FIRE PROTECTION IN MANNED MISSIONS: CURRENT AND PLANNED

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INTRODUCTION

While not officially endorsed, the race to place a manned base upon the surface of Mars is internally a forceful element within **NASA's** workforce (http://www.nasa.gov/osf). **NASA** employees are quietly working on the identification, development, and testing of new technologies needed to deliver astronauts to the surface of Mars and to ensure a base functional enough to become home to these travelers for **up** to two years duration while they await their replacement crews and return flights home (http://spaceflight. nasa.gov/ mars). This paper is intended to look briefly at some of the factors affecting the design and selection of one of the safety systems, Fire Detection and Suppression, needed to support such a mission.

MISSION TO MARS

The following is a simulated itinerary of a Human Mission to Mars (one crew, round trip):

Day 1: The Mars crew departs Earth on the Space Shuttle.
Week 1: The crew is delivered to the International Space Station, where they prepare for the Mission.
Week *2:* From the station, the crew embarks on an eight-month flight to the Mars orbit.
Week 39: The crew arrives in orbit around Mars and boards a vehicle that will transfer them to the surface of Mars. The crew remains **on** the surface of Mars for two years.
Week 149: The crew leaves the surface of Mars to return to Earth.
Week 188: The crew arrives at the Earth orbiting platform.
Week 189: The crew returns to Earth (**~3** 1/2 years total).

To accomplish this type of human-based mission, many technologies need to be developed and the mission infrastructure must be in place. The following sections address the vehicles and facilities needed for a *Mission to Mars* and the Fire Detection and Suppression (FDS) systems currently in place, where applicable, or the FDS concerns for each stage where it is currently undefined.

MISSION VEHICLES

Vehicles under development to support a human mission to Mars include the Reusable Launch Vehicle (RLV) used to transport astronauts from Earth's surface to the International Space Station **(ISS);** the Crew Return Vehicle (CRV) planned for emergency evacuation of the ISS; the Long-Duration Vehicle (LDV) for traveling between the Earth's orbit and the Mars orbit; and the Surface-to-Orbit Vehicles (SOV) for transporting personnel, equipment, and supplies to and from the surface of Mars. Each vehicle is a unique design, is expected to accommodate a different crew size and to have unique hazards associated with the purpose of the vehicle. The design and testing of the RLV and CRV are currently underway; the FDS is undefined for either of these vehicles. The Space Shuttle is currently used to transport crewmembers to and from the ISS. Halon 1301 portable fire extinguishers (PFE) are used on board the Shuttle. Smoke detection on the Shuttle operates on the principle of ionization-current interruption [1].

In the past two decades, on board the Shuttle, there have been 5 fire-threatening incidents where the crew was able to prevent a possible fire by removal of power and 15 false alarms or failures of the smoke detector circuits [2]. There were at least 2 flash fires, which were self-extinguishing and did not require crew action. One of the important conclusions from this FDS history in the Shuttle program is that during normal operations of a human-based mission there is an average of one fire or indication of a fire/year.

ORBITING PLATFORM IN LOW EARTH ORBIT

A human mission to Mars will likely begin from the International Space Station. Although the ISS may be an official point of departure, its primary role, basic and applied science, is unrelated. The FDS on board the ISS consists of portable fire extinguishers (PFE) and three types of detection systems. The modules supplied by the Russian Space Agency utilize water/foam PFEs. The Russian-provided Service Module has optical detection. The Russian-supplied FGB Module has ionization detection as will future Russian-provided modules. The rest of the ISS partners, NASA, NASDA, ESA, CSA, and INPE, are utilizing carbon dioxide (CO,) PFEs and laser-based scatter/obscuration detection. The CO, PFEs are a unique design; they are fitted with a tube, approximately 40 cm long, with a tapered nozzle located at the end of a tube. Each module consists of racks that are sealed and fitted with a port. In the event of a fire, a crewmemher inserts the nozzle of the cylinder into the port and discharges the cylinder. The design concentration is 10% partial pressure O, per the National Fire Protection Association standards for "deep-seated electrical fires." CO_2 was selected as the fire suppression agent for the ISS based upon extensive design and experiential data on CO, and its compatibility with the Environmental Controls and Life Support System (ECLSS). The ECLSS is designed to remove CO_2, which accumulates from the crew. Halon was not selected due to its incompatibility with the ECLSS, the regulatory phaseout of ODS, and the toxicity and corrosivity of its byproducts. Inert agents were not selected in part due to the lack of design and experiential data on them at the time the ISS was under design.

