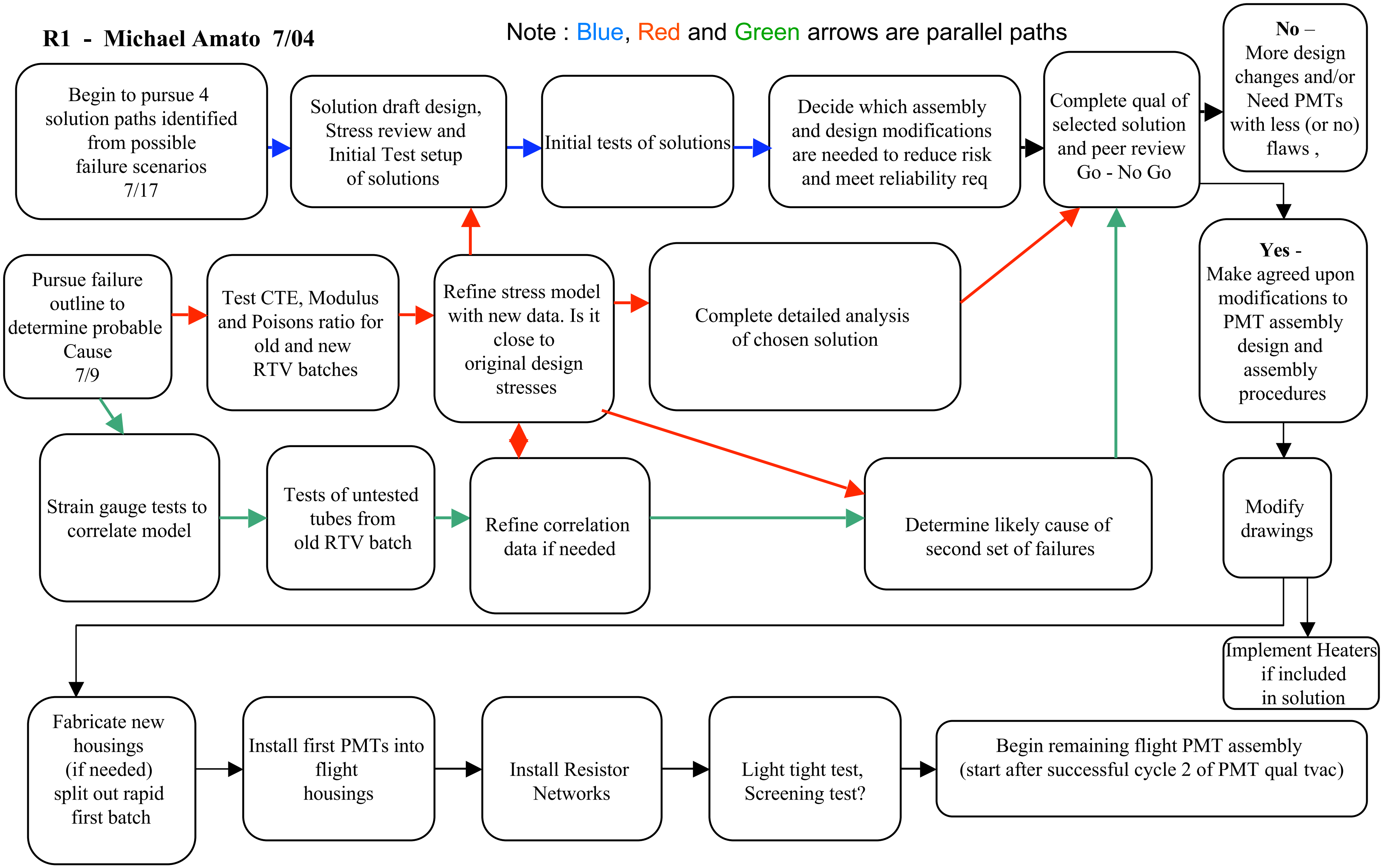
- **Determining Yield in current design** – ***see if there is a screening test that stresses the PMTs in a way that identifies almost all the PMTs that will fail without consuming lifetime of the PMTs that pass or making them more likely to fail.***
  - –Probably have to screen and partial life test large number of PMTs (which may be tough to then use as flight) to show it could work.

