Large Synoptic Survey Telescope	Doc Number **LCN-2281**	Subsystem Project Management	Change Type _x_ Release/Revise ___ Redline	Status LSST Camera APPROVED Effective Date 29 Jan 2019
Camera Change Notice	Originator Vincent Riot Bill Wahl Tim Bond	Control Level ___ Camera Subsytem _x_ Camera Proj Office ___ Camera CCB	Effectivity _x_ Affects Existing H'ware?	

Change Request Title

Scope Change for LSST Camera Channel Loss Mitigations

Documents Affected (completed by originator)

Doc Number	Document Title	New Rev	Redline CN's Incorporated
N/A	N/A	N/A	N/A

Other Supporting Documents (optional; completed by originator)

Doc Number	Document Title

Cost Account Affected (completed by originator)

WBS number of control account	WBS title	Last BCR date	Cost Change	Cumulative Cost Change
3.01	Project management		$23K	
3.04.01	Science Raft		$609K	
3.08	Integration and Test		$577K	

PMCS Documents (completed by configuration manager)

Doc Number	Document Title
BCR-86	

Approvals (completed by configuration manager)

Approvers	Approval Date	Camera Change Action Number
V. Riot, S. Ritz, B. Wahl, T. Bond, A. Roodman, J. Tice, J. Kenny, M. Nordby, G. Haller, S. Kahn, S. Herrmann, P. O'Connor	01/29/19	CCA0947

Change Description (completed by originator)

Content and Type of Change:

This change includes the following tasks:

- **Clean** the science rafts including Sensors
- Develop processes and hardware to **protect** the sensors on the science raft, including fixture upgrade for cleaning and reconstruction
- Develop design upgrades to **prevent** generation of particles during handling and operations

Four different plans have been identified and planned for the rafts, depending on their status and type of sensors. The four plans are as follows:

Category A:

To be disassembled, cleaned, retrofitted, re-assembled and qualified at BNL, re-verified at SLAC: applies to (1) rafts that were returned to BNL that require sensor replacement due to permanent damage or performance issues and (2) incomplete rafts at BNL that are currently on hold. There are 5 Rafts in this Category all of which will be reverified at SLAC.

Category B:

To be disassemble, cleaned, retrofitted and re-assembled at BNL, re-verified at SLAC: applies to (1) rafts that were returned to BNL that do NOT require sensor replacement and (2) completed/tested rafts at BNL that were never shipped to SLAC and are currently on hold at BNL. There are 6 Rafts in this category all of which will be reverified at SLAC.

Category C (e2v Only):

To be disassembled at SLAC and the sensor assembly (RSA) will be shipped to BNL for cleaning and retrofitting, then return-shipped to SLAC for re-assembly and re-verification at SLAC: applies to e2v based rafts currently at SLAC (e2v rafts require Sensor removal due to limited access to the wire bonds while installed on the RSA). There are 8 rafts in this category all of which will be reverified at SLAC.

Category D (ITL Only):

To be disassembled, cleaned, retrofitted, reassembled and re-verified at SLAC: applies to ITL based rafts already at SLAC. There are 4 rafts in this category.

Change Description (completed by originator)

Table 1: Summary of RTMs under assembly as of November 26, 2018.

RTM	Sensor Type	Current Location	Cat.	Status	Plan
RTM1	ITL	BNL **(returned)**	**B**	4 dead channels	To be disassembled, cleaned and retrofitted at BNL, re-verified at SLAC.
RTM2	e2v	SLAC	**C**	1 dead channel	To be disassembled at SLAC, sensor assembly (RSA) shipped to BNL for cleaning then return-shipped to SLAC for reassembly and re-verification.
RTM3	e2v	SLAC	**C**	0 dead channels	To be disassembled at SLAC, sensor assembly (RSA) shipped to BNL for cleaning then return-shipped to SLAC for reassembly and re-verification.
RTM4	e2v	SLAC	**C**	1 dead channel	To be disassembled at SLAC, sensor assembly (RSA) shipped to BNL for cleaning then return-shipped to SLAC for reassembly and re-verification.
RTM5	e2v	SLAC	**C**	0 dead channels	To be disassembled at SLAC, sensor assembly (RSA) shipped to BNL for cleaning then return-shipped to SLAC for reassembly and re-verification.
RTM6	e2v	BNL **(returned)**	**A**	Several shorts (Sensor will be removed)	To be disassembled, cleaned, retrofitted, reassembled and qualified at BNL, re-verified at SLAC.
RTM7	e2v	SLAC	**C**	0 dead channels	To be disassembled at SLAC, sensor assembly (RSA) shipped to BNL for cleaning then return-shipped to SLAC for reassembly and re-verification.
RTM8	ITL	SLAC	**D**	1 dead channel	To be disassembled, cleaned, retrofitted, reassembled and re-verified at SLAC.
RTM9	e2v	BNL **(returned)**	**A**	1 glowing sensor (Sensor will be removed)	To be disassembled, cleaned, retrofitted, reassembled and qualified at BNL, re-verified at SLAC.
RTM10	ITL	BNL	**A**	3 high-noise sensors	To be disassembled, cleaned, retrofitted, reassembled and qualified at BNL, re-verified at SLAC.
RTM11	ITL	BNL **(returned)**	**B**	3 dead channels	To be disassembled, cleaned and retrofitted at BNL, re-verified at SLAC.
RTM12	e2v	SLAC	**C**	0 dead channels	To be disassembled at SLAC, sensor assembly (RSA) shipped to BNL for cleaning then return-shipped to SLAC for reassembly and re-verification.
RTM13	e2v	SLAC	**C**	0 dead channels	To be disassembled at SLAC, sensor assembly (RSA) shipped to BNL for cleaning then return-shipped to SLAC for reassembly and re-verification.
RTM14	ITL	SLAC	**D**	1 dead channel	To be disassembled, cleaned, retrofitted, reassembled and re-verified at SLAC.
RTM15	ITL	SLAC	**D**	1 dead channel	To be disassembled, cleaned, retrofitted, reassembled and re-verified at SLAC.
RTM16	e2v	SLAC	**C**	0 dead channels	To be disassembled at SLAC, sensor assembly (RSA) shipped to BNL for cleaning then return-shipped to SLAC for reassembly and re-verification.
RTM17	e2v	BNL	**B**	0 dead channels (complete, on hold)	To be disassembled, cleaned and retrofitted at BNL, re-verified at SLAC.
RTM18	ITL	SLAC	**D**	0 dead channels	To be disassembled, cleaned, retrofitted, reassembled and re-verified at SLAC.
RTM19	ITL	BNL	**A**	1 high CTE sensor (Sensor will be removed)	To be disassembled, cleaned, retrofitted, reassembled and qualified at BNL, re-verified at SLAC.
RTM20	ITL	BNL	**B**	0 dead channels (complete, on hold)	To be disassembled, cleaned and retrofitted at BNL, re-verified at SLAC.
RTM21	e2v	BNL	**B**	0 dead channels (complete, on hold)	To be disassembled, cleaned and retrofitted at BNL, re-verified at SLAC.
RTM22	e2v	BNL	**A**	Incomplete (not constructed yet)	To be assembled with enhancements and retrofitted sub-components using special care and attention directed to inspecting Sensors and components for particulate, clean as necessary and qualify at BNL. This Raft will be re-verified at SLAC.

