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Best Practices for Organizational Resilience in the International Space Station (ISS) Program

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Nomenclature

CAIB	Columbia Accident Investigation Board
CAPCOM	Capsule Communicator
CTA	Cognitive Task Analysis
ENG	Engineering
EVA	Extravehicular Activity
FOD	Flight Operations Directorate
FCT	Flight Control Team
GC	Ground Control
HAP	Helmet Absorption Pad
IFI	Item for Investigation
IMMT	ISS Mission Management Team
ISS	International Space Station
JSC	Johnson Space Center
LVT	Low Voltage Trip
MC	Mission Control
MER	Mission Evaluation Room
MIB	Mishap Investigation Board
MSFC	Marshall Space Flight Center
NESC	NASA Engineering and Safety Center
PRACA	Problem Reporting and Corrective Actions
PRO	ISS Program Office
RAG	Resilience Analysis Grid
RE	Resilience Engineering
RQ	Research Question
SMA	Safety and Mission Assurance
SSP	Space Shuttle Program
TDT	Technical Discipline Team

1.0 Executive Summary

The International Space Station (ISS) is a multifaceted international sociotechnical system with a U.S. Operating Segment that is managed by the NASA ISS Program. This program is responsible for making high-stakes decisions for operations and safety in both flight and ground operations. Following a close call during an extravehicular activity (EVA) [ref. 1], in which an astronaut experienced impaired visibility and breathing, the Mishap Investigation Board (MIB) identified "normalization of deviance" as a reason that early signals were missed in identifying that the situation was taking a turn for the worse. The MIB recommended the ISS Program "institute requirements and behaviors that combat the tendency towards complacency." In 2016, the ISS Program requested an independent assessment by the NASA Engineering and Safety Center (NESC) Human Factors Technical Discipline Team (TDT) to provide guidance.

Conventional solutions to addressing complacency and normalization of deviance have remained elusive. Resilience engineering represents an emerging approach to risk management that focuses on an organization's ability to continuously recalibrate (i.e., accommodate change and recognize subtle cues signifying impending disruptions, changes, or pressures). This assessment employs principles of resilience engineering to determine where the ISS Program exhibits properties of a resilient organization and where there are opportunities to increase resilience.

Traditional organizational assessments utilize risk management approaches focused on reactive responses to risks identified through hazard analysis or following an accident investigation. The conventional method for managing risk and safety systems seeks to control and reduce variability in organizational performance, in part by instituting forms of restriction and compliance. While a tightly monitored system with more procedures and processes may prove effective in reducing or stabilizing some types of errors and accidents, it does not possess flexibility, transparency, or the ability to anticipate system changes or disruptions. A resilient organization is able to effectively adjust its functioning prior to, during, or following expected or unexpected disturbances, so that it can sustain required operations. In contrast, a brittle system operates at unsafe margins and fails to recognize warning signals or adjust in time to continue proper function.

The NESC assessment team used the Resilience Analysis Grid (RAG) framework to structure data collection and analysis [ref. 2], which identifies four basic capabilities of resilient systems:

- *Anticipate* – Knowing what to expect (i.e., how to anticipate developments and threats further into the future, such as potential disruptions, pressures, and their consequences).
- *Monitor* – Knowing what to look for (i.e., how to monitor what is or could become a threat in the near term). The monitoring must cover what happens in the environment and in the system (i.e., its own performance).
- *Respond* – Knowing what to do (i.e., how to respond to regular and irregular disruptions and disturbances by adjusting normal functioning).
- *Learn* – Knowing what has happened (i.e., how to learn from experience, in particular to learn the right lessons from the right experience).

Based on NESC assessment team member expertise and informal interviews with ISS personnel, the team identified two research questions (RQs) that would inform the inquiry:

1. How does the ISS Program handle unanticipated signals that indicate potential safety threats?
2. How does the ISS Program balance ongoing resource constraints with pressures for productivity and efficiency?

The NESC assessment team used these questions to identify additional issues related to the inquiry, identify research questions to ask, and identify potential sources for information. The RAG framework was used to develop specific queries to support RQ investigation.

Data were collected in three ways:

1. Structured interviews with 17 ISS personnel members across 8 roles and 4 organizations. These interviews were coordinated through the ISS Program contact, and the individuals were highly cooperative throughout the scheduling and interview processes.
2. Direct observation of real-time ISS operations, including four EVAs, one visiting-vehicle event, and a post-EVA debrief meeting.
3. Analysis of ISS documents, presentations, and transcripts of recorded meetings.

NESC assessment team used inductive thematic analysis to extract meaningful patterns and findings from the structured interviews with ISS crew and ground support personnel. Thematic analysis of qualitative data is a method for identifying, analyzing, and reporting patterns within data. [ref. 3]. Data analysis translated observed phenomena into findings that describe the work domain.

The findings and observations presented in Section 4.0 can be summarized as:

- The ISS Program relies on traditional approaches to risk management and linear causal models of events that oversimplify operational situations.
    - This approach can potentially affect detection of emerging unanticipated threats.
- The ISS Program is thorough in planning for known nominal and off-nominal events.
    - However, for some personnel, this thoroughness creates a presumption that all risks have been identified and planned for.
- ISS personnel feel they are encouraged to provide their own and seek out others' perspectives to inform decision making.
    - However, cross-organizational challenges and perceived mixed messages from ISS Program leadership can create unintended pressures to "stay quiet," resulting in missed opportunities to raise concerns.
- ISS Program roles are generally well-defined.
    - However, some ISS personnel do not adequately understand others' roles, which can lead to devaluing those roles, minimizing their influence, and failing to appreciate the impacts of their own decisions on others' responsibilities.
- The ISS Program values and relies on experts' operational experience and system knowledge in responding to planned and unplanned events.
    - However, ISS risks losing this expertise through retirement, rapid turnover, and insufficient means to transfer expertise to new personnel.

- The ISS Program values documentation.
    - However, the documentation and resolution processes are perceived by ISS personnel as onerous.
    - Lessons and trends are not consistently captured, and it is unclear to some ISS personnel how or if captured information is translated into results.

These findings resulted in 14 NESC recommendations, intended to improve the adaptive capacity of the ISS Program by enabling the following potential benefits:

- Improved ability to recognize and promote resilient performance
    - Leveraging new approaches to risk management
- Better preparation to respond to uncertain and unanticipated situations
    - Developing a practice to manage emerging risks and troubleshooting
    - Developing skills to notice when uncertainty is increasing
    - Training and practicing decision making under uncertainty
    - Gaining tangible experience with surprise, subtle cues, and uncertainty
- Improved ability to overcome effects of routine
    - Implementing structured pre-mission briefs focused on risks and contingencies
    - Making risk trade-off decisions explicit across all ISS teams
- Increased chances that people will speak up and be heard when they have safety concerns
    - Building relationships and cross-role understanding
    - Increasing involvement of other teams with ISS operational personnel in simulations and training
- Improved ability to manage uncertainty and system risks inherent in complex sociotechnical systems
    - Expanding incident analysis methods and learning from incidents
    - Identifying opportunities for process improvements by developing understanding of how work actually gets done
- Improved ability to learn and adapt from events
    - Expanding knowledge management programs
    - Implementing structured post-mission briefs focused on surprise and proximity to safety boundaries
    - Supplementing anomaly reporting and resolution processes with methods to improve learning and anticipation

The NESC assessment was limited to ISS participants who engaged in or directly supported real-time flight operations. The assessment did not include ISS international or commercial partners. The assessment timeframe was approximately 12 months, and this report was delivered in September 2017.

2.0 Problem Description, Background, and Scope

2.1 Problem Description

The ISS is a multifaceted international sociotechnical system with a U.S. Operating Segment that is managed by the NASA ISS Program. This program is responsible for making high-stakes decisions for operations and safety, both in flight and ground operations. Following a close call during an EVA [ref. 1], in which an astronaut experienced impaired visibility and breathing, the MIB identified "normalization of deviance" as a reason that early signals were missed in identifying that the situation was taking a turn for the worse. The MIB recommended the ISS Program "institute requirements and behaviors that combat the tendency towards complacency." The ISS Program requested an independent assessment by the NESC Human Factors TDT to provide guidance.

Conventional risk management is a continuous process that identifies risks; analyzes their impact in terms of likelihood and consequence; develops and executes risk response plans; supports informed, timely, and effective decisions to control risks and mitigation plans; and assures that risk information is documented and communicated to appropriate ISS personnel. Specifically, the risk process should assess continually what could go wrong (risks), determine which risks are important, implement strategies to deal with those risks, and measure the effectiveness of implemented strategies. Risk management focuses on reducing undesired outcomes by reducing the number or frequency of undesired events. These approaches emphasize predicting failure probabilities, executing plans to control risk, and documenting information to assess effectiveness of control strategies. NASA has a history of employing such approaches, which have been successful in promoting system safety. However, solutions to addressing concerns like complacency and normalization of deviance have remained elusive.

Resilience engineering represents an emerging approach to risk management that focuses on an organization's ability to constantly recalibrate (i.e., to accommodate change and recognize subtle cues signifying impending disruptions, changes or pressures). Thus, a distinction can be drawn between how an organization handles adverse events that have been planned for (i.e., via conventional risk management strategies), and how the organization recognizes when events fall outside of planned or predicted conditions. Unanticipated conditions or events may arise because a) the organization's model of the situation, environment, or performance envelope is incomplete, or b) the environment changes in ways that undermine the effectiveness of the employed risk mitigations [ref. 7]. Resilience engineering approaches to risk management assume that, for complex missions, situation models will always be incomplete and the potential for environmental changes will always be present. The focus of resilience engineering is on an organization's capacity to adapt relative to challenges to that capacity (i.e., what sustains or erodes the organization's adaptive capacity?) One factor that can reduce an organization's capacity to adapt is pressure to be productive and efficient, which can erode sources of resilience. The tension between being productive and being safe may lead to tradeoff decisions that are riskier than intended or desired.

One goal of this assessment was to employ resilience engineering principles to determine if the ISS Program exhibits properties of resilient performance by asking the following RQs:

RQ1: How does the ISS Program handle unanticipated signals that indicate potential safety threats?

RQ2: How does the ISS Program balance ongoing resource constraints with pressures for productivity and efficiency?

2.2 Background

The creation of NASA in 1958 was the beginning of the United States' mission to achieve human spaceflight. The Mercury, Gemini, and Apollo programs began the process of learning whether humans could survive in space for prolonged periods. The Space Shuttle Program (SSP) launched in 1981 and operated for 30 years, contributing to the assembly and operations of the ISS. Humans have now inhabited the ISS continuously since November 2, 2000.

The 1986 Challenger accident occurred during a time when great pressure and expectations for success were placed on the SSP [ref. 5]. The Challenger broke apart 73 seconds into its flight, killing all seven crew members. In addition to the proximate cause of the accident, the Rogers Commission Report identified numerous contributing organizational phenomenon. One such phenomenon was a highly compressed launch schedule, which led to abbreviated training schedules and a focus on short-term resource shortages. Another significant factor was a silent safety culture characterized by an insufficient means of reporting problems, inadequate trend analysis, misrepresentation of criticality, and a lack of involvement of safety professionals in critical discussions. In a later analysis of the Challenger accident, social psychologist Diane Vaughan developed her theory of normalization of deviance, which was defined as the gradual process through which unacceptable behaviors, practices or standards, through repetition without catastrophic results, become the acceptable organizational norm [refs. 8, 9].

In 2003, the orbiter Columbia was destroyed during re-entry into the Earth's atmosphere, resulting in the loss of seven crew members. The Columbia Accident Investigation Board (CAIB) conducted a 7-month inquiry, releasing a final report identifying proximate and root causes [ref. 4]. NASA was required to implement numerous changes before SSP missions returned to flight. The CAIB identified a broken safety culture as an organizational cause of the accident. Included in that broken safety culture were complacency and a systematic normalization of deviance.

The NESC was formed in 2003 to fill the need for an independent resource available to NASA programs that could provide alternative perspectives to complex technical issues. The NESC is independently funded and comprises teams of technical experts that provide objective engineering and safety assessments of high-risk projects to ensure mission success.

On July 16, 2013, two crew members were conducting maintenance outside the ISS during EVA 23. Forty-four minutes into the EVA, a crew member reported water from an unidentified source inside his helmet at the back of his head. The crew member continued working, but the amount of water increased and moved to his face. EVA 23 was terminated, and the crew ingressed to the ISS airlock. During the post-EVA debrief, it was reported that the crew member suffered from impaired vision and difficulty breathing due to water covering his eyes, nose, and ears. As a result, the event was classified as a High Visibility Close Call. An MIB was assembled to identify the causes of the event and make recommendations that NASA could implement to prevent similar future mishaps. The final report for the ISS EVA Suit Water Intrusion High Visibility Close Call investigation recommended the ISS Program "institute requirements and behaviors that combat the tendency towards complacency" [ref. 1]. In addition, the report identified normalization of deviance as a reason early signals were missed in identifying that the situation was taking a turn for the worse.

One of the lessons learned from these events is that technical and organizational factors contributed to the mishaps. Following the MIB recommendations from the EVA 23 close call, ISS Program management requested that the NESC Human Factors TDT provide an objective safety assessment of the current state of the ISS organization.

Efforts to improve the safety of an organization are frequently dominated by hindsight. We look at the future in light of what has happened in the past. "Tried and trusted" approaches to safety and risk prediction "are only changed when they fail, and then usually by adding one more factor or element to account for the unexplained variability," thus not acknowledging that variability is inherent in complex systems [ref.6]. The construct of "complacency" is often used in this way (i.e., as a unitary label, easily applied after the fact), but provides little information about how it should be addressed.

Complacency represents many challenges for organizations. First, the term is rarely explicitly defined. The term *complacency* is treated as self-evident, and thus is widely open to interpretation [ref. 10]. It is worth noting that while complacency was implicated in the Columbia accident and the EVA 23 close call, neither the CAIB nor the EVA 23 MIB defined the term. Parasuraman et al. define it as: *A state of being which may result in a decrease in … readiness to perform, based on an assumption of satisfactory system state* [ref. 11]. This definition highlights a second challenge associated with complacency (i.e., low mishap rates can make it difficult to avoid). Maintaining a state of vigilant readiness requires high levels of task feedback that indicate a need to maintain that state [ref. 12]. Thus, extended periods of "safe" operations can eliminate the feedback loop from the environment that is critical for reinforcing readiness to perform.

Furthermore, the second half of Parasuraman et al.'s definition highlights that complacency is a function of a person's trust and confidence in the procedures, processes, tools, and people that make up the safety system. Thus, another critical aspect of complacency is understanding the extent to which this level of trust is commensurate with the safety afforded by the system. A third challenge in addressing complacency is that it can be difficult for an organization to realize it is becoming complacent [ref. 13]. Often, it takes another serious mishap for an organization to realize and attempt to address complacency. Fourth, complacency is typically interpreted as an individual problem without sufficient consideration of organizational factors that allowed, facilitated, or invited it to occur [ref. 14].

Safety culture can be assessed at individual, group, and organizational levels [ref. 15]. The most easily measured behaviors occur at the individual level, and can manifest as instances of complacency and inaccurate risk awareness. At the group level, safety culture aspects can emerge as negative social norms (e.g., normalization of deviance, lack of communication, etc.). Safety culture at the organization level is often the most difficult to assess. However, behaviors that emerge at the individual and group level are often manifestations of the safety climate instilled by the parent organization [ref. 16].

Conventional risk management approaches emphasize predicting what could go wrong and instituting design changes, controls, and/or compliance strategies intended to reduce the likelihood or severity of risk. While a tightly monitored system with more procedures and processes may prove effective in reducing or stabilizing errors and accidents, it lacks the necessary flexibility, transparency, and ability to anticipate the system changes or disruptions that are inevitable in complex systems. A brittle system operates at unsafe margins and fails to recognize warning signals or adjust in time to continue proper function. In contrast, a resilient organization is able to effectively adjust its functioning prior to, during, or following expected or unexpected disturbances, so that it can sustain required operations.

Resilience requires maintaining a constant sense of unease that prevents complacency. The risk of decreased perceptual readiness can be combatted by identifying key words that indicate heightened risk or uncertainty, learning to recognize combinations of factors or patterns that indicate a possible stack-up of risk, or noticing when events are approaching or operating outside the boundaries of normal experience. Resilience requires knowledge of what has happened, what is happening, what will happen, and what to do. A resilient system must be proactive, flexible, adaptive, and prepared. It must be aware of the impact of actions and of the failure to take action [ref. 17]. Resilience engineering seeks to develop a systems approach to engineering and management practices, measuring sources of resilience, providing decision support for balancing operational production and safety tradeoffs, creating feedback loops that enhance the organization's ability to monitor and revise risk models, and targeting safety investments [refs. 18, 19]. Rather than asking, "Could this event have been prevented?" resilience engineering approaches ask, "How well did we respond to this unexpected situation?"

2.3 Scope

The ISS Program comprises multiple interrelated organizations and functions, each composed of multiple people, producing a vast, highly complex, and tightly interdependent system. Risk management opportunities arise throughout the ISS Program's operations. For example, an approved waiver for a failed qualification test during the design phase or a decision to de-manifest system spares to fly a science payload during prefight phase represent stimuli with associated decisions that affect crew safety. However, a poor risk decision occurring during these scenarios has the benefit of additional opportunities to mitigate and control the risk before it affects the crew during flight. The flight phase is the most constrained in terms of time, options, and information. During this phase, there is often only one opportunity to respond optimally to a situation. To that end, the NESC assessment team focused on ISS organizations, functions, and forums that execute or support real-time operations, including flight operations, engineering, safety and mission assurance, and the ISS Program office. Analysis of international partner and commercial partner organizations was outside the assessment scope.

3.0 Data Analysis

3.1 Preparation

In the investigation's initial stages, the NESC assessment team sought to understand resilient aspects of the ISS as an interdependent purposeful assembly of human, software, and hardware elements, termed a "sociotechnical system," [ref. 20] or a "joint cognitive system" [ref. 21]. To do that, the team formulated RQs, developed an interview guide, and recruited a sample of prospective participants.

Initial discussions considered the problem as assigned and provided opportunities for the NESC assessment team to learn about issues from the resilience engineering literature and prior experience (e.g., tight coupling) and NASA documentation (e.g., anomaly reports). The team decided to structure the analysis using the RAG framework [ref. 2], which identifies four basic capabilities of resilient systems:

- *Anticipate* – Knowing what to expect (i.e., how to anticipate developments and threats, such as potential disruptions, pressures, and their consequences, further into the future).
- *Monitor* – Knowing what to look for (i.e., how to monitor what is or could become a threat in the near term). The monitoring must cover what happens in the environment and what happens in the system itself (i.e., its own performance).
- *Respond* – Knowing what to do (i.e., how to respond to regular and irregular disruptions and disturbances by adjusting normal functioning).
- *Learn* – Knowing what has happened (i.e., how to learn from experience, in particular to learn the right lessons from the right experience).

This general framework was used to develop specific questions targeted to a particular domain. Based on NESC assessment team member expertise and informal interviews with ISS personnel, the team identified two RQs that would inform the inquiry, identify research questions, and identify potential sources of information. The RAG framework was used to develop specific queries to support RQ investigation. Examples of specific issues and queries identified for each RQ are shown in Tables 3.1-1 and 3.1-2.

Table 3.1-1. RQ1: How does the ISS Program handle unanticipated signals that indicate potential safety threats?

	Issue Number/Issue	Research Query	Source
Anticipate	Who is watching what? Is there a monitoring plan? How does ISS allocate attention? Reallocate attention?	What constitutes a signal that a potential threat to safety exists? What is a "weak" safety signal? Who is responsible for safety signals?	Interview Interview Artifact, Interview
Monitor	Who is responsible for identifying risks and signals of risk? How are signals evaluated? Do authority, role gradients exist? Are risks constantly re-evaluated? What is the process by which risks are re-evaluated in real-time?	How does NASA recognize safety signals? How does NASA assess signals? How is that communicated? How is it documented?	Interview Interview Interview Artifact
Respond	What criteria are used to discount hypotheses? How does info flow from panels and boards into Flight Ops? How do dissenting opinions make their way to decision makers? How quickly? Do authority, role gradients exist?	What happens when a signal is detected? Who participates in decisions? How? What is the decision process? How is it documented? Shared?	Interview Interview Interview Artifact
Learn	How are discrepancies resolved? How is training used to address "human" elements of ISS Does the ISS change in response to new knowledge? How?	Are findings implemented? What barriers prevent implementation? Do operations change? How?	Artifact, Interview Interview Interview

Table 3.1-2. RQ2: How does the ISS Program balance ongoing resource constraints with pressures for productivity and efficiency?

	Issue Number/Issue	Research Query	Source
Anticipate	How are priorities set? Are mechanisms in place to enhance coordination and effective overlap across organizations? How are competing pressures and operational trade decisions tracked? How are ongoing resource investments tracked? How is work load allocated? Reallocated?	What is your role in the ISS organization? Do you have what you need to do your job? If not, why?	Artifact, Interview Interview
Monitor	How are competing goals evaluated? Who is responsible for identifying risks and signals of risk?	Do agenda conflicts occur? If so, how? Are agenda conflicts resolved? If so, how? If not, why?	Interview Interview
Respond	Trade-off decisions—who has a voice? How are competing pressures and operational trade decisions tracked? What are criteria for backing off production goals? What blocks tapping in to distributed knowledge at the point and time of need?	Are all opinions, data given a fair hearing? How are trade-off decision made? Between operations and safety?	Interview Interview
Learn	How are anomaly reports classified and used? How are discrepancies resolved? Does the ISS change in response to new knowledge? How?	Who makes final decisions on findings? Who is responsible for implementing findings? Are some types of findings handled differently than others? What kind? How well are findings implemented? How useful are mishap reports?	Interview Artifact, Interview Interview Artifact, Interview Interview

Interview Guide. The NESC assessment team developed a guide (see Appendix A) to ensure that interview discussions addressed the investigation's RQs. For example, asking about ISS team structure enabled interviewers to learn about how the organization anticipates (i.e., RAG A) potential safety threats by allocating assignments and attention. The guide ensured a consistent approach among the interviews so the team could identify and tabulate patterns during the analysis phase. The interview guide questions were:

- *Phrased to elicit knowledge*—Questions invited the participants to describe their experiences. Interviewers listened for cues in responses that related to the RQ.
- *Simple*—The inquiry needed to be simple to get accurate responses about a complex challenge. Asking more simple questions rather than fewer complex/compound questions enabled the NESC assessment team to more easily interpret responses.
- *Open*—Queries needed to be open so interviewers would not steer participants' responses or generate conjecture.

