November 2, 2026 Aviation Investigation Report AIR-26-06

Require Adequate Corrosion Testing and Qualification of Long-Term Fire Retardants Used in Aerial Firefighting

Introduction

The National Transportation Safety Board (NTSB) is providing the following information to urge the United States Department of Agriculture Forest Service (USFS) to act on safety recommendations in this report. These recommendations address inadequate corrosion testing and qualification requirements for long-term fire retardants (LTFRs) used in aerial firefighting. The USFS's testing specifications and qualification process for LTFRs allowed a product with a novel LTFR chemistry to receive full qualification for use by large airtankers without adequate evaluation of its potential corrosive effects on aircraft materials and structures under representative operating conditions, including effects associated with the comingling of LTFRs based on fundamentally different chemistries.[1] Corrosion associated with such comingling could compromise the continued airworthiness and safe operation of large airtankers.

We identified these safety issues during our investigation, conducted at the USFS's request, of an incident involving significant corrosion discovered on two large airtankers under contract to the USFS that had carried and dispensed a new LTFR during operational trial in the 2023 fire season to determine product suitability during field use.[2] The NTSB determined that the probable cause of this incident was the use of a new LTFR with a chemical composition incompatible with the retardant previously in use for the integration-operational field evaluation without adequate

[1] Large airtankers are defined as fixed-wing aircraft with a tank load capacity of at least 1,800 gallons of fire retardant, according to the USFS (2012).

[2] Visit ntsb.gov to find additional information for this NTSB investigation (case number ENG24LA012). Use the CAROL Query to search safety recommendations and investigations.

testing and qualification.[3] The NTSB is issuing two safety recommendations to the USFS.

Background and Analysis

On March 11, 2024, the USFS informed the NTSB about corrosion found during postseason maintenance on two large airtankers. The first airplane, Tanker 02 (N474NA), a British Aerospace BAE-146-200A, was owned, operated, and maintained by Neptune Aviation Services of Missoula, Montana. The second airplane, Tanker 106 (N296EA), a McDonnell-Douglas DC-9-87 (MD-87), was owned, operated, and maintained by Aero Air of Hillsboro, Oregon.

The two airplanes were under contract to the USFS for the 2023 fire season and were subjected to a post-qualification integration-operational field evaluation (I-OFE) of a new fire retardant, Fortress FR-200, manufactured by Fortress North America. FR-200 used magnesium chloride ($MgCl_2$) as its active retardant salt and had received full qualification from the USFS in December 2022 to be carried and dispensed by its contract airtankers after completing required testing and an operational field evaluation (OFE) conducted from 2021–2022.

The airplanes involved in the 2023 post-qualification I-OFE used FR-200 exclusively for the first part of the 2023 season, from June 16, 2023, to August 13, 2023. During the second phase of the I-OFE, which ran from August 14, 2023, through November 21, 2023, they alternated between FR-200 and another retardant, MVP-Fx, an ammonium phosphate-based product manufactured by Perimeter Solutions and marketed under the Phos-Chek brand. MVP-Fx uses monoammonium phosphate (MAP) and diammonium phosphate (DAP) as its active retardant salts.

Until the qualification of novel $MgCl_2$-based LTFRs, all USFS-qualified products had used phosphate-based retardant salts. Because residual product remaining after a drop was expected to comingle with the retardant loaded next, the I-OFE was intended to evaluate the effects of integrating FR-200 and MVP-Fx—products based on fundamentally different chemistries—in the same airtanker systems and determine their suitability during field use.[4]

[3] Title 49 *Code of Federal Regulations* 830.2 defines an incident as "an occurrence other than an accident, associated with the operation of an aircraft, which affects or could affect the safety of operations." The occurrence of corrosion on the subject airtankers collectively constituted such an incident because it was associated with the airplanes' carriage and dispensing of a new LTFR during firefighting operations and affected primary structure and other components important to continued airworthiness and safe operation.

[4] A third phase of the I-OFE, in which "all federal-contracted large airtankers" would use FR-200 in combination with products from Perimeter Solutions' Phos-Chek line was planned for the 2024 firefighting season. The I-OFE was halted before this occurred.