- **Any combination of above with new PMTs** ***without so many glass flaws***
  - –First 6 units with modified Hamamatsu process are not flawless but are all dramatically better than any of the original tubes we have

PMT Weakness Issue Basic Top Level Paths - The sequel

R1 - Michael Amato 7/04

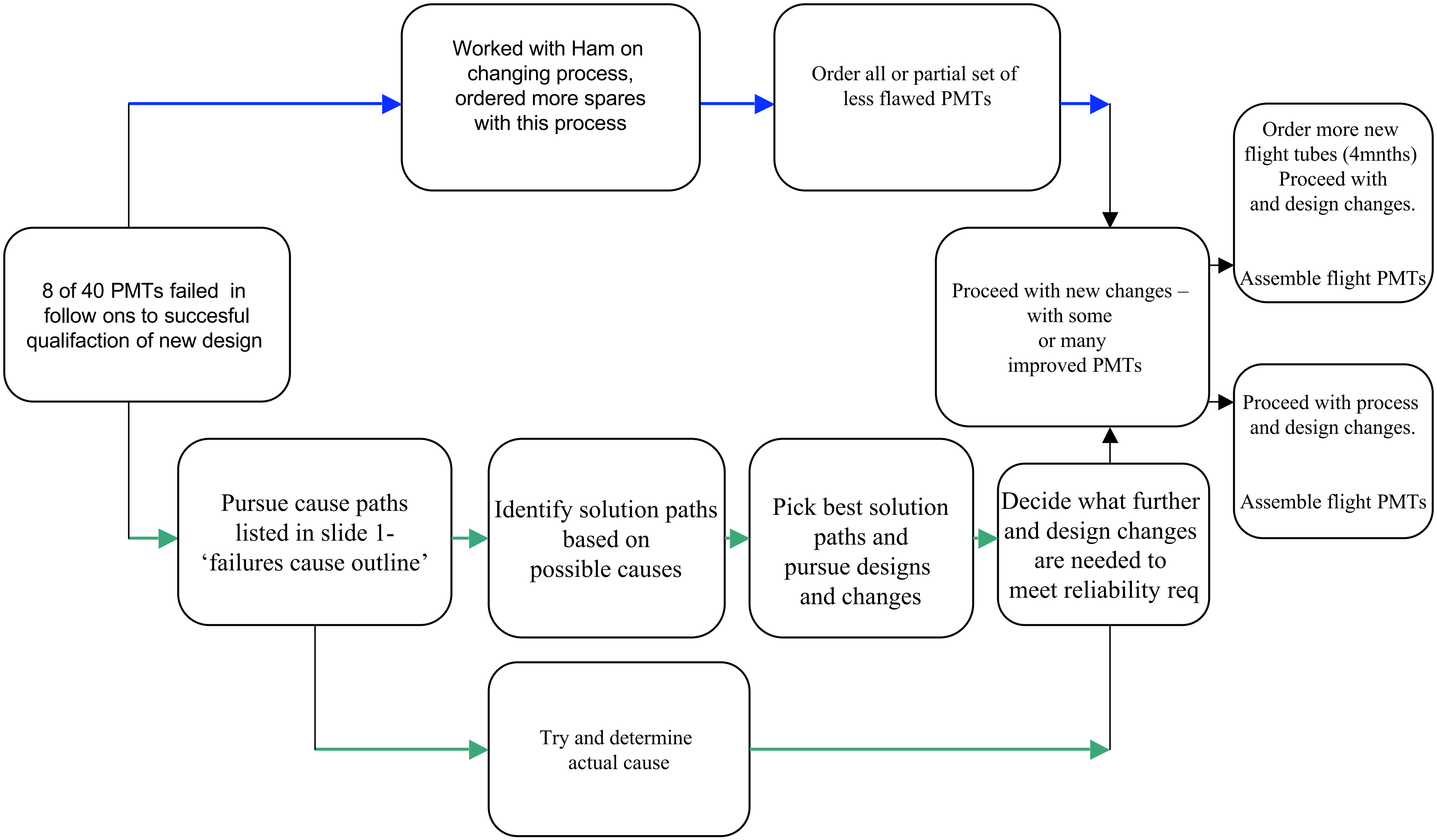
Note : Blue, Red and Green arrows are parallel paths