Change Description (completed by originator)

The proposed Corrective Action Plan described throughout this document is based on the following:

1. Unmitigated, channel loss from shorts resulting from particulates would not support the Science Raft and Camera specifications for the lifetime of LSST – a loss of 0.6% of channels (pixels) has been observed thus far and would likely increase if left unaddressed.
2. All processes, protocols, design of raft or test setup, fixturing, *etc.* at BNL and SLAC have been and will continue to be reviewed to fulfil the following goals. Additionally, lessons learned from the corrective action plan activities will be communicated to facilitate reviews of other sub-systems and the Camera to minimize the realized risk.
    a. "Sufficiently" clean components and sensors (to be defined)
    b. Protect hardware from further contamination and risk
    c. Prevent generation or build-up of particulate to minimize the opportunity for reoccurrence
    d. Verify functionality prior to and throughout reconstruction (see point 3 below regarding powering of Sensors)
3. Aliveness/connectivity testing will be performed only after cleaning and inspection results showing that Sensors are sufficiently clean for safe powering.
4. Specific rafts and raft sensor assemblies (RSAs) will be selected to progress through differing cleaning processes in parallel, at SLAC and/or BNL. This parallel approach will facilitate convergence on the most effective corrective action plan for Sensor cleaning (specifically) and gather supporting evidence to validate processes before proceeding to the remaining rafts. This includes the following work at their current location (as listed in the above table):
    a. S/N: RTM-004 (RTM #1; ITL) disassemble raft and RSA to remove sensors for cleaning. Process validation will be performed at BNL (Cat A).
    b. S/N: RTM-014 (RTM #11; ITL) disassemble raft and RSA to remove sensors for cleaning. Process validation will be performed at BNL (Cat B).
    c. S/Ns: RTM-009 (RTM #6; E2V) and RTM-012 (RTM #9; E2V) disassembled rafts and RSAs to remove sensors for cleaning. Process validation will be performed at BNL (Cat B and post-shipment process of Cat C).
    d. S/Ns: RTM-011 (RTM #8; ITL) and RTM-017 (RTM #14; ITL) disassembled rafts to clean <u>assembled RSAs</u> (including sensors). Process validation will be performed at SLAC (Cat D).
    e. The following rafts were inspected and limited samples were collected to provide some of the earliest supporting evidence, including microscope and SEM images with composition of the sampled locations:
        i. S/N: RTM-014 (RTM #11; ITL) at SLAC (prior to return-shipment) and at BNL (during receiving and disassembly process)
        ii. S/N: RTM-018 (RTM #15; ITL) at SLAC
        iii. S/N: RTM-021 (RTM #18; ITL) at SLAC
        iv. S/N: RTM-009 (RTM #6; ITL) at BNL
        v. S/N: RTM-012 (RTM #9; E2V) at BNL
        vi. S/N: RTM-013 (RTM #10; ITL) at BNL
5. Following results from testing the devices above, formalized procedures to clean and validate components will be reviewed, approved, and implemented at each site. This does not restrict improving said processes for cleaning and testing with formal approval for implementation.
6. Sensors will be removed and reinstalled on Raft Baseplates (sensor mounting surface of RSA) at BNL only since SLAC does not have the proper tooling and trained personnel (reason for Cat C – all e2v rafts – and

Change Description (completed by originator)

Cat A).

7. e2v wirebonds are too difficult to safely access on an assembled RSA for cleaning; therefore, all e2v sensors will be removed from the RSA, since it is assumed that cleaning is required (reason for Cat C – all e2v rafts)
8. At SLAC, all rafts will have an electro-optical (E/O) test at an operational temperature after cleaning and reconstruction with upgrades.
9. While not all particulates are conductive, and not all conductive particulate is large enough to short neighboring pins or channels, all sensors will be cleaned as thoroughly as possible.
10. With preventing particulate generation as a fundamental goal, the use and design of holes and fasteners are natural concerns – including fasteners in the raft as well as fixturing and test equipment – and, in addition to the LSST Camera Mechanical standards, the following designs are suggested, with inserts preferred:
    a. When threaded inserts (*e.g.*, Heli-Coils®) can be incorporated, the insert material should be Nitronic 60 and the fastener should be stainless steel, roll-formed, and uncoated.
    b. When inserts cannot be incorporated and the material of the hole is copper or aluminum, the fastener should be stainless steel, roll-formed, and coated with a dry lubricant (*e.g.*, WS_2, also known as dicronite®).
11. ITL rafts/sensors will be easier to clean than e2v rafts/sensors because of the ITL package ("pocket") design. (1) They do not have wirebonds, as they are bump bonded, and (2) the sensor package is fully enclosed, that is the mating surface fully seats against the raft baseplate and the interface between the PCB and package within the pocket is sealed.
12. It is crucial to prevent the permanent loss or significant degradation (physical integrity or electro-optical performance) to the sensors during the preliminary and production corrective action plan activities, since sensor production has concluded for both vendors with a limited quantity of spare devices. While not as impactful, this is also true for much of the custom raft hardware, such as the Raft Electronics Boards (REBs) and Raft Electronics Crate (REC) walls.
13. This plan is subsequent to the review conducted by the LSST Camera Project Office on Nov 16, 2018; see LCA-17281 for final report. Additionally, input was received from the review conducted by Project Planning & Oversight of the NPP Directorate at BNL on Dec 21, 2018; see DOC-31008 for final report.
14. Upon re-testing for full Electro-Optical performance at SLAC, rafts will be used as is if they stay consistent with LCA-48, LSE-59 and LPM-262 documents for sensor performance even if there are discrepancies with previous measurements. Raft violating these documents will be reviewed and addressed on a case basis.

Change Description (completed by originator)

The plan includes the cleaning flow as follows:

Note:

Approval was received to disassembly one production raft (RTM1; ITL in Cat B) for preliminary process validation of inspection and cleaning methods including one sensor – other production rafts at BNL have been disassembled, but no other Sensors have been cleaned or removed from the RSA.

Table 2: Summary of cleaning flow for RTM sub-assemblies.

Cat.	Raft Component	Location of Cleaning	Cleaning Flow and Method	Prototyped (evidence)
A & B	RSA	BNL	Remove all RSA components and e2v sensors and clean using approved procedures and methods stated below.	Limited validation to date. • ITL and e2v non-production and prototype sensors cleaned and inspected using all cleaning methods stated below. • One production Sensor (ITL-380) from RTM1 was cleaned using gas, swab, and extraction tool as stated below; preliminary tests showing a recovery of functionality and further testing will be performed to verify performance. • e2v non-production and prototype sensors cleaned and inspected using all cleaning methods stated below (training provided by a BNL Wire Bond expert). Note that early e2v sensors did not include gate protection diodes and wirebonds included on production the design. • Raft and RSA disassembly of RTM6 and RTM9 (both e2v) will be performed to test and validate cleaning methods and fixturing required to clean production e2v sensors.
	REC (Raft)	BNL	Disassemble REC components, inspect and clean using approved procedures and methods stated below.	Limited validation to date. • Inspection of particulate and residue after multiple fastening cycles of REC (S/N: LCA-11022-05) wall holes used for mechanical test raft #1 (MTR1); see DOC-31009. These REC walls were prototypes with nickel plating in all holes (including REC/Cryo holes). • Inspection and sample collection throughout receiving and RTM disassembly processes of RTM1. • ComRaft (S/N: RTM-031) will be the first raft constructed with modified REC walls. A close inspection for particulate generation will be performed for review.
	REB	BNL	Inspect and clean REB surfaces and components using approved procedures and methods stated below.	Limited validation to date. • REBs from disassembled RTM1 were inspected under a microscope after RTM disassembly, cleaned using a swab, then successfully tested for full functionality.