The USFS's specification for testing and qualification of LTFRs, which is discussed in detail in the Qualification Process section of this report, did not require another field evaluation after full qualification. However, citing "the introduction of new nontraditional LTFR chemistries" and "operational challenges" that had been observed previously when comingling Fortress products with Perimeter products, the USFS "determined an Integration Operational Field Evaluation was necessary to learn how to safely, effectively, and efficiently introduce the new product into the field"—particularly alternating or comingled use by large airtankers (USFS, 2023a; USFS, 2023b).

As part of the I-OFE, the USFS required the operators to install 2024-T3 aluminum test coupons inside the retardant tanks for subsequent examination by the USFS.[5] Coupons aboard comparable sister airplanes that did not carry FR-200 served as controls. The airtankers' inspection and maintenance schedules were determined by their respective operators.

Before the 2023 fire season, Tanker 02 had undergone an inspection and cleaning by Neptune; although some staining from previous operations was present inside the retardant tank, no corrosion was noted. Tanker 106 had been converted to a large airtanker earlier that year and was operating in its first fire season. Its retardant tank was new, and the conversion process had included extensive disassembly and inspection of areas that ordinarily would not be accessible until a major inspection. Any corrosion found during the conversion or the subsequent stripping and repainting of the airplane was repaired or otherwise mitigated before the airplane entered service, as documented in an engineering authorization by Aero Air. Both airplanes also underwent USFS inspection and approval before the I-OFE.

I-OFE Phase 1: FR-200 Only

On June 16, 2023, the first day of the I-OFE, Tanker 106 underwent two 2-hour inspections: one after its first FR-200 drop and another after four additional drops at the end of the day. Neither inspection identified discrepancies or evidence of corrosion.

As exposure continued, however, both airplanes developed signs of material degradation or residue accumulation during the FR-200-only phase.

By June 27, 2023, after Tanker 106 had carried 20 loads of FR-200—and before it had carried MVP-Fx—Aero Air found light pitting on one test coupon and pitting across the entire face of another coupon mounted elsewhere in the tank, as shown in figure 1.

[5] A test coupon is a standardized specimen of a material used to evaluate how that material responds to specified exposure conditions. In corrosion testing, coupons are examined and may be weighed before and after exposure to identify and measure corrosion.

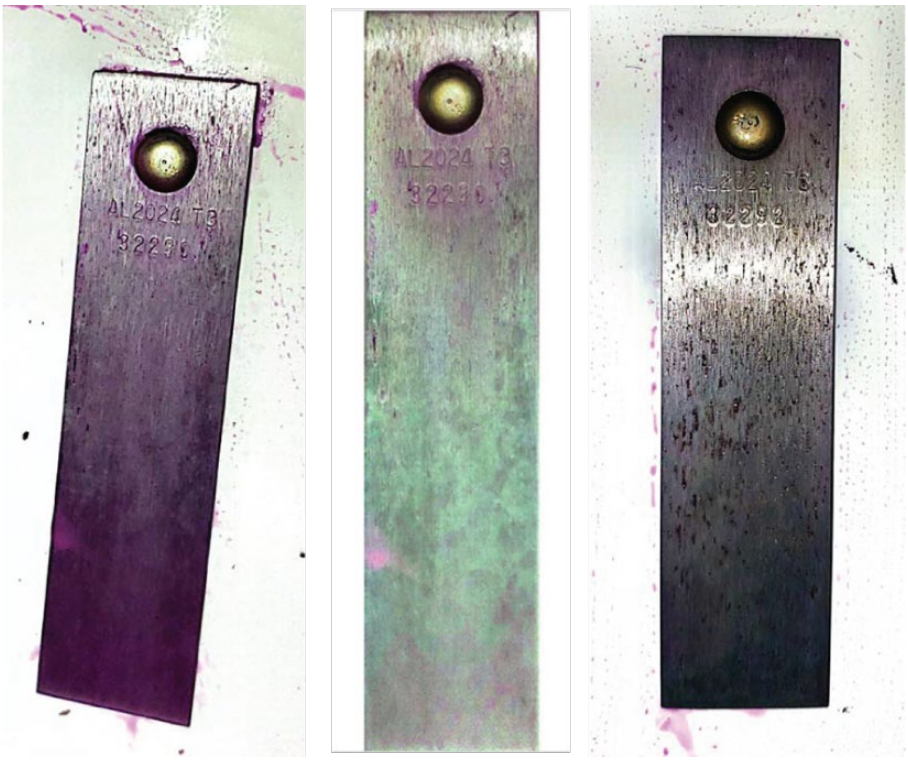


Figure 1. Test coupons from locations 1, 2, and 3 (left to right) on Tanker 106 as photographed June 27, 2023, after exposure to 20 loads of FR-200. (Source: Aero Air)

Note: Aero Air found "no corrosion on coupon 1" but noted "light pitting" on the coupon at location 2 and "pitting corrosion across [the] entire face of [the] coupon" at location 3.