- *Planned for more than one pass*—The interview guide initial version sought to understand the ISS domain and how it might or might not demonstrate resilience. As the investigation proceeded, the NESC assessment team expected to learn more about the ISS. Participants from different levels and sections of the ISS organization would provide insights to be analyzed, leading to an increased understanding that could lead to new questions.

3.2 Data Collection

Data for this analysis were collected in three ways: structured interviews with ISS personnel; direct observation of real-time ISS operations; and analysis of documents, presentations, and transcripts of recorded ISS meetings.

Structured Interviews. Formal interviews were conducted with 17 ISS personnel who directly supported the ISS Program in one of eight roles across four organizations, as shown in Table 3.2-1:

Table 3.2-1. Organizations and Roles of ISS Personnel Participated in Formal Interviews

Organization	**Role**
Flight Operations	Flight crew
	Flight director
	Operations Planner
	Training
Engineering	Mission Evaluation Room Manager
	Engineering Technical Authority
Safety and Mission Assurance	Safety
ISS Program	Increment Manager

Candidates for participation were identified via email requests from the NESC assessment team lead and distributed to ISS branch heads. The email request included a brief statement of the assessment purpose, the expected interview length (i.e., 90 minutes), and a request for contact information for up to three branch members who might be available to participate. All interviews took place during one of three weeklong visits by the NESC assessment team. Once individual contact information was received by the team lead, a 90-minute block of time was coordinated directly with each participant during one of the site visits.

All participants were interviewed individually by NESC assessment team members, including one lead interviewer accompanied by one or more note takers. Prior to participation, all interview participants were briefed on the study purpose by the lead interviewer and introduced to the team note takers. Participants were informed that they would not be identified personally in the analysis, and that they were free to withdraw or end the interview at any time. Note takers used word processing software on laptop computers to record interview questions and responses in real time. Notes included a mix of direct quotes and paraphrases of participant responses. Across the 17 interviews, all NESC assessment team members served as lead interviewers and note takers.

Real-Time Observations. Over the course of the investigation, NESC assessment team members observed four EVAs and one visiting-vehicle event (i.e., cargo vehicle berth to ISS) from two locations within the Mission Control Center: the observation room overlooking the Mission Control "floor," and a MER conference room. In both locations, space-to-ground voice loops were available. In addition, team attended an EVA readiness review, and a post-EVA debrief in the MER. Unplanned informal discussions with ISS personnel occurred sporadically before and after these meetings. These observations and informal conversations helped the team better understand the flow and pace of real-time ISS operations, and notes taken during these observations were available to supplement, support, and interpret data from the structured interviews.

Artifact Analysis. Archival data produced by ISS personnel were considered during the analysis, including the EVA 23 MIB report [ref. 1], the Corrective Action Plan detailing ISS Program responses to the EVA 23 MIB recommendations, and an audio recording of the ISS Mission Management Team (IMMT) EVA 23 go/no-go meeting. As with real-time observations, analysis of these archival data were available to supplement, support, and interpret data from the structured interviews.

3.3 3.3 Data Analysis

NESC assessment team members used inductive thematic analysis to extract meaningful patterns and findings from the structured interviews with ISS crew and ground support personnel. Thematic analysis of qualitative data is "a method for identifying, analysing, and reporting patterns (themes) within data. It minimally organises and describes your data set in (rich) detail." [ref. 3]. Analysis of data translated observed phenomena into findings that described the work domain. To be defensible, the process had to be rigorous and maintain continuity from data through analysis to identification of themes, findings, and recommendations.

The interview guide elicited participant responses on each aspect of the RAG cornerstones: anticipate, monitor, respond, and learn. The NESC assessment team began by reviewing notes from each of the data collection visits, which took place between December 2016 and February 2017. The analysis involved a structured and systematic pass through the data. While qualitative data coding software is commercially available, the cost and time needed to learn to use it led team members to use electronic spreadsheets to manually organize their work in the phases described in the following section.

Strength from the findings in this project relied on two traits (i.e., depth and breadth), and the data collection and analysis described was designed to capture them [refs. 22, 23]:

- Depth – Insight into operations, which comes from elicited knowledge by those who have intimate experience with the organization.
- Breadth – The number of roles that expressed similar points of view, representing the organization as a whole.

Systematic data review and coding. To prepare the notes for coding, the NESC assessment team copied content from each note taker into a common file for each interviewee, identifying which RQ and which of the four cornerstones the data point addressed. Each team member's notes were sorted according to interview topic, organized along the same lines as the interview guide. Team members identified the best examples from the notes for a particular topic, noting what worked and instances that could have affected the ISS Program's ability to adapt. In total, the team extracted 1,343 data excerpts across the 17 interview note sets.

Using the thematic categories developed during the NESC assessment team's working sessions, members coded interview sections according to their relevance to one or more themes. First, three team members coded a pilot sample of interviews independently and then met to compare use of coding categories, identify consistent and inconsistent application of categories, and discuss discrepancies. The outcome of these discussions was a refined set of category descriptions that provided guidance for subsequent data coding. The set of coding categories and definitions is presented in Appendix B. As coding progressed, themes and insights evolved as the team compared category descriptions with data.

Review and interpretation of coded data. With a consensus set of themes, each NESC assessment team member was assigned a subset of the data excerpts, referred to as "key data points," to review and interpret. Excerpts were coded according to whether they addressed RQ1 or RQ2, and which of the RAG cornerstones they related to. The key data points were then sorted into a common file of the subjects with the same role. As shown in Table 3.3-1, "context" is the question that led to the interviewee response citation. While participant NN1 assumed the ISS organization knows everything that could go wrong, participant NN2 showed awareness of how presumption can affect performance.

Table 3.3-1. Examples of Key Data Points Extracted from Structured Interviews

Theme	Source	Citation (Key Data Point)	Context
Presumption/bias	NN1	Everything that could possibly go wrong has already been thought about and there's a plan for it.	Are there general cues to emergent situations?
	NN2	I think that we got fooled. Don't be lulled into compliance. Do not latch onto that and start ignoring clues that may be counter to your theory.	What do you think about the wrong assumption?

Synthesis and integration. With the key data points assembled according to roles, NESC assessment team members were assigned separate sets to review and summarize, drawing insights from the data to address the RQs. Some data points could be applied to more than one insight. Table 3.3-2 shows four of the 19 data points that were assembled from various interviewees on the theme of "presumption bias," which led to the development of an insight (i.e., "Presumption leads to dismissing threats to safety,") that summarized their meaning.

Table 3.3-2. Example of Key Data Points Assembled Under Identified Insight "Presumption Leads to Dismissing Threats to Safety"

Master Order	Participant ID	Key Data Points	Category
		Presumption leads to dismissing threats to safety	
1	WW1	Where did water come from? Everyone jumps to most likely cause … crew member bumped drink bag; it had happened in the past. Crew – that water was cold (wouldn't think it would be cold if it was the drink bag) thinks they were missing that clue. If they'd had all this information, would they have figured it out?	RQ1 respond
9	XX1	Everything that could possibly go wrong has already been thought about and there's a plan for it.	RQ1 anticipate
27	YY1	Just didn't think that could happen [referring to EVA 23].	RQ1 anticipate, RQ1 respond
29	ZZ1	Was in MCC when EVA 22/23; striking to see how bad we missed it. We had suspected leaking of drinking water, and crew had reported that water had been stuck in the helmet. But assumed that water had been escaped by the drink bag.	RQ1 respond

In the final analysis phase, insights from NESC assessment team members were clustered into sets with similar meanings, and their similarity was confirmed by the ability to represent the set with a single "finding" statement. Table 3.3-3 shows how the insight, "Presumption leads to dismissing threats to safety," was included with those from three other team members.

Table 3.3-3. Example of Insights Assembled Under Identified Finding

Finding	Contributing Insights	Team Member
Some ISS personnel expressed high levels of certainty that all risks have been identified and have a plan or rule to manage them.	There is a belief within the ISS organization that every possible failure/anomaly has already been considered and there is a plan for it.	A
	Safety threats are potentially missed due to presumption bias.	B
	Presumption leads to dismissing threats to safety.	C
	Certainty all risks are identified with a plan or rule to manage.	D

NESC assessment team members reviewed the insights, merged them into 25 groups according to the RQs and RAG, and wrote findings. These statements noted resilient performance, needs for improvement, and implications that pointed toward NESC recommendations.

Assumptions and Limitations. This assessment was limited to NASA participants in ISS, and included no information from international or commercial partners. Furthermore, due to resource constraints and participant availability, data were collected from a sample representing a subset of roles in the ISS Program. In developing our findings and recommendations, the NESC assessment team relied on participants being forthcoming and truthful in their interviews. However, inclusion of artifact analysis enabled comparison and corroboration across data sources. Data were collected, analyzed, and interpreted within a resilience engineering theoretical framework. While this framework was deemed appropriate by the NESC assessment team based on the problem being addressed, analyses based on different theoretical frameworks could yield different insights from the data.

4.0 Findings, Observations, and NESC Recommendations

4.1 Findings

The following findings were identified based on the RQs identified in Section 3.1.

Selected data points from field visits and review of ISS documents are included after each finding below. A complete list of key data points from structured interviews, observations, informal conversations, and review of ISS documentation used to support each Finding, as well as the key for interpreting source codes (e.g., FOD, PRO, ENG, SMA, etc.) are presented in Appendix C.

F-1. ISS reliance on traditional risk management, (e.g., likelihood-consequence estimations, prediction of specific risks) increases reliability for recognizing and responding to known risks but may not support dealing with uncertainty, ambiguity, or surprise.

- Relevance: Reliance on prediction, without also focusing on preparedness for surprise, can leave ISS vulnerable when responding to unanticipated events.

- Selected examples (for complete list, see Appendix C):

  You can't plan for the world's worst day. You can plan for one or two failures. Once you get three or four deep, the oversight on that would be mind-boggling. This gets into safety and looking at their likelihood vs. consequence scale.—ENG4

  Safety asking about failure mode of hardware, and it wasn't even a credible safety mode, and we'd had controls/rules in place to address this for years.—SMA3

  If you don't have the data, you explain that you don't know and here's why you don't know. Program will take that into consideration when they make decision. Will talk about likelihood and consequences, even if you don't know.—ENG2

F-2. Reliance on pre-determined procedures enables the flight control team to operate independently of ISS Program management and respond consistently to events that fit those procedures.

- Relevance: Many expected and unexpected events are addressed by pre-determined procedures, which facilitate consistent and rapid responses to those events. However, repeated reliance and success in applying these procedures also creates potential vulnerabilities when faced with unanticipated events not covered by those procedures (see F-7, F-8).

- Selected examples (for complete list, see Appendix C):

  There is a clear division of decision authority. There is a depth of "pre-made" decisions. —FOD1

  We leave it to the flight ops team to deal with unexpected events. They'll plan lots of one-failure events.—PRO1

F-3. ISS personnel report relying on cues, such as tone of voice, self-reports, or available data telemetry streams, to perceive the condition or state of the crew.

- Relevance: While these cues provide useful information, they may be misleading or insufficient to support noticing and acting on urgent, life threatening situations.

- Selected examples (for complete list, see Appendix C):

  You'll hear fatigue in how the crew talks and in how they are breathing.—ENG3

  I listen to crew and can hear it in voices.—FOD2

  Scary thing was … incident crew member was so calm we didn't realize how [bad] it was. [In reference to EVA23]—FOD4

  "He doesn't panic, even though he was about to die—he was a Special Forces guy." —Video presentation, EVA23

  You only can see so much data. How we sample it [telemetry] is only as fast as we can understand it. Systems we have may only be able to give you so much data. COTS [commercial off-the-shelf] items are like that.—ENG4

F-4. ISS training of crew and flight control team is designed to improve general problem-solving skills through simulations with many issues arising at once.

- Relevance: Crew and flight control team training may not adequately cultivate sensitivity to subtle or chronic cues.
- Selected examples (for complete list, see Appendix C):

  Training was primarily full flight control team simulations. Ran through scenario—everything breaking all the time, unrealistic multiple simultaneous failures.—FOD5

  Training team will give eight malfunctions at once.—FOD1

  There are lots of components running through your mind—lasts 7 hours and could be up to 40 malfunctions. Big integrated case with all team members working (usually one big problem and several nitnoids).—FOD8

  I was just pushing buttons [during training simulations], not understanding.—FOD5

F-5. The ISS organization has taken steps to raise awareness of the concept, challenges, and risks associated with normalization of deviance.

- Relevance: The steps that have been taken may be insufficient to translate awareness about normalization of deviance into operational practice, so it can be used to manage drift toward safety boundaries (see F-6).
- Selected examples (for complete list, see Appendix C):

  They read Chapter 6 of the Columbia accident report over and over [every year]. Normalization of deviance.—FOD1

  We tell the guys, don't get stuck in complacency. Don't ignore clues that may be counter to your theory. It's important to continue to look at new data and verify that it is consistent with your theory.—FOD2

  CDRA is another. Low voltage trips circuit. We narrowed it down to one valve. Known overcurrent. Can easily become comfortable. "Ah, it's just another LVT." But is it?—ENG4

  If you look back on everything that bit us, it always falls back on lack of imagination and normalization of deviance. Makes sense in hindsight, but we didn't think everything through down to that level—FOD8

F-6. Repeated success in performing high-risk operations can lead to those operations being perceived as "routine," and can desensitize ISS personnel to the possibility of failure.

- Relevance: In extreme environments like ISS, the distance between acceptable and unacceptable risks can be small, so actively managing drift toward safety boundaries and maintaining a sense of precarious unease is particularly critical.
- Selected examples (for complete list, see Appendix C):

  CAPCOM asked astronaut for a glove/HAP check. Astronaut held gloves up. Didn't really show both sides. It was hard to see the gloves in the video, and then they went off screen even though astronaut was still doing the check. In MER conference room, XX *held up his hands and flip/flopped them as if to show how astronaut should've done it.—EVA38 Observation*

Always a struggle when risks are high and risk of significant failure is low. Trying to build sense of danger.—FOD4

Have some anomalies that go off twice a year. They are what they are, and you just keep going.—FOD2

"You get used to living in an off-nominal world."—ENG4

"Got to be careful ... not to cry wolf at every single thing."—ENG1

Constantly hearing about hardware, what might be breaking.—PRO2

Do we look with fresh eyes every time? I think so. I think we do try. If we put the same amount of rigor from the 100th one as the first batch, we'd never get anything done. We have found some efficiencies. We've been asked to find new ways.—SMA2

Problem with console just wanting to present new stuff, not stuff that's been lingering for months and months.—SMA3

Agency has become complacent. That worked last time so it's probably ok.—FOD8

I don't think the pre-Columbia *culture has changed.—SMA3*

F-7. Some ISS personnel expressed high levels of certainty that all risks have been identified and have a plan or rule to manage them.

- Relevance: In complex systems, surprises will happen, making a balance necessary between prediction of specific risks and preparation for unforeseen, ambiguous, or uncertain situations. Believing all risks have been identified can lead to a false sense of security that can weaken the ability to recognize and respond to novel situations.

We identify all bad scenarios and create plans.—ENG1

Every possible thing that could happen has been thought about.—FOD1

This always works. I can't think of when it didn't. [Using a pre-planned response to resolve anomaly]—PRO1

It's all documented, it's just a matter of knowing the cues that you're in that situation. What the cues are depends on the situation. —FOD1

I think that we got fooled [in reference to EVA23]. Don't be lulled into complacency. Do not latch onto that and start ignoring clues that may be counter to your theory. —FOD2

Thought we understood. In hindsight, it [leaking drink bag during EVA 22] was talking to us and we didn't hear it.—FOD4

F-8. Some ISS personnel expressed confidence that there will always be a way to stabilize the system in response to an unexpected event.

- Relevance: This expectation could delay an effective response in situations that require urgent action (i.e., when there is not time to stabilize the system first), particularly when cues to urgency are unanticipated (see F-2) or subtle (see F-4).

- Selected examples (for complete list, see Appendix C):

  We try to stop and get bigger picture before we jump in and fix the problem. Want to understand if it is a symptom of bigger problem.—FOD1

  Have documented emergency procedures that can put into effect no matter what happens. They go directly to these if something unexpected happens.—ENG1

  Stabilize system—shift to redundant system, recover, plan to repair.—PRO1

  If you have an unexpected event, FCT is trained to safe the crew and the system, and then engineers come to work the system.—ENG2

F-9. When assessing risks, some ISS personnel indicate a burden to prove that a circumstance is not safe, rather than that it is safe.

- Relevance: This results in drift toward riskier behaviors and higher risk tolerance than might be intended.
- Selected examples (for complete list, see Appendix C):

  I feel pressure to make the outcome be what program manager wants the answer to be, e.g., "Here's what I want, go talk to people to make sure that works," rather than, "Go prove to me this is safe."—SMA3

  Situation—flight director not listening during EVA. Had discussions with folks—he had said "no go" to EVA. Allowed to have right discussions. Flight director (FD) made decision to press. Communication breakdowns. MER asking for hold, FD didn't hold. Put suit in jeopardy for future use. Didn't go according to engineering expectations. —ENG1

  There is absolutely an influence to not throw in the towel. There is a resistance, because if you always throw the towel, you'll never get anywhere. You have to understand the influence your decisions have.—FOD2

F-10. Pressure to attract and retain science clients and projects can impose trade-offs with critical needs, such as maintenance.

- Relevance: As ISS systems age, those trades will become more frequent. One result of those trades is to lessen safety margins that have previously protected ISS from failure.
- Selected examples (for complete list, see Appendix C):

  If it has a higher level of risk, we work those issues harder. I think we do that well. We try to eliminate the risk. We don't want to risk crew or vehicle. Big thing now is science. Don't want to do something stupid that causes us to lose customers.—FOD6

  Big challenge with aging ISS is risk-based decisions operating at life expectancy. Trying to make it a national lab that shows science output as it ages is a challenge. That will be the decision point at which ISS goes into the ocean. As we work toward that point, challenge is managing the pressures of extending the life of the station, suits, etc.—PRO1

F-11. Extensive resources in terms of time and effort are required to resolve complex interdependencies and to plan and re-plan fragile schedules.

- Relevance: These resource requirements limit the ISS Program's ability to adapt to changing circumstances.

- Selected examples (for complete list, see Appendix C):

  Production pressures. Get this done. Sequence of events. Limited number of suits. Certification limits available time. Space station is tightly coupled. ISS is a space port. Takes weeks to prepare for events. —FOD1

  "If anything happens to the schedule, it crumbles."—FOD2

  Lots of dependencies of who's doing what; not everyone can be in the same spot doing everything. We normally deconflict this, and it takes weeks. —FOD6

F-12. The ISS organization provides mechanisms and opportunities to express dissenting opinions.

- Relevance: Speaking up is crucial for ISS safety, and providing a range of opportunities to do so supports resilient performance.
- Selected examples (for complete list, see Appendix C):

  Folks do speak their minds without repercussion, but they may not be confident that they're right.—SMA3

  When going to do an analysis: are you doing the right review, checks? After you have the data? Look at assumptions, verify model, and bring the right people in to talk about it. In that process—he can tell when they are uncomfortable. He goes to understand what they skipped. Have we been here before? Uncharted territory?—ENG1

  Make sure they [flight control team] have the opportunity to speak up. May have to ask individually. "Tell me what you would do."—FOD2

  For go/no-go decisions, they throw it down to a safety person and ask "What did we miss? What are we not thinking about?"—PRO1

F-13. Challenges in identifying whom to talk to, understanding different priorities, and overcoming perceived inequalities based on role and experience can impede ISS ability to collaborate, cooperate, and entertain fresh points of view.

- Relevance: ISS organizational structure can result in valuable perspectives being discounted or ignored.
- Selected examples (for complete list, see Appendix C):

  We had a big one with a leak on Progress. I got worried about that one. Our team tracked down that lines can freeze. FD said they told Russia that was the concern, they rolled their eyes. FD was trying to convince me it's not a big deal, but it WAS a big deal. Made it clear during the meeting that they were all rolling their eyes at our concern. FD clearly thought I was overreacting, but held the meeting, and gave everyone a chance to ask questions—SMA3

  The leak has existed for a year, but a new trend popped up and they didn't report it. They said they communicated at certain meetings, but didn't hear it at the 10 am.—ENG4

  Crossing large organizational boundaries is difficult. Inside Building 30, it's easier with people being closer.—SMA1

  A crew representative – especially if had done EVA—would have more weight. —SMA2

FD can be resistant to feedback. They may get too into the weeds. There may be some bias. Between CTO [chief training officer] and FD, there could be some issues if they don't get along. Every interaction is important. If you say something stupid to me, I may not trust you next time.—FOD8

When we have right engineering support, and can communicate in the MER, helps us make a better decision—FOD3

F-14. Deference to rank, fear of being wrong, and the perception of mixed messages from leadership about speaking up creates pressure among some ISS personnel to "stay quiet," especially in open forums.

- Relevance: Speaking up is crucial for safety, yet speaking up can feel risky. Inconsistent messages within an organization, expressed through culture, structure, and language, can make it harder for individuals to overcome a natural reluctance to speak up.
- Selected examples (for complete list, see Appendix C):

  At branch level we work well together. All GS-15 at this level. As you get lower, that gets "stovepiped." People feel less willing to bring things up. Used to working in their own sandbox. That could be better.—SMA1

  The crew's right—don't question the crew. Especially in an open forum. —SMA2

  Most questions asked were closed-ended questions (26 closed, 1 open). All questions asked were asked by Chair except one. Clarifying/crosschecking was done seven times. All crosschecking/clarifying done by Chair except one. People invited questions, but no one had questions.—Analysis of transcript of IMMT EVA23 Go/No-Go meeting

  "It's a little disturbing that we get this close to an EVA and all of a sudden something like this pops out. I'm glad it did, from the standpoint of we don't want to do something we don't want to do, but clearly somehow or another we missed something along the way." —transcript of IMMT EVA23 Go/No-Go meeting

  "The answer better be yes, because we said it on the loop." "Now is not the time for this question."—Observation of post-EVA Item for Investigation (IFI) meeting

  New guy sometimes hesitant to speak up—FOD2

  In an IMMT meeting, I would hesitate to bring up an unknown high-risk item. It would get people worked up.—SMA3

F-15. ISS relies on teamwork and cooperation to function effectively. ISS personnel believe that cross-organization cooperation is healthy, and have identified strategies, including training, rotations/details, and co-location to help improve engagement across role and organizational boundaries.