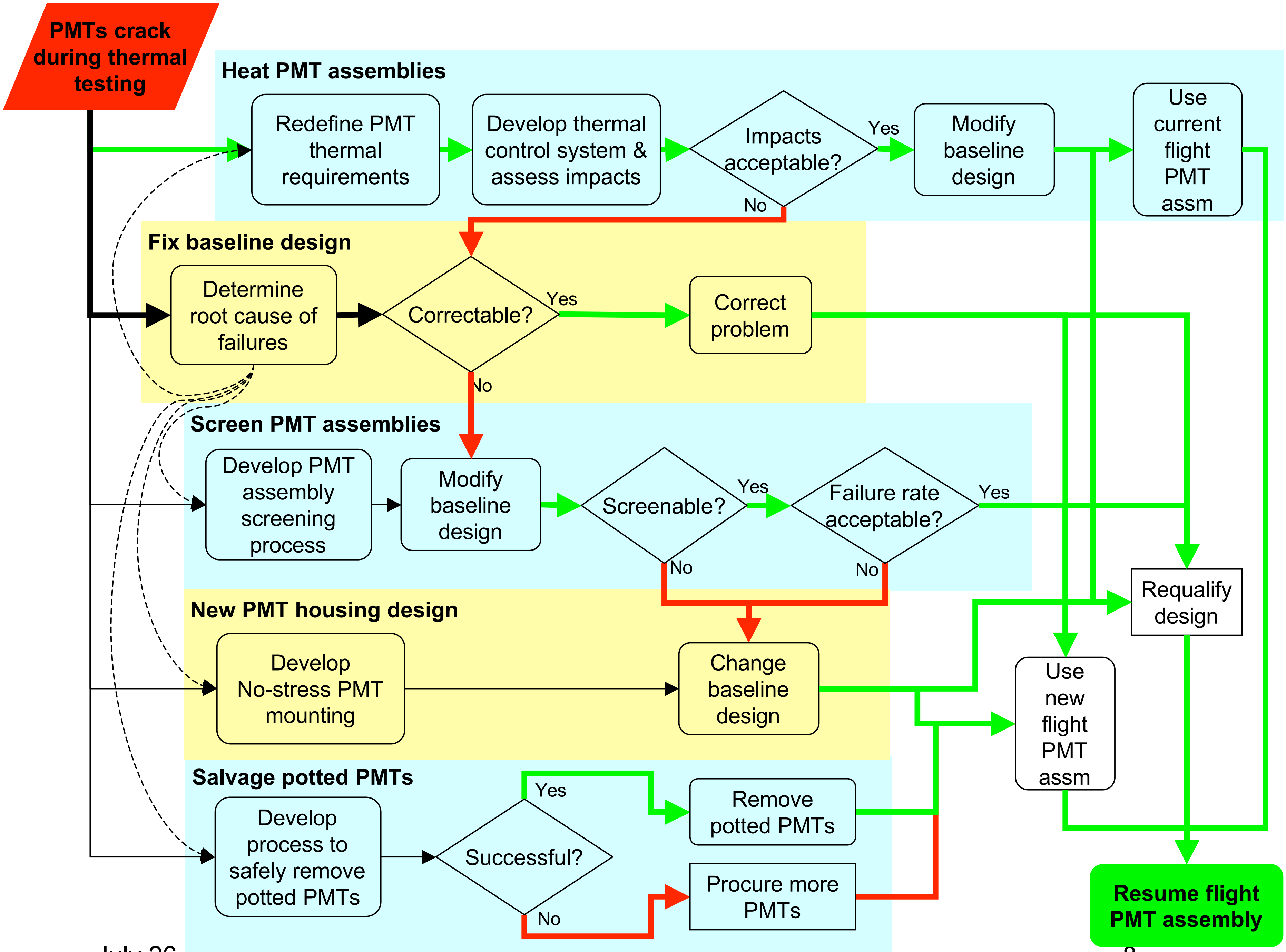


PMT Weakness Issue Testing and Modification Flow - draft

R1 - Michael Amato 7/04

Note : Blue, Red and Green arrows are parallel paths





PMTs crack during thermal testing
Heat PMT assemblies
Redefine PMT thermal requirements
Develop thermal control system & assess impacts
Impacts acceptable?
Yes
No
Modify baseline design
Use current flight PMT assm
Fix baseline design
Determine root cause of failures
Correctable?
Yes
No
Correct problem
Screen PMT assemblies
Develop PMT assembly screening process
Modify baseline design
Screenable?
Yes
No
Failure rate acceptable?
Yes
No
Requalify design
New PMT housing design
Develop No-stress PMT mounting
Change baseline design
Use new flight PMT assm
Salvage potted PMTs
Develop process to safely remove potted PMTs
Successful?
Yes
No
Remove potted PMTs
Procure more PMTs
Resume flight PMT assembly

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Why Don’t We Just Build and Test Several New Designs?

In light of the potential cost and schedule impact, an obvious question is why we don’t just try some of the many ideas that have been suggested to solve the problem.

The difficulty is that glass breakage is a probabilistic, not deterministic, failure. Two seemingly-identical glass items will break under different conditions. Some of the original tubes using a high-stress mounting survived all tests, for example. A single sample provides essentially no information. Qualification of a design requires a statistical sample.