Neptune's first tank entry of Tanker 02 during the I-OFE occurred on July 16, 2023, after the airplane had completed 64 drops of FR-200. Neptune reported that an anomaly in the system for indicating the tank's liquid level prompted the entry and that, by then, its maintenance crew had made several attempts to address buildup and leakage around the sealing surfaces of the tank's loading manifold, with little lasting success.

Neptune found gelatinous buildup, as well as black material and harder crystallized deposits on the tank level indication system components, on fasteners, and elsewhere inside the tank (see figure 2). Neptune reported that after the tank was rinsed with water, "most of the 'yogurt'-like substances and black material washed away" but that the harder crystalized material remained adhered.



Figure 2. Photographs of accumulated residue on Tanker 02 noted during first tank entry during I-OFE on July 16, 2023. (Source: Neptune Aviation Services)

Neptune next entered the tank on August 2, 2023, after a total of 107 drops, to troubleshoot continuing tank-level indication problems. It documented continued buildup of gray, ferrous material on magnetic areas; hard, crystallized material on Adel clamps; and continued buildup of gelatinous material on the floats and switches associated with the tank's liquid-level indication system, as well as on structural fasteners (see figure 3).[6] Neptune noted that there was no clear indication of corrosion on the surfaces of the test coupons. The tank was rinsed again following the inspection.

[6] Adel clamps are Teflon-cushioned metal loop clamps used with other hardware (such as screws, washers, and nuts) to secure and support wiring, tubing, hoses, and similar components while limiting movement, vibration, and abrasion.