- Relevance: Teams with cross-role understanding and empathy can better communicate, cooperate, and coordinate; this builds reciprocity, which is essential for resilience. However, challenges remain in maintaining this understanding across roles in complex organizations such as ISS (see F-16).

- Selected examples (for complete list, see Appendix C):

  There's a healthy tension among the three teams [engineering, flight ops, program office]. Flight wants to get things done. Engineers like to tinker with things.—ENG3

  Personalities are the driving factor. Different teams have different relationships—some are like families, but not all of them are like that.—ENG2

  More viewpoints we get, the better decision we can make.—FOD3

  There are several divers/trainers from Neutral Buoyancy Lab in the room. This is their first time sitting in on an EVA, even though several have been with NASA for many years. The purpose was to give them more of a big picture.—EVA 39 observation

F-16. Roles in ISS are well defined, yet some ISS personnel may not appreciate how their actions or decisions can affect others' responsibilities.

- Relevance: This can lead to incorrect assumptions, frustration, and loss of respect for individuals in other organizations within ISS.
- Selected examples (for complete list, see Appendix C):

  Ops people think/assume engineers are tracking the things that are repeating.—FOD2

  Doesn't know if someone is looking at the big picture or trending.—SMA2

  Person sitting right there—ground control (GC) —can't possibly know the impacts. The certainty with which they state "no impact" has bitten them a lot. When they say things like rebooting server or work on this satellite. "I know you say no impact … even though may take down all gateway tools." The ground control team explores and finds it may actually take down command and telemetry—this is a big deal.—FOD7

F-17. Training variability across ISS roles and exclusion of certain personnel/roles from participation in large-scale training simulations does not support team unification or the development of shared understanding.

- Relevance: Participation in training exercises and simulations builds adaptability, trust, and cross-role understanding that support managing complexity.
- Selected examples (for complete list, see Appendix C):

  MER guys don't get simulations, but I think they could benefit. Anyone that's making real-time calls during the events should be included in a sim. You can't show up day of and expect to be able to do it.—FOD2

  When something goes wrong, first thing that goes out the window is the plan. From a planning perspective—they don't get to exercise their skills as planner. They are always looking at tomorrow. Sim world—there is no tomorrow. When first started, sat in generic sims. Sat there. Became less and less useful so got excused.—FOD7

  They (roles who are not part of sims) aren't in sims because they don't have real-time impact. But I would love to have them in the sims so they can learn by osmosis—goes for Ops Plan, MER engineers, etc. Risk that I'm tying them up, has been decided that it's not worth it from a resources perspective—FOD8

Real-time ops is not really engineering responsibility. Right thing? Since heavy-duty assembly of ISS is complete, it's ok (not to be part of sims).—ENG2

F-18. When managing missions and troubleshooting issues, ISS personnel tend to focus more on software and hardware performance than on human performance.

- Relevance: Human performance is an integral part of the operation and mission of ISS as a sociotechnical system. Separate mechanisms to document human, software, and hardware issues can hinder development of a complete understanding of events during real-time operations and post-hoc analyses.

- Selected examples (for complete list, see Appendix C):

  4:34 into mission, the mood in MER conference room changes noticeably. Many conversations are occurring. Check-in with a manager at the table: What do you notice? "Relaxed." The mission—battery install—was accomplished. By 5:30, most people in the room have left. Observation: In this room, there seems to be a sense that the mission is complete because the main job was finished successfully yet astronauts are not safely back inside. As task risk goes down (task complete), human risk goes up (fatigue); focus seems to be on task risk. Note how the astronauts seem to be struggling more from here until the end of the EVA.—Observation of EVA38

  "We followed the flight rules. It was a crew member error. Not hardware failure." No IFI required, will write-up Anomaly Report (AR) just to document. Observation: Human error is a starting point for understanding what happened. In this situation, it seemed they identified it as a cause and moved on. Treating human and hardware as separate vs. human-technical system?—Observation Post-EVA IFI meeting

  IFI works well, but sometimes they don't include things he thinks they should include like human errors. Human errors wind up in ARs. If I were King for a Day there would be one system. ARs and IFIs one system.—SMA1

F-19. ISS uses linear causal models (e.g., root cause analysis, fault-tree analysis, and error chains) to analyze and understand mishap events.

- Relevance: Complex systems like ISS are not linear, and single isolated events are rarely causal, therefore these models can oversimplify operational situations and fail to accurately describe how success and failure occur in complex systems.

- Selected examples (for complete list, see Appendix C):

  "We did not control water quality on the ground and that led to us almost killing Luca. It's that simple."—Video presentation, EVA23

  Links in the error chain. What was the weak link? Use lessons learned to train this from NASA and other industries (aviation, Deep Water Horizon).—FOD1

  A fault tolerance approach. Structural fatigue and failure are more typical in the ISS.—FOD3

  You don't have to know what the failure mode is. You have to identify the impacts of the failure mode.—FOD8

Goal of Anomaly Resolution Team meeting is initial triage, trying to get to proximal cause. What happened, what data did we have, look at previous EVA, what could we do on orbit to troubleshoot—ENG3

F-20. The safety team's focus on compliance to control hazards, along with varying perceptions among ISS personnel about how safety functions should be managed, leads to the safety team being devalued and minimizes their influence on real-time safety management.

- Relevance: The safety team has the opportunity to define and manage safety across the ISS organization in a manner that is consistent, related to high-priority threats, and promotes resilient performance.
- Selected examples (for complete list, see Appendix C):

Safety realm is interesting, you have institutional safety who sits console, also have EVA safety, and then have payload safety. There are a lot of flavors of safety, we've had lots of discussions of roles and responsibility of safety.—ENG3

You can slice and dice safety in many different ways: ENG Safety, EVA Safety, Ops Safety, ISS Safety Review Panel (SRP)—FOD1

If signed off by 40 people no one owns it. One would assume responsibility.—FOD4

There is a perception that the safety people take it too far. They live by the rules and the rules only, and that is true for some people.—SMA3

Bad perception of them [safety] in ops. Not common skills or mutual corporate respect. Creates poor work environment.—FOD8

People who work in safety, they drive crew crazy with requirements..—FOD4

F-21. The ISS Program values technical expertise and relies on experts' operational experience and system knowledge when determining responses to planned and unplanned events.

- Relevance: Reliance on experts supports anticipation of and response to events. Continued success, however, depends on maintaining that expertise over time (see F-22).
- Selected examples (for complete list, see Appendix C):

There are a lot of interpretation letters—everywhere. How do you find the right thing? It's a risk. Rely on knowledge of people who've been there forever. —SMA2

We rely on flight controllers knowing the difference between routine and critical.—FOD3

We do get a lot of gut feelings with senior engineers, and we listen to them. —ENG4

Major Replan: When there are so many changes to a day, it no longer makes sense to follow normal process – steady state re-planning. A change so large, not possible to keep up with paperwork or process. Re-baseline the plan basically. Has a lot to do with instincts, experience on how bad it will be. Group decision. Sometimes I raise the flag to consider for major re-plan.—FOD7

F-22. **ISS risks losing expertise through retirement, rapid turnover, and insufficient means to capture and transfer expertise to new personnel.**

- Relevance: Given ISS reliance on experts when determining responses to planned and unplanned events (see F-21), loss of expertise poses a safety risk to ISS
- Selected examples (for complete list, see Appendix C):

  We're losing our engineers with the knowledge and there's a brain drain because they knew so much about things and now they're gone.—FOD4

  It is really important for program to figure out how to train for people holding his role (MER manager) for a shorter time (3-4 years vs. 10+)—ENG3

  Lots of turnover in ops safety, so we lose that experience. It took me a long time before I felt like I could add value. There were no training plans – there still aren't.—SMA3

F-23. **Documentation (e.g., ARs, IFIs, and lessons learned) is valued, yet the time and effort required by documentation and resolution processes discourage people from entering new information.**

- Relevance: This results in missed opportunities to capture lessons and trends, and to learn from events.
- Selected examples (for complete list, see Appendix C):

  Flight control team's perception of anomaly reporting process as being resource-intensive made them reluctant to invoke it. So resource intensive, such a pain in the ass … I don't want to open up. One of the flight controllers admitted he went home after EVA 22 and said, "You know, that's really bugging me that we don't know exactly where that leak came from. It was probably the drink bag, but we should look at that. But if we do, we'll never get to that next EVA in a week. Days and days doing a bunch of investigation and it'll be a red herring." So it was never reported.—Video presentation on EVA23

  Our processes are inconsistent, so makes me wonder and worry about how long some issues get left open. We don't have set criteria or good work instruction for our role, either.—SMA3

  "No one likes more paperwork."—ENG4

  "We are good on this one, no IFI." "That's what I like to hear."—Observation Post-EVA IFI meeting

F-24. **Although multiple processes are in place to document anomalies and lessons learned, some ISS personnel are unclear on how to use the documents or how the collected data are translated to results.**

- Relevance: This results in missed opportunities to learn from captured lessons and trends, and to learn from events.
- Selected examples (for complete list, see Appendix C):

  We do capture comments in debriefs and put it together for lessons learned, but I don't know how it is used.—FOD4

There is no prioritization—which are important? [ARs and lessons] look the same.—FOD3

Hard to answer. Usually info is there and people don't use it. Until something bad happens. Even when people do populate them, people don't look at them.—SMA1

F-25. The ISS Program's inconsistent use of "lessons learned" data limits its value.

- Relevance: Existing practices to support learning from experience lack consistent structure and limit opportunity to improve operations.
- Selected examples (for complete list, see Appendix C):

  No consistent structure [to lessons learned].—FOD5

  There are old lessons learned systems that are supposed to be filled out, and there's no incentive to do so. We don't have a formal one. Lots of stuff in lots of places. IFIs, PRACAs [Problem Reporting and Corrective Actions], ARs are all there. It's reviewable, but I don't know if people do.—SMA1

  Right now it seems like the documentation gets put on a shelf, but most info comes from those who experience it firsthand. But then once they go, you lose that knowledge.—ENG3

4.2 Observations

The following observation is offered for consideration:

O-1. Flight Control Team members monitor numerous voice loops simultaneously for verbal communication and behavioral cues (e.g., tone of voice), but receive no formal training on strategies or best practices for managing this task.

4.3 NESC Recommendations

The following NESC recommendations are directed to the ISS Program.

NESC Recommendations are organized across six potential benefits to the ISS Program, based on properties of organizations that perform in a resilient manner:

1. *Improved ability to recognize and promote resilient performance—O*rganization recognizes that it must monitor its own performance, as well as what happens in the environment. It actively manages and adjusts its adaptive capacity as it faces new forms of variation and challenge. The boundary conditions on current safety strategies are actively monitored, and strategies are adjusted or expanded to accommodate changing demands.
2. *Better prepared to respond to uncertain and unanticipated situations*—Organization recognizes that surprises will happen. They look for how they will be or have been surprised and prepare how they will adapt and respond to future surprises. Organization maintains the capacity to adjust activities, resources, tactics, and strategies in the face of different kinds of events, demands, and uncertainties. They notice increasing uncertainty as a cue and practice making decisions when uncertainty is high.
3. *Improved ability to overcome effects of routine*—Organization recognizes that real-world systems are characterized by complexity, uncertainty and dynamic resource constraints,

therefore past performance cannot guarantee future success. They pay attention to safety vs. productivity trade-offs, looking for drift toward riskier positions. They monitor for early cues to emergent risks. They plan how to handle interactions, different tempos, non-linear dynamics, and hidden dependencies. They manage work differently when approaching boundaries.

4. *Increased chances that people will speak up and be heard when they have safety concerns*—The organization actively seeks different perspectives and invites engagement within and between teams. Teams have insight into the responsibilities, challenges, and goals of the other teams with which they interact to build understanding and reciprocity. Leaders "leave rank at the door" and commonly elicit and offer help to people on the frontlines. The people who write the rules and procedures make the effort to understand the challenges faced by people using the procedures.

5. *Improved ability to manage uncertainty and system risks inherent in complex sociotechnical systems*—Organization recognizes the role of people in creating safety and resilience in sociotechnical systems. When analyzing events that involve people, the organization seeks to understand the perspectives of those involved and the conditions that actually exist. They use models and approaches that accurately describe how success and failure occur in complex systems.

6. *Improved ability to learn and adapt from events*—Organization learns from situations where uncertainty was high, cues were uncertain or ambiguous, or risk trade-offs were difficult. They also learn routinely: learning is quick, timely, and focused around developing people rather than documents.

Recommendations are accompanied by descriptions of resources intended to help the ISS Program instantiate these recommendations within the organization. A summary of the NESC recommendations and resources, organized around the benefits described above, can be found in Table 4.3-1.

Table 4.3-1. Summary of Recommendations, with Associated Benefits, Resources, and Findings

Benefits	*Recommendations*	*Resources*	*Findings*
Improved ability to recognize and promote resilient performance	**R-1. Leverage new approaches to risk management.**	Safety Concepts and Methods	**F-1**. ISS reliance on traditional risk management, (e.g., likelihood-consequence estimations, prediction of specific risks) increases reliability for recognizing and responding to known risks but may not support dealing with uncertainty, ambiguity or surprise.
Better prepared to respond to uncertain and unanticipated situations	**R-2. Develop a practice to manage emerging risks and troubleshooting.**	Real-Time Risk Assessment	**F-2.** Reliance on pre-determined procedures enables the flight control team to operate independently of ISS Program management and respond consistently to events that fit those procedures.
	R-3. Develop skills to notice when uncertainty is increasing.	Risk Language Flags	**F-3.** ISS personnel report relying on cues, such as tone of voice, self-reports, or available data telemetry streams, to perceive the condition or state of the crew.
	R-4. Train and practice decision making under uncertainty.	Sacrifice Decision Exercises	**F-7.** Some ISS personnel expressed high levels of certainty that all risks have been identified and have a plan or rule to manage them.
	R-5. Gain tangible experience with surprise, handling subtle cues, and uncertainty through development of simulations, interactive case studies, and scenario training.	Simulation with Subtle/Ambiguous Signals and Surprises	**F-4**. ISS training of crew and flight control team is designed to improve general problem-solving skills through simulations with many issues arising at once.
Improved ability to overcome effects of routine	**R-5. Gain tangible experience with surprise, handling subtle cues, and uncertainty through development of simulations, interactive case studies, and scenario training.**	Simulation with Subtle/Ambiguous Signals and Surprises	**F-5.** The ISS organization has taken steps to raise awareness of the concept, challenges, and risks associated with normalization of deviance.
	R-6. Implement structured briefs before high-risk work or missions such as EVAs.	Pre-Mortem Risk Identification	**F-6.** Repeated success in performing high-risk operations can lead to those operations being perceived as "routine," and can desensitize ISS personnel to the possibility of failure.
	R-7. Make risk trade-off decisions explicit among all ISS teams.	Sacrifice Decision Exercises	**F-7**. Some ISS personnel expressed high levels of certainty that all risks have been identified and have a plan or rule to manage them. **F-8**. Some ISS personnel expressed confidence that there will always be a way to stabilize the system in response to an unexpected event.

			F-9. When assessing risks, some ISS personnel indicate a burden to prove that a circumstance is not safe, rather than that it is safe. **F-10**. Pressure to attract and retain science clients and projects can impose trade-offs with critical needs, such as maintenance. **F-11**. Extensive resources in terms of time and effort are required to resolve complex interdependencies and to plan and re-plan fragile schedules.
Increased chances that people will speak up and be heard when they have safety concerns	**R-8. Build relationships and cross-role understanding.**	Collaborative Engagement	**F-13**. Challenges in identifying whom to talk to, understanding different priorities, and overcoming perceived inequalities based on role and experience can impede collaboration, cooperation, and fresh points of view.
		"Speaking-Up" Training	**F-14**. Deference to rank, fear of being wrong, and the perception of mixed messages from leadership about speaking up creates pressure among some ISS personnel to "stay quiet," especially in open forums.
	R-9. Increase involvement of other teams with ISS operational personnel in simulations and training.	Simulation with Subtle/Ambiguous Signals and Surprises	**F-16**. Roles in ISS are well defined, yet some ISS personnel may not appreciate how their actions or decisions can affect others' responsibilities. **F-17.** Training variability across ISS roles and exclusion of certain personnel/roles from participation in large-scale training simulations does not support team unification or the development of shared understanding.
Improved ability to manage uncertainty and system risks inherent in complex sociotechnical systems	**R-10. Expand incident analysis methods and learning from incidents.**	Staff Rides	**F-18**. When managing missions and troubleshooting issues, ISS personnel tend to focus more on software and hardware performance than on human performance. **F-19.** ISS uses linear causal models (e.g., root cause analysis, fault-tree analysis, and error chains) to analyze and understand mishap events.
	R-11. Identify opportunities for process improvements by developing an understanding of how work actually gets done.	Learning Team	**F-20.** The safety team's focus on compliance to control hazards, along with varying perceptions among ISS personnel about how safety functions should be managed, leads to the safety team being

			devalued and minimizes their influence on real-time safety management.
Improved ability to learn and adapt from events	**R-12. Develop or expand a knowledge management program.** **R-13. Implement structured briefs after high-risk work or missions such as EVAs.** **R-14. Enrich anomaly reporting and resolution processes.**	Knowledge Management Informal, Frequent After-Action Review Use of Story in Lessons Learned	**F-22**. ISS risks losing expertise through retirement, rapid turnover, and insufficient means to capture and transfer expertise to new personnel. **F-23**. Documentation (e.g., Anomaly Reports [ARs], Items For Investigation [IFIs], and lessons learned) is valued, yet the time and effort required by documentation and resolution processes discourage people from entering new information. **F-24**. Although multiple processes are in place to document anomalies and lessons learned, some ISS personnel are unclear on how to use the documents or how the collected data are translated to results. **F-25.** The ISS Program's inconsistent use of "lessons learned" data limits its value.

R-1. Leverage new approaches to risk management. These include Resilience Engineering (RE), Highly Reliable Organizing (HRO), and Safety-II, which focus on preparing for surprise, maintaining adaptive capacity, learning from success as well as failure, and explaining how safety is produced and work is done in complex socio-technical systems, such as ISS. ***(F-1)***

- *Justification:* Findings indicate that current ISS risk management practices may be ill-suited to the subtle and complex cues to safety threats that events such as EVA-22 and 23 posed. Recommendation 1 identifies resources to broaden the ISS approach to better handle such threats.
- *Resource:* Safety Concepts and Methods (RE, Safety-II, HRO)
    - What – Recent concepts in risk management have moved beyond thinking about safety solely in terms of something to control or avoid. Three of the primary schools of thought are RE, Safety-II, and HRO. Descriptions, similarities and differences among the recent approaches are summarized in Appendix D. These concepts can be contrasted with traditional approaches to safety and risk management, as depicted in Table 4.3-2.

Table 4.3-2. A Comparison of Traditional and Recent Schools of Thought in Safety and Risk Management

Traditional Safety	**RE/HRO/Safety-II**
People are a liability—control, correct	People are an asset—learn, adapt
Variability is a threat—minimize it	Variability is normal—manage it
Focus on incident rates	Focus on learning
Focus on what we don't want: injuries and incidents	Focus on what we want: how safety is created
Procedures are complete and correct.	Procedures are always under-specified and must be interpreted and adapted.
Systems are well designed, work as designed, and are well maintained.	Systems are complex and will degrade; there will always be flaws and glitches.

    - When – This recommendation serves as a starting point for implementing the remaining recommendations in this report.
    - Who – Safety team, operations personnel, training personnel
    - Why – These views represent a shift in perspective in managing risk and safety. The practices recommended in this report are based on these approaches.
    - How – Opportunities for learning about RE, HRO, and Safety 2 include exploration of published reports, identified as references in Appendix D. In addition, domain experts have designed and offered workshops on RE/HRO/Safety 2 fundamentals, which could be conducted with ISS personnel.

R-2. Develop a practice to manage emerging risks and troubleshooting. Include a structured exploration of risks, bringing in relevant experts and fresh perspectives during emerging risk situations. ***(F-2)***

- *Justification:* Findings suggest that the ISS organization may be vulnerable when responding to unanticipated, time-sensitive threats to safety. Recommendation 2 provides guidance on how ISS can incorporate different points of view in real-time response to an emerging risk by focusing specifically on what is different in the emerging situation.

- *Resource:* Real Time Risk Assessment (RTRA)
    - What – Short (typically 2 hours), structured, collaborative conversation to surface and assess risk and produce a plan of action.
    - When – Situations that are limited in extent, typically emergent, and may require rapid response. Typically applied just after an issue is identified but before formal issue tracking and resolution processes.
    - Who – Can be initiated by anyone. The FD could initiate by contacting a trained facilitator, freeing up the FD to focus on operations while the facilitator pulls together people who have relevant knowledge. RTRA roles are designed to bring in diversity, similar experiences, and a challenger. Safety team could be trained as facilitators.
    - Why – To provide structure around responding to emerging risks. People are part of one conversation compared to different roles conversing with FD separately on the loop; relevant expertise is identified in such a way that people who have something to offer will most likely be surfaced; and specific questions are used to ensure thorough exploration of risk: for example, "What is different?" is always asked. This is different from probabilistic risk assessment in that it is about collective sense-making that occurs as part of a conversation vs. an assessment or analysis, and there is less emphasis on probabilities.
    - How – Within 1 hour of being contacted, the facilitator convenes the group and leads the conversation, asking questions to surface risks, ensuring all are heard. This could be implemented in concert with TEAM 4.
    - References
        - Lay, E. & Branlat, M. (2013) Sending Up a Flare: Enhancing resilience in industrial maintenance through the timely mobilization of remote experts. *Proceedings of the 5th Resilience Engineering Symposium.*

R-3. Develop skills to notice when uncertainty is increasing. Monitor for early cues, and plan to move into a more vigilant mode of operating when detecting signs and language that indicate risk or uncertainty is increasing. ***(F-3)***

- *Justification:* Findings describe how ISS organization perception of and methods of dealing with uncertainty risk missing subtle threats to safety. Recommendation 3 provides resources to improve ISS skills with timely recognition of uncertain and risky situations.
- *Resource:* Risk Language Flags
    - What – Identify cues in language (risk language flags) to help spot early signs of problems by prompting noticing risk, uncertainty, and rate of change.
    - When – Anytime.
    - Who – Train all to recognize these risk flag phrases.
    - Why – Helps people notice early signs of risk and uncertainty, pulls people out of "tunnel vision," and makes risk and uncertainty explicit: "I hear risk." During EVA 23, the team noticed risks but didn't trigger out of the presumption that the drink bottle was leaking. This method teaches that when risk flags are heard, pause, notice, and make the risk or uncertainty explicit by speaking it.
    - How – Teach to recognize risk flags, or subtle signals that indicate risk and uncertainty exist or are increasing. Then once heard, speak it to make it explicit: "I hear risk …" Example phrases: "I've never seen … ," "We've never done … ,"

“We’re going to do this very slowly … ,” “We don’t have time to … .” “Not sure,” “Worse than,” and indicators of uncertainty such as “maybe,” or “probably.” From EVA 23 transcript: “I feel a lot.” (indicates magnitude like “worse than”); “Don’t think (uncertainty) it’s coming from my bag”; “Yes, but feels like a lot (magnitude) of water”; “Cannot tell you the source” (uncertainty); “I don’t understand (uncertainty) where it’s coming from”; “My head is really wet.” (magnitude); “It’s increasing.” (Rate of change). This list could be supplemented with phrases common to ISS, possibly culled from transcripts where surprising events occurred. The planner on the desk in MC could be leveraged to bring a fresh set of eyes and to listen for risk flags during EVAs.

