**JSC/EC5 Spacesuit Knowledge Capture (KC) Series Synopsis**

**All KC events will be approved for public using NASA Form 1676.**

*This synopsis provides information about the Knowledge Capture event below.*

**Topic**: Space Shuttle Extravehicular Mobility Unit Spacesuit Development for the International Space Station

**Date:** June 8, 2016 **Time:** 1:30 p.m. to 2:45 p.m. **Location:** JSC/B5S/R3102

**DAA 1676 Form #: 36698**

This is a link to all lecture material and video \\js-ea-fs-03\pd01\EC\Knowledge-Capture\FY16 Knowledge Capture\20160608 Steele Water Quality Module\1676 Review

*A copy of the video will be provided to the NESC Academy Online, NASA Technical Library and STI Program's YouTube, EA Engineering Academy, Spacesuit Knowledge Capture, and JSC History Office domains when the DAA 1676 review is complete.

**Assessment of Export Control Applicability Restricted:**

This Knowledge Capture event has been reviewed by the EC5 Spacesuit Knowledge Capture manager in collaboration with the author and is assessed to not contain any technical content that is export controlled. It is requested to be publicly released to the NESC and JSC Engineering Academy, as well as to STI for distribution through NTRS or NA&SD (public or non-public) and with video through DVD or Large File Transfer request or YouTube viewing with download of any presentation material.

* This file is also attached to this 1676 and will be used for distribution.

*For 1676 review use Synopsis Steele Water Module 6-08-2016.docx*

**Presenter:** John Steele

**Synopsis:** John Steele, a chemist and technical fellow from United Technologies Corporation, provided a water quality module to assist engineers and scientists with a metric tool to evaluate risks associated with the design of space systems with fluid loops. This design metric is a methodical, quantitative, lessons-learned based means to evaluate the robustness of a long-term fluid loop system design. The tool was developed by a cross-section of engineering disciplines who had decades of experience and problem resolution.

**Biography:** John Steele has been a chemist in the United Technologies Corporation (UTC) Aerospace Systems Windsor Locks Materials Engineering Group for 33 years and a UTC technical fellow for 9 years. He has provided chemistry-related expertise for numerous development, design, manufacturing, and field-support activities. Mr. Steele's contributions encompass a wide range of environmental control, life-support, and thermal control systems that his business unit provides to NASA and the military. Mr. Steele wrote or co-wrote 43 technical papers related to his areas of expertise. He also holds 19 U.S. Patents awarded for novel chemical analysis techniques, specialty coolants, and multi-purpose coatings. Mr. Steele earned three masters of science: one from Central Connecticut State University in chemistry and two from Rensselaer Polytechnic Institute (one in engineering management and one in environmental management and policy).

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# Development and Implementation of a Design Metric for Systems Containing Long-term Fluid Loops

**Instructor: John W. Steele**

**June 8, 2016**

# Course Objectives

Upon completion of this course, you will be able to do the following:

- Identify common failure modes for long-term fluid loops
- Understand basic risk resolution approaches to consider for systems containing a long-term fluid loop
- Quantify the risk associated with the design of a system containing a long-term fluid loop

# Agenda

- Background
- Examples of Long-term Fluid Loop Mishaps
- Common Failure Modes
- Resolution Approaches
- Long-term Fluid Loop Design Metric Tool
- Example of Metric Tool Use
- Summary/Questions

# Background: Driven by a Repeat Mishap Resolution – Kaizen Event

Note: All fields in YELLOW are required

**Space Systems**
**Project Proposal/Charter**

| | | | |
|---|---|---|---|
| Project Name: | Develop Long-life Fluid Loop Design Standard Document<br><br>Standard Work Kaizen | Project Scope: | Development of a standards document for the design, management and recovery from upset for long-life fluid loop ECLSS hardware/systems |
| Chartering Team | | Deliverables: | Document with a set of standards for the design, management and recovery from upset for long-life fluid loops |
| Rationale: | There have been recurring operational problems with long-term HS SS ECLSS hardware that contains fluid loops (primarily water). Common failure modes include long-term fluid instability, lack of system/component tolerances to contaminants, inadequate maintenance approaches, and a lack of planned methodology for on orbit recovery from an upset. The HS SLS Business Unit would greatly benefit by the establishment of design standard for such hardware. The initial payback to such an effort would be cost avoidance for potentially affected Programs. There is the potential for new business opportunity enhancement as well for Commercial Space ECLSS hardware offerings. This is envisioned as a three-phase approach as follows:<br><br>- Preliminary outline prepared by the Project Lead<br>- 2-day Kaizen with a group of business unit experts<br>- Consolidation of expert input and final write-up by the Project Lead | | |
| Sr. Mgt. Sponsor: | J. Ferketic | Customer(s): | SS Engineering Community |
| BOEs Required (Y/N) Y | Event Passport Required (Y/N): N | Cost or Schedule Metrics Required (Y/N): | N |
| Project Lead: | J. Steele | | |
| Kaizen Team Members: | Galen Kulp (Systems), Dorsey Schaper (Design), Tony Rector (Chemical Engineering), John Steele (Chemistry), Derrick Obara (Materials and Processes), Jesse Peterson (Facilitator), Steve Dionne (Preliminary Design – Commercial), Art Colling (Project), Matt Dowling (Facilitator) | | |