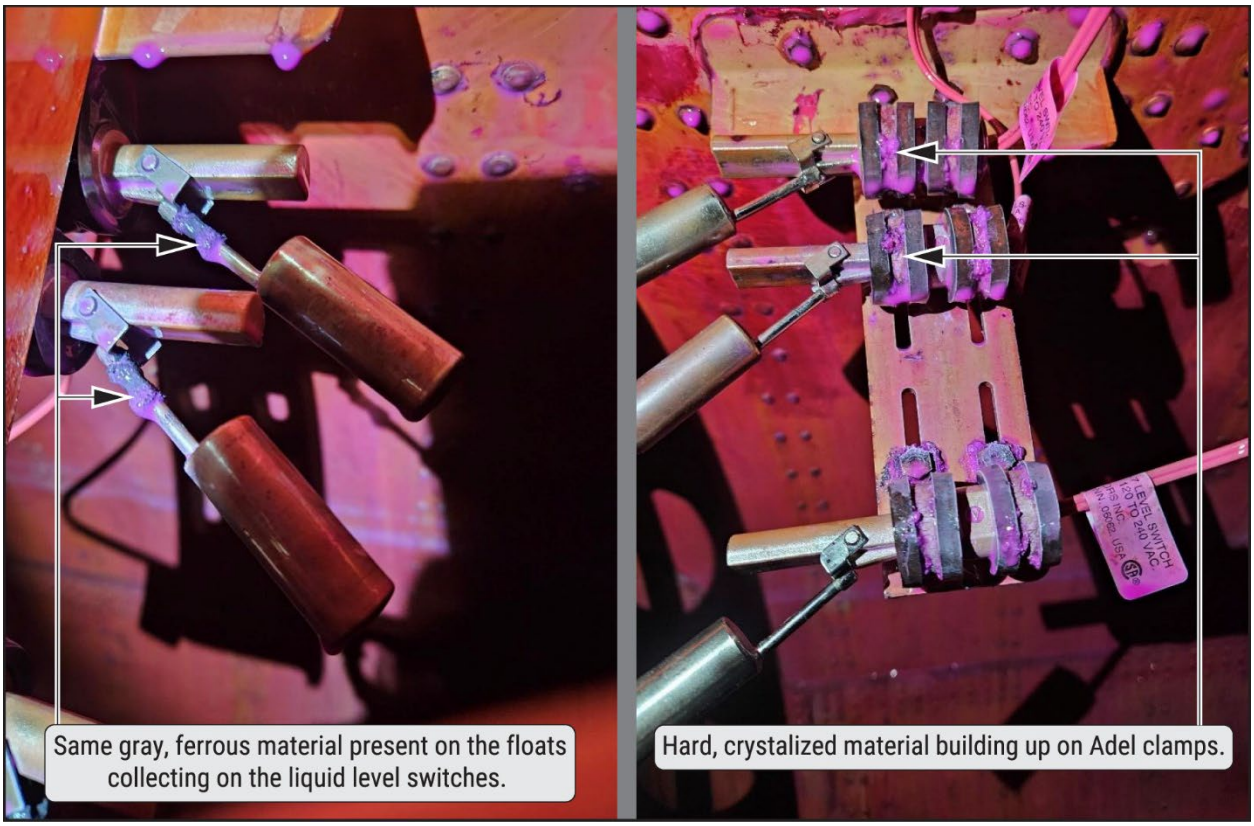


Figure 3. Buildup of gray ferrous material on Tanker 02's floats and associated liquid level switches (left) and hard, crystallized material on Adel clamps (right) observed during inspection on August 2, 2023. (Source: Neptune Aviation Services)

On August 14, 2023, in preparation for the second phase of the I-OFE, in which commingling would occur, Neptune entered the tank to install an additional set of test coupons. After washing the tank with water, Neptune observed a buildup of ferrous black particles on the dump valves that had been dislodged from the tank walls and floor during washing (see figure 4).



Figure 4. Black ferrous material collecting on top of Tanker 02's dump valve after being flushed from walls of tank on August 14, 2023. (Source: Neptune Aviation Services)

I-OFE Phase 2: Comingling

Neptune performed an inspection of the tank interior again on August 16, 2023, after the comingling began and the airplane had dumped one load of each retardant. The inspection report noted the presence of gelatinous or hard, crystallized material on the heads of many structural fasteners and gray, ferrous material on magnetic areas (figure 5). A comparison of Tanker 02 with corresponding areas on a control airplane that had carried only MVP-Fx showed no gelatinous material or hard, crystallized deposits on the control airplane's structural fasteners and Adel clamps. The inspection report further noted that the growth of the deposits on Tanker 02 "seemed to be much quicker than in previous tank entries."