- References
  - Lay, E., Branlat, M., & Woods, Z. (2015). A Practitioner’s Experience Operationalizing Resilience Engineering. In C. Nemeth & I. Herrera (Eds.). Special issue on Resilience Engineering. *Reliability Engineering and System Safety*. 141. http://dx.doi.org/ 10.1016/ j.ress.2015.04.006.

R-4. Train and practice decision making under uncertainty. *(F-7)*

- *Justification:* Findings describe how the ISS organization may have a false sense of security that can weaken its ability to recognize and respond to surprising situations. Recommendation 4 provides guidance to improve ISS skills with timely response to uncertain and risky situations.
- *Resource:* Sacrifice Decision Exercises (Safety vs. Productivity Tradeoffs)
  - What – Use Sacrifice Decision Exercises to identify and draw out the details of tough cases, then build scenarios to train decision making via low fidelity simulations or tabletop exercises. According to Naturalistic Decision Making theory and recognition-primed decision modelling, people make quick decisions by pattern-matching. Scenarios could also be used in more extensive simulations.
  - When – Anytime.
  - Who – Designed and led collaboratively by safety, training, and experts in a specific role. Designed for specific roles based on tough decisions people in those roles need to make.
  - Why – To provide simulated experiences to fill gaps in experience and build intuitive decision making skills through developing a larger repertoire of strategies for making tough decisions under ambiguous conditions. Also, builds awareness of the nature and implications of safety vs. productivity trade-offs.
  - How – Use sacrifice decision exercises to build scenarios for low-fidelity simulations or tabletop exercises for these types of events:
    - Something unexpected occurred, uncertainty was high, operating close to safety boundaries (example: close to limits on flight rules) or running out of margin (time, people, oxygen, CO_2 limits during EVAs, etc.) to respond.
    - Events where waiting until uncertainty was resolved was too late.
    - Events where anomalies were minimized or not addressed when they could have been serious, and an event in which anomalies were handled well. Build contrasting cases.
    - Potential sources: Significant Incidents and Close Calls in Human Spaceflight: EVA Operations, and ask experts to identify critical, difficult,

or frequent decisions that involve safety-productivity trades as part of a sacrifice decision workshop.
    - Build scenarios that train noticing uncertainty as a signal. Decisions become more difficult when evidence is not definitive and uncertainty is high, but when people wait for evidence to be defined, they may get too close to safety boundaries. Teach to recognize and make sacrifice decisions explicit. Sacrifice decisions are often implicit, which can lead to drift to riskier positions.
  - References
    - Crandall, B., Klein, G., & Hoffman, R. (2000). *Working Minds: A Practitioner's Guide to Cognitive Task Analysis*. Cambridge, MA: MIT Press.
    - Klein, G. (2003). *The Power of Intuition: How to Use Your Gut Feelings to Make Better Decisions*. New York: Doubleday.

R-5. Gain tangible experience with surprise, handling subtle cues, and uncertainty through development of simulations, interactive case studies, and scenario training. ***(F-4, F-5)***

- *Justification:* Findings describe how current ISS practices may not adequately prepare personnel for handling surprise, uncertainty, or combating the effects of routine. Recommendation 5 provides guidance to make simulations and training more authentic, and enable personnel to anticipate and respond to surprising events more effectively.
- *Resource:* Simulations with Subtle/Ambiguous Signals and Surprises
  - What – Interactive enactments of scenarios using cases that include contingencies, no definitive hypotheses, and difficulties that are not easy to resolve.
  - When – Frequently.
  - Who – People from all teams who interact with or support mission control.
  - Why – To gain tangible experience with surprise, handling subtle signals, and uncertainty. To improve coordination and cooperation in teams, practice decision making under uncertainty, and increase understanding of social aspects of problem solving such as influences of leadership and culture. ISS currently does large simulation exercises with either nominal operations or with cases where many things going wrong. This suggestion involves simulations with fewer things going wrong at one time, but more branches and more unknowns; high levels of uncertainty.
  - How – Scenarios have high levels of uncertainty with more branches and more unknowns. Selected tactics:
    1) Test noticing subtle signals: a runner brings a message in, the sim master is watching not only if the team notices but how fast the team notices (rate of change matters in complex systems). If not noticed early, the situation cascades.
    2) Test "deference to expertise," mix inputs around to see if they know who get involved (building cross-role understanding).
    3) Inject statements to help people key into language that indicates risks or trade-offs, such as "Good enough for government work," or "Let's just keep moving." Identify phrases common to ISS that indicate trade-off decisions are being made.

4) Include situational awareness calibration: At a critical juncture, when uncertainty is high, team leader calls a time out and asks everyone to write down answers to: What is the primary goal right now? Why is it a priority? What is our biggest worry? What will happen in the next 15 minutes?
5) After simulations, have a conversation about how sacrifice decisions were made and what was used to justify them, the consequences of making small sacrifices early vs. larger sacrifices later, how managing the problem changed when approaching boundaries, and if change in uncertainty was recognized as a signal.

- References:
  - Former national incident management team commander, including Columbia shuttle recovery, and former Wildland Fire Lessons Learned Center manager. http://www.org4resil.com
  - Wildland Fire Lessons Learned Center https://www.wildfirelessons.net/home

R-6. Implement structured briefs before high-risk work or missions such as EVAs. Set expectations before mission to facilitate consideration of risk and contingencies. ***(F-6, F-7, F-8)***

- *Justification:* Findings indicate a need for ISS to actively manage drift toward safety boundaries. Recommendation 6 provides an approach to build and maintain a sense of unease.
- *Resource:* Pre-Mortem Risk Identification
  - What – Pre-mortem is a method to bring in diverse perspectives in identifying risks. Based on prospective hindsight, "thinking fast" (automatic, intuitive, subconscious thought processes), and leveraging cognitive diversity, a pre-mortem involves imagining that an event has already occurred, then generating plausible reasons for the occurrence.
  - When – Before performing work or when planning a project or mission. This would be an additional method to be added to those already used by planners.
  - Who – Those responsible for planning and identifying contingency plans prior to a mission or event.
  - Why – To identify risks and contingencies. Pre-mortem differs from probabilistic risk assessment and other analytical methods for identifying risks in that it taps into intuition and uses prospective hindsight, which can stimulate a different kind of creative thought, creating richer mental models than foresight predictions.
  - How – Pre-task: This situation just happened; how did it happen? Planning: 1) Here's the plan. 2) Now imagine the plan spectacularly fails. Sometimes, if "spectacular" is left out the failures are too anemic. 3) Go around the room and ask each participant, one at a time, to describe their imagined failure with specific details including consequences. Write responses on a flipchart. Guidelines: Do not take a lot of time on this even for complex plans. Do not let the boss, who owns the plan, facilitate the conversation. Don't let people talk over ideas before going around the room one by one. Insist people describe the consequences of the failure: If someone offers, "The truck wrecked," ask for a more specific failure that shows what happened and the consequences: "The truck drove through the bumper plates that were supposed to stop it and injured workers inside the

building." Keep contingency planning separate from the pre-mortem. Works best if people have diverse knowledge and experiences that are germane to the problem.

  - References:
    - Klein, G. (2007, September). *Performing a Project Premortem*. Harvard Business Review. https://hbr.org/2007/09/performing-a-project-premortem
    - Kahneman, D. (2011). *Thinking Fast and Thinking Slow*. New York, NY: Farrar, Straus, and Giroux.
    - Page, S. (2011). *Diversity and Complexity*. Princeton, NJ: Princeton University Press.

R-7. Make risk trade-off decisions explicit among all ISS teams. Develop a consistent leadership approach to risk tolerance for decisions that sacrifice production- or efficiency-related goals to manage risks when approaching safety boundaries. ***(F-9, F-10, F-11)***

- *Justification:* Findings describe how safety could potentially be compromised under pressure to produce science results. Recommendation 7 offers ways to make those trade-offs explicit and combat drift toward riskier behavior.
- *Resource:* Sacrifice Decision Exercises (Safety vs. Productivity Tradeoffs) (see R-4 for description).

R-8. Build relationships and cross-role understanding. Improve cooperation and coordination and support "speaking-up" through role switching, job shadowing, asking open-ended questions, team training on speaking up, leaving rank at the door, and creating an environment where all contributions are valued. ***(F-13, F-14)***

- *Justification:* Findings identify a need for the ISS to better incorporate various points of view when dealing with safety threats. Recommendation 8 offers resources to break down barriers and better understand safety across the organization.
- *Resource:* Collaborative Engagement
  - What – Collaborative engagement is a systematic method that includes turn-taking, cross-checking, asking clarifying questions and zoom-in/zoom-out.
  - When – During group or team operations or activities, during problem solving meetings and risk decision meetings, and during shift changes.
  - Who – Individuals responsible for facilitating and/or leading a group effort or meeting, decision makers, and any individual participating in a group or team effort.
  - Why – To help make sense of situations, improve situational awareness, and guard against tunnel vision. Also reduces barriers resulting from seniority, position, or personality variances within a team or group. While these tactics may be practiced by some already, this method proposes to formalize the practice to ensure that it becomes a habitual part of group and individual behavior.
  - How –
    1) Turn-taking. Ensure all get an opportunity to talk and question.
    2) Cross-checking. Invite people to cross-check by asking, "What am I missing?" and watch for typical mistakes; ask what, if, and why questions; play devil's advocate; and bring in fresh perspectives.

3) Asking clarifying questions. Confirm understanding or clear up knowledge gaps. During shift changes, the person coming on shift asks: "What are you worried about?" "What else could go wrong?" "What else should I be concerned with?"
4) Zooming in/out. Zoom in to get a close look at select details, subtleties, and nuances. Zoom out to see the big picture, including general patterns and context. The combination of both provides a more complete assessment.

- References:

  - Rayo, M.; Mount-Campbell, A.F.; O'Brien, J.M.; White, S. E.; Butz, A.; Evans, K; & Patterson, E. (2013). Interactive Questioning in Critical Care During Handovers: A transcript analysis of communication behaviors by physicians, nurses and nurse practitioners. *BMJ Quality and Safety*. 23(6) http://qualitysafety.bmj.com/content/early/2013/12/12/bmjqs-2013-002341.short
  - Patterson, E.; Woods, D.; Cook, R.; & Render, M. (2016). Collaborative Cross-Checking to Enhance Resilience. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, Vol. 49, Issue 3, pp. 512-516.
  - Van Dalen, B.; Slagmolen, R.; & Tang, R. (2009). *Mindful Organizing: How to Manage Unexpected Events and Unwanted Processes.* Nijmegen, Netherlands: Apollo Publishing.
  - Dekker, S., (2011). *Drift into Failure*. Boca Raton, FL US: CRC Press.

- *Resource*: "Speaking-Up" Training:
  - What – Team training and scripts can remove barriers to speaking up. Rules, scripts, and mnemonics are used to support speaking up in aviation and healthcare. Several are presented here. The "two-challenge rule" supports the notion that all members of a team, even subordinates, share responsibility for a safe outcome and are obligated to speak up (even repeatedly). Advocacy-inquiry is a script for challenging others using a conversational technique that is assertive and collaborative. When combined with a briefing that emphasizes joint responsibility for safety, use of the two-challenge rule and advocacy-inquiry scripts has been shown to improve the frequency and effectiveness with which people speak up to superiors.
  - When – Bringing up concerns, especially when there is a large power distance.
  - Who – Empowers anyone who needs to bring up a concern, but especially those with less power in an organization. Integrate into existing Crew Resource Management training, and extend to those within the organization who might not normally receive the training.
  - Why – Speaking up is crucial for safety. Scripts are designed to maximize receptiveness and minimize defensiveness. Practicing speaking up as part of training will help embed it in the culture.
  - How – Practice skills and scripts for speaking up in low-fidelity simulations. Two-challenge rule: Challenge and question twice, if needed,

then get help if still not heard. Advocacy-Inquiry: Advocacy is a statement that describes opinion or position. Inquiry is a question, usually in the form of a genuinely curious request for the other person's thoughts. Example advocacy/inquiry combined with the two-challenge rule:

1) "I'm concerned that we only have a single inhibit; can you clarify your view on why this is ok?"
2) I see the plan is to … I'm still concerned it's unsafe. What do you think?
3) If the plan continues, get additional help (escalate).

CUS mnemonic: I am **c**oncerned … I am **u**ncomfortable … This is a **s**afety issue. The trigger words of *concerned, uncomfortable,* and *safety* are used to pull people, including leadership, out of tunnel vision and get them to pause and listen.

- References:
  - Grote, G. (2015). Promoting Safety by Increasing Uncertainty—Implications for Risk Management. Safety Science 71, 71 – 79.
  - Pian-Smith, M.C.M.; Simon, R.; Minehart, R.D.; Podraza, M.; Rudolph, J.; Walzer, T.; & Raemer, D. (2009). Teaching Residents the Two-Challenge Rule: A simulation-based approach to improve education and patient safety. Simulation Health 4, 84-91.

R-9. Increase involvement of other teams with ISS operational personnel in simulations and training. Connect them to real-time operational issues and improve coordination and cooperation. ***(F-16, F-17)***

- *Justification:* Findings indicate that ISS training does not include all personnel that might benefit, or that might benefit ISS by participating. Recommendation 9 offers ways to leverage simulations to build more unified and collaborative teams.
- *Resource:* Simulations with subtle/ambiguous signals and surprises (see R-5 for description).

R-10. Expand incident analysis methods and learning from incidents. Include means to understand human adaptive capabilities (e.g., context, perspective of those involved, goal conflicts, pressures, and coordination/cooperation) and systems views (e.g., mechanisms, interplay, progression over time, and emergent phenomena). ***(F-18, F-19)***

- *Justification:* Findings point out the ISS organization's traditional engineering view and handling of threats to safety can miss subtle cues such as those in EVA-22 and 23. Recommendation 10 points to resources that can expand ISS abilities to detect and manage such threats.
- *Resource:* Staff Rides
  - What – Staff rides, also called event analyses, are a way to look at an event from multiple perspectives and provide a window into the system through the idea that minor deviations, surprises, mistakes, and recurring problems often reveal much about the state of the system. Findings are assessed against a "mindful" maturity model to identify areas for improvement.
  - When – After an event, near miss, or surprise or to address recurring problems.
  - Who – People involved in an event. Interviewers from different disciplines and levels in the organization.
  - Why – To gain a diverse, multi-faceted view of the situation from which the unexpected event emerged and to use events to steer culture vs. going in and

fixing a single piece. This method may be especially useful with participants inside an organization (flight controllers and FD, or MER manager and consoles) and also with participants from organizations that touch (e.g., flight controllers and MER consoles, or flight controllers and flight surgeons/biomedical engineers). This is different from an investigation or root cause analysis in that what people find depends on their background and where they start in the interview carousel; there's not a single "true story." A staff ride provides context, perspective of those involved, and a system view (e.g., goal conflicts, pressures, how well coordination and cooperation worked, progression over time, etc.), compared with linear, causal analyses that may oversimplify situations surrounding an event.

- How – Staff ride method:
  1) Interviewers are trained in humble questioning and a Mindful/HRO safety maturity model.
  2) Teams of interviewers question people who were involved in an event as experts in the situation.
  3) Teams come back together to reflect on their collective experience, exploring, "What's happening in the organization?" "What's happening in the team?" "What is the experience of the individual?"
  4) Improvement actions are identified.
- References:
  - Gebauer, A. (2013). Mindful Organizing as a Paradigm to Develop Managers. Journal of Management Education. 37(203). http://www.corporate-learning.org/wp/wp-content/uploads/2010/08/Gebauer-2012-Mindful-Organizing-as-a-Paradigm-to-Develop-Managers.pdf
  - Wildland Fire Leadership Development Program. https://www.fireleadership.gov/toolbox/staffride/main_about_staff_rides.html
  - Robertson, W.G. (1987). The Staff Ride. Center for Military History. U.S. Army. Washington, DC. https://www.fireleadership.gov/toolbox/staffride/downloads/the_staff_ride.pdf

R-11. Identify opportunities for process improvements by developing an understanding of how work actually gets done. Compare with how work is "supposed" to be done according to procedures and rules. Safety team participation can better connect them with operational needs and build bridges with operations teams. ***(F-20)***

- *Justification:* Findings describe how the ISS safety role needs to be better connected to operational needs. Recommendation 11 identifies how the ISS safety role can better serve those needs.
- *Resource:* Learning Team
  - What – People close to the work are brought together for a short period to explore how work actually gets done compared with how work is supposed to be done per procedures, rules, etc. to determine what the organization can learn from the differences and how it can improve. Duration: Two hours in meetings, plus "soak time." Products: Learning team report, improvement actions.
  - When – Post-event. Can be after a near-miss or also an interesting success.

- Who – Team of five or six people plus a coach. Team should include at least one person from outside the process (fresh eyes), and the people who interface with the process. Typically managers are not on the team or in the room. Safety team could be trained to coach.
- Why – To learn and improve, with a side benefit of building bridges between organizations. Not an investigation. Not focused on "one true story" or causes. Instead, tells the story of each person as they saw the event or did work, bringing in complexity and context, understanding normal variability and how work gets done.
- How –
  1) First session: Learning mode only for an hour, to explore how work is done and create a "wall of discovery." Start back in process, not at the event. Make this session information rich, full of context.
  2) Soak time: Allows time to process things.
  3) Second session: Start in learning mode, then move to solutions. If event-focused, you are done when you understand why it made sense for people to do what they did.
- Suggested learning team topic: Where and how were EVAs re-planned due to a safety concern or anomaly? Look for an example in which anomalies were underplayed (minimized or not addressed when they could have been serious) and an example in which anomalies were handled well. Build a set of contrasting case studies for organizational learning.
- References:
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  - Conklin, T. (2016). *Better Questions.* Boca Raton, FL: Taylor and Francis/CRC Press.

R-12. Develop or expand a knowledge management program. Gather, capture, organize, preserve, analyze, and share knowledge. Elicit and integrate expertise from ISS personnel before they change roles or depart to ensure their knowledge is not lost to the organization. ***(F-22)***

- *Justification:* Findings demonstrate that ISS personnel consider knowledge capture and transfer to be insufficient for the organization's needs. Recommendation 12 offers approaches for improvement.
- *Resource:* Knowledge Management
  - What – A knowledge management program gathers, captures, organizes, preserves, analyzes, presents, shares, and disseminates knowledge, ensuring it is not lost to the organization. Organizational, procedural, and conceptual knowledge and skill are the most important assets for NASA and the ISS organization. Training and experience develop undocumented and tacit knowledge that is lost to NASA when personnel depart, unless it is captured.
  - When – Incorporate knowledge capture as part of the transfer and retirement procedure.
  - Who – Senior personnel with valuable expertise and more junior personnel with fresh insights into the ISS organization

    - Why – Senior team members' expertise is the basis for their professional intuition, for being able to make good assessments and decisions under stressful conditions. They have developed patterns and rules of thumb for how they expect things to work in a variety of situations. This enables them to make more accurate and reliable judgments and decisions, perform faster, and build richer "mental models" of how their domain functions than novices can.
    - How – A number of methods can be used in a knowledge management program. Concept maps are used to represent expert knowledge and represent the structure of the elicited knowledge. A task diagram can help the elicitors specify the subtasks that are best suited for further Cognitive Task Analysis (CTA). Knowledge audit is a method structured around several elicitation probes designed to uncover the elements of expertise in a particular work domain. Critical decision method is a CTA technique to identify the cognitive strategies and demands experts handle.
    - References:
        - Crandall, B.; Klein, G.; & Hoffman, R. (2006). *Working Minds. A Practitioner's Guide to Cognitive Task Analysis*. Cambridge, MA: MIT Press
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        - Schraagen, J.M.; Chipman, S.; & Shalin, V. (2003). *Cognitive Task Analysis*. Mahwah, NJ: Lawrence Erlbaum Associates.

R-13. Implement structured briefs after high-risk work or missions such as EVAs. Explore how personnel were surprised, how they understood proximity to safety boundaries, what went well, and what opportunities exist for improvement. ***(F-23)***

- *Justification:* Findings describe how ISS learns and documents its learning, and how current documentation processes need to be improved. Recommendation 13 addresses improving how ISS learns from missions by focusing on developing individual and team skills.
- *Resource:* Informal, frequent after-action reviews
    - What – Structured, facilitated conversations held right after completion of a task, project, or mission. AARs are more about developing people than correcting things.
    - When – Quick and immediate. Hold an AAR anytime there are lessons to be learned. The more frequent and informal the better, but especially if people were surprised, something unexpected happened, the task/project/mission is critical, and when things went right.
    - Who – People in all roles.

   - Why – To create learning that is focused on developing individuals and teams, vs. cross-organization or documented lessons. Probing surprise supports noticing how often we are surprised.
     - ISS personnel reported EVA and mission debriefs vary depending on who leads them, and questions tend to be about specific concerns that arose during the mission. Debriefs after simulations are led by flight directors, with them discussing what the team did and did not do well. Teams learn more if the leader begins with open-ended questions that generate dialogue before sharing feedback.
     - ISS personnel mentioned that frequent learning conversations are part of the aviation culture but not ISS culture.
   - How – Create a safe environment. What is shared stays inside the team unless they choose to share more broadly. Start with team self-reflection by asking a few open-ended questions, such as:
     1) What was planned and expected to happen?
     2) What actually happened?
     3) What surprised us?
     4) What went well and why?
     5) What can be improved and how?
     6) What did we learn that would help others?