Change Description (completed by originator)

C	RSA	BNL; and, SLAC for RSA Thermal Straps	Remove RSA components to return-ship to BNL. Remove all RSA components and e2v sensors and clean using approved procedures & methods stated below.	See Category A for RSA – RSAs of CatC rafts (e2v only) are similar to e2v RSAs of CatA rafts
	REC (Raft)	SLAC	Disassemble REC components, inspect and clean using approved procedures and methods stated below.	See Category A for REC – RECs of CatC rafts are similar to RECs of CatA rafts
	REB	SLAC	Inspect and clean REB surfaces and components using approved procedures & methods stated below.	See Category A for REB – REBs of CatC rafts are similar to REBs of CatA rafts
D	RSA	SLAC	Remove all RSA components assembled RSA and clean using approved procedures & methods stated below.	Limited validation to date. • Assembled, non-production RSAs inspected with different equipment to evaluate the best inspection tool. • ITL non-production and prototype RSAs cleaned using all cleaning methods stated below.
	REC (Raft)	SLAC	Disassemble REC components, inspect and clean using approved procedures and methods stated below.	See Category A for REC – RECs of CatD rafts are similar to RECs of CatA rafts
	REB	SLAC	Inspect and clean REB surfaces and components using approved procedures and methods stated below.	See Category A for REB – REBs of CatD rafts are similar to REBs of CatA rafts

Change Description (completed by originator)

The plan includes the following cleaning methods to be available and used as needed, commensurate with level and type of contamination observed, difficulty related to access, and fragility.

Note:

The cleaning methods are ranked in order of preference to use; the ranking does not indicate the order of operations nor specific methods employed in a production setting as this depends on the kind of contamination after disassembly. Note that from contamination levels established through inspections of hardware and sensors, the rank of "1" is expected to be the primary method for cleaning.

All components will be inspected for particulate prior to use in the RSA and Raft assembly.

Table 3: Summary of cleaning methods for RTM sub-assemblies and components, ranked by preference of use.

Raft Component and Sub-components	**Cleaning Method**				**Other Methods & Process Details**
	Low Velocity Gas	*Q-Tip Swab*	*Small Tool for Extraction*	*Vacu-um*	
RSA					
E2V Sensors	**1**	**--**	**2**	**--**	• Note further testing is required to develop a procedure which ensures particulate is removed (not just displaced) on an e2v sensor when using the low velocity gas as the primary cleaning method.
ITL Sensors	**4**	**2**	**3**	**1**	• Inspection by Borescope on Assembled RSA at SLAC. • Note further testing is required to develop a procedure which ensures particulate is removed (not just displaced) on an ITL sensor when using the low velocity gas as the lowest ranked cleaning method.
RSA Thermal Straps	**2**	**--**	**3**	**1**	• High Velocity Blast • Manipulate Braid to Loosen Particulate
RTDs & Heaters	**1**	**2**	**3**	**4**	• Ohmic Test prior to RTM Assembly
Raft Baseplate (No Sensors)	**2**	**4**	**3**	**1**	• High Velocity Blast when using the 2nd ranked cleaning method. • Excess Stycast Removal (Razor blade and/or soldering iron) • Wipe with Ethanol

Change Description (completed by originator)

REC (Raft)					
REC Thick Walls	**1**	**--**	**3**	**2**	• High Velocity Blast when using the primary cleaning method. • Chase Threads with Clean Hardware • Blast, Chase and Extract one to three times, depending on use of inserts • Due to machined modifications, Final Vacuum Cleaning (Wet Solution) and Bake, with standard cleaning procedures
REC Thin Walls	**2**	**--**	**3**	**1**	• High Velocity Blast when using the 2nd ranked cleaning method. • Wipe with Ethanol
Radiation Shield	**2**	**--**	**--**	**1**	• Wipe with Ethanol
Hold-Down Assemblies	**2**	**--**	**3**	**1**	• High Velocity Blast
REB Thermal Straps	**2**	**--**	**3**	**1**	• Manipulate Braid to Loosen Particulate
Clamp Rods	**2**	**--**	**--**	**1**	• Chase Threads with Clean Hardware • High Velocity blast • Final Vacuum Cleaning (Wet Solution) and Bake, with standard cleaning procedures
Misc. RSA and REC Hardware (Fasteners, *etc.*)	**1**	**--**	**--**	**--**	• Provide New Hardware, as appropriate • Visual Inspection prior to Use, new or reused hardware • High Velocity Blast • Final Vacuum Cleaning (Wet Solution) and Bake, with standard cleaning procedures
REB (Boards)	**3**	**2**	**--**	**1**	On REBs connected to sensors with non-imaging channels: • Functional Test prior to RTM Assembly at site of raft disassembly. • Measure the resistance of the 100 Ohm resistors on each circuit's output drain.

Change Description (completed by originator)

The plan includes the following raft fastener and insert upgrade as follows. This applies to all rafts:

Note:

Not all holes will include modifications for heli-coils or other enhancements as not all locations can accommodate the modification (see Appendix A).

Table 4: Summary of design changes to fasteners and holes on the RTM, with relevant engineering changes and validation evidence.

Fastener or Insert Location	Previous specification (dimension, insert and material)	New specification (dimension, insert and material)	Engineering check (engagement, etc.)	Prototype (evidence)	Location of repair
M3 Screw used to attach Hold-down Pin Catch to REC Thick Wall (See Hole A in Appendix A)	Stainless steel, roll-formed, uncoated M3 fastener into Copper (See Hole A in Appendix A)	Stainless steel, uncoated, roll-formed M3 fastener into Nitronic 60 Heli-Coil (See Hole A in Appendix A)	• See Hole A in Appendix A. • New design still meets recommended heli-coil use. • The torque specification will be modified to an appropriate value to accommodate design/material changes.	Measured low counts of particulates using uncoated screws on Nitronic 60 Heli-coils. Additional testing using uncoated screws on Nitronic 60 Heli-coils on a sample REC wall did not find a large quantity, and the particles are smaller than samples from disassembled production rafts (RTM1 and RTM11). See DOC-31009.	• BNL: Procures Hardware • BNL: CatA, CatB, CatC • SLAC: CatD
M6 Screw used to attach A-frame or U-frame (See Hole B in Appendix A)	Stainless steel, roll-formed, uncoated M6 fastener into Copper (See Hole B in Appendix A)	Stainless steel, uncoated, roll-formed M6 fastener into Nitronic 60 Heli-Coil (See Hole B in Appendix A)	• See Hole B in Appendix A. • New design still meets recommended heli-coil use. • The torque specification will be modified	Measured low counts of particulates using uncoated screws on Nitronic 60 Heli-coils. Additional testing using uncoated screws on	• BNL: Procures Hardware • BNL: CatA, CatB, CatC • SLAC: CatD