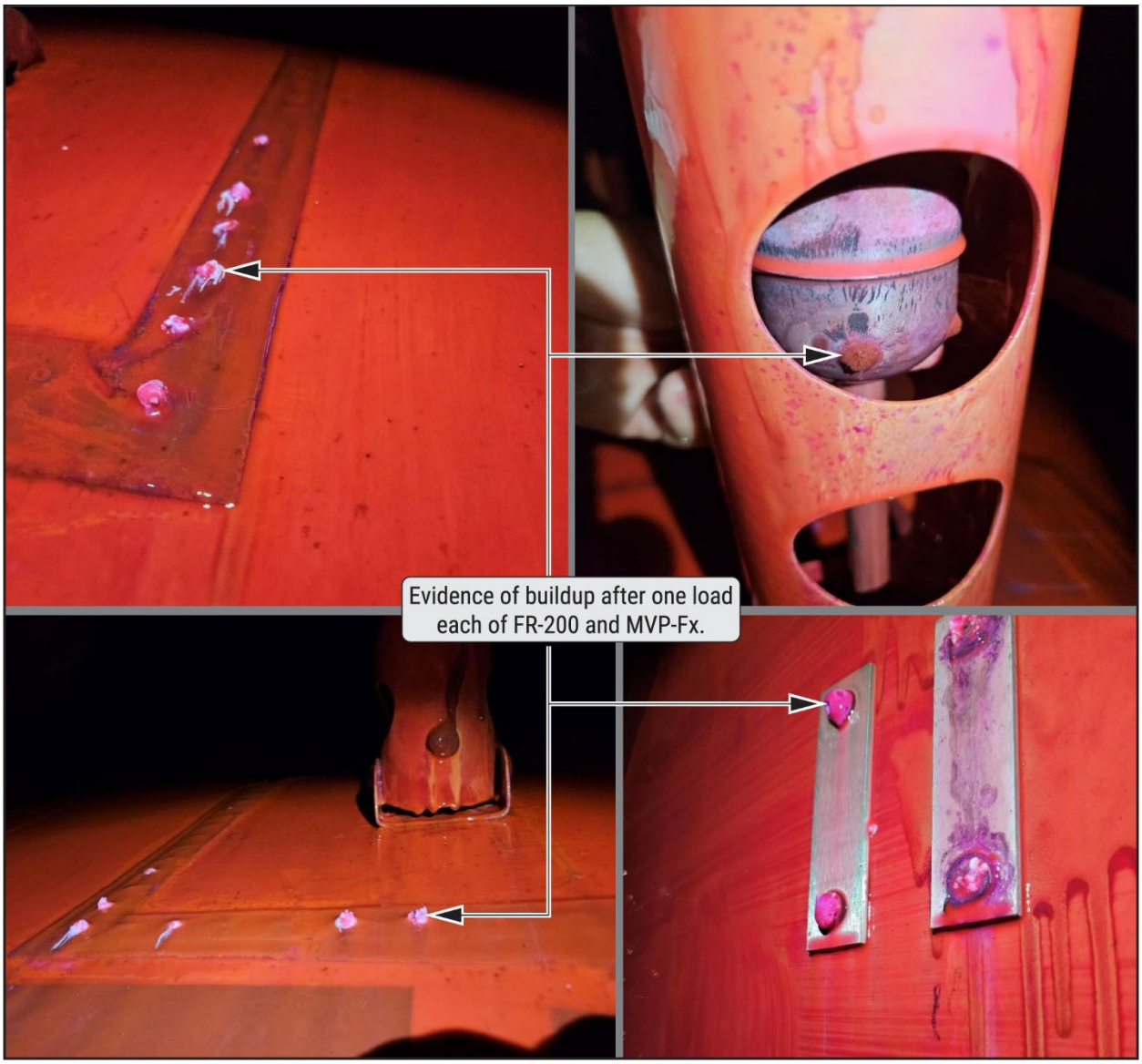


Figure 5. Rapid growth of precipitant deposits on exposed steel surfaces inside Tanker 02's tank, after its first comingled load on August 16, 2023. (Source: Neptune Aviation Services)

During the I-OFE's second phase, starting from August 16–19, 2023, Tanker 02 delivered 10 alternating loads—5 each of FR-200 and MVP-Fx—beginning with FR-200 and ending with MVP-Fx. It was loaded with one load of FR-200 on August 26, 2023, delivered it on August 29, 2023, then delivered one load of MVP-Fx later that day. Tanker 02 next delivered one load of FR-200 on September 23, 2023, and one load of MVP-Fx on September 26, 2023, followed by one load of FR-200 on October 8, 2023. On October 31, 2023, it delivered five alternating loads—three of MVP-Fx and two of FR-200—beginning and ending with MVP-Fx. It subsequently delivered one load of FR-200 on November 14, 2023, and one load of MVP-Fx on November 21, 2023.

Tanker 02 delivered no retardant on any other days during the second part of the I-OFE, during which it delivered a total of 11 loads of each product, alternating products after every load. After the I-OFE ended on November 21, 2023, Tanker 02 remained under contract and delivered seven additional loads of MVP-Fx, on December 9, 2023.

Tanker 106 experienced a slightly different exposure pattern during the same phase. Whereas Tanker 02 alternated products after every load, Tanker 106's operations included both alternating sequences and several days on which it carried only FR-200.

Before Tanker 106's first comingling operation, a new set of test coupons was installed alongside the original coupons at each of the three locations in the tank. Tanker 106 delivered one load of FR-200 on August 15, 2023, and one load of MVP-Fx the following day. A 3-hour inspection performed immediately after the August 16, 2023, load of MVP-Fx found minor pitting on the original and new coupons at locations 2 and 3. On August 17, Tanker 106 delivered five loads in an alternating sequence—FR-200, MVP-Fx, FR-200, MVP-Fx, and FR-200.