     Then provide quick and valid feedback. Could probe trade-off decisions, such as "When we decided to … (push CO_2 limits, do this get-ahead, etc.), how did it turn out?" Avoid creating an environment of critique, as this stifles learning.
   - References:
     - Darling, M.; Parry, C.; & Moore, J. (2005, July-August). Learning in the Thick of It. *Harvard Business Review*. https://hbr.org/2005/07/learning-in-the-thick-of-it
     - Shmuel, E. & Inbar, D. (2005). After-Event Reviews: Drawing lessons from successful and failed experience. *Journal of Applied Psychology*. 90(5), 857-871. http://dx.doi.org/10.1037/0021-9010.90.5.857

R-14. Enrich anomaly reporting and resolution processes. Supplement with methods to improve learning from past experiences and anticipating future developments. ***(F-24, F-25)***

- *Justification:* Findings showed ISS personnel consider the cost of documentation outweighs the benefit, as comments indicate the benefits of those efforts are unclear. Recommendation 14 offers resources to improve how ISS builds and maintains collective memory, deep knowledge, and a larger repertoire of decision-making strategies.
- *Resource:* Use of Story in Lessons Learned.
   - What – When people are viewed as sources of safety and resilience, everything and everybody focuses on learning to enable improvisation and local self-organization.
   - When – On a routine basis.
   - Who – Everyone.
   - Why – Build collective memory (memory shared by multiple people in an organization), deep knowledge, and a larger repertoire of strategies for making

decisions. Learning experiences are frequent, interactive, reflective, and designed to build expert decision-making and professional judgement. Gathering and documenting in a database is less important. Learning is mainly through sharing, reading, or hearing stories (experiences); studies show when we are engaged in a story, the same areas of the brain are activated as when we carry out a similar action, in other words memories from stories can be as strong as memories from actual experiences. Other studies show that we are more apt to be influenced by stories than non-narrative messages.

- How – Expert decision-making and professional judgment is built through:
  1) Reading, hearing, and telling context-rich stories.
  2) Working through well-designed interactive case studies that enable discovery of the "second story" (i.e., perspective of those involved, including goal conflicts, challenges, dilemmas, and system vulnerabilities).
  3) Recognizing patterns through study of short, related vignette collections.
  4) After-action reviews. A good story or case study builds suspense, asks thought-provoking questions, contains a predicament or conflict, and describes the scenario such that people can put themselves in the shoes of those who were involved.
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    - Moyer-Gusé, E. & Nabi, R.L. (2010). *Explaining the Effects of Narrative in an Entertainment Television Program: Overcoming Resistance to Persuasion,* Human Communication Research, 36, 26-52.
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    - Simmons, A. (2001). *The Story Factor: Inspiration, Influence, and Persuasion Through the Art of Storytelling*. Basic Books.
    - *Callback*, Aviation Safety Reporting System. https://asrs.arc.nasa.gov/publications/callback.html
    - Wildland Fire Lessons Learned Center, "Two More Chains." https://www.wildfirelessons.net/home
    - *HindSight*, European Organisation for the Safety of Air Navigation. http://www.skybrary.aero/index.php/HindSight_-_EUROCONTROL

5.0 Definition of Terms

Corrective Actions	Changes to design processes, work instructions, workmanship practices, training, inspections, tests, procedures, specifications, drawings, tools, equipment, facilities, resources, or materials that result in preventing, minimizing, or limiting the potential for recurrence of a problem.
Finding	A relevant factual conclusion and/or issue that is within the assessment scope and that the team has rigorously based on data from independent analyses, tests, inspections, and/or reviews of technical documentation.
Joint cognitive system	Interdependent human and machine elements making up a system that can modify its behavior on the basis of experience so as to achieve specific antientropic ends. [ref. 21]
Lessons Learned	Knowledge, understanding, or conclusive insight gained by experience that may benefit other current or future NASA programs and projects. The experience may be positive, as in a successful test or mission, or negative, as in a mishap or failure.
Normalization of deviance	The gradual process through which unacceptable behaviors, practices, or standards, through repetition without catastrophic results, become the acceptable norm for an organization. [ref. 9]
Observation	A noteworthy fact, issue, and/or risk, which may not be directly within the assessment scope, but could generate a separate issue or concern if not addressed. Alternatively, an observation can be a positive acknowledgement of structure, tools, and/or support provided by a Center, program, project, or organization.
Problem	The subject of an independent technical assessment.
Recommendation	A proposed measurable stakeholder action, directly supported by specific finding(s) and/or observation(s), that will correct or mitigate an identified issue or risk.
Resilience engineering	A paradigm for safety management that focuses on how to help people cope with complexity under pressure to achieve success. [ref. 24]
Sociotechnical system	People and equipment directly dependent on their material means and resources for outputs. The core interface consists of relations between a nonhuman system and a human system. [ref. 20]
Systems Approach	The application of a systematic, disciplined engineering approach that is quantifiable, recursive, iterative, and repeatable for the development, operation, and maintenance of systems integrated into a whole throughout the life cycle of a project or program.

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Appendix A. Structured Interview Guide Used by NESC Assessment Team

Interviewer asks	*Interviewer listens for*	*Notes*
Thanks for being willing to talk with us and for sharing your background. We're interested in talking with you about ISS operations today.		
		Notes
Please briefly describe your role on the ISS team.	How do new/diverse team members participate in ISS operations? (Ref: MIB Rec 18)	
Who else do you work with on the ISS team? Could you draw a diagram on this piece of paper showing that?	To what extent are individuals explicitly/exclusively tasked with looking for signals that the situation has changed from planned?	
How well do you think these relationships work with regard to maintaining the safety of ISS operations?	How are organizational priorities set across competing goals?	
	How are competing pressures and operational trade decisions tracked?	
	How is attention allocated across signal sources?	
	How many signal sources are monitored by each person?	
	Is there an explicit monitoring plan for dynamic events? If so, how is it developed?	
	Who is responsible for monitoring proximity to edge of resource boundaries?	
	How is proximity to resource boundaries (i.e., approaching edge of resource envelope) identified?	
		Notes
What systems or tools do you use in your work?	Do you have the resources you need to perform your role?	
Are they what you need? If not, why not?	What mechanisms are in place to support information exchange and coordination across organizations?	
	What mechanisms are in place that hinder information exchange and coordination across organizations?	
	How are ongoing resource investments tracked?	

		Notes
How do you prepare in the hours leading up to an event such as an EVA or visiting vehicle? What pre-briefs/conversations do you have right before a mission? Can you tell me about one of these? How would you describe the general pre-mission "mood"?	Looking for practices that shape pre-EVA mindset; are there conversations to create a sense of unease and wariness?	
Is the pre-brief process basically the same from mission to mission, or does it change? If it changes, why? What are the circumstances that might lead to changes in the pre-brief process?	How does the pre-brief process change when the mission involves something that's never been done before? (i.e. higher uncertainty)	

		Notes
What are the indications that there is something you need to pay more attention to? Something you want to know more about, or something you want to watch to ensure it doesn't develop into a problem?	How does ISS recognize small signals? Who is responsible for monitoring for and responding to small signals? Recognizing indicators that risk has increased - change in tempo, uptick in communication, tone of voice, stress level, language (risk flags) etc. Are anomalies (differences, nuances, discrepancies, outliers) actively looked for? To what extent do displays support identifying signals that situation has changed from planned?	
Are all of these indications important?	What criteria are used to evaluate hypotheses about cause of signal?	
How do you know which of these indications are important?	What constitutes a threat to safety: differences, nuances, discrepancies, outliers? Recognizing the signal—differences, nuances, discrepancies, outliers ex. leak	

		Notes
What are the indications that things are taking a turn for the worse?	How does ISS recognize that a small signal may actually be a threat?	
How do you recognize that an indication constitutes a threat to mission or crew safety?	What constitutes a signal that a potential threat to safety exists? How is a “small signal” defined? (i.e., small signals that things are taking a turn for the worse)	
Do any of these indications get missed? If so, how does that happen?	How are ISS personnel trained to monitor and respond to surprising events and/or small signals?	
	To what extent does training support identification of signals that situation has changed from planned?	
	What members of the ISS org participate in training to respond to surprising events?	
		Notes
When you do notice something that concerns you, what do you do?	What happens once a small signal is detected?	
How do you decided whether a concern is worth speaking up about?	Do they probe, look for how it’s different than previous experiences, look for alternative explanations, diverse perspectives and expertise?	
What happens after a safety concern is raised? Walk me through the process step by step. It’ll help if you draw a diagram of the process on this piece of paper.	How is small signal detection communicated across the team, from signal detector to decision maker?	
	Does this process differ depending on the role of the person who first detected the signal?	
	What is the decision process for identifying a response to a detected signal?	
	Who participates in the decision process?	
	Do decision makers look for details and discrepancies, i.e. “complexify” (resilient)? Or do they press for a solution and try to simplify (brittle)?	
	Who participates in resolving anomalies?	
	Are some types of findings handled differently than others (if so, what kind)?	
	How are competing goals identified?	
	Who is responsible for identifying existing, potential, and/or emerging goal conflicts?	

		Notes
Does everyone agree during this process?	How do authority gradient and roles affect assessment of small signals?	
What happens if they don't?	How do dissenting opinions make their way to decision makers?	
Do you need to negotiate about what to do?	How does information flow across those involved in decision process?	
If yes, how does that work?	How are decisions and any dissenting opinions documented?	
	How are goal conflicts resolved (or if not, why not)?	
	How are competing pressures and operational trade decisions tracked?	
	Who participates in goal trade-off decisions?	
	Are all opinions and data given a fair hearing?	
	What are the barriers within ISS to resolving goal tradeoffs?	
		Notes
What happens next?	How are mission risks re-evaluated in real time on the basis of identified signals?	
Are changes made during operations?	How have operations changed to better support performance in dynamic, ambiguous, and/or surprising situations?	
If so, who does that?	How are anomaly resolutions implemented and verified?	
Does that change how ISS operates in real time? If yes, how?	Who is responsible for implementing resolutions?	
	In what ways do operations change as a result of new information?	
	What are the criteria for backing off production goals to address other (e.g., safety) goals?	
	How is proximity to resource boundaries dynamically re-evaluated in real time?	
		Notes
How are safety concerns documented? A mishap report?	How are anomalies documented?	
Tell me about mishap reports. Do they matter? If yes, how? If not, why not?	What are barriers that prevent implementation / change?	
	How useful are mishap reports?	
	What are the challenges to using mishap reports to identify new risks and risk signals? (Ref: MIB Rec 13)	
	What are the challenges to using mishap reports to maintain risk awareness by ISS personnel? (Ref MIB Rec 17)	
	How are documented anomalies resolved?	
	How well are anomaly resolutions implemented?	

		Notes
Does the process you described change how ISS operates?	Does ISS change in response to past anomalies?	
Does the process you described change how ISS trains?	How has the FIT/ART process changed ISS response to failures for the better/worse? (Ref: MIB Rec 18)	
	How have operations changed to better support recognition and resolution of competing goals?	
	Does ISS change in response to events that went well?	
	How is information documented about events that went well?	
	How do past successes impact training?	
	How are after action reviews used to identify things that went well in operations and in training?	
	How are anomaly reports used in training development?	
	What are the criteria for inclusion/exclusion of anomaly reports in training scenario development (e.g., severity of outcome, salience of onset cue, pace of cue onset; predicted vs unpredicted, involvement across orgs)? (MIB Rec 17)	
	What determines who participates in training? (MIB Rec 16)	
	How are real-time trades between productivity & safety trained?	

	Notes
Are there any other items we haven't discussed that you'd like to mention?	
Thanks for your time. What you've provided will be a great help to the ISS Program.	

Appendix B. Data Coding Categories and Definitions Created to Support Thematic Analysis

Theme	Theme Title	Definition	Example(s)
1	**Documentation process**	Recording of information, lesson, or best practice to be used by the organization	Unwieldy documentation
2	**Handling conflict**	How disagreements or different perspectives on an issue are raised, considered, and resolved	
3	**Identifying cues to surprise**	Early signals that something unplanned and/or unexpected is happening first indications that things are taking a turn for the worse	
4	**Job roles and accountability**	"Own" job perception and responsibilities	Decision ownership; balance of power across roles; lack of understanding of each other's jobs
5	**Knowledge loss/Role of expertise**	Role of expert knowledge/experience in the organization	Is there protection against loss of knowledge due to retirements, changing jobs etc.
6	**Normalization of deviance**	Unacceptable practice or standards that gradually become acceptable; as the deviant behavior is repeated without catastrophic results, it becomes the social norm for the organization	
7	**Predetermined procedures**	Pre-determined responses that are based on predicted/anticipated risks	
8	**Presumption bias**	Something is assumed to be true with very little evidence or rationality	
9	**Response to surprise**	Behaviors that result once an unplanned and/or unexpected stimulus is recognized	
10	**Risk & risk management**	How the organization conceptualizes, anticipates or controls risk	Cross-checking; planning for slack; shifting mode of operating in response to threats
11	**Role of safety organization**	How the safety organization is perceived by other groups within ISS	
12	**Safety perception**	How the individual conceptualizes "being safe"	How safety is achieved, maintained, and/or threatened; level of comfort; perception of risk

Theme	Theme Title	Definition	Example(s)
13	**Seeking other perspectives**	The extent the organization actively seeks, receives and acts upon alternate points of view, dissenting opinions, etc.	
14	**Time pressure**	Extent to which there is (in)sufficient amount of time to complete goals	Workload; tight coupling; sensitivity to the rate of change
15	**Tradeoffs**	Situation in which one of two or more things must be chosen	Trades among limited resources; pressures to produce/perform; safety
16	**Training (mis)match with ISS Ops**	Extent to which what is learned during training does or doesn't match the knowledge and skills needed to perform in an operational setting	
17	**Mental models**	How an individual "thinks about the world"	Ideas, schemas, or notions that shape how they think about and interpret safety, their job, the organization, human behavior, etc.

Appendix C. Key Data Points to Support Each Finding

Key data points were identified for the following sources:

- Observation EVA 37
- Observation EVA 38
- Observation EVA 39
- Observation post-EVA IFI meeting
- Conversation post-EVA
    - Informal conversations with ISS staff following EVA observations
- Transcript of IMMT EVA23 Go/No-Go meeting
    - Audio recording of the ISS Mission Management Team meeting, held on July 15, 2013, was obtained by request and transcribed by the assessment team for analysis.
- Video Presentation EVA 23
    - A video recording describing the events of EVA 23, presented by the EVA 23 MIB chairperson, was obtained online.
    - NASA Project Management and Systems Engineering Forum. (2016). Retrieved September 30, 2016, from http://www.ustream.tv/recorded/88356593.
- Formal interviews with ISS staff from four organizations:
    - ENG (Engineering)
    - FOD (Flight Operations Directorate)
    - PRO (ISS Program Office)
    - SMA (Safety and Mission Assurance)

Note that all references to individual names have been removed, and all personal pronouns have been converted to masculine gender to protect ISS staff identities.

F-1. ISS reliance on traditional risk management, (e.g., likelihood-consequence estimations, prediction of specific risks) increases reliability for recognizing and responding to known risks but may not support dealing with uncertainty, ambiguity, or surprise.	
Source	**Finding and Supporting Evidence**
Video Presentation EVA 23	Gaps in data and theories present risk … if don't have the full data set, understand where gaps exist and what risks this presents. Be aware of what you know as fact versus what you're assuming or inferring. Never have all the data. If don't have, understand gaps and where you could be wrong. Make sure you know what you know and you understand what you don't know. (uncertainty)
FOD4	I'm more worried about the things that could kill us. Micrometeorite. Toxic gas from overheating wires.
ENG2	His office. They look at all failure modes based on criticality. Ask right questions.
ENG2	If you don't have the data, you explain that you don't know and here's why you don't know. Program will take that into consideration when they make decision. Will talk about likelihood and consequences, even if you don't know.
FOD2	Work on both micro level—this box failed. Macro level—out of these small things that have happened, which is the biggest threat today?
FOD3	We err more on consequence side when we have time.
ENG3	Likelihood and consequences scorecard. Understand current situation. Understand consequence. If wrong, then what is worst that can happen? With existing safeguards, how does situation play out? What is likelihood and how to mitigate?
ENG3	What is the worst thing that can happen?
ENG4	Need to look at what the safety organization does. Likelihood-consequence scale. If it's a high likelihood, we'll plan for that. If it's a high consequence, we'll definitely plan for it. Each visiting vehicle has its own set of flight rules.
ENG4	You can't plan for the world's worst day; you can plan for one or two failures. Once you get three or four deep, the oversight on that would be mind-boggling. This gets into safety and looking at their likelihood vs. consequence scale.
SMA2	Protecting the crew and the space station from catastrophic/critical events that are likely to occur. Critical is not necessarily credible.
SMA3	Safety asking about failure mode of hardware, and it wasn't even a credible safety mode, and we'd had controls/rules in place to address this for years.

F-2. Reliance on pre-determined procedures enables the flight control team to operate independently of ISS Program management and respond consistently to events that fit those procedures.	
Source	**Finding and Supporting Evidence**
ENG1	Have documented emergency procedures that can put into effect no matter what happens. They go directly to these if something unexpected happens.
FOD1	Flight rules enable us to operate independently.
FOD1	Flight rules tell us what is safe and what is not. As long as we operate within flight rules, we don't need to go to program.

PRO1	Don't want people in mission control having to go to someone outside mission control before deciding/acting. For example if there's a fire, want to move quickly to prevent cascading failure.
PRO1	Want FOD in MC to be able to respond autonomously if possible.
PRO2	Know this ahead of time. Activate Team 4—separate ops team to recover this functionality. They have a separate team in order to not distract current ops team; to enable current ops team to still focus on mission.
SMA1	Team 4—when we are one failure away from loss of vehicle. There are several key failures; we know what they are. Pump module is one of them. Because of pump, we started Team 4. Used to be big 11, more now. Contingency planning.
ENG2	Safety is governed by flight rules; look for deviations.
FOD1	There is a clear division of decision authority. There is a depth of "pre-made" decisions.
PRO1	We leave it to the flight ops team to deal with unexpected events. They'll plan lots of one-failure events.
PRO1	If something happens that has not been talked about, then it falls to FOD to decide.
ENG4	Each vehicle has a set of flight rules, and those have been really vetted.
FOD6	FD has task list of things that can be done whenever there's time.

F-3. ISS personnel report relying on cues such as tone of voice, self-reports, or available data telemetry streams to perceive the condition or state of the crew.

Source	Finding and Supporting Evidence
Video Presentation EVA 23	Luca sucked some water off his helmet—it tasted horrible but he didn't say it—this was a clue. (early clue) If he says increasing … they'll make him come inside … and he doesn't want to. Luca was lost when he rotated his body—he had no idea where he was—blind and couldn't hear. He doesn't panic, even though he was about to die—he was a Special Forces guy. Q: Luca was talking, voice changed, anyone trained to notice his voice changed, that he doesn't sound quite right? C: It's hard in real time, it's tricky (to tell how crew is doing from tone of voice). That spent a lot of time looking at human factors. We didn't hear from Luca for 5 minutes. One flight controller in back room said hey, we need to ask how Luca is doing, but it never got to flight operations. It's hard in real-time ops.
ENG3	You'll hear fatigue in how the crew talks and in how they are breathing.
FOD5	You pick up on it by knowing them
FOD1	We spend time with them to get to know them, to hear what they sound like, to sense when they're tired.
FOD3	Tone on loop matters. Conveys uncertainty or confidence.
FOD2	Surgeon POV monitors them; the crew might seem fine, their heart rate and metabolics are good.
FOD4	I listen to crew and can hear it in voices.
FOD2	He can tell how tired crew is. "You can tell." Can hear in voice, go slower, they start making mistakes.

FOD2	Crew calls down something unusual: "smelling something funny;" "I'm hearing a noise." If they share it, they are concerned. Out of family. They are immediately concerned. If hears Russians talking about something out of family. For example: "lot of liquid."
FOD2	"It's all about relationships, history; I know the people." Trust.
FOD4	Everyone in MCC is supposed to listen to crew, but flight director and CAPCOM would get more subtle cues than most.
ENG4	You only can see so much data. How we sample it is only as fast as we can understand it. Systems we have may only be able to give you so much data. COTS items are like that.
ENG3	Relative to EMUs, there are various sensors and historically they drop out during an EVA. It's a known issue, but you have to think is that really the reason why it went out.
FOD8	There's a lot to body language, inflection, tone. Lots of FDs want that there, but I want them to be calm.
FOD4	Scary thing was … incident crew member was so calm we didn't realize how [bad] it was. [In reference to EVA23]
SMA2	First you have to report it. Rely on crew on reporting. Assume going great if don't hear about it.

F-4. ISS training of crew and flight control team is designed to improve general problem-solving skills through simulations with many issues arising at once.

Source	Finding and Supporting Evidence
Conversation post-EVA	They sim rescuing crew who is incapacitated during EVA in pool. His team works with people outside NASA to come up with failure scenarios (brings requisite variety—resilient). He spoke of doing "mini-sims" with his group only (lower cost than full-blown sim and easier to execute). In these sims, his team role plays others in mission control such as flight director (resilient—active learning, increased understanding of other roles). In some sims, they gradually increase a suit parameter, looking for when people notice and how they react to small changes (resilient—train to spot weak signals).
Video Presentation EVA 23	There were several instances where risk and uncertainty ("I feel a lot." "Don't think." "Feels like a lot." "Cannot tell source." "Don't understand." "It's really wet." "It's increasing.") were indicated in the language used by the crew. It is possible to use sims to train language to help people notice when risk or uncertainty are increasing and when making risk trades ("Let's just keep moving.").
FOD5	All these things happening simultaneously is not realistic.
FOD5	Training was primarily full flight control team simulations. Ran through scenario—everything breaking all the time, unrealistic multiple simultaneous failures.
FOD1	Most sims are not meant to show us how the malfunctions look, but to prepare the training team for situations and to do problem resolutions.
FOD1	Training team will give eight malfunctions at once.
FOD8	Fundamental reason for sims is to execute and develop team skills. Three focused on by me in big sims are leadership & teamwork, communication, and SA & threat assessment.

