The Apollo 1 Fire

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January 27, 2017, will mark the 50th anniversary of the tragic Apollo 1 fire that took the lives of the Apollo 1 crew: Virgil I. "Gus" Grissom, Edward H. White II, and Roger B. Chaffee; and also marked a turning point in the race to the lunar landing.

Apollo 1 (AS-204) would have been the first manned flight of the Block I Apollo command and service modules on a 2-week orbital flight and using the Saturn 1B launch vehicle. Launch date was scheduled for February 21, 1967, from LC 34 at Kennedy Space Center. Earlier proposals in March 1966 involved Apollo 1 and Gemini 12 in a rendezvous mission planned for November 1966. This was quickly discarded as the command module could not be made ready in time. Simulations had been previously performed with the command module twice in the altitude chamber at Kennedy Space Center (October 18 with the prime crew and December 30 with the backup crew). The day of the fire was a "plugs out" simulation on the launch pad with the prime crew. In all three of these tests, the capsule was over-pressurized with 100% O_2 for several hours to check the capsule for leak rates.[2]

On the day of the fire, the crew entered the command module on LC 34 at 1:00 p.m. and the hatch was closed at 2:45 p.m. After hatch closure, the capsule was over-pressurized to 16.7 psi with 100% oxygen. The countdown continued with several holds to trouble shoot problems and stood at a scheduled hold at T minus 10 minutes at 6:30 p.m. The crewmembers reported a "fire in the cockpit" at 6:31 p.m. and attempted an emergency egress but were quickly overcome by smoke and an intense fire which ruptured the capsule due to high cabin pressure. Flames in the hatch window were seen on the white room video. Thick smoke and a transient fire engulfed the white room on the pad after the capsule ruptured and delayed rescue. The pad ground crewmembers were able to remove the hatch after 5 min (ironically, the hatch did not have an emergency blowout feature due to the Liberty Bell 7 hatch failure on Grissom's Mercury flight) and three flight surgeons arrived in the white room very shortly after hatch removal. It was clear that the crew had expired and they were not removed from the capsule until almost 8 hours after the fire, partly because their space suits had melted to the interior of the capsule. Autopsy showed that they had expired from asphyxiation due to hypoxia and carbon monoxide, but also had third degree burns over 25–50% of their bodies.[1]

Before the Apollo 1 fire, several fires in high-oxygen environments had occurred. On March 23, 1961, just less than 3 weeks before the first Vostok manned spaceflight, cosmonaut Valentin Bondarenko died after a fire in a high-oxygen concentration (60%) isolation chamber. This tragic experience was concealed by the Soviet government, only to be disclosed in 1986. Four fire events took place during manned U.S. Air Force and U.S. Navy chamber tests in the late 1950s and early 1960s. Three of those were tests of cabin atmospheres planned for Mercury and Gemini, and their crews escaped with injuries ranging from smoke inhalation to first and second degree burns. One of those tests occurred in 1962, when USAF Colonel B. Dean Smith and a colleague narrowly escaped a fire in a pure oxygen altitude chamber at Brooks Air Force Base in San Antonio, TX, while testing the Gemini space suit. Three other high-oxygen concentration chamber fire events involved unmanned tests of Apollo life support systems in the 2 years prior to Apollo 1, at least one of which used pure oxygen at the planned cabin pressure of 5 psi. Unfortunately, only 4 days after the Apollo fire, the Air Force lost two veterinary technicians in a pure oxygen chamber fire.[11]

Several articles in the *Journal of Aerospace Medicine* prior to the Apollo 1 fire show that the fire hazards of a high oxygen concentration cabin atmosphere were well known. The increased flammability of materials in a pure oxygen atmosphere even at low pressure was demonstrated in the Manhigh Air Force high altitude balloon program and so a 5.5 psi 60% oxygen atmosphere was chosen.[12] Air Force Aeromedical Laboratory studies showed that the fire hazard increased with a cabin pressure below 6.75 psi due to the lack of nitrogen. It was realized that the presence of an inert heavy gas such as nitrogen had a fire suppression effect.[6] However, Brooks AFB isolation chamber studies also showed that high oxygen concentration at low pressure did not cause oxygen toxicity and the extreme advantages due to structural weight savings in a spacecraft were pointed out.[7–10,] When designing the Mercury spacecraft, a low pressure pure oxygen atmosphere was chosen because of the extreme savings in structural weight, the decrease in cabin leak rate, and the simplification with a one gas system. The fire hazard with high oxygen concentration was pointed out, but dismissed in that, so as to mitigate the fire hazard risk, "the desire here was to have as low a total pressure as possible."[5] NASA chose the pure oxygen low pressure atmosphere not only for Mercury, but also for Gemini and Apollo, and then conducted validation tests using manned altitude chambers at multiweek durations. During those tests two fires occurred, highlighting the known fire hazard, but were explained away as "the inclusion of an inert gas does not eliminate the serious problem of potential spacecraft fires. In other words, any habitable atmosphere will support combustion. Hazard reduction (in a two gas atmosphere) is not considered operationally significant in currently planned spacecraft."[8] Studies by the Naval Air Development Center showed that flammability greatly increased as the concentration of oxygen increased and the concentration of nitrogen decreased. It was recommended that oxygen concentration not exceed 40% and nitrogen concentration should never be below 20% unless a

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heavy inert gas (Argon) was substituted.[3] There were not any studies in the literature investigating the obviously even more extreme fire hazard of a pure oxygen atmosphere at over-pressures.

The Apollo 204 Accident Review Board that investigated the accident found five main causes:

- An ignition source most probably related to "vulnerable wiring carrying spacecraft power" and "vulnerable plumbing carrying a combustible and corrosive coolant";
- A pure oxygen atmosphere at higher than atmospheric pressure;
- A cabin sealed with a hatch cover which could not be quickly removed at high pressure;
- An extensive distribution of combustible materials in the cabin (mostly Velcro); and
- Inadequate emergency preparedness (rescue or medical assistance, and crew escape).

The Block II Apollo command module was redesigned to correct these flaws and, most significantly, the hatch was redesigned. The in-flight cabin atmosphere of 100% oxygen at 5 psi could not be changed as it was inherent in the design and critically allowed for the extremely light structural weight of the command and lunar modules (indeed the Mercury, Gemini, and Apollo programs would not have been feasible). Launch pad procedures were changed so that a two gas system would be used during launch pad capsule over-pressurization. These changes delayed the resumption of manned Apollo flights by 20 months, but allowed the lunar module and Saturn V development to catch up with the rest of the program. Even more important was the change in perfectionism and culture of safety which permeated the manufacturers and NASA for the rest of the Apollo Program, which led to a successful Lunar landing by Apollo 11 on July 20, 1969. Launch Complex 34 was used for the Apollo 7 launch and then dismantled, The Apollo 1 command module is in a secure storage facility at NASA Langley Research Center and has never been accessed or viewed by the public.[4]

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