

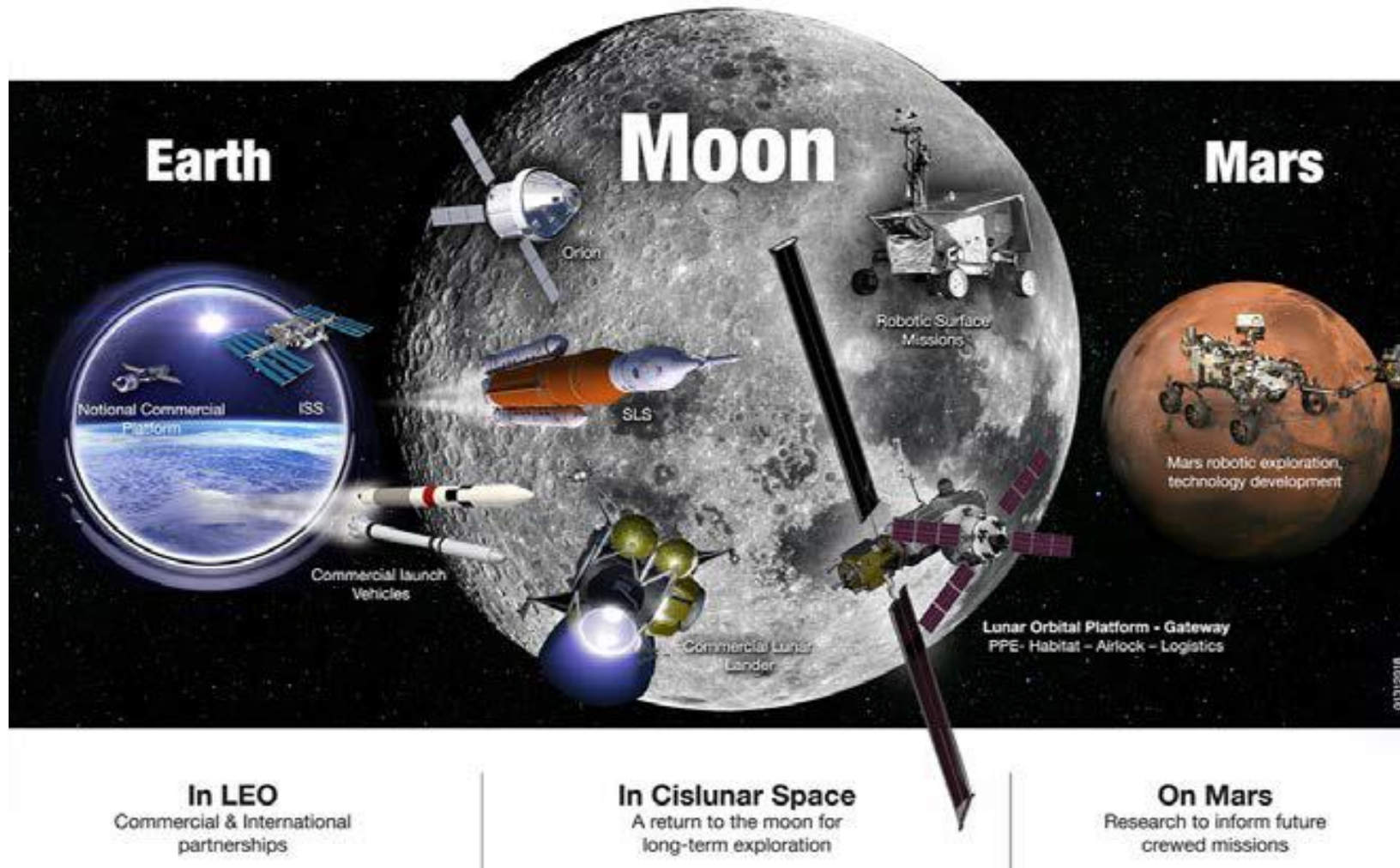


Spacecraft Fire Safety Needs for Exploration

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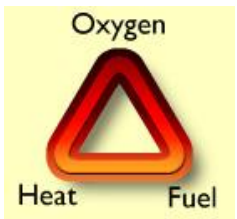
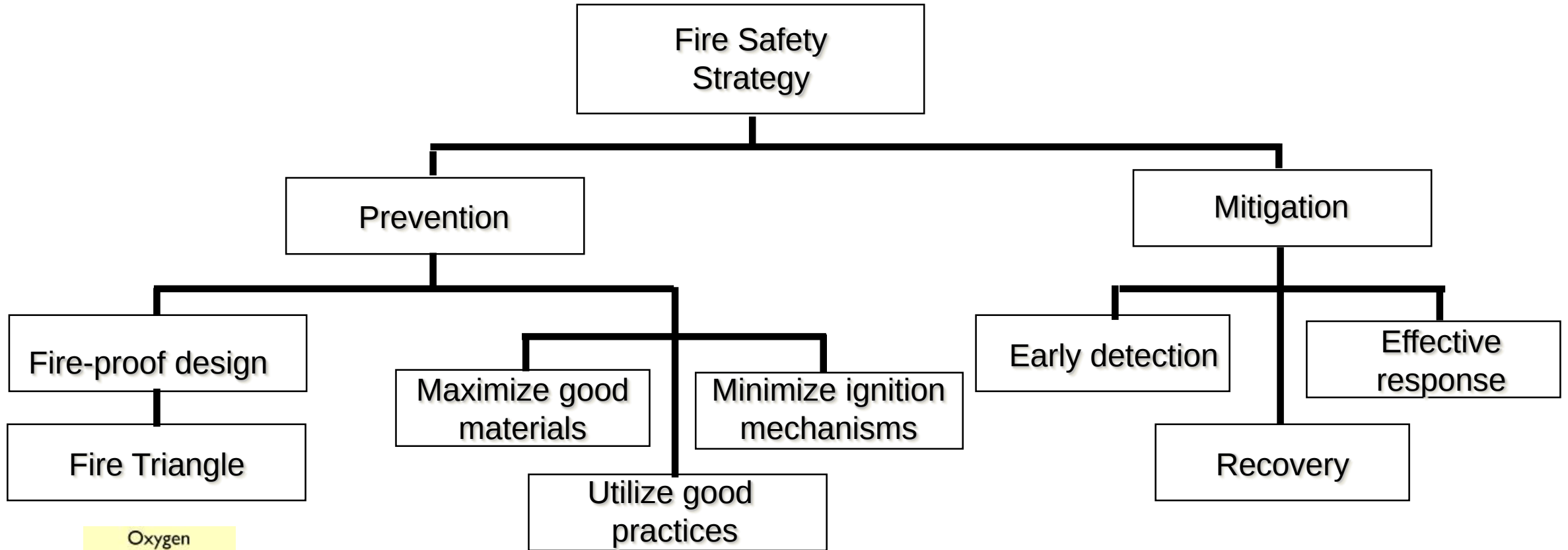


- No matter the mission or the destination, each will present unique fire safety challenges for spacecraft or habitats
- Spacecraft designers and mission operations personnel will (generally) not realize the extent of