------------------ **Cost Estimate ($K)** ------------------

| Space Systems | Houston | Pomona | Rocketdyne | Rockford | Windsor Locks |
|---|---|---|---|---|---|
| 8.5 | | | | | |

**Charge #'s**

| | | | | | |
|---|---|---|---|---|---|
| | | | | | |

| | |
|---|---|
| Schedule: | 2- month |

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| | |
|---|---|
| Improvement Goals: | • Enhancement of future designs<br>• Uniform Program recommendations for existing designs<br>• Selling point to the Commercial Space market |
| Mgt. Rpt. Protocol: | Periodic updates to Transformation Team |
| Pilot Plans: | None |
| Benchmarking Plans: | None |
| Training Plan: | None |
| Procedural Plan: | Potential adoption into the Business Unit Design Standards Documents |
| Communication Plan: | Communication memo to affected Programs and New Business |
| Deployment Plan: | Deployed per Design Standards for future programs and per existing Program as appropriate |

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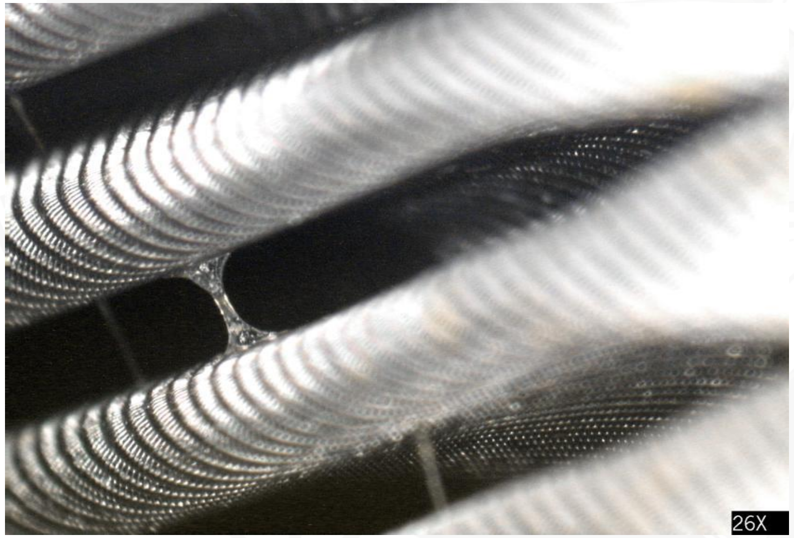
# Rationale Examples