Change Description (completed by originator)

			to an appropriate value to accommodate design/material changes. • Interface is shoulder screw with loose-fit on smooth surface (THRU hole). To minimize particulate, Kapton tape will be included around the shoulder to prevent galling between the fastener and aluminum A-frame.	Nitronic 60 Heli-coils on a sample REC wall did not find a large quantity, and the particles are smaller than samples from disassembled production rafts (RTM1 and RTM11). See DOC-31009.	
M3 Screw used to attach the REC Leg to the REC Thick Wall (See Hole C in Appendix A)	Stainless steel, roll-former, uncoated M3 fastener into Copper (See Hole C in Appendix A)	Stainless steel, uncoated, roll-formed M3 fastener into Nitronic 60 Heli-Coil (See Hole C in Appendix A)	• See Hole C in Appendix A. • The torque specification will be modified to an appropriate value to accommodate design/material changes. • New design increased screw length increases engagement of screw and Heli-coil. • New design increased engagement of REC Wall and heli-coil.	Measured low counts of particulates using uncoated screws on Nitronic 60 Heli-coils. Additional testing using uncoated screws on Nitronic 60 Heli-coils on a sample REC wall did not find a large quantity, and the particles are smaller than samples from disassembled production rafts (RTM1 and RTM11). See DOC-31009.	• BNL: Procures Hardware • BNL: CatA, CatB, CatC • SLAC: CatD
Heli-coil Inserts for REC Holes	N/A – Not in Previous Design	Nitronic 60 heli-coils, with machined	• See Hole A, Hole B, and Hole C in	Measured low counts of particulates using	• BNL: Procures Hardware

Change Description (completed by originator)

(Holes A-C) (See Hole A-C in Appendix A and lines above)		modification to REC Walls to accommodate the inserts (See Appendix A and lines above)	Appendix A and lines above.	dicronite screws on copper and uncoated screws on Nitronic 60 Heli-coils. Additional testing using uncoated screws on Nitronic 60 Heli-coils on a sample REC wall did not find a large quantity, and the particles are smaller than samples from disassembled production rafts (RTM1 and RTM11). See DOC-31009.	• BNL: CatA, CatB, CatC • SLAC: CatD
M3 Screw for REC Thin Wall to Thick Wall (See Hole D in Appendix A)	Stainless steel, uncoated M3 fastener into Copper (See Hole D in Appendix A)	No planned modification to these holes of the REC Walls. Stainless steel, dicronite coated, roll-formed M3 fastener into Copper (No Dimensional Changes – see Hole D in Appendix A)	• See Hole D in Appendix A. • The torque specification will be modified to an appropriate value to accommodate design/material changes.	Measured low counts of particulates using dicronite screws on copper. Additional testing using uncoated screws on Nitronic 60 Heli-coils on a sample REC wall did not find a large quantity, and the particles are smaller than samples from disassembled production rafts (RTM1 and RTM11). See DOC-31009.	• BNL: Procures Hardware • BNL: CatA, CatB, CatC • SLAC: CatD
M3 Screw used to attach the Adjustment	Stainless Steel, uncoated M3 fastener into Copper	No planned modification to these holes of the REC Walls.	• See Hole E in Appendix A. • Dimensional calculation finds	Measured low counts of particulates using dicronite screws	• BNL: Procures Hardware • BNL: CatA,

Change Description (completed by originator)

Collar (See Hole E in Appendix A)	(See Hole E in Appendix A)	Stainless steel, dicronite coated, roll-formed M3 fastener into Copper (No Dimensional Changes – see Hole E in Appendix A)	too little material in REC walls for heli-coils. • The torque specification will be modified to an appropriate value to accommodate design/material changes.	on copper. Additional testing using uncoated screws on Nitronic 60 Heli-coils on a sample REC wall did not find a large quantity, and the particles are smaller than samples from disassembled production rafts (RTM1 and RTM11). See DOC-31009.	CatB, CatC • <u>SLAC</u>: CatD
REC/Cryo Holes (See Hole F in Appendix A)	Stainless Steel, uncoated hardware into Copper Holes are utilized by a variety of activities: • Fasteners for GO/NOGO Gauge • Threaded Rods for TS7 and Grid Insertion or Removal • Fasteners for TS7. • Shipping hardware (see MF08 and A-frames in Table 6). (See Hole F in	No planned modification to these holes of the REC Walls. • A review of all processes interfacing to these holes to verify dicronite coating is used. • Rafts installed in the Camera will be held by dicronite coated fasteners. (No Dimensional Changes – see Hole F in Appendix A)	• See Hole F in Appendix A. • Dimensional calculation finds too little material in REC walls for heli-coils. • Any changes to these holes may affect overall raft assembly registration with external tooling or hardware (such as raft installed or removed from TS7 or Camera).	Measured low counts of particulates using dicronite screws on copper. Additional testing using uncoated screws on Nitronic 60 Heli-coils on a sample REC wall did not find a large quantity, and the particles are smaller than samples from disassembled production rafts (RTM1 and RTM11). See DOC-31009.	• <u>BNL</u>: Procures Hardware • <u>BNL</u>: CatA, CatB, CatC • <u>SLAC</u>: CatD

Change Description (completed by originator)

	Appendix A)				
M3 Screw used to attach the REB Thermal Strap Assembly to the Raft (*via* REB Cold Bar)	Stainless Steel, uncoated M3 fastener into Copper	No planned modification to the holes of the REB Cold Bars. Stainless steel, dicronite coated, roll-formed M3 fastener into Copper	• Redesign and modification to all REBs would greatly impact the schedule impact. • To prevent mixing dicronite coated and uncoated hardware, REB Thermal Strap Assemblies will not be installed until fasteners are available. • The torque specification will be modified to an appropriate value to accommodate design/material changes.	Measured low counts of particulates using dicronite screws on copper. Additional testing using uncoated screws on Nitronic 60 Heli-coils on a sample REC wall did not find a large quantity, and the particles are smaller than samples from disassembled production rafts (RTM1 and RTM11). See DOC-31009.	• BNL: Procures Hardware • BNL: CatA and CatB • SLAC: CatC and CatD

Change Description (completed by originator)

The plan include the following raft hardware upgrades as follows. This applies to all rafts. All new hardware will progress through the standard cleaning methods.

Table 5: Summary of new hardware for the RTM and sub-assemblies, with relevant validation evidence.