the fire safety question they need answered until a solution is needed (quickly)



- **Fire Safety Strategy and Risk**
- **Review of the Fire Safety Roadmap**
- **Development of Fire Safety Requirements**
- **Spacecraft Fire Safety Workshop**

- Fire safety in a spacecraft or surface habitat is inherently a risk-based exploration capability



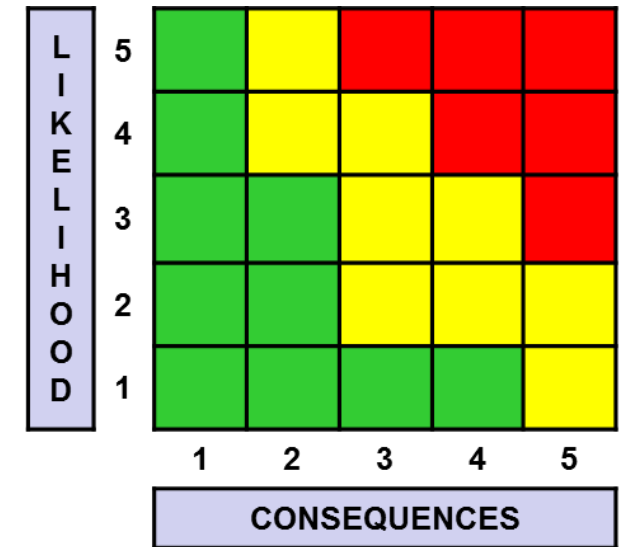
➤ What are typical risk statements for exploration missions?