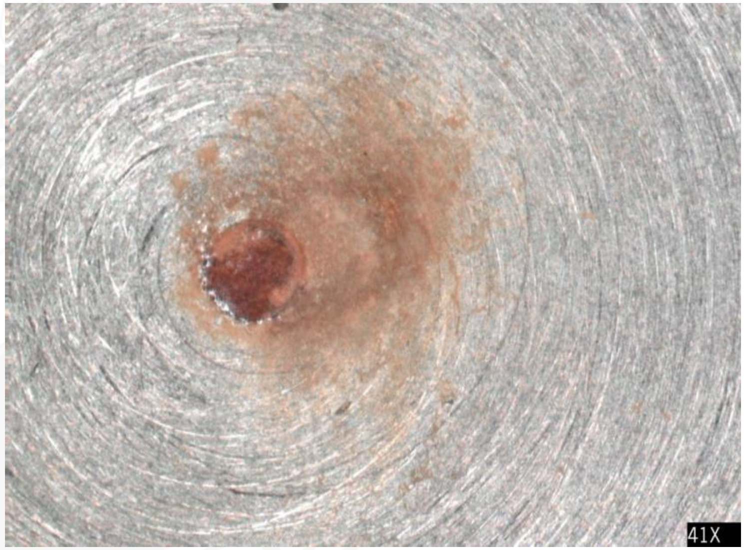
- **Extravehicular Mobility Unit (EMU) Transport Water Loop** – Inorganic precipitation and uncontrolled biological growth led to the fouling of the Item-123 Fan/Pump/Separators on International Space Station (ISS) post-Columbia. The fix was hardware and a process to periodically scrub and disinfect the loops on-orbit.
- **EMU Feed Water Loop** – The ISS Water Processor Assembly (WPA) water is not compatible with the EMU Sublimator. Fixes are being worked, and will likely include a scrubber bed and a Sublimator Porous Plate Orbital Replacement Unit (ORU) design.
- **WPA Waste Water Mostly Liquis Separator (MLS) ORU** – Several episodes of biofouling has occurred with this hardware. A temporary fix has been put in place External Filter Assembly (EFA), but this issue has yet to be fully resolved.
- **Oxygen Generation Assembly (OGA) Electolysis Cell Water Recirculation Loop** – Corrosion products have led to filter fouling and cell cation contamination, requiring an ORU replacement. An existing scrubber bed has been implemented as a temporary fix. A tailored bed for this application is being considered.
- **ISS Internal Active Thermal Control System (IATCS) Coolant Loop** – Inorganic precipitation and uncontrolled microbial growth led to gas trap and pump package fouling. Fixes included a reformulation of the coolant, periodic adjustments to the coolant constituents, and periodic addition of a biocide.
- **Shuttle Urine Processor Assembly (UPA) Collection and Stabilization** – Inorganic fouling of the Phase Separator led to system fouling on orbit. The fix was a reformulation of the pre-treat chemicals.
- **Orion IATCS Coolant Loop** – Corrosion product fouling of the NASA/JSC long-term Moon base coolant loop technical demonstrator led to heat exchanger fin stock fouling. The fix was use of a reformulated coolant.

# EMU (Spacesuit) Example – Fouling

- EMU - developed in the late 1970s
- Upgraded for the ISS in the 1990s
- On-orbit use time has drastically increased and is still increasing
- Long-term water coolant loop stagnation after the Shuttle Columbia accident lead to the fouling of tight tolerance magnetically coupled pumps with biofilm and inorganic precipitates rendering the EMUs non-usable