Upgrade	Description	Prototyped (evidence)	Location of part fabrication	Location of part cleaning	Location of repair
e2v Pocket Cover	PEEK cover inserted in Raft Baseplate to prevent particulate from passing through (into the area of wire bonds).	• 3D printed prototype to ensure reliable fit; area of aperture reduced enormously. • Design includes threaded, blind holes to remove the cover and mitigate any additional particulate during removal. • With published properties of the material, the cover design provides 0.008 inch with an interference fit at the lowest expected temperatures in Camera operations. This fit in this extreme case is sufficient to hold the cover in place as well as continue to protect the sensors.	BNL	BNL	• <u>BNL</u>: All rafts
ITL Pocket Cover	PEEK cover inserted in Raft Baseplate to prevent particulate from passing through (into the area of the JST connector contacts).	• 3D printed prototype to ensure reliable fit; area of aperture reduced enormously. • Design includes threaded, blind holes to remove the cover and mitigate any additional particulate during removal. • With published properties of the material, the cover design provides 0.008 inch with an interference fit at the lowest expected temperatures in Camera operations. This fit in this extreme case is sufficient to hold the cover in place as well as continue to protect the sensors.	BNL	BNL	• <u>BNL</u>: CatA, CatB, CatC • <u>SLAC</u>: CatD

Change Description (completed by originator)

RSA Thermal Strap Braid Sleeve	Unheated shrink wrap tubing (Teflon) around copper braid to prevent generation of particles from abrasion of copper braids	• The addition of tubing does not affect the fit, form or function of the RSA Thermal Strap performance. Flexibility of RSA Thermal Strap was tested with tubing and it was not adversely affected. • Regarding the REB Thermal Straps, the tubing would have a significant and negative impact on flexibility, hence why this design change will not be implemented on them. • Operational restrictions are be required to ensure the tubing does not shrink; however, current temperature limits (+40 degC on RSA) are much lower than what is required to activate shrinking.	BNL & SLAC	BNL & SLAC	• <u>BNL</u>: CatA and CatB • <u>SLAC</u>: CatC and CatD
Stycast on RSA Thermal Strap End Blocks	Apply stycast to both end blocks, where copper braid is cut to prevent release of potential particulate	• Extensive thermal testing of RSA Thermal Strap included stycast filler; and, demonstrated performance unaffected. • REB Thermal Strap End Blocks are not open, therefore Stycast cannot be applied, and low risk of particulate escaping.	BNL & SLAC	BNL & SLAC	• <u>BNL</u>: CatA and CatB • <u>SLAC</u>: CatC and CatD
REC Bushing	Increased size and design to limit movement between RSA and REC	• Dimensional calculation for tighter fit to select appropriate bushing design and sizes. • Design incorporates two sizes within the part, which chosen size will be selected during raft assembly. • Transport of rafts between SLAC and BNL using RTM Shipping Bracket demonstrating a fixed position is achievable with applied forces.	BNL	BNL	• <u>BNL</u>: CatA and CatB • <u>SLAC</u>: CatC and CatD
e2v Sensor Stud Cover	PEEK cover inserted on	• None to date; high confidence in design and protection.	BNL	BNL	• <u>BNL</u>: CatA, CatB, CatC

Change Description (completed by originator)

(Bullet)	sensor mounting studs to prevent generation of particles from abrasion of copper braids	• This is a secondary form of mitigation – the primary form is the Teflon tubing around the copper braid. • Exposed threads on ITL sensor mounting studs are turned down to facilitate assembly. This prevents any stud cover design to engage with threading. Note also that ITL sensor mounting studs will not include diconite coating and are manufactured using single point threading.			• SLAC: CatD

Change Description (completed by originator)

The plan includes the following fixture upgrades as follows. This applies to all rafts and operations at all sites. Fabrication and cleaning will be completed at the same location as the upgrade.

Note:

Not all holes will include modifications for heli-coils or other enhancements as not all locations can accommodate the modification.

Regardless of upgrades to all fixtures and equipment listed throughout this document, all fasteners will be reviewed to ensure the appropriate design is chosen to mitigation particle generation (such as dicronite coated fasteners when Nitronic 60 heli-coils cannot be implemented).

Table 6: Summary of modifications to test equipment and fixturing interfacing with the RTM during handling, testing assembling, and shipment, with relevant engineering changes and validation evidence.

Fixture name	Description of Upgrades	Location of upgrade	Location of use	Prototyped (evidence)
MF08 – RSA Handling Hardware The following are included: • Hole 1: Four locations for MF08 Cover • Hole 2: Two locations for MF08 Frame • Hole 3: Eight locations for Dogged Screws • Hole 4: Eight locations for Shipping Hardware • Hole 5: Four locations for L-covers	• For Hole 1, change stainless steel screws to static dissipative nylon. • For Hole 2 and Hole 3, fasteners will remain stainless steel, roll-formed, uncoated. • For Hole 4, Kapton tape will be added to the backside (facing the sensors) to protect the sensors from any generated particulate. • Design options for Hole 5 are still being considered. • If required, upgrades will be implemented onto RSAs and RTMs in phases as hardware or access becomes available. • MF08 upgrades at SLAC can be applied using the *Z*-stage. It is the safest setup for removing or installing MF08 from an assembled RTM. • MF08 upgrades at BNL can be applied after the sensors are removed, as this is expected for all RSAs at BNL.	BNL & SLAC	BNL & SLAC	Limited validation to date. • High confidence design changes will generate less particulates as well as protect the hardware from any generated particulate. • Testing using uncoated screws on Nitronic 60 Heli-coils on a sample REC wall did not find a large quantity, and the particles are smaller than samples from disassembled production rafts (RTM1 and RTM11); see DOC-31009.

Change Description (completed by originator)

MF07 – Single Sensor Handling Hardware (MF07A = E2V MF07B = ITL)	Change all stainless steel screws to static dissipative nylon.	BNL	BNL	Limited validation to date. • High confidence design change will generate less particulates.
A-Frame and U-Frame – RTM Handling Hardware	Design options are still being considered, including but not limited to the following. • Use of heli-coils, where practical. • Where heli-coils cannot be implemented, change hole design to clearance or TRHU hole with an appropriate nut for fastener engagement. • Change uncoated stainless steel shoulder screw which engages the REC to dicronite coated.	BNL & SLAC	BNL & SLAC	Limited validation to date. • Measured low counts of particulates using dicronite screws on copper and uncoated screws on Nitronic 60 Heli-coils. Additional testing using uncoated screws on Nitronic 60 Heli-coils on a sample REC wall did not find a large quantity, and the particles are smaller than samples from disassembled production rafts (RTM1 and RTM11). See DOC-31009.
RTM Insertion Fixture (TS22)	• Add an additional washer to increase the gap between the hand wheel and bearing plate to generate less particulates during actuation. Note this upgrade was initially performed at SLAC. • Note that SLAC will replace this fixture with TS22B (see below). • Change the threaded rods, fasteners for the REC/Cryo interface, and fasteners for clamping the REB Thermal Strap Assemblies to the coldpate to dicronite coated.	BNL	BNL & SLAC	Installed washer successfully relieved contact interface between hand wheel and bearing plate; zero particulates were measured during all trials.
Redesigned RTM Insertion Fixture (TS22B)	When available and approved, TS22B will replace the current TS22 at SLAC. • ACME Screw wheel threads replaced with Teflon nut for	SLAC	SLAC	Installed non-production rafts (MTR) into TS7 several times with the new fixture. • The initial installation verified the installation