Similarly, analysis provides only a probability of failure, not an absolute value of where a tube will fail.

We have a limited supply of these Hamamatsu phototubes. They are not off-the-shelf items but have a lead time of about 4 months and a unit cost of about $1700. Every tube we commit to a test reduces our supply, which is already marginal in terms of spares. We have 50 additional tubes on order, but 100 tubes have already been mounted using the current design.

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Summary

- Despite our qualification program, the method for potting ACD phototubes into housings is still producing breakage of tubes at low temperatures.
- The number of possible causes of this problem is limited, but no one possibility stands out as most likely. We are investigating all possibilities through a combination of analysis and test.
- Four candidate solution paths have been identified for improving the mounting scheme for new tubes and making the already-potted tubes useable for the ACD. Design studies are in progress, but we need more information about cause before selecting one or more approaches for testing.

PMT Action Item List

1	Perform CTE meas on RTV-566 (multiple lots)	P. Joy	9-Jul	COMPLETE
2	Strain gage thermal test on Al housings	M. Viens	7/13/2004	COMPLETE
3	Develop heater concept	M. Amato	7/15/2004	COMPLETE
4	Extract and inspect failed PMTs	C. He	7/15/2004	COMPLETE
5	CTE measurements on additional RTV samples	P. Joy	7/17/04	COMPLETE
6	Remove good PMT from housing	C. He	7/26/04	COMPLETE
7	Perform modulus and poissons measuremnts on multiple RTV samples	C. He	7/26/04	
8	New mounting design	S. Schmidt	7/16/04	COMPLETE
9	Fab parts for new design	Lee N.	7/19/04	COMPLETE
10	Assemble new design	Paul H.	7/21/2004	COMPLETE
11	Instrument new design with strain gages	S. Schmidt	7/23/2004	COMPLETE
12	Thermal test new design along with 7 uncycled PMTs potted with old RTV batch (monitor strains)	M. Viens	7/27/2004	
13	Model new design for stress	Ryan S.		
14	Finish improvements to model	Ryan S.		
15	Model slit modification to existing PMTs potted in housings	Ryan S.		
16	Test RTV for shrinkage	P. Joy		
17	Partial life test of surviving PMTs	P. Joy		
18	Thermal Cycle test spare/qual PMTs. Use PMTs that pass in qaul EC	P. Joy	7/21/2004	
19	Put all applicable PMT data in one table	S. Schmidt	21-Jul	COMPLETE
20	Correlate FEM model to actual measured strains	Ryan S.	21-Jul	
21	Order 21 new PMTs from Hammamatsu	Bob H.	7/9/2004	COMPLETE
22	Lay out new failure and path charts	M. Amato	7/29/2004	
23	Thermal cycle 5-10 bare tubes	P. Joy		
24	Determine max temperature rate of change on orbit	C. Peters	26-Jul	
25	Review handling procedures	K. Segal	27-Jul	
26	Determine a screening process that would allow potted PMTs to fly	M. Amato		
27	Determine if removing silicone from PMTs could weaken PMTs	P. Joy	7/27/2004	

Actions continued

Quick summary reminder of <u>some</u> of the important PMT items for 7/26;

- **Testing and reporting on the two removal techniques (turn and peel, slit and soak) for already potted PMTs (action 6)**
- **Status of surviving PMTs in partial life test (action 17).**
- **Any updates of stress model (action 14), analysis to slit modification for already potted PMTs (action 15), possibly start analysis of CTE compensation concept (action 13)**
- **Strain gauges for 7 un cycled PMTs potted with old RTV batch and strain gauges for future tests of mechanical CTE compensation concept (action 12 and ?).**
- **Fill any missing RTV batch materials data. Poisson's ration at cold temps, confirmation of some properties of old batch (actions 16, 5 and ?).**
- **Assembly of 1st mechanical solution concept (actions 9 and 10)**

New or modified actions from 7/26 (draft Amato);

28 - Remove two 'worst' flight PMTs with machining and solvent method.Consider performance retest of PMTs removed this way to confirm no perf. loss

7 *addition* - Check repeatability etc for poisons ration results

30 - One last ditch effort for Poisons ration data for old batches. Is there no way to get uncured source from old batches. Can we use an existing sample to get relative difference from tested samples. This is important for this week.

31 - By thursday can we try and get a table or curves that matches or points out likely stresses on the outer surface with the known RTV material properties for each RTV batch. For the old batches we will have to assume a range for Poisson's. Create a summary of all strain gauge data to PMT and batch to discuss any implications.