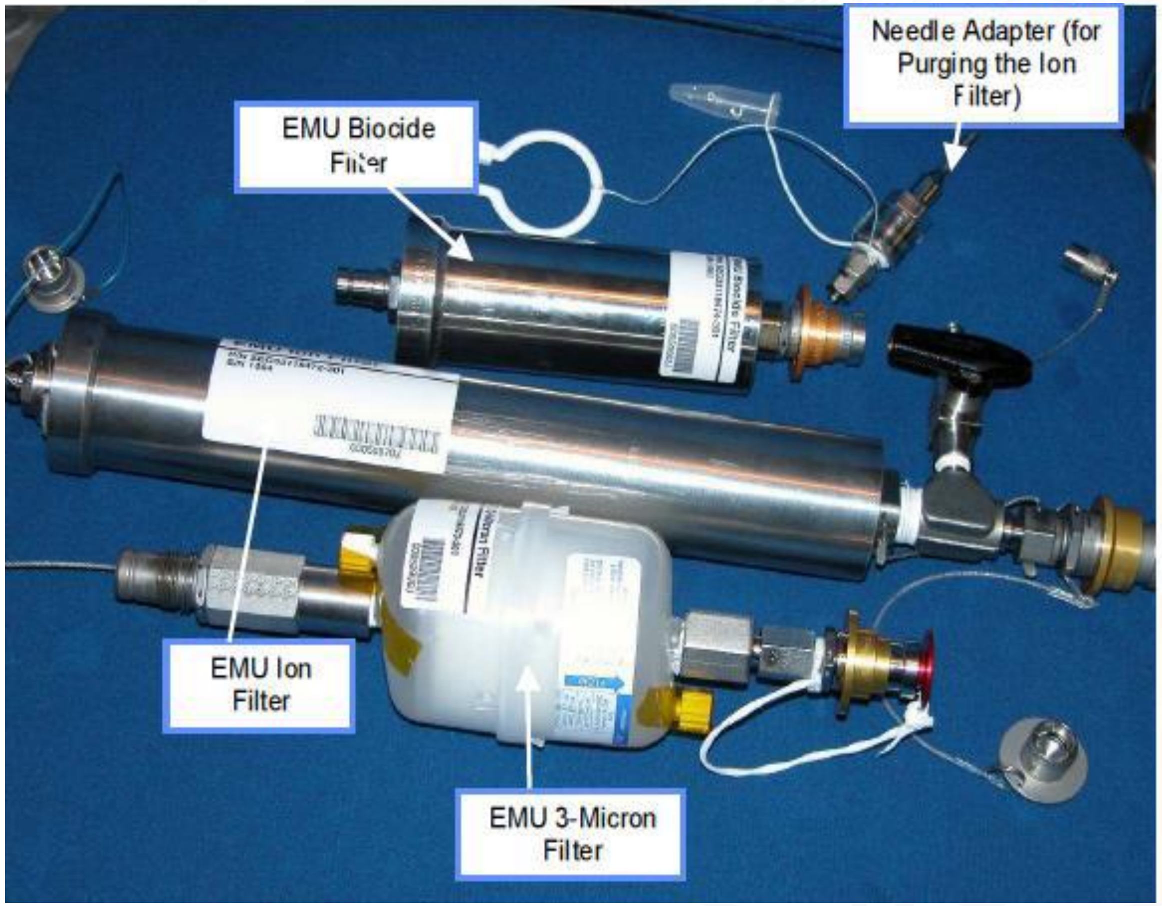

Biofilm Blocking Gas Trap



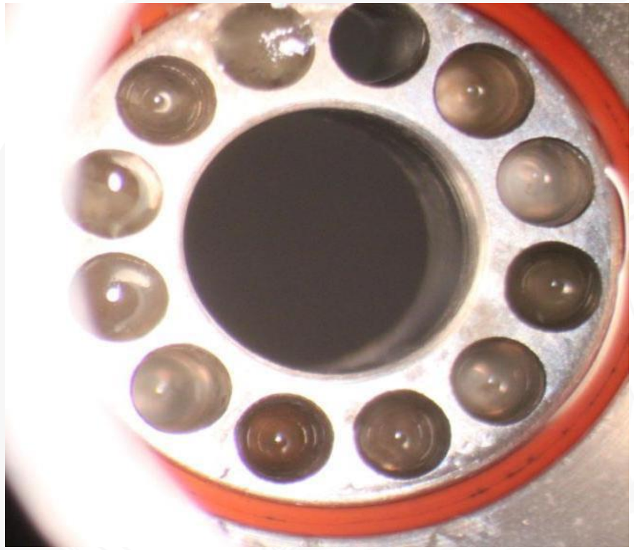

Inorganic Precipitates Blocking Water Passage

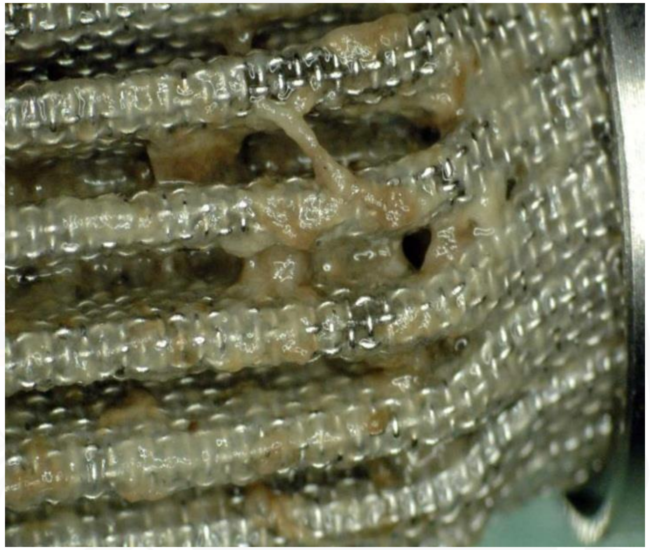
# EMU Example – Resolution

Implementation of a periodic water coolant loop scrub cycle with an ion exchange resin/activated carbon bed followed by the addition of a biocide with an iodine resin bed was the fix put in place.

