# Understanding Ignition of Oxygen System Components by Particle Impact

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Fire hazards in oxygen-enriched environments have long been recognized as a significant threat to safe space flight and related ground support operations. NASA's history of fires in oxygen-enriched environments is significant and includes events such as the Apollo 204 command module fire (later renamed Apollo 1), in which astronauts Roger Chaffee, Gus Grissom, and Ed White lost their lives; and Apollo 13, in which the oxygen tanks were destroyed resulting in loss of the mission. In 1980, a fire in the 6,000-psi secondary oxygen pack plumbing destroyed a $3.4M extravehicular mobility unit intended for use in the Space Shuttle Program (figure 1).

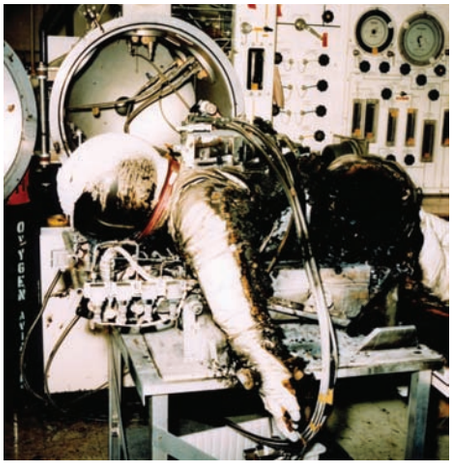

***Fig. 1.*** *Extravehicular mobility unit destroyed in a fire.*

Because of these fire events, NASA has made a significant investment in understanding and controlling the fire hazards in oxygen-enriched environments. Test facilities developed at NASA White Sands Test Facility (WSTF) in the early 1970s perform hazardous tests using high-pressure oxygen. In the early 1980s, engineers at the NASA Lewis Research Center (later renamed NASA Glenn Research Center) became concerned that small, metal particulates borne in the 4,000-psi warm, gaseous oxygen in the shuttle Main Propulsion System (MPS) might cause a fire when they internally impinged the valve controlling oxygen flow to the external liquid oxygen tank. This particle impact ignition mechanism was reported in the open literature, but no specific tests or analysis had been performed on the shuttle MPS and the gaseous oxygen flow control valve (FCV). WSTF developed a particle impact test system and performed tests that produced a catastrophic fire in the shuttle MPS FCV (figure 2). As a result of this fire, the shuttle MPS gaseous oxygen FCV was redesigned using ignition and burn-resistant materials. The FCV in use today is not vulnerable to this ignition mechanism.

***Fig. 2.*** *Fire in the space shuttle MPS flow control valve.*

## Analysis of particle impact ignition mechanism

The particle impact ignition mechanism continues to be investigated at WSTF using analysis and testing techniques. WSTF has developed a protocol for analysis of valve components intended for use in oxygen systems: *Guide for Oxygen Compatibility Assessments on Oxygen Components and Systems* (NASA/TM-2007-213740). This guide for oxygen compatibility assessments describes the particle impact ignition mechanism as "heat generated when small particles strike a material with sufficient velocity to ignite the particle and/or the material." It further describes the characteristic elements necessary for ignition by particle impact as: particles that can be entrained in the flowing oxygen; gas velocities, typically greater than approximately 100 ft/s; and an impact point ranging from 45 deg to perpendicular to the path of the particle. It also indicates that test data show, in most cases, the particulate must be flammable to produce ignition of the target material.

Using this description of the particle impact ignition mechanism and the characteristic elements necessary for it to produce a fire event, an analysis can determine the likelihood of a particle impact fire. This analysis, of course, will make use of published WSTF particle impact test data.

To better understand the flow patterns inside oxygen system components, WSTF uses computational fluid dynamics computer software. This analysis technique enables engineers to visualize the velocity, temperature, and pressure fields inside components; to project the paths of particles carried along by the flowing oxygen; and, finally, to predict impact points within the component. This tool (figure 3) enhances WSTF's understanding of the particle impact ignition mechanism and enables WSTF engineers to design test programs to validate or nullify particle impact ignition hypotheses.

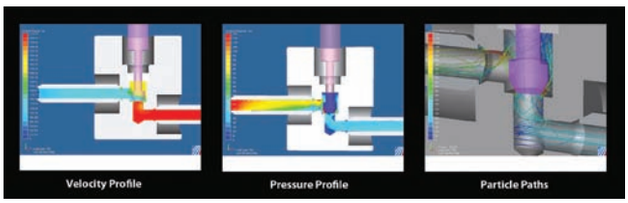


***Fig. 3.*** *Outputs from a computational fluid dynamic calculation.*

## Testing of particle impact ignition mechanism

Most recently, WSTF performed particle impact tests of the high-pressure oxygen valve shown in figure 4. This high-pressure, stainless-steel manual valve was impacted with a variety of particulate mixtures (Table 1) at temperatures ranging from 120°F to 150°F and at 4,000 psi inlet pressure. A pre- and posttest view of the valve is shown in figure 4.

| Particulate Mixture | Material | Size and Configuration | Amount |
|---|---|---|---|
| A | 316 SS | –60 mesh | 100 mg |
| B | Iron | –60 mesh<br>–50 + 100 mesh | 100 mg (50 mg of each mesh) |
| C | Iron | –60 mesh<br>–50 + 100 mesh | 1,000 mg (500 mg of each mesh) |

***Table 1.*** *Particulate mixtures used for testing of a high-pressure, stainless-steel manual valve.*

We performed 300 tests using particulate mixtures A and B without igniting the valve. However, on the first test using particulate mixture C, a catastrophic fire resulted in destruction of the valve (figure 4).

A serious fire hazard related to particle impact ignition exists in oxygen-enriched atmospheres. WSTF engineers are actively studying this important ignition mechanism and making progress in understanding how to mitigate the hazards it poses. The state of the art is being advanced by WSTF's analysis and testing efforts. This information is continually being applied to NASA's current and future efforts to sustain safe space travel and ground support operations.

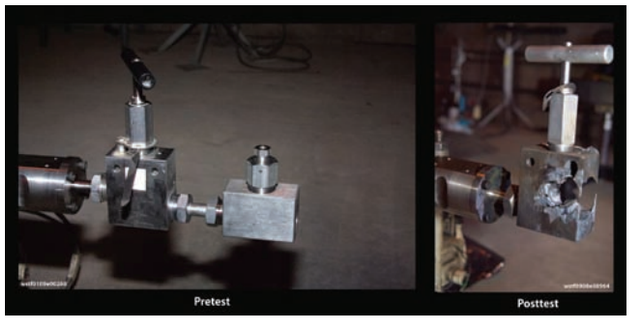


***Fig. 4.*** *Pre- and posttest views of a high-pressure, hand-operated valve tested at 4,000 psi.*



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