FOD8	We condition ourselves to learn from our mistakes, and we want our flight controller to do this, too. You have to learn to manage physiological reaction and respond appropriately. We need to elicit that reaction so they can learn to respond.
FOD8	Identify how you feel when you're performing well. You need to be able to identify when you've deviated from that and learn how to recenter yourself.
FOD8	We have nine major timelines we run, from EVAs to ones without major planned ops. We might integrate a debris avoidance maneuver with late notification of need to avoid. Integrate systems malfunctions that interfere with ability to keep timeline to run procedure. Sims are time pressured and completely unrealistic.
FOD8	When you're presented with problems you haven't seen before, that comes down to problem solving—that's what we're going for on all levels of training. We can't prepare them for everything, so we're relying on their analytical skills.
FOD8	There are lots of components running through your mind—lasts 7 hours and could be up to 40 malfunctions. Big integrated case with all team members working (usually one big problem and several nitnoids).
FOD8	Not a lot of desire to put in one malfunction, see how team handles it, and walk away. Not a strong push to make it like real time. We would lose a lot of training efficiency.
FOD5	I was just pushing buttons [during training simulations], not understanding.
FOD2	Everything begins as something small. [In reference to safety threats in real-world operations]
FOD8	We focus on managing individuals' behavior for their benefit. But for SA/teamwork, we teach that if you sense that someone is behaving poorly, it's your responsibility to act—so teach response, not how to recognize.
Conversation post-EVA	In some sims, they gradually increase a suit parameter, looking for when people notice and how they react to small changes (resilient—train to spot weak signals).

F-5. The ISS organization has taken steps to raise awareness of the concept, challenges, and risks associated with normalization of deviance.

Source	Finding and Supporting Evidence
FOD1	They read Chapter 6 of the Columbia accident report over and over [every year]. Normalization of deviance.
FOD2	Don't let them get away with "it happened before—it's ok."
FOD2	Real time … normalization of deviance. For us, "Have we seen it before?" assumption is if we see something funny. The guy in control center may not be aware of it. Their tool is the anomaly response database (AR). When did it happen before? Engineering team dispositioned it. Is this inside the framework? Is it interesting that it happened again? A "one off"? Happened twice, a third time, are they wrong?
FOD2	We tell the guys, don't get stuck in complacency. Don't ignore clues that may be counter to your theory. It's important to continue to look at new data and verify that it is consistent with your theory.
ENG4	We still question what's "normal."
ENG4	We expect things to not always go so well. These are first-time pieces that have not been tested in space.
FOD8	As you start to rationalize certifying a flight controller, every time you lower the bar it becomes the new normal, and it always comes to bite you. The most powerful thing

	you can do is to constantly remind ourselves of our foundations and how dangerous this job is and sharpen each other.
FOD8	For years we had been simming that CO2 sensor fails when it gets wet, but that's not the only reason it fails. Also train not to jump to conclusions.
FOD8	If you look back on everything that bit us, it always falls back on lack of imagination and normalization of deviance. Makes sense in hindsight, but we didn't think everything through down to that level.
FOD8	Help people understand how to communicate risk (e.g., answer the question you're asked, but if you don't understand why you were asked, need to speak up about that, too).

F-6. Repeated success in performing high-risk operations can lead to those operations being perceived as "routine," and can desensitize ISS personnel to the possibility of failure.	
Source	**Finding and Supporting Evidence**
Video Presentation EVA 23	We'll never know everything … about our hardware, systems, or operations, and the longer we operate the hardware, the more likely we are to believe that we do. Our systems are complicated; no single person understands how any of them work. And yet when they work successfully, we convince ourselves we do understand how they work. We'll never know everything, always have to continue learning. Very last shuttle flight—learned things they'd never seen before. Every flight we learn new things.
Observation EVA 37	SpaceX rocket explosion at Canaveral that day. In MER conference room, managers were learning more about this vs. watching EVA. ... Were not engaged with EVA. Normalization of EVA risks in general?
Observation EVA 39	EVA started 45 minutes ahead of schedule. Inquiry: Last-minute changes to plans can introduce brittleness. Where might there have been gaps, support people missing, etc.?
Observation EVA 39	4:39 into EVA. Four people left in MER manager conference room. More than 12 people were in the room earlier in the day. Normalization of EVA risks in general?
Conversation post-EVA	Trades last EVA. The light was sticky. Astronaut used hand (glove) as a hammer. After they assessed gloves, they were declared "no go" for now (these gloves were pulled from service for the time being). We heard later from EMU safety that there'd been an incident in the past where astronaut had injured their hand and severely damaged glove by pounding with it. Astronaut didn't report it; they found out when glove came back with blood on it. Breaking through glove could cause loss of pressure, which could be life-threatening.
Observation EVA 38	CAPCOM asked astronaut for a glove/HAP check. Astronaut held gloves up. Didn't really show both sides. It was hard to see the gloves in the video and then they went off screen even though astronaut was still doing the check. In MER conference room, XX held up his hands and flip/flopped them as if to show how astronaut should've done it.
FOD4	Always a struggle when risks are high and risk of significant failure is low. Trying to build a sense of danger.
FOD4	Since failure is low, there can be complacency.
ENG1	"Got to be careful ... not to cry wolf at every single thing."

ENG1	Just didn't think that could happen [Referring to EVA 23].
ENG2	On orbit ops—if we start seeing deviations from flight rules, that's a warning sign.
FOD2	Have some anomalies that go off twice a year. They are what they are, and you just keep going.
FOD2	Most of these people have done this for years. So when they see something new, it's concerning.
FOD2	With the suits—is this ok? Definitely a handoff between ops and engineering. He wants to keep track of everything. People assume engineering is tracking longer-term, repeat issues and making sure not normalizing stuff. (implication was he wasn't sure this was happening)
PRO1	Look for where there is another occurrence; is it a fluke or systemic?
PRO1	Importance of risk-based decisions is increasing as important systems are at life expectancies. … For example, space suits reaching life expectancy.
PRO1	Water in helmet—was not called out as scenario.
PRO2	"It happens all the time," the need to evaluate and prioritize.
PRO2	Constantly hearing about hardware, what might be breaking.
PRO2	The signal can be if someone wants to operate something outside of its normal operation. This is not automatically ruled out, because depending on the situation it may be the best path.
ENG3	In EVA 22 there were signals. Off-nominal signatures.
ENG3	Yes, I think relative to EMUs, there are various sensors and historically they drop out during an EVA. It's a known issue, but you have to think is that really the reason why it went out.
ENG4	"You get used to living in an off-nominal world."
ENG4	A team knew changes in trends of ammonia leak; they see flux all the time. They didn't communicate the information up.
ENG4	CDRA is another. Low voltage trips circuit. We narrowed it down to one valve. Known overcurrent. Can easily become comfortable. "Ah, it's just another LVT." But is it?
ENG4	Most of time are nominal ops.
ENG4	Remote power control (RPC) trips are an example. If you don't see any further issues you get comfortable with it. Similar ones, you've done testing and documented in a 90-page PRACA. But what if it's not?
FOD7	I read console logs every day. Sometimes a trend like crew called down that stowage note was missing … then you dig into and find activity added last minute … coordinated with owner but don't know if should have stowage note. Happened a few times in a week or two. I thought—now I will start asking, "Do you have a stowage note with that?" When crew calls about quality of products and there's a trend. I think planners maybe have started to slip on this. Go reread rules and make sure you are being careful.
SMA2	Do we look with fresh eyes every time? I think so. I think we do try. If we put the same amount of rigor from the 100th one as the first batch, we'd never get anything done. We have found some efficiencies. We've been asked to find new ways.
SMA2	He thinks it could still happen. When he was a flight controller he's seen how they protect the crew. It could happen again. [In reference to event like EVA23 mishap]

SMA2	There is a move afoot to become more flexible. Relax standards.
SMA3	XX doesn't want to provide second inhibit on a mechanism that has no history, but hasn't been driven in 3 years. If we do it, we're in single-inhibit case. XX's issue: "It has never failed closed," but that doesn't mean it can't.
SMA3	Hearing something that I haven't heard of before that I need to go get more information about it from people.
SMA3	I don't think the pre-Columbia culture has changed.
SMA3	Problem with console just wanting to present new stuff, not stuff that's been lingering for months and months.
SMA3	So many things that get missed in safety reviews. Something that big! What else are we missing? There are so many problems with suits. You wonder what's going on there.
FOD8	Agency has become complacent. That worked last time so it's probably ok.

F-7. Some ISS personnel expressed high levels of certainty that all risks have been identified and have a plan or rule to manage them.

Source	**Finding and Supporting Evidence**
ENG1	Have documented emergency procedures that can put into effect no matter what happens. They go directly to these if something unexpected happens.
ENG1	We identify all bad scenarios and create plans.
ENG2	Not often against a flight rule. They have one "flight rule teeth clenching" discussion per year.
FOD1	Every possible thing that could happen has been thought about.
FOD3	Probably hardest decision. Grey areas with no good option … those are the hard days.
PRO1	But almost everything has preplanned response to stabilize.
PRO1	This always works. I can't think of when it didn't [Using a pre-planned response to resolve anomaly].
FOD5	Solution for crew for unexpected off-nom is talk to the ground.
ENG1	(How do you define risk?) Crew life—but we have clear flight rules so that's an area we're never talking about. Mission success—this is his risk arena. Typically not talking anything they haven't already talked about for hours at a board meeting. Ex. BEAM module…inflatable module that's on orbit. Flight rule was not workable, their analysis was conservative. We understand the risk: the BEAM might leak. Went from FS 2 to FS 1. Mission success.
FOD1	It's all documented, it's just a matter of knowing the cues that you're in that situation. What the cues are depends on the situation.
FOD1	Example: Lithium Ion batteries on ISS are very safe. Everything that could go wrong with a battery has been designed out. They study how it's supposed to work and what it looks like if it is failing.
FOD3	Despite best intentions, run into situations haven't thought of before.
PRO1	Plan in advance, what things could happen?
PRO1	Stop at one failure (don't go to two failures).

PRO1	When anomaly does happen, they instantly roll to documented responses.
FOD7	Org is good at responding to change, but nobody is perfect. Things will get missed. Other downside besides visibility and late changes. Communication issues may not be checked as closely. Everyone turns on A+ game when this happens, though. Take a plan and take a lot of stuff off—that stuff has to go somewhere. Put program priorities at risk; things fall through the cracks.
Video Presentation EVA 23	ISS community perception that drink bags leak, but this particular design leak bag has never leaked. Opportunity to add structure to troubleshooting process, standard question: “What's different?”
Video Presentation EVA 23	“Water in suit tasted nasty—has iodine in it—and was cool—freezing. Water in drink bag is body temp. Luca didn’t mention until much later that water tasted bad. Questions are now implemented in a checklist. Not worried about this problem now. Will be something else.”
FOD4	Suspected leaking drink bag. Kind of assumed it was the bag. Pushing body against bag and hard shell of suit. [In reference to EVA23]
FOD2	I think that we got fooled [in reference to EVA23]. Don’t be lulled into complacency. Do not latch onto that and start ignoring clues that may be counter to your theory.
ENG4	Ammonia leak … super small ammonia leak we’ve had for a long time. Over the course of 6 years Thermal systems guys sat on it but didn’t think it was a great deal. Looking at trend over a year, a small leak looks incidental. Fluctuates all the time. As we get more technical stuff on orbit we can see more things. Escalated in the sense of not communicating it up.
FOD4	Thought we understood. In hindsight it [leaking drink bag during EVA 22] was talking to us and we didn’t hear it.

F-8. Some ISS personnel expressed confidence that there will always be a way to stabilize the system in response to an unexpected event.

Source	Finding and Supporting Evidence
Video Presentation EVA 23	Spent 67 minutes in terminate. Still no sense of urgency (not responding with urgency to surprise and uncertainty). Terminate is different than abort where it’s immediate and they get inside fast. This didn’t happen. Instructions to Chris—stay and clean up, then meet Luca at airlock.
FOD4	You have to instill that sense of being able to commit to a decision without waiting.
FOD4	You have to make decisions right here and right now. You can’t phone a friend. You have to make a decision right here and right now.
FOD5	Follow procedure such as how to safe a system.
ENG2	If you have an unexpected event, FCT is trained to safe the crew and the system, and then engineers come to work the system.
ENG1	Very rarely do we have to make a lot of risk trades real time. Failures upon orbit—power systems, computers … designs space station to be resilient, flexible to failures. Redundancy, back-ups, allow time for discussions.
FOD1	We try to stop and get bigger picture before we jump in and fix the problem. Want to understand if it is a symptom of bigger problem.
FOD3	Sometimes there isn’t time to get best people to confer. That’s where we’re the last line of defense.

PRO1	Priority is to make crew safe and stabilize the system.
PRO2	Contingencies are those you thought of ahead of time. FOD contingency gets to safe, and MER gets to true nature of failure. You can only do so much with pre-work. We then develop a plan to get our way out.
ENG4	We plan for potential failures. If that puts us in position for loss of attitude, we always have to prepare for loss of attitude, can we get into a safe position to assess further. It's all about getting into a safe position so then we can assess what to do next.
FOD6	If crew is not given sufficient time to prepare for something, like EVA. Most dangerous thing the crews do. Crews may say they need more time. We try to make that happen. Crew has a big say. We take what they say very seriously. Not possible to do everything with scheduling; it's a big team effort.
ENG1	Have documented emergency procedures that can put into effect no matter what happens. They go directly to these if something unexpected happens.
ENG2	Need time to think about next step.
FOD1	We're not landing on the Moon. If we have something we need to postpone, we can say, "Let's just not do that." Most of the time they have the option to delay. "Let's just not do it right now."
FOD2	Everyone is busy and the why, why, why communication can break down between ops and engineering.
FOD2	Spend time dealing with "the pie plate that falls off."
FOD3	Am I making a decision now that cannot be changed, or have I passed the point of no return?
PRO1	Stabilize system—shift to redundant system, recover, plan to repair.
PRO1	They question: Did we cause it? Did it just break? Current state? Initial ops responses—stabilize then recover. Cycle it.
FOD8	Failure, Impact, Workaround—our version of Aviate, Navigate, Communicate (but we have that, too).

F-9. When assessing risks, some ISS personnel indicate a burden to prove that a circumstance is not safe, rather than that it is safe.

Source	Finding and Supporting Evidence
Video Presentation EVA 23	Don't assume something is safe because have done it before. Assumed EMU never had serious accident, therefore was safe, so we get complacent. We're talking to a lot of people, including the military, and said how do we fight this? They said they don't know. Human nature is a tough one to fight.
ENG1	It's a high-risk environment. "Shit happens."
ENG1	Situation—flight director not listening during EVA. Had discussions with folks—he had said "no go" to EVA. Allowed to have right discussions. Flight director made decision to press. Communication breakdowns. MER asking for hold; FD didn't hold. Put suit in jeopardy for future use. Didn't go according to engineering expectations.
FOD2	Ask the question: Are there dissenting opinions? His team is trained to speak up. His expectation is for people to speak up. Joint ops panels may not be trained in that. He might have to ask—individually. Let someone else make the decision—tell me what

	you would do. Wrap up; give decision and the rationale why. Write this down in logs. Collecting for dissenting opinions for ISS—some people are very good at this. Look for it being consistent across the whole program
FOD2	Culture in orgs, other areas of NASA … come to blows … not productive in control center when solving a problem.
FOD2	There is absolutely an influence to not throw in the towel. There is a resistance because if you always throw the towel, you'll never get anywhere. You have to understand the influence your decisions have.
PRO1	Operational efficiency next—trying to squeeze the most out of what they have—new techniques or tricks
PRO1	If program sees flight rule being written—this is how we're going to manage—program can say, "We don't like that."
PRO2	Engineering hardware owners and FOD operators have differing opinions on how to recover.
SMA3	He doesn't want to provide second inhibit on a mechanism that has no history, but hasn't been driven in 3 years. If we do it, we're in single-inhibit case. His issue: "It has never failed closed," but that doesn't mean it can't (repeat of Columbia).
SMA3	I feel pressure to make the outcome be what program manager wants the answer to be, e.g., "Here's what I want; go talk to people to make sure that works," rather than, "Go prove to me this is safe."
SMA3	[Program Manager] has to trade mission assurance and safety. In Safety, we don't have to make those trades. Part of the problem is that he wants us to make those decisions for him. He pushes us for decisions, and if we say no, there can be some pressure. Go talk to safety and see if we can get there (to condition that may have single-fault tolerance), but I can't go to safety and ask that.
SMA3	They'll [program managers] find something to fit the risk to what their perception is.

F-10. Pressure to attract and retain science clients and projects can impose trade-offs with critical needs, such as maintenance.

Source	**Finding and Supporting Evidence**
Video Presentation EVA 23	Very heavy emphasis to maximize crew time on orbit for utilization (for science). Have to be very careful when talk about this because it is entirely appropriate. Space station is $100 billion laboratory—we have to do science, we have to emphasize getting work done on station. The problem is when engineering or safety would ask the programs to investigate failures, investigate hardware, and do maintenance on their equipment. They frequently were told no. They began to assume if they asked for crew time they'd be told no, so they quit asking. The program managers who are making the decisions have no idea what risks trades are being made. Emphasize to lower-level folks—if you have concerns, you have to raise them up.
ENG1	However you get into competing risks of—we are flying for a reason—if we were completely risk-averse, we'd never do anything. We'd bring the crew home.
ENG1	Science—with that comes risky activities.
FOD2	Future fears: Commercial crew. Maintenance and science pressures with older ISS.

FOD3	Week-by-week or month-by-month basis. Within shift, he has what he wants to accomplish; if he can't do this, it matters less. Come back to office: why didn't we get more science done? Insulate teams in FICCR from constant pressure.
PRO1	Big challenge with aging ISS is risk-based decisions operating at life expectancy. Trying to make it a national lab that shows science output as it ages is a challenge. That will be the decision point at which ISS goes into the ocean. As we work toward that point, challenge is managing the pressures of extending the life of the station, suits, etc.
PRO1	Science is prioritized against systems maintenance
PRO2	Repairs need to be made, but depends on effect on mission.
ENG3	Times when there's a problem—everybody laser focuses. When there is lower tension, there is more conflict, such as, "We don't really need to do that maintenance."
FOD6	If it has a higher level of risk, we work those issues harder. I think we do that well. We try to eliminate the risk. We don't want to risk crew or vehicle. Big thing now is science. Don't want to do something stupid that causes us to lose customers.
FOD6	Trying to work with folks outside of the Agency. It's a national laboratory, but processes to get up there and lack of confidence in schedule make it a challenge to get repeat customers. Contracts with big companies mean we have to stay in their good graces.
FOD7	Very dependent on crew onboard and objectives and vehicle traffic and how much science to do. Current crew—maniacs at getting things done—getting an extra person worth of work done per week.

F-11. Extensive resources in terms of time and effort are required to resolve complex interdependencies and to plan and re-plan fragile schedules.

Source	Finding and Supporting Evidence
ENG1	Very rarely make a lot of trades real time.
ENG2	We're a very reactionary organization—don't always have the time as a workforce to be proactive.
FOD1	"We don't have enough crew time to do all our stuff."
FOD1	EVA this week and next week, for example. All has to do with the suits. Can take suit back out in a week. Have to do a lot more with the suit if you let it sit a long time.
FOD1	Everything we do on station is tightly coupled.
FOD1	Now, crew doesn't have enough awake time to re-plan their day. Crew members are "always chasing the red line," trying to complete required tasks.
FOD1	Production pressures. Get this done. Sequence of events. Limited number of suits. Certification limits available time. Space station is tightly coupled. ISS is a space port. Takes weeks to prepare for events.
FOD1	We want to do multiple EVAs back to back as they're more efficient use of crew time.
FOD2	"If anything happens to the schedule, it crumbles."
FOD2	For the HTV that just arrived, there are tightly choreographed events over next couple months and need that arm. They must get on top of it NOW. Clock is running.

FOD2	Here's the clock … 30-minute problem, one-hour problem, three-hour problem. Example 30-minune problem: You lose voice with crew. If lose cooling, you lose voice—it overheats. Ten computers are down; which needs to come up first? Some scenarios, such as lose cooling to half vehicle, are tiered failures. (It's like a) Tetris board—need to do this to do this—controlled by different people. What first, how to do, time frame to work within.
FOD2	There is an influence in everything that we do that you don't want something to be the thing that causes you to be an all stop.
FOD2	Time is the consumable that the other elements don't have to work with. It's like fuel. Have to be strategic and prioritize.
PRO1	They try to schedule crew work such that they'll have the capacity to respond to unplanned failures.
PRO2	IDRD and CSRD is a list of things you can do on a mission, but that doesn't mean you will have enough time to do it—got to prioritize things to do.
ENG3	Schedule is very crewmember-dependent—assess how they did in training, then add a factor to pad the work.
FOD6	Three replan modes: Steady state—everyone wants to be in this. Slip plan—ahead of time, you know there's an event that might happen, and you've already prepared an alternative (e.g., a vehicle doesn't launch on schedule). We have enough manpower to create one back-up plan ahead of time. Has to go through same reviews. Major replan—have to scrap plan and redo it.
FOD6	Example: We do a two-week face-to-face meeting at four months out and another one-week meeting at one month out. Everyone is trying to integrate schedules, and program says, "By the way, we've got a new launch date for SpaceX." Thousands of activities to replan. Had to redo all the work of the previous day. Happened four days in a row. Causes a lots of political issues. I don't want to get too much into that, but it's a big deal. I understand how difficult their job is. SpaceX may provide optimistic date, but good program person will tell us to build plan based on what we really think schedule is going to be. If someone wants us to build to the unrealistic schedule that keeps changing, it's hard to build a product you can feel good about. Vehicles get unrealistically planned on a chart, and we sometimes have to build plan around that.
FOD6	If crew is not given sufficient time to prepare for something, like EVA. Most dangerous thing the crews do. Crews may say they need more time. We try to make that happen. Crew has a big say. We take what they say very seriously. Not possible to do everything with scheduling, it's a big team effort.
FOD6	Lots of dependencies of who's doing what; not everyone can be in the same spot doing everything. We normally deconflict this, and it takes weeks.
FOD6	Planners go into sandbox, work with counterparts at other centers using shared configuration tool. Involves talking priorities. Tradeoffs: we were going to have crew do all of this stuff, but it was canceled, so also have to give crew something to do today (can't waste crew time).
FOD6	SpaceX is going to launch on Monday, Progress is going to launch on Tuesday, etc. Things are usually very, very tight. Job of the planner is to protect the crew, and so is everybody else. Thankfully, we have the flight director's ear.
FOD6	This is a hot topic for flight controllers—biggest struggle is being able to depend on flight schedules, because they change so often, and nothing has as big an impact of

	vehicles arriving and leaving. Hard to get international partners to move things around.
FOD6	Usually planned very optimistically. This is probably the biggest area of tension between program office and planners like us.
FOD7	In terms of team, a bad day is chasing a SpaceX launch. Slipping, slipping. Had to wave off a rendezvous. Had to re-plan again. Do a certain # times. Stressful. Gets old. Groundhog Day situations. For this recent instance (of SpaceX vehicle rendezvous delay); it was a real slap in face. Typically, once launched never had problem with rendezvous, so it was a shock. Massive amount of changes to critical information were required in a very short time.
FOD7	There are improvement opportunities such as places where they are set up for failure: told to make a plan happen, but know it's not going to be ok.
FOD7	Very dependent on crew onboard and objectives and vehicle traffic and how much science to do. Current crew—maniacs at getting things done—getting an extra person worth of work done per week.
SMA1	We need to have someone who has the time to go fix something. Takes a lot of time to change things. It's a big ship to steer.