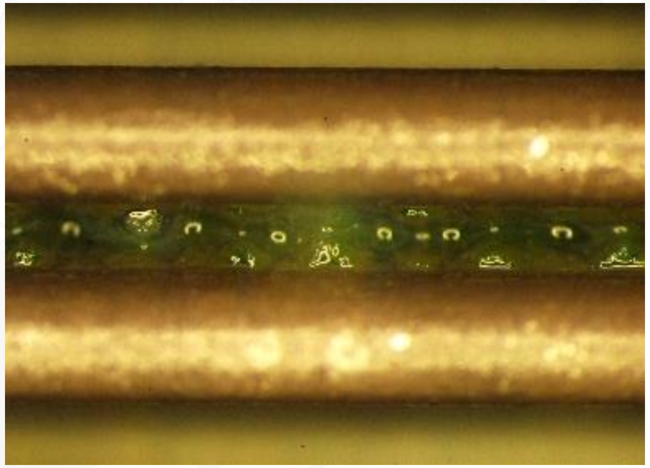



## Other Examples of Mishaps





Biofouling - Front-end of the ISS Potable Water Processor



Propylene Glycol Coolant Instability Aluminum Phosphate Precipitates Orion Program

# Common Failure Modes

- Lack of design robustness
- Long-term fluid instability and/or reactivity
- Inadequate means to monitor fluid health during long-term use
- Inadequate maintenance procedures
- Lack of adequate in-service fluid requirements
- Minimal “design for recovery” planning
- No centralized knowledge-capture or lessons-learned to pass on to other programs with similar fluids and/or applications

# Resolution Approaches

- Fix/resolve as-needed – reactive (not recommended)
- Pre-emptive maintenance for existing systems based on lessons learned from similar systems (empirical evolution)
- Design Standard Metric for hardware features and fluid health control to assess and react to risk, before a mishap occurs (focus of this course) – proactive

# Design Metric - Description

- A quantitative means to judge the risk associated with United Technologies Aerospace Systems (UTAS) hardware containing fluid loops in any phase of the Program
- Applies to systems with fluid loops (continual or intermittent), closed and open loops, aqueous, and non-aqueous (based on assumption of charged with fluid or "wet" state for >6 months)
- Multi-purpose metric tool:
  - ➢ New design – PD [preliminary design], DD [detail design] and V&V [validation & verification] stages
  - ➢ Revisit existing designs (risk mitigation, new business opportunities)
  - ➢ Forward work – demonstrate lessons learned expertise, capture and use

# Design Metric – Development Plan

- Establish working team of experts (chemistry, microbiology, chemical engineers, materials & processes, design, systems)
- Historical system data capture (review past mishaps)
- Current UTAS Space hardware/system status
- Standardized approach development:
  - Tech Standard & Standard Work
  - Retroactive implementation as appropriate
  - Common fixes for recurring issues
- Evaluate opportunities to expand and leverage:
  - Other UTAS Business Units
  - Current customer base (new business opportunities)
  - Cite as a core competency for new business competition