Tanker 106 subsequently delivered only FR-200 on August 25, August 26, August 29, and September 12, 2023, completing two, three, one, and five loads, respectively. On both October 30 and 31, it delivered the same five-load alternating sequence used on August 17. On November 14, it delivered one load of MVP-Fx. Tanker 106 delivered no retardant on any other days during the second part of the I-OFE, during which it delivered a total of 21 loads of FR-200 and 8 loads of MVP-Fx.

Two notable conditions were documented early in this period. On August 25, 2023, Aero Air found corrosion on both 40-inch flat-steel springs that retained the aft upper tank's negative-pressure vent doors; the right spring had fractured about 1 inch from its attachment to the vent door. The springs had been installed new during the airplane's modification in late 2022, were inspected every 30 cycles or 90 days and replaced every 180 days, and, according to Aero Air, had historically neither corroded nor failed. Aero Air attributed the spring failure to FR-200 exposure.

On September 5, 2023, Aero Air found corrosion and missing paint inside an inboard main landing gear door around the hinge and forward corner. Paint that had been applied earlier that year as part of the airplane's conversion for tanker service was bubbling and lifting in a manner resembling chemical paint removal, exposing bare metal with corrosion that Aero Air considered inconsistent with the airplane's short time in service. Aero Air also found corrosion on the inboard flap track, inboard flap-fairing hardware, and aft baggage-door rub-strip hardware and reported that corrosion of the severity observed on the flap components would ordinarily require 18 to 24 months to develop, although Tanker 106 had entered service less than 3 months earlier. Aero Air further reported that significant salt deposits remained on

the airplane after end-of-duty-day washing and required several additional hours of mechanical scrubbing to remove.

Postseason Findings

After the airplanes completed their 2023 season, the operators began detailed postseason inspections and maintenance. By March 11, 2024, those activities had identified corrosion involving the retardant tanks and components as well as external airplane structure, and the USFS informed the NTSB of the findings. An NTSB-led structures group examined Tanker 02 on March 13, 2024, and Tanker 106 on March 14, 2024. The group selected several items from both airplanes for further examination at the National Institute of Standards and Technology (NIST) laboratory in Boulder, Colorado. Because the operators continued to disassemble, inspect, and repair the airplanes after the NTSB-led examinations, the investigation record also includes additional findings subsequently documented by the operators and repair facilities.

During the March 13, 2024, examination of Tanker 02, the group observed conditions consistent with those Neptune had documented during postseason maintenance, including significant corrosion throughout the internal tank structure, particularly near fasteners, joints, and locations where dissimilar metals were connected. Corrosion was found on an aluminum vent door and spar where a stainless steel hinge was attached, on painted aluminum structure near stiffeners and lap joints, and around steel fasteners with aluminum collars. Investigators also observed bubbled or separated protective coatings, accumulated corrosion products, and dried retardant adhered to the tank structure. No corrosion was found on Tanker 02's control airplane, which had carried only phosphate-based retardants during the season.

For Tanker 106, Aero Air began a detailed postseason inspection in January 2024. During that inspection, Aero Air identified intergranular corrosion in a lower-cap doubler on the right-wing forward spar beneath the wing-to-body fairing.[7] Drilling within the affected area indicated that corrosion extended through more than half of the doubler's thickness. Before the March 14, 2024, group examination, Aero Air removed the damaged section and stripped its protective coating. The group documented an approximately 4-inch area of exfoliation corrosion affecting most of the doubler's thickness (see figure 6). The airplane manufacturer identified the doubler, which extended from the side of the fuselage toward the wingtip, as primary structure. The doubler's external location on the airplane's belly near the wing root

[7] Intergranular corrosion is localized corrosion that progresses along the boundaries between the microscopic crystals, or grains, that make up a metal, potentially weakening the material with comparatively little visible surface damage. Exfoliation corrosion is one type of intergranular corrosion.

placed it in an area exposed to the retardant plume, as illustrated in figure 7. Aero Air subsequently fabricated and installed a replacement section.



Figure 6. Exfoliation corrosion on Tanker 106's right wing forward spar lower cap doubler.