Risk Statements for Spacecraft Fire Safety



1. Given that flame spread over solid materials is different in normal- and reduced-gravity, there is a possibility that current material screening standards will not adequately identify the fire risk on a spacecraft or habitat. (Test Methods)

- a. Material properties
- b. Ambient pressure and oxygen mole fractions
- c. Material configuration
- d. External heat flux
- e. External flow direction and velocity



2. Given that solid fuel ignition is influenced by heat transfer and that heat transfer is strongly influenced by gravity level, there is a possibility that ignitability of a solid material could be influenced by the spacecraft or habitat environment. (Ignition)

- a. Ignition energy
- b. External pre-heating
- c. Ambient pressure and oxygen mole fractions

Risks for Fire Safety



3. Given that the rate of fire growth, driven by convective flow in normal gravity, will be different in reduced gravity, there is a possibility that the conditions inside a vehicle or habitat could quickly become hazardous to the crew and equipment (Fire Growth)
 - a. Heat release rate
 - b. Production of smoke and toxic products
4. Given that during an exploration mission, the crew may not be able to evacuate to another vehicle during a fire event, there is a possibility that they will not have the proper personal protective equipment to respond to the fire while confined to that vehicle. (Fire Response)
5. Given that the type and rate of production of pyrolysis combustion products are influenced by ignition and surface temperatures, there is a possibility that the pre-ignition fire signatures for fires in reduced gravity could be different from those in normal gravity. (Fire Detection)

6. Given that a fire may propagate in spite of early detection and initial response, there is a possibility that an active fire suppression system will need to be activated. (Fire Suppression)
 - a. Compatible with the environmental control and life support system
 - b. Suitable for confined spaces with the crew present
 - c. Crewed and non-crewed periods

7. Given that the fire mitigations were effective, may allow the mission to continue, there is a possibility that with appropriate clean up that the vehicle could be restored and the mission could continue. (Post-fire Clean-up)
 - a. Atmospheric contaminants
 - b. Surfaces
 - c. Electronics
 - d. Identification of when cleanup is complete

Spacecraft Fire Safety Roadmap



- ◆ NASA-GRC has maintained the Spacecraft Fire Safety Roadmap for the past 5 years
- ◆ Two years ago, we developed co-coordinators of that roadmap
 - Stephanie Casper, NASA-JSC
 - Gary A. Ruff, NASA-GRC
- ◆ The reason for having co-coordinators is to increase interaction and awareness about vehicle/program fire safety needs and testing opportunities
 - Test data are invaluable to validate modeling of fire scenarios
- ◆ Since then, we have identified vehicle needs, hardware development, and testing opportunities on the Spacecraft Fire Safety Roadmap...
 - ...in addition to the technology development activities that we have traditionally tracked

Spacecraft Fire Safety Roadmap (1 of 3)