Experience has shown that combustible materials will accumulate (i.e., waste products, testing equipment materials, documents, etc.), configurations will change, and the chance of human error will increase. There are no fire or alarm data yet on the ISS; however, there are some historical data available on the Russian Space Station MIR. The FDS on board the MIR consisted of a combination extinguisher of foam and water. The detection system was optical-based. During the 10 years that MIR operated, there were several small fires [2], and there was one major fire event on February 24, 1997. The fire event on February 24, 1997 was due to a failed solid-fuel oxygen generator (SFOG). The crew activated several extinguishers but appears to have been unable to extinguish the fire. It is believed the fire was self-extinguished when the SFOG ran out of fuel. During this fire event, the smoke in at least two of the MIR modules was so thick that the crewmembers could not see their own hands in front of their faces [3].

FLIGHT TO *MARS*

The transport from low Earth orbit to the Mars orbit will take 6-18 months depending upon the flight path (http://mars3.jpl.nasa.gov/mgs/realtime/odyssey.jpg; http://mars.jpl.nasa.gov/odyssey/mission/trajplot.html). The crew will be transported to the ISS utilizing either the Space Shuttle or an RLV. From there, they will board a long-duration vehicle (LDV) for the long flight. Once they reach the Mars orbit, they will transport to the surface in a vehicle specifically designed for surface-to-orbit (SOV) transfers. Many designs have been proposed for the LDV and the SOV; however, NASA has not yet officially begun work on either vehicle. It is difficult to design safety systems until the general vehicle design has begun. The crew size, radiation protection, method of propulsion, and quantities and types of supplies carried on board are just a few of many factors that will influence the ultimate design and selection of the safety systems.

Hazards on the long duration flight from Earth to Mars include radiation exposure from the Sun, impact from meteorites, and high thermal gradients. Compounding this is the likelihood that the vehicle could not return to Earth in an emergency. There is little to no chance of rescue or resupply for the crew during the flight to Mars. The psychological stress can be expected to increase as the flight moves further from Earth. In addition, the fire hazards and the chance of false alarms on board are likely to increase as waste products accumulate and the crew becomes more relaxed in their procedures. The wear on the vehicle and its equipment will also contribute to the likelihood of false alarms and increased fire hazards as is the case for any facility on Earth. The safety systems must be of a high reliability and redundant where possible, while being of minimal weight, space, and impact to the vehicle power requirements. The optimum scenario would be a non-intrusive, automatic FDS system with manual backup.

MARS BASE

Some technologies currently under research and development to support a human mission to Mars include the propellant production equipment, which will be sent ahead of the manned missions to begin production of the fuel needed for the return flight to Earth. These systems will land upon the surface of **Mars** and automatically begin operation (www.nasa.gov/oss). They will also produce commodities for the manned facilities including oxygen generation. The Martian atmosphere is extremely thin, –7 mbars (less than 1% of Earth's), and consists of approximately 95.3% CO_2, 2.7% N_2, 1.6% argon, 0.15% O_2, and **0.03%** H_2O (http://seds.lpl.arizona.edu/nineplanets/nineplanets/mars.html). The average temperature is –218 **K** and ranges from 140 to 300 K. Other surface level climatological conditions include very strong winds and vast dust storms that on occasion engulf the entire planet for months. The gravitational acceleration on **Mars** is about **0.38** g, where g is the Earth sea-level acceleration (normal gravity) of 9.8 m/s^2 [I]. A human occupied Mars base would likely include a habitat area, a plant growth chamber, a lab and operational space, and the propellant production equipment/facilities. The fire hazards and the utilities available to support the FDS will be defined as the Mars base design develops. The level of acceptable risk is expected to be extremely **low** due to the isolation of the crew from Earth support and the potential deleterious effects to the mission and crew in the event of a fire. The crew cannot feasibly return to Earth until Mars has reached a point in its orbit placing it in close proximity to Earth. As a result, the safety systems must be highly reliable. False alarms, leaking equipment, and accidental discharges would place undue psychological stress on the crew. Optimally, the fire suppression equipment would be rechargeable from commodities available upon the planet. This leads to a slight preference for CO_2, as it is the most plentiful commodity in the Mars atmosphere (data on the Martian soils are insufficient at this time; however, it is believed the surface materials are primarily carbonate rocks).