Figure 7. Photograph of Tanker 106 dropping a plume of retardant in July 2026. (Source: Logan Fransted)

The March 14, 2024, examination also documented corrosion involving the retardant tank and numerous external airplane components. Findings included corrosion on an inboard flap-fairing attachment fitting and its serrated plates; both main landing gear doors, hinges, and hinge pins; brake-cooling ducts; electrical connectors in the wheel wells; an inboard flap; the aft cargo door skin; and brake components. Within the retardant tank, investigators observed pitting and crystalline deposits in a tank-door seal groove, corrosion on tank-door operating components, deteriorated sealant, and magnetic particles adhering to portions of the structure. Investigators also found loose foam wedges that had retained about 1 quart of liquid retardant and newly installed rotary actuators that exhibited corrosion.

Aero Air continued disassembling and inspecting Tanker 106 after the March 14, 2024, examination and documented additional corrosion in the lower fuselage and wheel well areas. Two keel-skin panels required repairs, including a large internal doubler and several smaller reinforcing plates. Corrosion damage also required replacement of an approximately 44-inch section of a longeron and repairs to structure at two fuselage stations. Aero Air replaced more than 90 electrical connectors and several control cables because of corrosion. Aero Air reported no corresponding corrosion on Tanker 107, the control airplane that had not carried FR-200.[8]

Aero Air also found corrosion in all three engines installed on Tanker 106. In July 2024, an NTSB structures group representative observed the engines' disassembly and inspection at the overhaul facility, which had begun the prior month. The right engine, which had remained installed throughout the I-OFE, exhibited residue and corrosion extending from the inlet and compressor sections through the combustor and turbine sections; 61 parts or modules were rejected by the technicians performing the work because of excessive corrosion or contamination that obstructed cooling passages.

The engine installed on the left side of Tanker 106 at the start of the I-OFE exhibited similar corrosion, and 53 parts or modules were rejected by technicians performing the work for the same reasons. The engine that replaced it on the left side, installed September 17, 2023, accumulated substantially less exposure during the I-OFE; it exhibited residue and light corrosion, but no parts were rejected after cleaning. The overhaul facility reported that the corrosion levels in the two more extensively exposed engines were unusual. Tanker 106's auxiliary power unit also contained retardant residue, exhibited unusual corrosion, and required overhaul.

The following table summarizes the progression of conditions documented on both airplanes, from their pre-I-OFE baselines through postseason disassembly and inspection.

[8] Tanker 107, an MD-87 (N297EA), was not present during the NTSB's examination.

Table. Progression of documented conditions on Tankers 02 and 106.

Period	Tanker 02	Tanker 106
Pre-I-OFE condition	A preseason inspection and cleaning found some staining inside the retardant tank but no corrosion.	The airplane had recently been converted for airtanker service, including installation of a new retardant tank and inspection and repair of previously accessible structure.
Phase 1: FR-200 only	The first tank entry, on July 16 after 64 drops, documented gelatinous, black, and crystallized deposits. An August 2 entry after 107 drops documented continued accumulation, although the test coupons showed no clear corrosion.	Two inspections on June 16 after five loads found no discrepancies or evidence of corrosion. On June 27, after 20 loads, Aero Air documented light pitting on one test coupon and pitting across the face of another.
Phase 2: transition and comingling	An August 14 precomingling tank entry documented ferrous particles dislodged during washing. After one load of each product on August 16, Neptune reported that deposit growth appeared substantially faster than during previous entries. Tanker 02 carried 11 loads of each product during the phase, alternating products after every load.	After the first load of each product, an August 16 inspection documented pitting on original and newly installed coupons. Tanker 106 subsequently carried both alternating sequences and FR-200-only loads, totaling 21 FR-200 loads and 8 MVP-Fx loads. Aero Air documented corroded vent-door springs, one of which fractured, and corrosion and coating damage on external airplane components.
Postseason findings	Investigators documented corrosion throughout the internal tank structure, particularly near fasteners, joints, and dissimilar-metal connections, along with deteriorated coatings, corrosion products, and retained residue. No corresponding corrosion was found on the control airplane.	Inspections documented exfoliation corrosion affecting primary wing structure and corrosion involving the tank, fuselage, landing-gear and flap components, electrical connectors, control cables, engines, and auxiliary power unit. No corresponding corrosion was found on the control airplane.