POC(s): Stephanie Casper, Gary Ruff
Revised: 1/22/2020



GROUND ACTIVITY

ISS / LEO

ORION

GATEWAY

LUNAR SURFACE

MARS TRANSIT

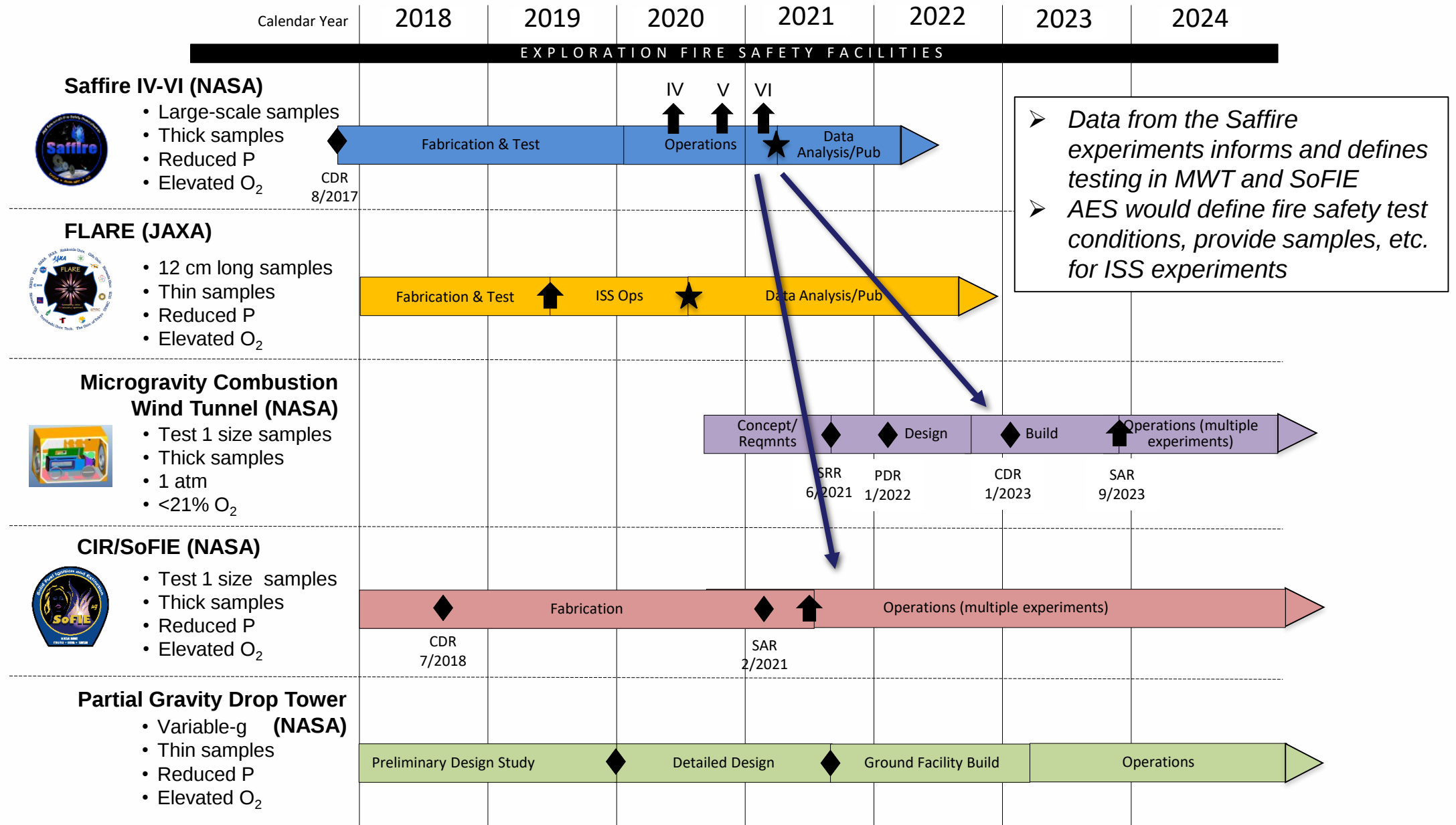
MARS SURFACE

EVENTS/MILESTONES

DECISION POINT

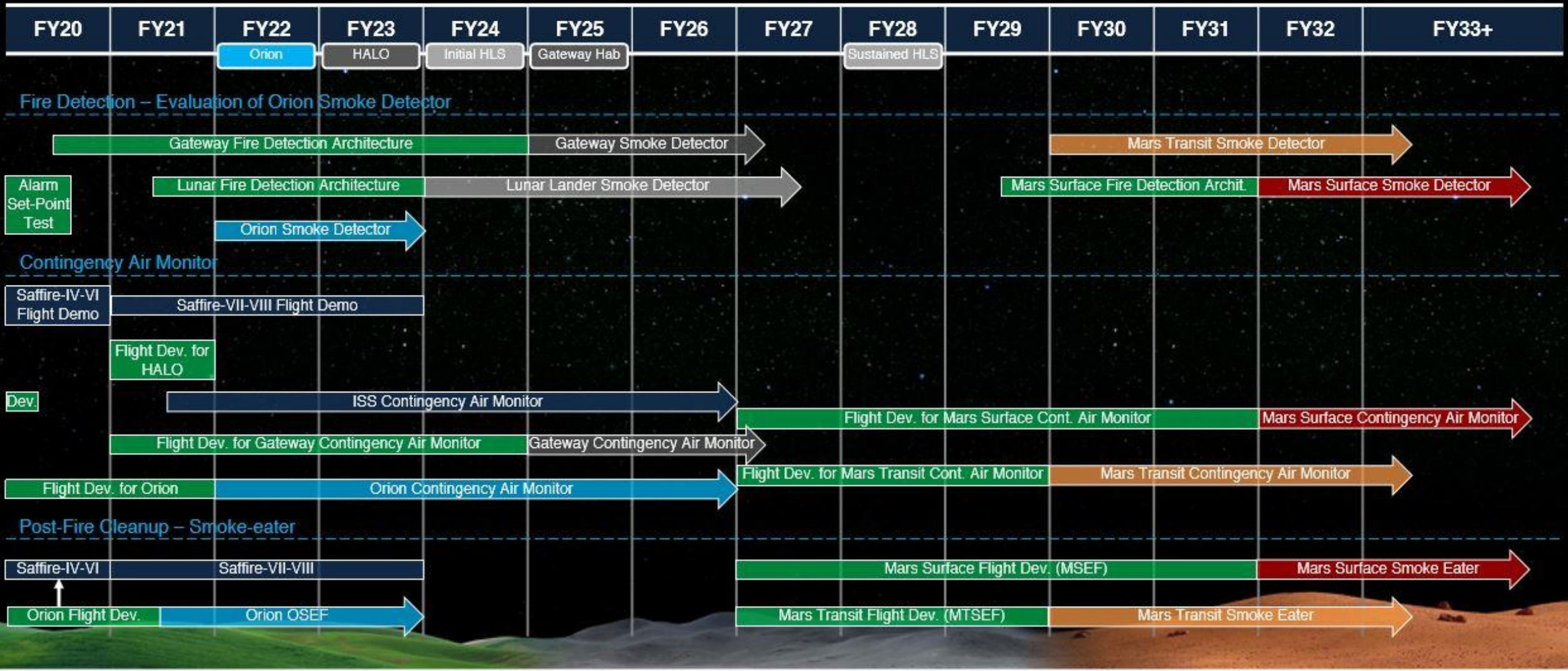
Objectives (FOM/KPPs): (1) Quantify the effect of gravity level, ambient conditions, material properties, configuration, and flow on the flammability of relevant spacecraft materials relative to flammability tests conducted in normal gravity