F-12. The ISS organization provides mechanisms and opportunities to express dissenting opinions.

Source	Finding and Supporting Evidence
Transcript of IMMT EVA23 Go/No-Go meeting	Used round-robin, a good practice to ensure each person has a chance to express their concerns.
ENG1	When going to do an analysis: are you doing the right review, checks? After you have the data? Look at assumptions, verify model, and bring the right people in to talk about it. In that process—he can tell when they are uncomfortable. He goes to understand what they skipped. Have we been here before? Uncharted territory?
FOD1	If data doesn't make sense, they talk about it. They teach this. They teach them to not be quiet when things are uncertain. "Talk about it."
FOD2	Every new guy (in mission control) sits with me 8 hours in middle of night on a Saturday. They can be hesitant to engage upper management. Their job is to make sure they are comfortable with it.
FOD2	Make sure they have the opportunity to speak up. May have to ask individually. "Tell me what you would do."
FOD2	One of the strongest features of ISS is the ability of the high-level managers to dig down to find the information they need without it being filtered through multiple management structures.
FOD3	Goal is to get everyone together and weigh in.
FOD3	More viewpoints we get, the better decision we can make.
FOD3	Want people to speak up before the last minute.
PRO1	Chairs do a good job of asking for their opinions.
PRO1	For "go/no-go" decisions, they throw it down to a safety person and ask, "What did we miss? What are we not thinking about?"

ENG4	About 80% of the people who work here want to work here. You get frustrations if one thing happens and then another right after that. We try to be a venting source to help them hold it together. Have a lot of technically expert people, passions, and sometimes expressions of concerns can come out a little harsh.
ENG4	Good to do it at this meeting since it's an audience of so many and other teams may hear something that impacts their system.
ENG4	If there are dissenting opinions, they go into the minutes. If there are any discussions with XX, would put a post-FIT discussion showing what XX discussed and paperwork that follows suit.
ENG4	Some are more challenging as they don't branch out of their circle of trust, others are really great at branching it.
SMA1	I meet with XX every month. I ask, "What are we doing, imposing anything that gets in your way?" "What is making life difficult for you?"
SMA1	IMMT reps are outspoken and not wallflowers.
SMA1	It's case by case. Usually bubbles up from the console, through IMT. But they can't be everywhere. Nice thing about this structure is there are two paths to bring up safety concerns to higher authority.
SMA1	Or they can submit an anonymous report. I don't think I've ever seen that system used.
SMA2	"Great input" he is really inviting. (Leadership sets the tone) Welcoming appearance to whole panel. Come on up to the table, pull a seat right up next to me. At end of the meeting, he polls everyone in the room—by name—not just people at the table.
SMA2	My role is to build a healthy consensus. Good to have a diverse group.
SMA3	Folks do speak their minds without repercussion, but they may not be confident that they're right. If they miss the mark, you can tell that others think they don't know what they're talking about.
FOD8	Always needs to be someone that has a dissenting opinion.
FOD8	Help people understand how to communicate risk (e.g., answer the question you're asked, but if you don't understand why you were asked, need to speak up about that, too).
FOD8	Leadership hovers around FD position, but it doesn't live there. Individuals have to step up.
ENG4	If we have a dissenting opinion, we bring that to the program.

F-13. Challenges in identifying whom to talk to, understanding different priorities, and overcoming perceived inequalities based on role and experience can impede ISS ability to collaborate, cooperate, and entertain fresh points of view.

Source	Finding and Supporting Evidence
Video Presentation EVA 23	No one applied knowledge of physics of H_2O behavior in 0 g to water coming from the PLSS vent loop. Opportunity to add structure to troubleshooting process such that relevant experts are contacted at point and time of need (real-time risk assessment process).
Video Presentation EVA 23	Stay hungry and vigilant—ask questions. Having diversity and new members on a team can help with infusion of new … and questions. Diversity of thought … (he had an example where they) pulled people from a different backgrounds, just damn good

	engineers that knew nothing about EMUs. Within an hour were asking questions they'd not thought about. Bring in people from the outside to look at what you're doing.
Observation EVA 39	Sometime near end of EVA: There is tension on loop. Someone says "micromanager." One person says "I think they (astronauts) have more cognition than anyone on ground."
Observation post-EVA IFI meeting	… "Crew moved quickly" when off normal. "Things happened versus waiting/ checking with ground." To crew: "Please check with us before …" "Please don't hit things with your glove or boot."
ENG1	"Got to be careful ... not to cry wolf at every single thing."
FOD3	When we have right engineering support, and can communicate in the MER, helps us make a better decision.
ENG4	The leak has existed for a year, but a new trend popped up and they didn't report it. They said they communicated at certain meetings, but didn't hear it at the 10 am.
ENG4	Some [people] are more challenging as they don't branch out of their circle of trust, others are really great at branching it.
SMA1	Crossing large organizational boundaries is difficult. Inside Building 30, it's easier with people being closer.
SMA1	If people don't integrate and they get in their own little group, they get "stovepiped" and don't merit respect from others.
SMA1	If you ask 20 different people, you'll get 20 different answers.
SMA2	A crew representative—especially if had done EVA—would have more weight.
SMA2	Equal weight no. He sat right next to chair—would think he would have been powerful based on position (at table) (but he wasn't).
SMA3	It's hard for low-level engineering to talk to SRP chair and tell them they messed up and need to fix this. And they have their own battles they're working.
SMA3	Sometime not at meetings because they just didn't think safety. If I were sitting over in building 30, it would be easier for me and get them to think of me.
SMA3	We had a big one with a leak on Progress. I got worried about that one. Our team tracked down that lines can freeze. FD said they told Russia that was the concern, they rolled their eyes. FD was trying to convince me it's not a big deal, but it WAS a big deal. Made it clear during the meeting that they were all rolling their eyes at our concern. FD clearly thought I was overreacting, but held the meeting and gave everyone a chance to ask questions.
FOD8	FD can be resistant to feedback. They may get too into the weeds. There may be some bias. Between CTO and FD, there could be some issues if they don't get along. Every interaction is important. If you say something stupid to me, I may not trust you next time.
Conversation post-EVA	Astronaut answers are sometimes nuanced or ambiguous. Sometimes ground doesn't understand what they meant, may be confusing. Last EVA, astronaut commented that the squeal in his headset could lead to loss of hearing. They thought he said he'd lost hearing. But it was his way of saying, "This is important—pay attention to it." He speculates astronauts may be concerned about their answers impacting their ability to fly again.

FOD2	How healthy is the suit over 15 EVAs? A lot is falling on the engineering community. I hope people are questioning engineering. Everyone is very busy; that can break down.

F-14. Deference to rank, fear of being wrong, and the perception of mixed messages from leadership about speaking up creates pressure among some ISS personnel to "stay quiet," especially in open forums.	
Source	**Finding and Supporting Evidence**
Video Presentation EVA 23	Anyone in any org (engineering, safety, ops, program, etc.) could have had a considerable impact in preventing EVA 23 mishap. From lowest level, flight controller, safety, or engineering sitting on console. Anyone could have asked, "How do you know the drink bag leaked at end of EVA 22?" As leaders we have to get people to open their mouths and raise hands and ask questions. They're not always going to be right but they will be sometimes, and we as leaders encourage and reward the behavior.
Observation EVA 39	Conversations at the table in MER conference room tend to be quiet and between pairs of people. On EVA, object floated away and it's uncertain what it is. This is not discussed openly in this room. Some people in the room are not sure if it's been communicated to astronauts. Relevance: Weak signals could be buried in the side conversations.
Transcript of IMMT EVA23 Go/No-Go meeting	Mixed message: 37:48. Chair: Okay, we had some discussions ahead of time about this, and I'm fine to take it off. "It's a little disturbing that we get this close to an EVA and all of a sudden something like this pops out. I'm glad it did, from the standpoint of we don't want to do something we don't want to do, but clearly somehow or another we missed something along the way." These are discussions that need to happen at an engineering type board, so someone needs to go off and talk about that. "It's late, and I'd just as soon, for all the reasons you mentioned, just go ahead and take it off the list."
Transcript of IMMT EVA23 Go/No-Go meeting	Mixed message: 40:26 Chair: "Back on that, I do want to say I'm glad this came up. We do want to talk about this kind of stuff. Until they're out the hatch, we can be tweaking this stuff right up to the very end. But we do need to go back and understand how we go this late in the flow. I'm not mad or upset that it came up. It needed to come up. What we need to do now is to go back and try to address it and try to understand how we cannot let something like this get this far again." "Great job, whoever came across this? This is good."… Take this discussion off-line. "I don't want the real-time team having to debate this in the front room at the very end. That's not what we need to do as a community."
Transcript of IMMT EVA23 Go/No-Go meeting	Most questions asked were closed-ended questions (26 closed, 1 open). All questions asked were asked by Chair except one. Clarifying/crosschecking was done seven times. All crosschecking/clarifying done by Chair except one. People invited questions, but no one had questions.
Observation post-EVA IFI meeting	Meeting leader begins by bringing up the issues they noticed. "The first one I noticed was …" Observation: The practice of the leader querying the team before sharing their own thoughts/observations opens conversation and thinking while the opposite may close/stifle communication. If leader goes last, newer team members are more likely to share; often they have a fresh, valuable point of view and insights.

Observation post-EVA IFI meeting	"The answer better be yes, because we said it on the loop." "Now is not the time for this question."
FOD4	Some people don't want to go down on record. If being recorded, they may not want to be brutally honest.
FOD2	New guy sometimes hesitant to speak up.
FOD3	I typically let people weigh in once.
PRO1	Chairs do a good job of asking for their opinions.
PRO1	FOD—now has crew, adds a layer, crew office still at meetings. Used to come to meetings with two positions on a topic, now sort issues out before they come in.
ENG4	Good to do it at this meeting since it's an audience of so many, and other teams may hear something that impacts their system.
FOD7	Pre-increment stuff … but we covered … things that drive things that happen during increments—there are improvement opportunities, such as places where they are set up for failure. Told to make a plan happen, but know it's not going to be OK.
SMA1	Are there people intimidated by bringing something to [a manager or board]? Yeah, we know that. We try to have an open-door policy, to make it as unintimidating as possible.
SMA1	At branch level we work well together. All GS-15 at this level. As you get lower, that gets "stovepiped." People feel less willing to bring things up. Used to working in their own sandbox. That could be better.
SMA2	Be very careful of your words. Chairman doesn't want something stirred up that causes partner ... Doesn't want to be surprised. Not in that meeting.
SMA2	The crew's right—don't question the crew. Especially in an open forum.
SMA3	Example, on most recent EVA GNG, there was a get-ahead task that became a primary task, and there was risk associated with it. I didn't really care, since we'd already bought off on the risk. But for person tasked with mission assurance, this was a big deal. The IMMT wouldn't have been the right place to fight it.
SMA3	I feel pressure not to have public discussion at IMMT.
SMA3	I feel pressure to make the outcome be what program manager wants the answer to be. "E.g., here's what I want, go talk to people to make sure that works," rather than, "Go prove to me this is safe."
SMA3	In an IMMT meeting, I would hesitate to bring up an unknown high-risk item. It would get people worked up.
SMA3	They'll [program managers] find something to fit the risk to what their perception is.
SMA3	Those [IMMT meetings] are like a check-the-box meeting. Any issue that needs any type of acceptance has been talked already. That's the way we've been conditioned.

F-15. ISS relies on teamwork and cooperation to function effectively. ISS personnel believe that cross-organization cooperation is healthy, and have identified strategies, including training, rotations/details, and co-location to help improve engagement across role and organizational boundaries.	
Source	**Finding and Supporting Evidence**
Observation EVA 39	There are several divers/trainers from Neutral Buoyancy Lab in the room. This is their first time sitting in on an EVA, even though several have been with NASA for many years. The purpose was to give them more of a big picture.
ENG1	If you have an unexpected event, FCT is trained to safe the crew and the system, and then engineers come to work the system.
ENG1	There is a "healthy tension" between Engineering, Ops, and PO.
ENG2	Personalities are the driving factor. Different teams have different relationships—some are like families, but not all of them are like that.
FOD1	FCT has been working together for each planned dynamic situation for at least 6 months, and this wasn't their first time doing this.
FOD1	It all gets back to training – making sure that folks that aren't FDs aren't making FD decisions.
FOD2	Conflict has no place in that room. It's not productive, and it's trained out of people.
FOD2	They build a team that can handle many contingencies. Teamwork, team problem-solving; is this working right?
PRO1	But we have to understand the failure first and that is where and why we have FITS and ARTS and MER (engineers that own the hardware) and FOD (the operations perspective).
ENG3	There's a healthy tension among the three teams [engineering, flight ops, program office]. Flight wants to get things done. Engineers like to tinker with things.
SMA1	Ten years ago ops sent some up-and-coming managers here for a rotation to learn. Before, it was us-versus-them, "we're the cop" mentality. Rather than "no," we switched to respond, "Yes, as long as …" Took a while for NA to change. Now we get a lot better information exchange and cooperation.
SMA1	Within Building 30, everyone works closely together. Without thinking, they always get safety involved.
SMA2	Healthy tension, such as with engineering; if there's gray area, engineering will say "it says this!" (Referring to rules). FOD, crew bring different perspectives. Do have disagreements. His job is to build consensus—like foreman of the jury—what are the facts? Deal with the facts.
FOD8	FD often has most influence on student. If FD is happy, everyone is happy, but sometimes FD is misinformed and student learns the wrong thing. I work with FD during sim to stay on same page. FDs can be resistant to input from CTO (chief training officer). Doesn't happen often.
ENG4	Over past few years, the flight control team has improved relationship with us. In early part of ISS had general thought flight control team could handle it. Now have bi-weekly tag-ups with international partners, monthly with all MER teams.
FOD3	More viewpoints we get, the better decision we can make.

F-16. Roles in ISS are well defined, yet some ISS personnel may not appreciate how their actions or decisions can affect others' responsibilities.	
Source	**Finding and Supporting Evidence**
FOD5	Astronauts are required to work the mission control center now, so they understand who does what and the decision-making process.
ENG1	Count on FOD to know what they are doing and know when to call engineering.
FOD1	There is a clear division of decision authority. There is a depth of "pre-made" decisions.
FOD2	A lot of things (like the use of the suits over time) are responsibility of engineering.
FOD2	Ops people think/assume engineers are tracking the things that are repeating.
PRO1	Medical folks don't use chits to capture changes or document requests: "Tried to talk to medical folks about chits, but right now capture that internally."
ENG3	Primary mission is to respond to anomalies on ISS, plan for events coming up.
ENG4	(Relationships) Between sub-system teams? There's always room for improvement. Depends on personalities. Some have challenge with moving out from their circle of trust. Others are great. Sometimes can be the system. Software guys, it's hard to get them to tell you stuff.
FOD7	Person sitting right there—ground control (GC)—can't possibly know the impacts. The certainty with which they state "no impact" has bitten them a lot. When they say things like rebooting server or work on this satellite. "I know you say no impact … even though may take down all gateway tools." The ground control team explores and finds it may actually take down command and telemetry—this is a big deal.
SMA1	Conditions where people are manipulating the system to make life easier for themselves. Example: [Contractor X] asked to build a cable, but no integrated hazard analysis performed. Trying to figure out why an escapee like that happened. We had a guy on the acquisition, but he was a quality guy and not a safety guy.
SMA1	90% of that water in the helmet investigation was, "Hey boss, do you know what those guys are doing?" Learning what the EVA team actually did … and management had not had any idea of what they actually did.
SMA2	Doesn't know if someone is looking at the big picture or trending.
FOD8	But I would love to have them in the sims so they can learn by osmosis—goes for Ops Plan, MER engineers, etc.
FOD7	On console, less responsibly expected from Ops planner. Knows that some FDs don't have respect for their team in general.
FOD7	Would be hard for us to kill the crew. Consider my job—very important—to keep crew from being overworked. Always fighting this battle. "Success oriented plan" is high work load. I escalate if needed. Could even involve surgeons.

F-17. Training variability across ISS roles and exclusion of certain personnel/roles from participation in large-scale training simulations does not support team unification or the development of shared understanding.	
Source	**Finding and Supporting Evidence**
FOD4	Schedules are driven by Russian travel, so crew are rarely together. So there is a lot less familiarity. It's not like it used to be on space shuttle, because they practiced so much and knew each other so well.
FOD5	(At the end of the sim) flight director leads the after-action review on the loops. People are in different rooms and countries. No consistent structure.
FOD5	Monthly air crew meetings—how I screwed up, case studies, ingrained in their culture for aviation but don't do anything similar with ISS.
ENG1	A lot of it [training] is through knowledge transfer, people talking to each other—engineers talking to engineers informally.
ENG2	Real-time ops is not really engineering responsibility. Right thing? Since heavy-duty assembly of ISS is complete, it's ok (not to be part of sims).
FOD2	Engineering …. couple years ago, set up a sim—2012—fixing cooling. They (engineering) didn't come to the sim.
FOD2	For FD, not all the people are there, so it's hard to replicate in sims.
FOD2	MER guys don't get simulations, but I think they could benefit. Anyone that's making real-time calls during the events should be included in a sim. You can't show up day of and expect to be able to do it.
FOD3	There is some cost in updating procedures and plans and not having simmed it or run in the NBL.
FOD3	They have some formal training (in critical steps), but it's not drilled into them; it's gained with experience.
FOD7	Also involved in developing training for my team. Make training more uniform—there are inconsistences. Most training is real time on console versus sims. Trying to get "same flight controller" at end (of training); as much as you can with humans.
FOD7	When something goes wrong, first thing that goes out the window is the plan. From a planning perspective—they don't get to exercise their skills as planner. They are always looking at tomorrow. Sim world—there is no tomorrow. When first started, sat in generic sims. Sat there. Became less and less useful, so got excused.
SMA2	That is missing (a certification or training process for those on the panel) —he noticed when he started.
SMA3	Breakdown with our MER safety console, because they're not really acting as integrators. A lot of them are new. They're going to the flight rules, not going to the hazard report (and flight rules came from those).
SMA3	Used to review design for emergency ops, but we gave that up. Not involved in design, but are there during sims. But there aren't a lot of big sims.
Conversation post-EVA	Sometimes they work with people outside NASA to come up with failure scenarios. He spoke of doing "mini-sims" with his group only (lower cost than full blown sim and easier to execute). In these sims, his team role plays others in mission control such as flight director.
FOD8	We do smaller sims for things like visiting vehicles, etc., with assigned team.
FOD8	They (roles who are not part of sims) aren't in sims because they don't have real-time impact. But I would love to have them in the sims so they can learn by osmosis—

	goes for Ops Plan, MER engineers, etc. Risk that I'm tying them up, has been decided that it's not worth it from a resources perspective.

F-18. When managing missions and troubleshooting issues, ISS personnel tend to focus more on software and hardware performance than on human performance.

Source	Finding and Supporting Evidence
Video Presentation EVA 23	Assumed EMU never had serious accident, therefore was safe, so we get complacent. We were talking to a lot of people, including the military, and said, "How do we fight this?" They said they don't know. Human nature is a tough one to fight. ... Struggle with how do you take these lessons learned from these failures and from other industries and get them to people so they can find them faster? Only way he knows is to talk about them. … We almost killed Luca! Consequences are we kill people. People have to take this to heart—that it is YOUR responsibility to fix these problems. Almost all the issues are because program managers didn't understand the risks. To help the program managers, to help them understand the risks.
Video Presentation EVA 23	Luca feeling water in his ears. Trouble hearing. Can you give us status? Is it true you cannot hear? Luca: I can hear perfectly, but my head is really wet. It's increasing. (rate of change) At the same time hundreds of conversations going on over loops on ground, and they weren't having any better luck figuring out where water was coming from. • 67 minutes in terminate. Still no sense of urgency (according to CH). • 73 minutes: Luca status? Luca: "I'm at airlock; I have a lot of water." You can hear him struggling. No one on ground worried (according to CH). The ground hadn't heard from Luca in 5 minutes until then. (Silence is cue things are getting worse, gap in monitoring person during unexpected event.) Response appears to be more focused on source of water (technical cause) and less on condition of Luca (person).
Video Presentation EVA 23	A Russian crew member started to pull Luca's helmet off before equalizing pressure in suit (helmet would have popped off, taking anything it hits with it). Karen noticed and grabbed his hand and pulled it away, otherwise the helmet would have taken Luca's nose off. Have now trained Russian astronauts in how this thing works. This corrective action was specific to this issue. Did NASA look at what system gaps could be associated with this? Also, breakdowns or injuries sometimes occur during the response to an event and are triggered by, or happen to, the people responding. Thus, when in crisis response mode, resilient organizations switch to higher level of monitoring/collaborating/communicating.
Observation EVA 37	In some ways the actions are highly structured, other ways not. Engineering aspects structured, human interaction not as structured.
Observation EVA 38	4:34 into mission, the mood in MER conference room changes noticeably. Many conversations are occurring. Check-in with a manager at the table: What do you notice? "Relaxed." The mission—battery install—was accomplished. By 5:30, most people in the room have left. Observation: In this room, there seems to be a sense that the mission is complete because the main job was finished successfully. Yet astronauts are not safely back inside. As task risk goes down (task complete), human risk goes up (fatigue); focus seems to be on task risk. Note how the astronauts seem to be struggling more from here until the end of the EVA.
Observation EVA 38	Mission is declared successful once main task is completed, not when crew is safely back inside. Once main task was successfully complete, NASA leadership who had

	been in MER conference room departed. Yet crew was still in space and tired, thus risk to crew may be higher near end of EVA.
ENG4	We have IFIs for human error, don't you worry about that. ARs track anything that's off-plan.
FOD6	That's a really hard thing. There are a lot of pieces. If human error, we can document through AR, which requires identifying a corrective action. Close it out. Other things don't fit within that tool. You scheduled something for 30 minutes, but it took 2 hours. The crew can make a note on the plan and the whole FCT team can see it.
SMA1	IFI works well, but sometimes they don't include things he thinks they should include, like human errors. Human errors wind up in ARs. If I were King for a Day there would be one system. ARs and IFIs one system.
Observation post-EVA IFI meeting	"We followed the flight rules. It was a crew member error. Not hardware failure." No IFI required, will write up AR just to document. Observation: Human error is a starting point for understanding what happened. In this situation, it seemed they identified it as a cause and moved on. Treating human and hardware as separate versus human-technical system?