## Long-Life Fluid Loop Design Metric Tool – Architecture for Implementation

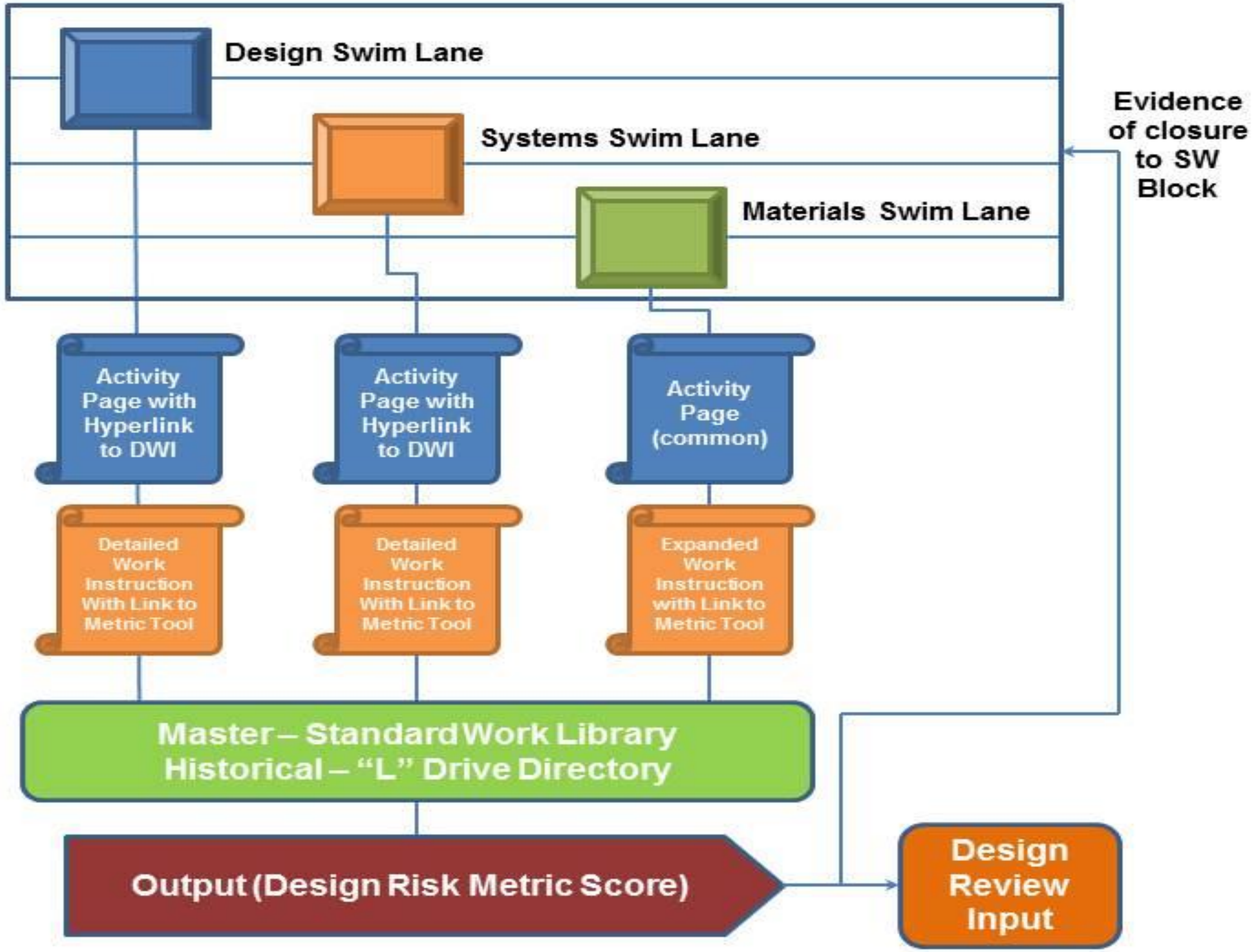
1) **Standard Work** flow maps for "Generic System " and "Generic Mechanical Component", (PD, DD & V&V)

2) **Activity Pages** that address design requirements . Cite Long-Life Fluid Loop Design Standard output requirement.

3) **Expanded Work Instructions** for long-term fluid loops detailing purpose, applicability, UTAS or Eng. Documents for written instructions, hyperlinks to Master Survey and historical storage site, etc.

4) **Standard Work Library and "L" Drive Locations:** Master – SW Library Historical – "L" Drive Potential Sharepoint move

5 **Report Output** with risk metric based on functional group input. Present at PD, DD and V&V reviews and serves as evidence of closure.



# Design Metric – Expanded Work Instruction Content

- Purpose (of work instruction)
- Applicability (type of product it applies to)
- Definitions
- Input Source (requirements)
- Tools (references and the subject Design Metric))
- Procedure (step-by-step instructions)
- Output (format of communication)
- Success Criteria (means to determine adequate output)

# Generic Standard Work – Mechanical Component and Generic System Maps

| Design Phase | Eng. Spec. | Systems | Design |
|---|---|---|---|
| Preliminary Design (link) | • Establish materials and processes (M&P) Flow Down Requirements | • SLS-GSY-2-SYS-030 "Preliminary Thermal / Fluid Analysis"<br>• SLS-GMC-2-SE-010 "Component Requirements Review" | • SLS-GMC-2-MD-110 Concept Review C2 |
| Preliminary Design (check) | • Perform Preliminary M&P Design Review | • SLS-GSY-2-SE-131 "Concept Review (S1)" | • SLS-GMC-2-MD-110 Concept Review C2 |
| Detailed Design (link) | • Design Review M&P Selection | • SLS-GSY-3-SE-030 Manage Schematic and Interface Changes<br>• SLS-GMC-3-SE-020 Manage Schematic and Interface Changes | • SLS-GMC-2-MD-110 Concept Review C2 |
| Detailed Design (check) | • Complete M&P Data Items | • SLS-GSY-3-SE-035 Systems Review (S3) | • SLS-GMC-3-MD-115 "Design Definition / Layout Approval (C3)" |
| V & V (link) | • Create Verification by Analysis Documents | • SLS-GSY-4-SE-030 "Finalize Validation Plan" | N/A |
| V & V (link) | • Create Verification by Analysis Documents | • SLS-GMC-4-SE-050 "Review / Update Verification Procedures" | N/A |