Facilities for Flammability Studies



Spacecraft Fire Safety Roadmap (2 of 3)

POC(s): Stephanie Casper, Gary Ruff
Revised: 1/22/2020

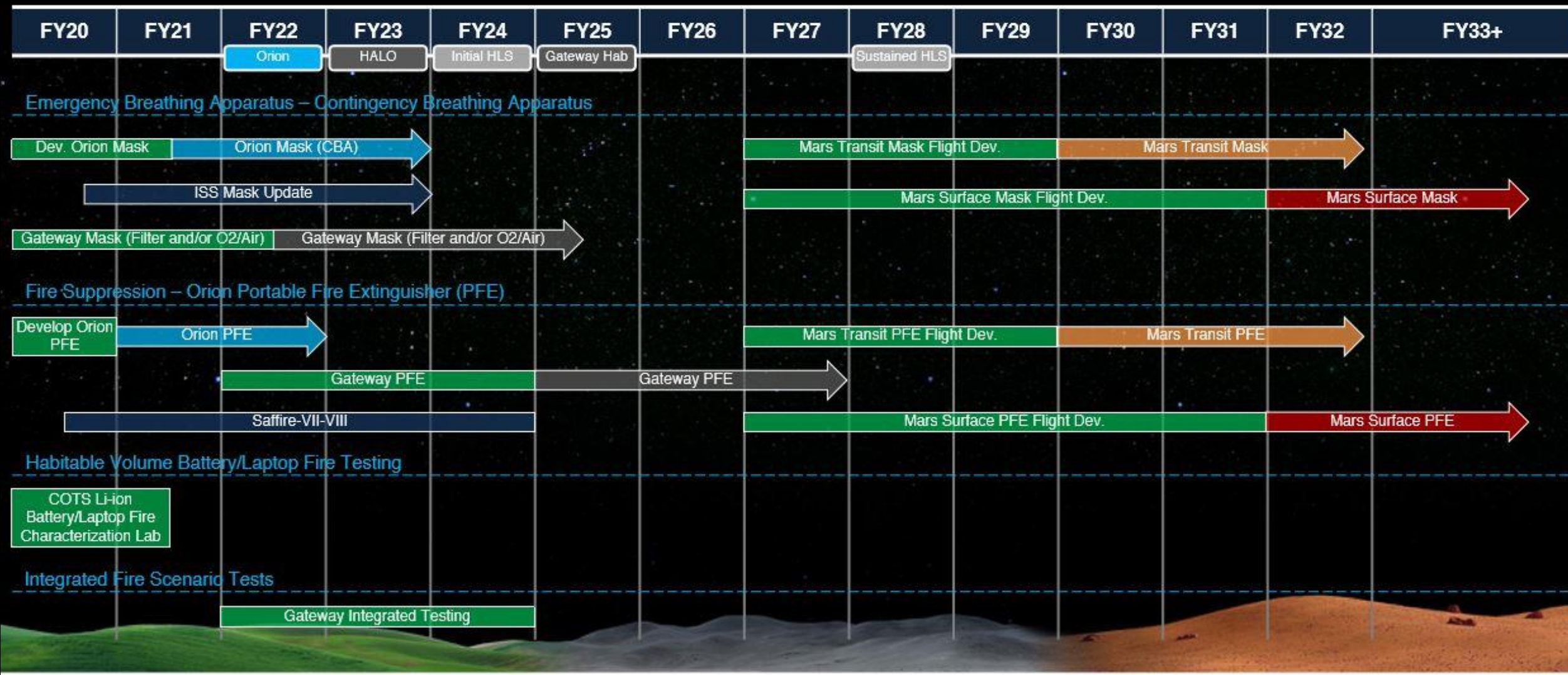


- GROUND ACTIVITY
- ISS / LEO
- ORION
- GATEWAY
- LUNAR SURFACE
- MARS TRANSIT
- MARS SURFACE
- EVENTS/MILESTONES
- DECISION POINT

Objectives (FOM/KPPs): (2) Provide the crew effective hardware and procedures to respond to and recover from a spacecraft fire event (3) Validate the fire detection and response protocols through tests and modeling of fire scenarios

Spacecraft Fire Safety Roadmap (3 of 3)

POC(s): Stephanie Casper, Gary Ruff
Revised: 1/22/2022



Objectives (FOM/KPPs): (2) Provide the crew effective hardware and procedures to respond to and recover from a spacecraft fire event (3) Validate the fire detection and response protocols through tests and modeling of fire scenarios

Evaluation of Future Fire Risks

- ◆ As shown in the roadmap, Orion has developed a fire safety strategy that includes fire detection, contingency air monitor, breathing masks, and fire suppression
- ◆ HALO, HLS, and Gateway are in the early phases of developing their strategies
 - Their programs will have to determine if the past solutions are suitable or if their unique mission increases risk requiring a unique solution
 - Cost and schedule vs. risk
- ◆ As we push forward into new missions, we get further and further from what we know
 - Our ability to accurately quantify the risks decreases dramatically
- ◆ Examples include:
 - Partial gravity
 - flammability
 - detection
 - suppression
 - Elevated oxygen mole fraction and reduced pressures
 - Dormancy

What is the perceived risk for a spacecraft fire?