Change Description (completed by originator)

	elimination of generated particulate. • Wheel driven through sealed roller bearing. • Change the threaded rods, fasteners for the REC/Cryo interface to dicronite coated. • Change the fasteners for clamping the REB Thermal Strap Assemblies to the coldplate to dicronite coated.			and removal processes • A second cycle verified the absence of particulate generation during use.
Shipping Bell Jar	• Heli-coils will be installed into the C-Clamps.	BNL & SLAC	BNL & SLAC	Measured low counts of particulates using dicronite screws on copper and uncoated screws on Nitronic 60 Heli-coils. Additional testing using uncoated screws on Nitronic 60 Heli-coils on a sample REC wall did not find a large quantity, and the particles are smaller than samples from disassembled production rafts (RTM1 and RTM11). See DOC-31009.
TS7-Cryostats	• Dicronite coated fasteners for the front and back TS7-Covers (flanges). • Dicronite coated fasteners for all *in-situ* (captive) fasteners interfacing with the REC/Cryo holes in the REC Walls (Hole F in Appendix A). • Dicronite coated fasteners for all *in-situ* fasteners used to attach the REB Thermal Straps to the coldplate.	BNL & SLAC	BNL & SLAC	Measured low counts of particulates using dicronite screws on copper and uncoated screws on Nitronic 60 Heli-coils. Additional testing using uncoated screws on Nitronic 60 Heli-coils on a sample REC wall did not find a large quantity, and the particles are smaller than samples from disassembled production rafts (RTM1 and RTM11). See DOC-31009.
Aliveness Bench	• Threaded holes on the benchtop's surface are used for earthquake restraints. • Fasteners used will be dicronite coated and cleaned before each use.	SLAC	SLAC	Threaded holes will be tested with fasteners and empty frame to confirm low counts of particulate generation.

Change Description (completed by originator)

	• Threaded holes are blind holes and will be vacuumed prior to each use.			
REC/BOT Handling Tool	• Change four fasteners on the load cells to include Nitronic 60 inserts. The fasteners are dicronited. • Change four fasteners on the integration bracket to include Nitronic 60 inserts. The fasteners are dicronited. • Change four threaded rods which engage the integration bracket to include Nitronic 60 inserts and dicronite coating on the threaded ends. • Change two fasteners used for the RSA alignment tool to dicronite coated.	SLAC	SLAC	High confidence hardware and process changes will generate less particulates as well as protect the protect rafts and sensors from generated particulates.
SLAC Aux Room Science RTM Storage Cabinet	• Threaded holes in the mounting surfaces of the storage cabinet are used for earthquake restraints. • Fasteners used will be dicronite coated and cleaned before each use. • All threaded holes are THRU holes and allow particulate to fall into a confined area below the mounting surface (*i.e.*, optical breadboard).	SLAC	SLAC	Threaded holes will be tested with fasteners and empty frame to confirm low counts of particulate.

Change Description (completed by originator)

The plan includes the following processes upgrades or new processes as follows. This applies to all rafts and operations at all sites.

Note:

All components will be inspected for particulate prior to RSA and Raft assembly.

When cleaning *via* vacuum and or wiping of raft or fixture hardware during processes (assembly, disassembly, mounting or unmounting rafts to fixturing), access to clean hardware in process is restricted and, additionally, the added equipment (such as a vacuum) and handling to use it can pose an additional risk to raft hardware. All cleaning activities not explicitly required by the procedure will be at the discretion of the operator evaluating hardware by visual inspection (by eye or borescope); however, if particulate is found, there will be an obligation to document the finding and clean the hardware using appropriate and approved methods.

Excluding disassembly, verification using non-production rafts and the initial production rafts specified below will be completed prior to proceeding with the remaining production rafts.

Table 7: Summary of modifications to processes, procedures and protocols during handling, testing, assembling and shipment, with relevant validation evidence.

Procedure description	Location of execution	Change to procedure	Process prototyped
RSA/RTM Disassembly	• BNL: CatA, CatB, CatC • SLAC: CatC and CatD	• Include vacuum suction during initial break of Stycast in disassembly instructions. • RSAs cleaned at SLAC (CatD) will be disassembled (including RSA Thermal Strap Assemblies).	• Access for vacuum tip is available during RSA disassembly for the initial break of stycast. • Disassembly of non-production rafts shows access for a vacuum tip is extremely limited and poses an additional handing risk.
ITL RSA Cleaning	BNL: CatA and CatB	• Perform cleaning of sensor after disassembly.	• The first production rafts to proceed through this process will be RTM #1 and RTM #11.
Assembled ITL RSA Cleaning	SLAC: CatD	• Perform cleaning of an assembled RSA.	• Using a borescope with an appropriate tip size, viewing the ITL sensor pocket on an assembled, non-production RSA was achievable. • Final cleaning methods to be established using

Change Description (completed by originator)

			non-production rafts (MTR) to review and confirm efficacy. • The first production raft to proceed through this process will be RTM #8 or RTM #14.
E2V RSA/Sensor Cleaning	BNL: CatA, CatB, CatC	• Perform cleaning of sensor after disassembly.	• Cleaning methods and tools have been tested on non-production sensors. • The first production raft to proceed through this process will be RTM #6 then RTM #9.
MF07 Cover Installation and Removal (MF07A = E2V MF07B = ITL)	BNL: CatA, CatB, CatC	• Ethanol wipe of cover before installation and after removal.	High confidence hardware and process changes will protect rafts and sensors from generated particulates.
RSA Thermal Strap Assembly Upgrades	• BNL: CatA, CatB, CatC • SLAC: CatD	• Install RSA Thermal Strap Braid Tubing. • Apply Stycast to RSA Thermal Strap Assembly End Blocks.	• At BNL, the first rafts to be assembled with upgraded RSA Thermal Strap Assemblies will be ComRaft and RTM #1. • At SLAC, the first production rafts to be assembled with upgraded RSA Thermal Strap Assemblies will be RTM #8 or #14.
RSA Assembly: • Sensor Insertion • Installation of All Remaining RSA Hardware	BNL: CatA, CatB, CatC	• Include e2v Pocket Cover in assembly instructions, with vacuum suction afterward. It will be installed after all sensors are installed on the RSA. • Include e2v Sensor Stud Cover in assembly instructions. Note that the Stud Cover will be installed on all RSAs (CatC) at BNL. • Include final vacuum suction of the backside of the RSA after it is fully assembled.	• The first RSAs to proceed through this process will be ComRaft and RTM #1.

Change Description (completed by originator)

RSA Assembly: • RSA Thermal Strap Assembly Installation • Pocket Cover Installation	SLAC: CatC and CatD	• Perform Pocket Cover installation after cleaning (CatD), with vacuum suction afterward. • Perform RSA Thermal Strap Assembly installation and apply Stycast (CatC). Note that it was not in the baseline plan for RSA work to be performed at SLAC. • Include final vacuum suction of the backside of the RSA after it is fully assembled.	• The first RSAs to proceed through this process will be non-production RSAs (MTR). • BNL staff will provide training to SLAC staff for all relevant RSA assembly activities. • The first production RSAs to proceed through this process will be RTM #8 or #14.
RSA Aliveness Testing	• BNL: CatA, CatB, CatC • SLAC: CatC and CatD	Perform aliveness testing on three sensors at a time of a fully or partially populated RSA using an available production REB. Note that E/O testing of an RSA was not in the baseline plan.	• At both sites, the first RSAs to proceed through this process will be RTM #6 or RTM #9.
Heli-coil Insertion into Copper REC Walls	• BNL: CatA, CatB, CatC • SLAC: CatD	• Parts visually inspected prior to REC wall assembly. • Vacuum suction after heli-coil insertion.	High confidence hardware and process changes will generate less particulates as well as protect the protect rafts and sensors from generated particulates.
RTM Assembly: • RTM Assembly • GO/NOGO Verification of REC Hole Locations	• BNL: CatA and CatB	• Include the redesigned REC Bushing in assembly instructions. • Vacuum REC holes after any interface with hardware. • Verify any interface with REC/Cryo holes use appropriate hardware to minimize particulate generation.	• The first RTMs to proceed through this process will be ComRaft and RTM #1.
RTM Assembly: • RTM Assembly • GO/NOGO Verification of REC Hole Locations	• SLAC: CatC and CatD	• Include the redesigned REC Bushing in assembly instructions. • Vacuum REC holes after any interface with hardware. • Verify any interface with REC/Cryo holes use appropriate hardware to minimize particulate generation.	• The first RTMs to proceed through this process will be non-production RSAs. • The first production RTMs to proceed through this process will be RTM #8 or #14.