FIRE PROTECTION PROGRAM OVERVIEW FOR MISSION SUPPORT

NASA has relied upon Halon 1301 for fire protection in unique applications like the Launch Pads and Platforms, in the Launch and Payload Processing Facilities, and in the Firing rooms, as well as, on board the space shuttle. By 1988 NASA had over 85,000 lbs installed in systems agency-wide. Kennedy Space Center systems comprised nearly 90% of the agency use. Many of the installed applications were deemed "critical" **as** a result of a thorough review by NASA management. Due to worldwide phaseout of ozone depleting substances including halon, NASA is pursuing alternatives to halons. KSC initiated the agency's phaseout and was given responsibility for the management of the agency's halon bank by NASA HQ in 1990. KSC was also designated as the agency's ***Lead Center for Fire Protection*** in 1998 due to extensive expertise in fire protection. In 1999, KSC initiated the Halon Alternatives Research & Phaseout Program (HARPP) to further R&D in the area of halon alternatives, to develop FDS options for human missions, and to continue the management of the agency's Halon Bank (http:/iharppiksclnasa.gov).

HARPP OBJECTIVES

The program objectives are to provide safe, efficient non-halon fire protection for payload and vehicle processing facilities/systems, launch facilities, human space flight vehicles, orbiting platforms, and the Moon and Mars bases. The program will include partnerships with **US** military organizations, academia, industry, and non-government organizations to ensure success and sharing of resources and knowledge. The program includes the continued responsible management of NASA's halon phaseout program taking it to its completion, including the final disposition of all halons. Finally, the program will ensure commercialization and/or the transfer of technologies developed through this program.

KEY TECHNICAL ELEMENTS OF HARPP

Human missions and the vehicles and facilities involved are unique. They are each designed for a specific purpose and are one-of-a-kind. The environments are non-standard and are different for each type of mission. Consequently, the safety systems, including the fire detection and suppression, are developed to minimize the risks associated with the vehicle, the base, the environment, and the mission. The following elements are necessary to address the research, development, and testing necessary to provide the optimum FDS for a specific human-based mission. Some of the elements can be conducted at least partly in parallel, but in general they are listed in the order of implementation.

- Hazards Analysis: Analyze hazards expected to be present based upon equipment, commodities, etc.
- Space Flight Materials Flammability Research and Analysis: Analyze the heat release rate, flammability, flame spread rates, etc. of the materials to be utilized in the Mission.
- Microgravity Combustion Research: Study the flame spread rate and characteristics in the gravitational environment to be encountered in the Mission.
- Flame and Smoke Detection Research & Development: It has been shown that fire signature characteristics can be affected by the level of gravity. Identify which types of fire and fire precursor signals to sense; typical signatures include smoke, gaseous products, heat, radiation, and pressure rise [l].
- Fire Suppression Agent Research and Development: The suppression agent may be selected from current technologies based upon the environment and resources available during the Mission, or research into a new agent may be the most desirable option.
- Combustion Byproduct Research: The combustion byproducts of the fire suppression agent selected may be found to possess unacceptable byproducts in general, as a result of the atmospheric conditions of the Mission, or due to incompatibilities with other operational equipment such as the ECLSS.
- ECLSS Compatibility Study: The functionality of the FDS must be unhindered by the operation of the Environmental Control and Life Support System (ECLSS), and the ECLSS cannot be damaged by the FDS. For example, in the event of a leak, an accidental discharge, or a fire-based scenario, the suppression agent should not cause failure of the ECLSS.
- System Development: Whether new agent is developed or an existing suppression agent is used, the delivery system will need to be developed with high emphasis given to space, weight, delivery, and reliability. Unique design considerations include gravitational accelerations below 1 g, forced ventilation, limited accessibility, and the need for crew maintainability and/or reparability.
- Agent/System Testing: The agent will need to be tested in the delivery system ideally in a microgravity environment (i.e., on board the ISS). Failure modes analysis will need to be performed on the system and redundancy built in where feasible.
- Integration and Installation: The selected FDS will need to be physically and logistically integrated into the mission elements (vehicle, modules, etc.).
- FEMA: Analyze the potential failure modes of the equipment.

SUMMARY

Designing for a human space mission involves unique conditions and thus unique approaches. Research and analysis are non-trivial due to "non-standard" conditions such as gravitational acceleration, atmospheric pressures, and gaseous constituents. Design challenges for all of these non-standard conditions are compounded by the presence of humans. Experience has shown that false alarms and fires can and should be expected. What should not be assumed is that all fire scenarios can be identified. Therefore the FDS system must be as flexible in capability as possible. An optimum scenario is to be able to provide several FDS options for a given mission to allow for downselecting or adapting to fit the specific design of the mission as it evolves. Given the number of elements that must be addressed in designing an FDS system for a human-based space mission and the lead time necessary to accomplish those that involve research and technology development, work in this field must be occurring now—well in advance of a formal mission announcement.

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