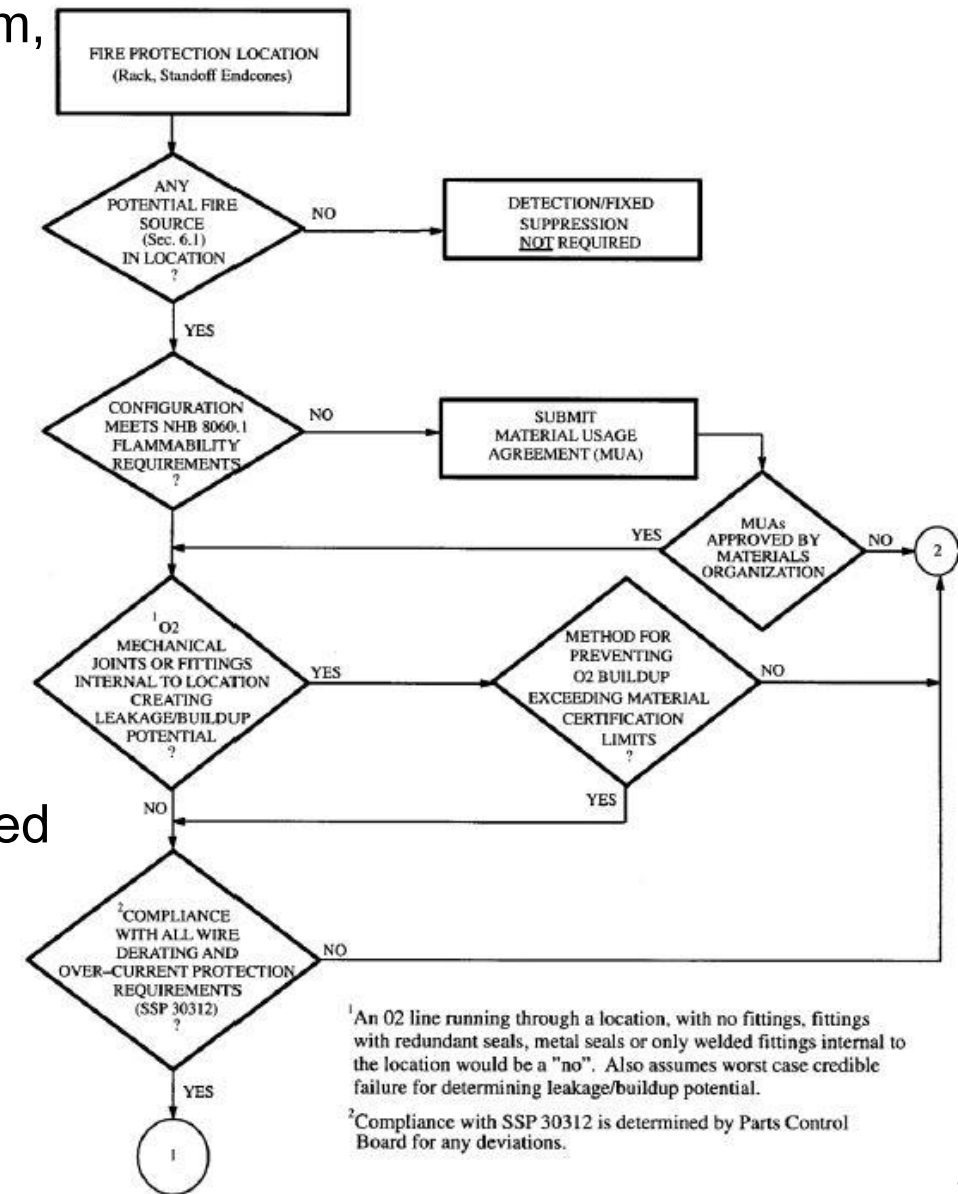


- Programs that have conducted probabilistic risk assessments have generally rated the fire risk very low
 - Depending on assumptions, risk of Loss of Vehicle by a fire could be on the order of 1 in 300,000 to 1 in 3,000,000
- To a Program Manager, low probabilities indicate a fire event is very unlikely
 - In some cases, there is no real belief that a fire could occur
- This drives decisions that impact how a vehicle program addresses the fire risk beginning in the design phase
 - Flammability and material control
 - Isolation from ignition sources
 - Detection
 - Suppression
- This trend will probably continue unless we provide a clear set of requirements and/or guidelines that all Programs need to follow

Determining the Need for Fire Detection and Suppression