Change Description (completed by originator)			
RTM Installation into and Removal from TS7-Cryostat (TS22 and TS22B)	• BNL: CatA • SLAC: All Rafts	• Vacuum suction of exterior holes during A-frame installation and removal. • Clean A-frames prior to next use. • Vacuum suction and wipe TS7 holes and hardware after RTM removal and prior to next installation. • Vacuum REC holes after any interface with hardware. • Verify any interface with REC/Cryo holes use appropriate hardware to minimize particulate generation.	• As the first production RTM planned for testing in TS7 with all modifications, a rate-of-rise test on RTM #22 will validate the design of the modifications against Camera Contamination Control Plan requirements. This will be completed at BNL.
MF08 Cover Installation and Removal	• BNL: CatA, CatB, CatC • SLAC: All Rafts	• Ethanol wipe of cover before installation and after removal. • After each removal on an assembled RTM, visually inspect the holes for the MF08 Cover with a borescope to check for particulate. If needed, clean with a Q-tip soaked in ethyl alcohol.	High confidence hardware and process changes will protect rafts and sensors from generated particulates.
RSA/RTM Shipping and Receiving	• BNL and SLAC: CatA, CatB, CatC	• Provide instructions for packaging and receiving activities using an approved RSA shipping method. • After removing hardware between the Bell Jar and A-frame (or RSA shipping fixture), vacuum suction all holes and hardware. If needed, clean with a Q-tip or wipe soaked in ethyl alcohol. • After removing hardware between the A-frame and raft, vacuum suction all holes and hardware. If needed, clean with a Q-tip or wipe soaked in ethyl alcohol. • Verify any interface with REC/Cryo holes use appropriate hardware to	High confidence hardware and process changes will protect rafts and sensors from generated particulates.

Change Description (completed by originator)

		minimize particulate generation.	
Raft Installation into and Removal from Camera/Grid	• <u>SLAC</u>: All Rafts	• All fasteners used to attach the REC to the Camera Cryoplate are dicronite coated. The original torque specification included dicronite, and it will remain at 2.8 N-m. • All fasteners used for the REB Thermal Strap Assemblies and Camera Coldplate are dicronite coated. The original torque specification included dicronite, and it will remain at 2.0 N-m. • Include vacuuming the Cryoplate holes prior to raft installation in traveler instructions. • Change the threaded handling rods to deploy the REB Thermal Strap Assembles to dicronite coating on the threaded ends.	High confidence hardware and process changes will generate less particulates as well as protect the protect rafts and sensors from generated particulates.
Improvements to ESD Grounding Scheme and Safety Protocols	BNL & SLAC, All Rafts	• BNL to implement 3-point Ground – Common Ground for MF08, REB Thermal Strap Assembly, and REC Walls. • Common at both sites.	• SLAC manufactured grounding “trident” cables for both sites. • Measured zero Ohms of each attachment point prior to use on RTM.
Improvements to Monitoring and Safety Protocols for RTM Operation (Power-on and Imaging)	• <u>BNL</u>: CatA, CatB, CatC • <u>SLAC</u>: All Rafts	• Disallow power-up until verified clean to prevent further damage due to particulates. • SLAC to implement additional safety and monitoring precautions and protocols. • SLAC to use previously determined settings on any atypical channels/raft/REBs. • Both sites to implement refinement of fault protection (shorts) testing.	SLAC power-on and shorts test scripts were validated with non-production rafts using the for Camera Cryostat hardware and software environment. This software will be ported for use on a benchtop and in TS7 at both sites.

Change Description (completed by originator)

The plan includes the following newly designed fixtures as follows.

Table 8: Summary of new test equipment and fixturing for RTM handling, testing, assembling and shipment, with relevant engineering changes and validation evidence.

Fixture name	Description	Location of part design	Location of part fabrication	Prototyped (evidence)
e2v Sensor Cleaning Fixture	A majority of the design is complete, but further considerations are being evaluated before finalizing the design with input from cleaning of non-production sensors. • Safely hold e2v sensor for inspection and cleaning under microscope setup. • Provide unfettered access to clean all wirebonds on e2v sensors.	BNL	BNL	Inspect and clean prototype or non-production e2v sensor on the new fixture with the proposed station and equipment for production cleaning.
RSA Shipping Hardware	• Ship assembled RSAs (excluding RSA Thermal Straps) in Bell Jar, up to three. Note that shipment of RSAs was not in the baseline plan. • Utilizes current RTM Bell Jar and Shipping Crate designs.	BNL & SLAC	BNL	• Ship non-production RSAs (from an MTR) using the new RSA shipment hardware and the current Bell Jar and Shipping Crate. • Review quality of selected shipment method using data loggers and visual inspection after receiving from MTR RSA shipment.
Fixturing for RSA Aliveness Test (e2v Only)	• Design utilizes off-the-shelf components and hardware to hold the dedicated REB (no cold bars) and slide it over the RSA during testing. Note that only three sensors at a time will be tested. • Because the REB will not have cold bars, a fan will be required to cool the raft during testing. • Safely hold one REB above the RSA to conduct aliveness tests at 90 degrees.	BNL	BNL & SLAC	• Verify access to sensors and stability of setup with non-production RSA and REB. • At both sites, the first RSAs to proceed through this process will be RTM #6 or RTM #9.

Change Description (completed by originator)

	• Safely allow operator to mate/demate sensors and REB, as well as position and hold all test equipment and cabling. • This testing will confirm basic functionality between shipments of RSAs from BNL to SLAC.			
RTM Shipping Bracket	• 3D printed bracket to prevent movement or loosening of connection between RSA and REC during shipment. • Temporary fixture for shipment prior to REB Bushing upgrade to raft; not expected for use after a raft is upgraded.	BNL	BNL & SLAC	RTM Shipping Bracket was installed on four rafts before shipment and movement between the REC and RSA was checked after receiving. After receiving, force which initially displaced the REC assembly it was found that similar force on the REC did not displace the assembly as it did before use with the shipping bracket.

Change Description (completed by originator)

The cost for the change as it relates to technical effort is captured below. The positive numbers are the bottom up cost estimate for the new scope. In parenthesis is the funding remaining that will be used to offset the cost, leading to a total impact on the last row.

Table 9: Summary of cost for changes related to the technical effort.