F-19. ISS uses linear causal models (e.g., root cause analysis, fault-tree analysis, and error chains) to analyze and understand mishap events.

Source	Finding and Supporting Evidence
Video Presentation EVA 23	"We did not control water quality on the ground, and that led to us almost killing Luca. It's that simple."
Video Presentation EVA 23	61 minutes in, more things going wrong (with EMU). (Systems in the EMU are highly interconnected, tightly coupled, and are beginning to fail at an increasing rate; cascading.) "It's increasing (water) . (Rate of change matters.) At the same time, hundreds of conversations are going on over loops on ground, and they weren't having any better luck figuring out where water was coming from.
FOD1	Links in the error chain. What was the weak link? Use lessons learned to train this from NASA and other industries (aviation, Deep Water Horizon).
FOD3	A fault tolerance approach. Structural fatigue and failure are more typical in the ISS.
FOD3	Error chain—anytime we've had loss of crew or catastrophic event, leading to that is a series of mistakes. We usually don't find just one error. So we see the error chain and hope that one of those mistakes is broken or removed to lead to a more positive outcome.
ENG3	Case study—flipped switch, heat exchanger subtle clues—almost froze it and put ammonia back in cabin. … He led this close call investigation. Design assumptions—we are in this condition—we'll be safe—traced back to design requirement—requirement to bypass and isolate—should have been to thermally isolate and verify … pervasive assumption—we are in this configuration—we must be safe. Biggest thing that came out of it: how to do fault tree and look at these situations.
ENG3	Goal of Anomaly Resolution Team meeting is initial triage, trying to get to proximal cause. What happened, what data did we have? Look at previous EVA; what could we do on orbit to troubleshoot?
ENG3	Video on how to do a Fault Tree is a good two hours we use to train MER managers.

ENG3	Training documentation. Lessons learned. In MER manager group, we make sure guidelines are up to date. How to's. Get lessons learned into training. Case studies. Root cause.
FOD8	You don't have to know what the failure mode is. You have to identify the impacts of the failure mode.

F-20. The safety team's focus on compliance to control hazards, along with varying perceptions among ISS personnel about how safety functions should be managed, leads to the safety team being devalued and minimizes their influence on real-time safety management.

Source	Finding and Supporting Evidence
Transcript of IMMT EVA23 Go/No-Go meeting	Safety comments related to EVA are associated with controlling hazards—sharp edges, inhibits. 1:05:34. SAFETY. "All the NCRs and hazard reports associated with EVA23 have been signed and approved by the SRP. The SRP has no outstanding work as it affects EVA23." The EVA procedure has been reviewed, and all electrical inhibits are in place and mechanical inhibits are sufficient. All the proper notes are in there for the sharp edges, and tie-down plans have met all of our requirements. "So we have no constraints. I'd like to thank the safety team for pointing out the P-clamp issue and bringing it to the Program's attention. That's all I have."
FOD4	People who work in safety, they drive crew crazy with requirements.
FOD1	You can slice and dice safety in many different ways: ENG Safety, EVA Safety, Ops Safety, ISS Safety Review Panel (SRP).
PRO1	Everyone owns safety.
PRO2	OE Safety person is assigned to IMT during planning period for Ops TAG IMMT has safety person. JSC safety rep. OE rep.
ENG3	Safety realm is interesting; you have institutional safety who sits console, also have EVA safety, and then have payload safety. There are a lot of flavors of safety. We've had lots of discussions of roles and responsibilities of safety.
FOD6	[Safety personnel] have a much bigger role with systems guys, MER, engineering. From a planners' standpoint, WPR (weekly planning review, or "whopper") where everyone is there. Don't interface with them a whole lot, but for maintenance tasks, there can be lots of last-minute changes that safety is tracking, because it's dynamic. Safety still has to get sign-offs on open paperwork, etc.
SMA1	Before it was very us versus them, and they weren't really part of the team. "No, you can't do this because of this," was the mantra. Switched it to become more part of the team: "Yes, you can do that because of this." Once they did that, respect got much better. Now stuff gets communicated back and forth. And they can understand why the safety guy feels that way.
SMA1	Because we levy a lot of requirements on them, there was a perception that we were difficult to work with. Trying to change the perception.
SMA1	Real-time safety is flight director following flight rules. Console and IMMT reps are everyday response. If they do notice something, they can send it through the MER manager to the flight director.
SMA1	In the past, requirements have been perceived as silly because people didn't know the context.
SMA2	I know how rigorous we are. We need to be more flexible and apply a little more common sense.

SMA2	Protecting the crew and the space station from catastrophic/critical events that are likely to occur. Critical is not necessarily credible.
SMA3	Flight controllers much more plugged in to safety, but can still struggle with safety's role.
SMA3	Safety asking about failure mode of hardware, and it wasn't even a credible safety mode. We'd had controls/rules in place to address this for years.
SMA3	I still hear from FCT every day because they want safety to be more involved. There's not a lot of people who take ownership in safety.
SMA3	There are so many things that I see in the real-time world that get missed in the safety reviews.
SMA3	There is a perception that the safety people take it too far. They live by the rules and the rules only, and that is true for some people.
SMA3	We had a big one with a leak on Progress. I got worried about that one. Our team tracked down that lines can freeze. FD said they told Russia that was the concern, they rolled their eyes. FD was trying to convince me it's not a big deal, but it WAS a big deal. Made it clear during the meeting that they were all rolling their eyes at our concern. FD clearly thought I was overreacting, but held the meeting and gave everyone a chance to ask questions
SMA3	We're told not to worry about mission assurance (getting work done) versus safety, even though we're S&MA.
FOD8	If you want to advance, you should have to work safety—put your top performers in rotation through safety. Safety is a powerful organization, and that community needs to get stronger. When you see underperformers go to safety, it erodes relationship with that org.
FOD8	Impression that safety doesn't know what they're talking about, which is a problem.
FOD8	Mission success should be something that safety should have to consider—it's frustrating for an ops guy.
FOD8	Safety has to function from requirements. They do a really good job of making things safe, but they don't appreciate the applicability (of their requirements in operations).
FOD8	Bad perception of them [safety] in ops. Not common skills or mutual corporate respect. Creates poor work environment
FOD4	If signed off by 40 people, no one owns it. One would assume responsibility.

F-21. The ISS Program values technical expertise and relies on experts' operational experience and system knowledge when determining responses to planned and unplanned events.

Source	**Finding and Supporting Evidence**
ENG1	Count on FOD to know what they are doing and know when to call engineering.
FOD1	Operational culture. Depth of training. Experts you have access to. Preplanned deviations. Anomalies database. Chit system. All are available to us. By the time you're in the room, you're pretty conversant with the culture.
FOD2	Helped that he'd monitored telemetry. Strength is their variety of people (flight directors) —backgrounds and knowledge.
FOD2	In the ops meetings, they can get the people who know the stuff, the engineers.

FOD2	It's all about networks of people. These guys know that being able to reach all the way down and get person who knows what's up (is important). Strongest part of ISS. Get information directly.
FOD3	If something goes off-nominal during business hours, we'll ask for an engineering solution.
FOD3	We rely on flight controllers knowing the difference between routine and critical.
FOD3	When we have right engineering support, and can communicate in the MER, helps us make a better decision.
FOD3	Whole set of engineering folks, in case something is off-nominal, we may contact them.
PRO1	If something totally unexpected happens, rely on their operational experience.
PRO1	Use a lot of corporate knowledge to develop lessons learned.
PRO2	People are senior and able to deal with it.
ENG4	So you have to make that call, whether you flag it or trust the experts.
ENG4	We do get a lot of gut feelings with senior engineers, and we listen to them.
FOD7	Major replan: When there are so many changes to a day, it no longer makes sense to follow normal process—steady state re-planning. A change so large, not possible to keep up with paperwork or process. Re-baseline the plan, basically. Has a lot to do with instincts, experience on how bad it will be. Group decision. Sometimes I raise the flag to consider for major re-plan.
SMA1	Lots of system managers with knowledge. They know the issues and can go back and find it.
SMA1	On program side in Building 30, we've been doing it so long we have a strong team.
SMA2	Have a person who knows the requirements well on the panel. Looking at same requirements day-in and day-out.
SMA2	There are a lot of interpretation letters—everywhere. How do you find the right thing? It's a risk. Rely on knowledge of people who've been there forever.
SMA3	Just hearing something was off-nominal. I get mission reports and read those. I'll ask the experts what they think, and then they can go back to people and ask what it means.
FOD8	I use some of my own experience to measure things like when team is getting overwhelmed.
F-22. ISS risks losing expertise through retirement, rapid turnover, and insufficient means to capture and transfer expertise to new personnel.	
Source	**Finding and Supporting Evidence**
FOD4	We're losing our engineers with the knowledge, and there's a brain drain because they knew so much about things and now they're gone.
ENG1	A lot of it is through knowledge transfer, people talking to each other—engineers talking to engineers informally.
ENG2	Lots of folks are about to retire, and there's no plan to move new folks in.
ENG2	Resiliency of workforce—experience, expertise, to keep it high in engineering need to get younger people in system manager positions.
FOD3	They have some formal training (in critical steps), but it's not drilled into them; it's gained with experience.

FOD3	What doesn't [work well] is someone who is not knowledgeable but wants to be part of the conversation.
ENG3	But in 5 years, awareness will decline and staff will transfer, and that may be lost.
ENG3	It is really important for program to figure out how to train for people holding his role (MER manager) for a shorter time (3-4 years versus 10+).
ENG3	Change in training, documentation, lessons learned. How to take what's in minds of these folks and get them into new folks.
ENG3	Right now it seems like the documentation gets put on a shelf, but most info comes from those who experience it firsthand. But then once they go, you lose that knowledge.
ENG3	That's the real risk here. New people won't know all the nuances that older generation knew.
SMA3	Haven't been trained what to do, and lots of turnover at that position [MER safety console]. I think they can fix it if they realize it's their job.
SMA3	Lots of turnover in ops safety, so we lose that experience. It took me a long time before I felt like I could add value. There were no training plans—there still aren't.
SMA3	They don't get trained. But when they get good, they move on and leave.

F-23. Documentation (e.g., ARs, IFIs, and lessons learned) is valued, yet the time and effort required by documentation and resolution processes discourage people from entering new information.	
Source	**Finding and Supporting Evidence**
Video Presentation EVA 23	Flight control team's perception of anomaly reporting process as being resource intensive made them reluctant to invoke it. So resource intensive, such a pain in the ass … I don't want to open up. One of the flight controllers admitted he went home after EVA 22 and said, "You know, that's really bugging me that we don't know exactly where that leak came from. It was probably the drink bag, but we should look at that. But if we do, we'll never get to that next EVA in a week. Days and days doing a bunch of investigation and it'll be a red herring." So it was never reported.
Observation post-EVA IFI meeting	Seemed to want to avoid writing IFIs. "We are good on this one, no IFI." "That's what I like to hear."
FOD2	"If you are thinking about writing one, write it." Don't want people to be afraid of the paperwork. Database is mined. Other orgs, the shuttle program for example, to pull an anomaly (enter AR report) it's a big deal. They have to "Declare it" (an anomaly) and clear before FRR before entering it in AR database. If not a big deal, close it.
FOD2	Lots of people are afraid of paperwork.
FOD2	Now many [anomaly reports] open and overdue.
FOD2	Problem—there is so much data on ISS. May be time to relook at search capability (in AR system). But not terribly broken.
FOD2	Community wide, writing ARs is inconsistent.
FOD3	Nice to have a way of tracking anomaly and lessons learned.
FOD3	There is no prioritization—which are important? [Anomaly reports and lessons] look the same.

FOD3	Usually something if hardware damage or crew hurt. Or if there was a high likelihood that something would've happened. Usually goes to engineering, and then often they'll say, "This has nothing to do with us," and kick it back to ops.
PRO1	May not even show up in PIER. Where it would go … I don't know. If have anomaly that requires emergency response, have in IDRD. If significant, form investigation team.
ENG3	Do we need new paper (IFI or PRACA)? It's a very rigorous process. Because it's rigorous, there's sometimes pushback on doing it.
ENG3	There's sometimes pushback on taking paper. MER managers are responsible for maintaining consistency. Every 6 months we rotate someone into an "IFI Marshall" role.
ENG4	"No one likes more paperwork."
SMA2	We don't know [about safety issue] unless someone writes it down.
SMA2	Rely on technical lessons learned, like how you test a pressure vessel, batteries, and structural things.
SMA3	Our processes are inconsistent, so makes me wonder and worry about how long some issues get left open. We don't have set criteria or good work instruction for our role, either.

F-24. Although multiple processes are in place to document anomalies and lessons learned, some ISS personnel are unclear on how to use the documents or how the collected data are translated to results.

Source	Finding and Supporting Evidence
FOD4	We do capture comments in debriefs and put it together for lessons learned, but I don't know how it is used.
FOD4	Yes. Crew notes. An electronic record that a procedure stank. Or whatever. They turned into action items in a day. They turn around in a day.
ENG2	Data will set you free. If you have data, program will do the right thing.
ENG2	Rely on experiences so lessons learned—need to be proactive on searching them out. Maybe stress to workforce to search lessons out.
FOD3	Nice to have a way of tracking anomaly and lessons learned.
FOD3	Don't know of a formal process. [For detecting anomaly trends]
FOD3	There is no prioritization—which are important? (anomaly reports and lessons) Look the same.
PRO1	May not even show up in PIER. Where it would go … I don't know. If have anomaly that requires emergency response, have in IDRD. If significant, form investigation team.
ENG3	Change in training, documentation, lessons learned. How to take what's in minds of these folks and get them into new folks.
ENG3	Real magic is how you disposition these things. I can't say we have significant training on this. How to balance opening paper on everything and handwaving them all away.
ENG3	We try to take lessons learned out of spreadsheets. We document them, and they just go on a shelf.

ENG4	You only can see so much data. How we sample it is only as fast as we can understand it. Systems we have may only be able to give you so much data. COTS items are like that.
SMA1	Hard to answer. Usually info is there and people don't use it. Until something bad happens. Even when people do populate them, people don't look at them.
SMA2	Doesn't know if someone is looking at the big picture or trending.
SMA2	Don't have lessons database that could share with other suppliers.
SMA2	There are so many documents. We are working on cleaning up a lot of our documents. A lot of interpretation documents. I would say that's risk to our success.
SMA3	Learning to pull safety documentation and do the training. They can't keep up with the workload.
SMA3	Problem with console just wanting to present new stuff, not stuff that's been lingering for months and months.

F-25. The ISS Program's inconsistent use of "lessons learned" data limits its value.	
Source	**Finding and Supporting Evidence**
Conversation post-EVA	They ask about difficulty of task, if instructions were clear. If something happened in a way that was unexpected. They don't have standard questions. Post return debrief questions tend to be the same, but this debrief is led by FD lead and questions vary with who is leading it.
FOD5	Monthly air crew meetings—how I screwed up, case studies. Ingrained in their culture for aviation, but don't do anything similar with ISS. Lot of things they do with T38 program that could be used as a model.
FOD5	No consistent structure [to lessons learned].
ENG2	Doesn't see official lessons learned database that everybody talks about.
FOD3	Nice to have a way of tracking anomaly and lessons learned.
PRO1	Intent is always there to make changes from lessons learned, but it's all over the place in terms of importance.
PRO1	Program lessons learned—admin, process, ops functions—how did we pack a pack, did we fly medicines at the right time? These lessons go into a database for posterity.
PRO1	Use a lot of corporate knowledge to develop lessons learned.
PRO2	I keep a PowerPoint and populate it as things go along to serve as a lessons learned file.
PRO2	Lessons learned do help us to update the IMCOH-Increment Manager Operations Handbook.
ENG3	Right now it seems like the documentation gets put on a shelf, but most info comes from those who experience it firsthand. But then once they go, you lose that knowledge.
ENG4	Daily notes that get sent out each day to over 500 people. We've tried to adapt and become more electronic database.
FOD6	We do lessons learned at the end of an increment. E.g., we need a new protocol for something or we saw this multiple times, etc. Lead Ops Planner will come up with PowerPoint with lessons learned at the end of the increment, and what board it needs to be elevated to. After internal reviews with management, gets

	communicated to other panels. Always needs improvement that this gets closed out. If you're about to start your work, to go back to look at previous team's work to make sure you don't make the same mistakes. We have a meeting where we talk about lessons learned, but you're going to miss some folks. Trying to implement increment-to-increment consistency is a really challenging thing—how to not lose lessons that you learned in each increment.
SMA1	There are old lessons learned systems that are supposed to be filled out, and there's no incentive to do so. We don't have a formal one. Lots of stuff in lots of places. IFIs PRACAs, ARs are all there. It's reviewable, but I don't know if people do.
SMA2	Don't have lessons database that could share with other suppliers.
SMA2	Formal lessons learned of panel not formally documented.
SMA2	Goal is he would love to have a one-pager (that documents hazards, good design practices, requirements for common products): here are the hazards, good design practices for designing a pressure system, a good containment … same thing week after week—same debates.

Appendix D. Comparison of Current Concepts in Risk Management

Recent concepts in risk management have moved beyond thinking about safety solely in terms of something to control or avoid. Three of the primary schools of thought are: Resilience Engineering (RE), Safety 2, and Highly Reliable Organizing (HRO). The table below provides a comparison of these concepts in risk management.

	Resilience Engineering (RE)	Safety-II	Highly Reliable Organizing (HRO)
Description	"Resilience is the ability of an organization to adjust its functioning prior to, during, or following changes and disturbances, so that it can sustain required operations under both expected and unexpected conditions." —*Erik Hollnagel* "Resilience is graceful extensibility." —*David Woods* (Graceful extensibility is positive capability to stretch near and beyond boundaries when surprise occurs.)	Safety-II considers that work goes well most of the time and we need to learn from this "normal work" instead of focusing almost solely on the rare events with adverse outcomes.	HROs have these characteristics in common: They track small failures (preoccupied with anomalies and deviations), resist over-simplification, defer to expertise, maintain capabilities for resilience, and are sensitive to operations. HROs have systems and practices to increase mindfulness (a mental orientation that continually evaluates the environment and the organization). They organize themselves such that they are able to notice the unexpected in the making and halt its development. If the unexpected breaks through their defenses, they focus on swift restoration of near normal system functioning.
Distinctions for Safety	Complex systems are not inherently safe. It takes variety to manage variety; since work in complex systems is variable, people must be variable (adaptable) to be safe.	Safety-II proposes that safety is a dynamic event—namely, the event that goes well. Safety is a condition where the number of successful outcomes (meaning everyday work) is as high as possible. It is the ability to succeed under varying conditions with a focus on how safety is created, acting to make things go right. Understanding the variability of everyday work is the basis for safety. This is contrasted with traditional safety (Safety-I), which is defined and managed by looking at the absence of safety (harm, accidents, and injuries): "We are safe if there is no "lack of safety."	Safety is a dynamic non-event. Stay alert! We are never safe. Safety involves managing the unexpected with a goal of performing dependably under variable conditions.

	Resilience Engineering (RE)	Safety-II	Highly Reliable Organizing (HRO)
World view	Real-world systems are characterized by complexity, ambiguity, uncertainty and resource constraints. Not everything can be known, not everything can be predicted, and not everything can be investigated.	It's necessary to know what is usual—what usually happens or should happen—to notice and understand what is unusual. The gap between "work as done" (what actually happens) and "work as imagined" (what designers, managers, authorities believe happens or should happen; procedures, rules, plans) must be acknowledged, not for the purpose of closing the gap (as in compliance) but to understand the gap and reconcile the differences (there are lessons in the gap).	In the eyes of HROs, it takes deep expertise, mindfulness, and collective sense-making (process of creating shared meaning, understanding, and awareness) to navigate high-risk environments. There's balance between enabling improvisation and being rigorous and thorough, such as during FOD walkdowns on aircraft carrier decks.
Key perspectives	Surprise will happen; change is constant.	Work is always variable; performance adjustments are ubiquitous and necessary; and actions succeed or fail for the same reasons.	Uncertainty is the only certainty. Subtle signals exist prior to failures. We are always vulnerable.
People	RE emphasizes the need for adaptability and context sensitivity (capabilities provided by expertise), as opposed to views in which, with "a little more effort," things can be defined and controlled. Workers are local experts. Learning is done on a routine basis to support developing deep knowledge and decision making skills. Resilient organizations build relationships to support collaboration and reciprocity.	Practitioners, with their local perspectives and ability to vary performance, are necessary for system flexibility and resilience; they continuously create safety. Effective leaders are in close touch with work as done. Look for how people create and maintain good working conditions, how they compensate for what is missing.	Agency of people, both individually and collectively, is highly valued. People are encouraged to share observations and intuitive gut feelings. HROs consider how action shapes cognition and vice versa, tapping into theories of embodiment. They consider other cognitive processes, such as attention, perception, decision-making, and biases. Leaders don't have superior knowledge or viewpoints; thus, don't make all the decisions independent of followers.
Capabilities	Adaptive capacity (ability or potential to adjust activities, resources, tactics, and strategies in the face of different kinds of events, demands, and uncertainty) and flexibility are essential and are developed in the planning of operations. Prediction of risks is balanced with preparing for surprise.	Resilience is not something a system has, but something a system does. Resilient performance means the organization can function as required under expected and unexpected conditions and requires potentials to anticipate, monitor, respond, and learn.	HROs are capable of early detection and collective sense-making. They are attuned to patterns that breed crisis-enabling conditions. They have strong practices for cooperation and leading under conditions of uncertainty (ex. incident commanders).

	Resilience Engineering (RE)	Safety-II	Highly Reliable Organizing (HRO)
Systems	Focus is on the sociotechnical system. RE pays attention to system boundaries and plans how to handle interactions, different tempos, non-linear dynamics, hidden dependencies, and tight couplings. Slack (available, spare resources of any sort which can be called on in times of need) enables flexibility and the ability to respond when near system boundaries.	Systems are defined as having many parts and functions and hidden or unforeseeable connections. Non-linear models are used to describe how both acceptable and unacceptable outcomes emerge from everyday performance adjustments.	Focus is on social systems. Complex social systems are unpredictable and they cannot be controlled, only navigated. "I may not know what is happening, but I know what to do." Firefighter, LA. Reality is dynamically co-constructed as compared to a Cartesian view that we all experience the same reality.
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