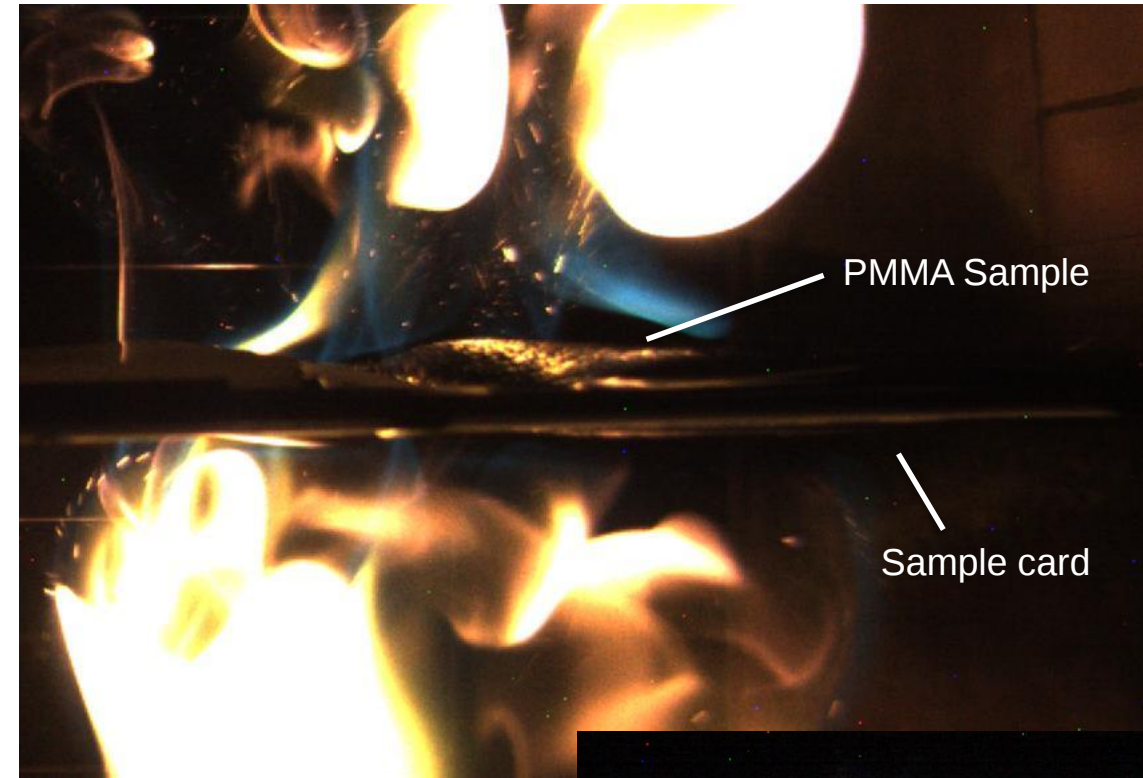
- ◆ When NASA was developing the ISS (Space Station Freedom, at the time), a flow chart was developed to determine if fire detection and suppression was required based on:
 - Ignition sources
 - Material flammability
 - Presence of forced air flow
 - Wire derating, ...
- ◆ The outcome of the flow chart (after two more pages) is whether fire detection and/or suppression is required
- ◆ This is now in SSP 50808 which is an interface requirements document for ISS visiting vehicles
 - Including commercial crew
- However, the flow chart hasn't changed since it was developed for ISS itself
 - Questions with applicability of some of the statements
 - Must try to interpret the intent
 - Doesn't account for new test results and data