# Design Metric Questionnaire – Page 1

| | System Definition | Functional Group | No | Limited | Mostly | Yes | N/A | COMMENT |
|---|---|---|---|---|---|---|---|---|
| 1 | Is there a well-defined, full system interface, especially if UTAS Space is not designing the entire fluid loop? | Systems | ○ | ○ | ○ | ○ | ○ | |
| 2 | Is there a well-defined set of fluid requirements and properties that must be maintained through the life cycle of the fluid loop? | Systems | ○ | ○ | ○ | ○ | ○ | |
| 3 | Have all modes of system operation been identified and conveyed to the IDP Team? | Systems | ○ | ○ | ○ | ○ | ○ | |
| 4 | Have you ensured that the fluid property changes that may occur over the range of operation will meet the application needs? | Systems | ○ | ○ | ○ | ○ | ○ | |
| 5 | Have you reviewed the literature and/or benchmarked similar best-in-class systems to ensure up-to-date design practices and approaches have been incorporated? | Systems | ○ | ○ | ○ | ○ | ○ | |
| 6 | Are there identified risks associated with the selected fluid that may impact performance of the system over the life of the design that have been budgeted and/or planned for? | Systems | ○ | ○ | ○ | ○ | ○ | |
| 7 | Have you ensured that identified risks are shared with internal and external customers? | Systems | ○ | ○ | ○ | ○ | ○ | |
| 8 | Have you involved the appropriate HS Space long-life fluid loop design experts from Design, Systems Engineering, Engineering Specialist Group and Advanced Technologies early in the design process? | Systems | ○ | ○ | ○ | ○ | ○ | |
| 9 | Have you reviewed lessons learned for similar systems previously designed by UTAS Space? | Systems | ○ | ○ | ○ | ○ | ○ | |
| 10 | Have you captured any new lessons learned from the development of this system into Standard Work? | Systems | ○ | ○ | ○ | ○ | ○ | |
| 11 | Have you revisited this questionnaire when significant changes to the fluid or significant changes to components that can affect fluid quality have occurred? | Systems | ○ | ○ | ○ | ○ | ○ | |
| | **Material Definition** | **Functional Group** | **No** | **Limited** | **Mostly** | **Yes** | **N/A** | **COMMENT** |
| 1 | Have you researched and/or tested materials compatibility with the working fluid to ensure proper wetted materials are selected? | Engineering Specialists | ○ | ○ | ○ | ○ | ○ | |
| 2 | Have you identified potential corrosion products or material extractables that may impact system performance? | Engineering Specialists | ○ | ○ | ○ | ○ | ○ | |

# Design Metric Questionnaire – Page 2

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 3 | Have you researched and/or tested fluid compatibility with the base-line wetted materials to ensure that corrosion products and/or non-metallic material extractable will not adversely impact fluid quality and/or performance requirements? | Engineering Specialists | ○ | ○ | ○ | ○ | ○ | |
| 4 | Have you evaluated the need for performance enhancing additives to the fluid such as biocides, corrosion inhibitors, pH buffers, etc.? | Engineering Specialists | ○ | ○ | ○ | ○ | ○ | |
| 5 | If the baseline fluid is considered to be inadequate, have you evaluated alternatives or in-house fluid formulations and/or additives? | Engineering Specialists | ○ | ○ | ○ | ○ | ○ | |
| | **Design** | **Functional Group** | **No** | **Limited** | **Mostly** | **Yes** | **N/A** | **COMMENT** |
| 1 | Have you ensured that the customer requirements for the fluid loop are realistic? If they are not, have you revisited the requirements with Project? | Design | ○ | ○ | ○ | ○ | ○ | |
| 2 | Have you minimized the fluid loop wetted component complexity such that restrictive flow passsages have been eliminated to prevent the collection points for precipitates and/or biological material? | Design | ○ | ○ | ○ | ○ | ○ | |
| 3 | Have you ensured compliance with the appropriate fluid loop related sections of TS 0301, TS 0601 and TS 3506? | Design | ○ | ○ | ○ | ○ | ○ | |
| 4 | Have you ensured the incorporation of appropriate rated filters to protect critical components? (filter rating finer than critical component tolerance)? | Design | ○ | ○ | ○ | ○ | ○ | |
| 5 | Have you incorporated design features that will ensure that the system will operate as required in the presence of corrosion products or material extractables that will be present as identified by the Engineering Specialists Group? | Design | ○ | ○ | ○ | ○ | ○ | |
| | **Validation** | **Functional Group** | **No** | **Limited** | **Mostly** | **Yes** | **N/A** | **COMMENT** |
| 1 | Has the Advanced Technologies, Engineering Specialist Group or other entity used ground-based simulation hardware or a technical demonstrator breadboard under system-like conditions (internal and external) to prove-out adequate fluid performance of the system through the required life cycle? | Engineering Specialists | ○ | ○ | ○ | ○ | ○ | |
| | **Maintenance/Recovery** | | **No** | **Limited** | **Mostly** | **Yes** | **N/A** | **COMMENT** |
| 1 | Have you evaluated the stability of the fluid over the life cycle of the system for all system operational transitions that could potentially impact the solubility of fluid constituents (temperature or pH excursions, presence or absence of nucleation sites, etc.) particularly for mixtures? | Engineering Specialists | ○ | ○ | ○ | ○ | ○ | |