Raft number	#1 - SR Inspect, Clean, Reconstruction, RTM Qual	#2 - SR Inspect, Clean, Reconstruction	#3 - I&T Disassemble REC, Inspect and Clean	#4 - I&T Disassemble REC, Ship to BNL	#5 - SR Inspect, Clean, Reconstruction (RSA Only)	#6 - I&T RTM Construction	#7 - I&T RTM Test	#8 - Phasing Impact	#9 - Shipping Containers, REC Walls, A-Frames, Other	Total (impact)
RTM01		41,700 (32,998)					16,419 (14,614)			10,507
RTM02				10,786	23,972	9,326	14,811 (-)			58,895
RTM03				10,786	23,972	9,326	14,811 (-)			58,895
RTM04				10,786	23,972	9,326	14,811 (-)			58,895
RTM05				10,786	23,972	9,326	14,811 (-)			58,895
RTM06	48,908 (31,939)						16,419 (14,614)			18,773
RTM07				10,786	23,972	9,326	14,811 (-)			58,895
RTM08			20,400			9,326	14,811 (-)			44,537
RTM09	54,008 (31,939)						16,419 (14,614)			23,873
RTM10	48,699 (40,151)						16,419 (-)			24,966
RTM11		41,700 (37,678)					30,595 (28,790)			5,827
RTM12				10,786	23,972	9,326	28,987 (14,176)			58,895
RTM13				10,786	23,972	9,326	28,987 (14,176)			58,895
RTM14			20,400			9,326	28,987 (14,176)			44,537
RTM15			20,400			9,326	18,275 (14,176)			33,825
RTM16				10,786	23,972	9,326	18,053 (14,176)			47,961
RTM17		41,700 (-)					16,419 (14,534)			43,586
RTM18			20,400			9,326	15,095 (14,534)			30,287
RTM19	54,008 (16,277)						16,419 (14,572)			39,578
RTM20		41,700 (16,277)					16,419 (14,614)			27,228
RTM21		41,700 (16,277)					16,419 (14,614)			27,228
RTM22	52,509 (62,614)	41,700 (32,998)					16,419 (-)			6,314
Misc								12,109	178,878	190,987
Total (impact)	**75,210**	**105,269**	**81,599**	**86,291**	**191,775**	**111,907**	**189,241**	**12,109**	**178,878**	**1,032,278**

In addition, $141K of labor is expected to be provided as contributed from UC Davis throughout item #3, #4, #6 and #7 for a cost reduction.

The level of effort cost impact is estimated below for 33 days of additional level of effort. Additional travel is added to support contributed labor coming from UC Davis.

Table 10: Summary of level of effort cost impact for changes related to the technical effort.

Sub-system	Resource	Hours/Dollars	Cost
3.01	Camera Project Management FY21	220 in FY21 (293 from FY20 carried over)	$23K
	Project Administrator FY21	98	
	Financial Manager FY21	117	
	PMCS Support FY21	117	
	Config, Document Manager FY21	49	
3.02	System Engineer FY21	147 in FY21 (293 from FY20 carried over)	
	Requirement manager FY21	98	

Change Description (completed by originator)

3.04.01.01	Sub-system manager FY19 extension by 6 months	132	$156K
	Travel FY19 extension by 6 months	$4,500	
	Materials & Supplies FY19 extension by 6 months	$1,250	
	Assembly & Test Facility - FY19 Consumables extension by 6 months	$3,336	
	Assembly & Test Facility - FY19 Contracting Services extension by 6 months	$3,365	
	Assembly & Test Facility - FY19 Cleanroom Space Charge extension by 6 months	$33,000	
	Assembly & Test Facility - FY19 Maintenance extension by 6 months	$5,294	
3.08.01	IT&C Subsystem Support-- FY21 extension by 2 months	147	$121K
	IR2 Facility Management - FY21 extension by 2 months	147	
	IR2 Facility Maintenance & Consumables – FY21 extension by 2 months	$8,544	
	UC Davis Travel	$45,000	

Justification for Change:

The project experienced 0.5% pixel loss from the month of August 2018 through the month of October 2018, at which point a stop work was issued to prevent further losses. An in-depth review was conducted on 11/16/2018 (see report LCA-17281), where the cause for the loss of channels was traced to a likely root cause being the presence of metallic particulates short-circuiting the CCD sensors. The external committee concurred that the current amount of particulate contamination is severe enough that particles must be removed and hardware retrofitted to prevent catastrophic failure of the camera during operation.

The project has two risks related to this issue that are marked as HIGH, which are described below. The mitigations to reduce these two risks to an acceptable level is currently not funded, estimated at $1.1M and is necessary to contain the risk exposure to insignificant and ensure project success.

Table 11: Summary of changes to risk registry.

SS ID	Risk Title	Risk Description (if/then)	Prob ability	Cost	Schd	Perf	Score	Current Exposure	Mitigation Title	Unfunded Cost	Prob ability	Cost	Schd	Perf	Score	Residual Exposure
Srft-078	CCD Channel loss due to shorts caused by metal particulate	IF metal particulate is generated from Science Raft hardware and/or construction processes, THEN the science raft team will have to address design changes and support retrofit.	5	3	3	2	15.8	High	Remove and prevent particulate generation	$500K	2	2	3	1	4.7	Insignificant
IT-045	Metal Particulate Contamination	IF metal particulate are generated or present inside the cryostat THEN additional efforts will be required for decontamination and re-verify.	5	3	3	2	15.8	High	Alternative Designs and Handling	$600K	1	3	3	2	3.2	Insignificant

Impacts and Hardware Affected:

22 Science Rafts will be impacted by this change.

All fixtures used to handle and assemble rafts will be impacted by this change

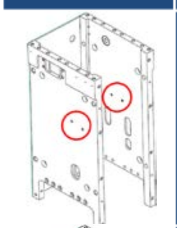
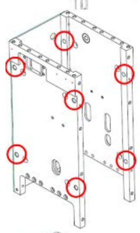
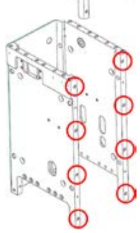
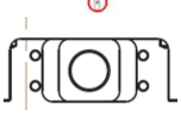
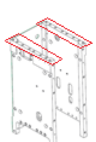
Not implementing this change would leave the LSST camera subject to increased number of lost channels appearing likely to an unacceptable levels.

The cost impact is ~$1.2M and 33 days of schedule delays.

Change Description (completed by originator)

Appendix A – REC Wall Upgrades:

Table 12: Summary of fasteners for REC Walls, with initial design and modifications.

Image	Hole Title	Original Design			Modified Design		
		Dimension	Engagement Length	Threads of Engagement	Heli-Coil Design	Engagement Length & Change	Threads of Engagement
	A	M3X0.5-6H THRU	4.34 mm	8.68	1D M3 Heli-Coil	3 mm (-1.34 mm)	6
	B	M6X1-6H THRU	6.32 mm	6.32	1D M6 Heli-Coil	4.48 mm (-1.84 mm)	4.48
	C	M3X0.5-6H THRU	2.82 mm	5.64	2.5D M3 Heli-Coil	6.82 mm (+4 mm)	13.64
	D	M3X0.5-6H x 8	4.3 mm	8.6	N/A – Cannot Implement & No Design Changes		
	E	M3X0.5-6H THRU	3.5 mm	7			
	F	M4X0.7-6H x 8MIN	Varies with Activity and Tooling	Varies with Activity and Tooling			