Fire Suppression Requirements



- ◆ How do you qualify a spacecraft fire suppression system?
- ◆ On Earth, there are test fires that you have to demonstrate that your system can extinguish
 - For spacecraft, what is your likely fire?
 - How do you account for micro- or partial-gravity?
- ◆ For a fixed fire suppression system in a compartment, what suppressant concentration must be reached and how long must it be held there?
 - For the Saffire-IV PMMA sample, we turned off the flow for 20 seconds
 - The fire didn't extinguish and began to grow when we turned the flow back on
 - In a spacecraft, suppressant could have been used to “knock down” the fire but wasn't held at the desired concentration long enough for surface to cool
- ◆ Additional focused tests may be required to develop guidance on these questions



Above: Deflagration as a residual flame ignites MMA vapors on the top and bottom surface



Right: Decaying flame on the upper surface when the flow is off

Typical Fire Suppression Requirements



- ◆ Once you determine the need for fire detection or portable/fixed fire suppression, you have to verify it by “analysis, inspection, and demonstration”

“The verification shall be considered successful when the analysis, inspection, and demonstration show that a fire in the pressurized volume can be detected and suppressed before it can propagate.”

- ◆ How this activity is done is mainly left up to the Program
 - The extent to which it is performed often depends on the Program’s perception of the risk
 - As always, safety personnel have to accept the verification but it becomes difficult if the only difference is in the perceived risk
- ◆ NASA doesn’t have a clear set of items that must be demonstrated or process that the system developers must perform to “certify” a fire detection or suppression system
 - This is where you could build in the knowledge of microgravity flammability, detection, and suppression
 - Make the steps clear, almost like a checklist, where the findings of each step must be reported
- ◆ This requirements development activity would be a great help to developers of future spacecraft to define exactly what a fire detection, suppression, and cleanup system should do

- ◆ At the last FLARE workshop, I mentioned my desire to conduct a fire safety workshop to identify needs not only in flammability but all aspects of protecting a spacecraft (any spacecraft) from an on-board fire
- ◆ We were making some progress in developing the content in Fall 2019 and had started meeting to discuss format, agenda, etc.
- ◆ Then COVID-19 came along and we were consumed with learning how to do our normal work from home, Saffire-IV operations, ...
- ◆ Because of some recent activities we have had with the NASA Engineering Safety Council (NESC), they are pushing to address some of the topics I identified fairly soon
 - We are re-starting our efforts to plan and conduct for this workshop
- ◆ It could be held as early as late-November but could be early in 2021
- ◆ Intent:
 - Review existing Gateway and HLS plans for %O₂, pressure envelope and monitoring
 - Identify hardware options, where applicable
 - Identify knowledge and capability gaps
 - Identify tests, modeling, analysis required to address those gaps
 - Update fire safety roadmap and track progress at closing the gaps

Back-up

NASA Spacecraft Fire Safety Mitigation

Goal: Optimize spacecraft fire safety systems *to minimize the risks of fire* that contribute to loss of system, mission or crew during exploration missions

● Design Reference Missions

Habitable,
remote
environment,
dormancy,
partial-g

Low-g, limited
escape (if any),
elevated O₂,
uncertain
configuration

Hazards

Differences in low-
and partial-g
flammability, fire
detection, and
suppression

Evidence

Loss of systems,
vehicle, and
crew;
toxic gas and
aerosol
exposure

Risks

Design
standards,
flight rules,
procedures,
and
equipment
specifications

Standards

Mitigations

Deliverables:
Flammability screening
protocols, verified
computational models,
fire response
equipment qualification
requirements