# Design Metric Questionnaire – Page 3

| | | | | |
|---|---|---|---|---|
| 2 | Have you evaluated the need for periodic additive adjustments while the hardware is in service (i.e. periodic addition of a biocide, corrosion inhibitor, pH buffer)? | Engineering Specialists | ○ ○ ○ ○ ○ | |
| 3 | Have you ensured an ease of maintenance approach to the design such that vulnerable components (i.e. filters) can easily be serviced and/or changed out once the system is in operation? | Design | ○ ○ ○ ○ ○ | |
| 4 | Have you developed a preventive maintenance plan such that life-limited components (i.e. filters) are changed out in a routine manner? | Systems | ○ ○ ○ ○ ○ | |
| 5 | Have you evaluated the need for sensors to ensure the maintenance of fluid health while the system is in service (i.e. pH, conductivity)? | Systems | ○ ○ ○ ○ ○ | |
| 6 | Have you incorporate design features for a periodic sampling of the fluid for external analysis while the hardware is in service? | Design | ○ ○ ○ ○ ○ | |
| 7 | Have you evaluated the need for a permanent or periodic ion exchange/organic adsorbent bed in the design? | Engineering Specialists | ○ ○ ○ ○ ○ | |
| 8 | Have you incorporated design features that will allow for fluid loop recovery in the event of a fouling and/or precipitate upset? | Design | ○ ○ ○ ○ ○ | |
| 9 | Have you considered the periodic cycling of the fluid during long periods on non-use? | Systems | ○ ○ ○ ○ ○ | |
| 10 | Does the fluid require periodic change-out, and will the system design readily accommodate this? | Systems | ○ ○ ○ ○ ○ | |

| Factor | Score |
|---|---|
| System Definition | 0 |
| Material Definition | 0 |
| Design | 0 |
| Validation | 0 |
| Maintenance / Recovery | 0 |
| ***Overall Total (Average)*** | ***0*** |

**Submit**

**Clear Survey**

**Scoring Key: 0 - 50 = High Risk of Failure**
**51 - 70 = Moderate Risk of Failure**
**71 - 85 = Low Risk of Failure**
**86 - 100 = Optimal Design**

# Design Metric – Scoring of Questionnaire

- Score each factor as indicated:

  - No = 0 - Limited = 1

  - Mostly = 2 - Yes = 3

  - N/A = no score (do not include in the % calculation denominator)

- Total score of answered questions / # of answered questions x 100 = % per category (categories = System Definition, Material Definition, Design, Validation, maintenance/Recovery)
- Average of %s per category = overall total average
- Report scores at each level design review

  - 0 – 50 = High Risk of Failure
  - 51 – 70 = Moderate Risk of Failure
  - 71 – 85 = Low Risk of Failure
  - 86 – 100 = Optimal Design

Sanity Checked with Several Known UTAS Fluid-Loop Systems

# Summary

- Long-term fluid loop designs have been particularly challenging, resulting in several UTAS Space Systems mishaps.
- Many of the mishaps share common, recurring failure modes indicating that a tool could be developed to quantify risk for existing and future designs.
- A Design Metric for Systems containing long-term fluid loops has been developed and integrated into the UTAS Space Standard Work Tool.
- The Design Metric can be used at any state of a program and is of most use for an evolving design.