Note: Dates identify when conditions were observed or documented and do not necessarily establish when they first developed.

Qualification Process

The rapid development and extent of the corrosion observed during and after the I-OFE prompted the NTSB to examine whether that qualification process adequately evaluated the effects of LTFRs on aircraft materials and structures.

FR-200 successfully completed the USFS process for full qualification before the I-OFE began.[9] Full qualification means that a product has satisfied all applicable requirements of USFS Specification 5100-304d, *Long-Term Retardant, Wildland Firefighting*, and has been listed on the Qualified Products List (QPL) according to approved mix ratio and application methods.[10]

The USFS had used aerially applied LTFRs for decades without significant corrosion problems reported on its contract aircraft. Beginning in the 1960s, these products were formulated using MAP, DAP, ammonium polyphosphate (APP), and ammonium sulfate as their active retardant salts. In 2007, the USFS eliminated ammonium sulfate because of toxicity concerns and revised its LTFR specification to permit only MAP, DAP, APP, or combinations of those phosphate-based salts. Perimeter Solutions acquired the Phos-Chek business in 2018 and inherited the product line's position, dating to 2006, as the only supplier of phosphate-based LTFRs qualified for USFS use.[11] Perimeter reported that its phosphate-based products and their predecessors had been used to dispense more than 500 million gallons of retardant from airtankers.

The USFS stated that beginning around 2018, the agency sought to qualify products from additional manufacturers to reduce the risks associated with relying on

[9] The December 8, 2022, Qualified Products List (QPL) listed FR-200, at a water-to-concentrate mix ratio of 2.4:1, as fully qualified for application from multi-engine and single-engine fixed-wing airtankers and helicopter buckets, as well as from ground equipment; it was not qualified for use from fixed-tank helicopters. QPL listing made FR-200 eligible for purchase by federal agencies, states, and others and, once procured, for loading and dispensing by the listed aircraft types during operational firefighting, including on National Forest System lands. Full qualification did not itself award Fortress a supply contract or obligate the USFS to purchase FR-200.

[10] This specification is a qualification requirement for federal procurement governed by 41 *United States Code* 3311 and *Federal Acquisition Regulation* subpart 9.2. Before establishing such a requirement, an agency must document why it is necessary, identify and make available the standards that products must meet, publicly announce the requirement through the federal government's contracting website, and allow potential suppliers an opportunity to demonstrate that their products meet the standards. These rules do not require the formal public notice-and-comment process used to adopt federal regulations.

[11] Before 2006, Fire-Trol and Phos-Chek were competing lines of phosphate-based LTFRs. In 2005, the USFS amended Specification 5100-304b to exclude retardants containing YP Soda, a corrosion inhibitor used in Fire-Trol products, and require gum-thickened formulations. Fire-Trol consequently no longer had a product qualified under the amended specification, leaving Astaris, then the owner of Phos-Chek, as the USFS's sole LTFR supplier beginning in 2006.

a single source and create a more competitive market. As part of that effort, at the direction of the Department of Agriculture, the USFS superseded Specification 5100-304c with Specification 5100-304d in January 2020, removing the requirement that LTFRs use phosphate-based retardant salts. The revision continued to permit phosphate-based salts but also allowed manufacturers to submit products for qualification that used other retardant salts. The remaining requirements were largely unchanged. Fortress subsequently submitted FR-100 and FR-200, two $MgCl_2$-based products that were substantially different from the legacy phosphate-based retardants and became the first new LTFRs added to the USFS QPL in more than 20 years. Chemically, FR-100 and FR-200 were materially equivalent; like Perimeter's products, both were supplied as concentrates to be mixed with water before use, and their only significant difference was physical form: FR-100 was a powder and FR-200 was a liquid.

Specification 5100-304d established the physical, performance, testing, environmental, and delivery requirements for placing an LTFR on the QPL. The USFS National Technology and Development Program (NTDP) conducts the required testing and administers the qualification process. Because the normal stability-testing process could take up to 24 months, the specification also established accelerated stability-testing procedures through which a product meeting the interim requirements could receive interim qualification while final testing remained incomplete. A product that satisfied all the laboratory evaluation requirements could receive conditional qualification.

FR-200 successfully completed the laboratory evaluation requirements and received conditional qualification in August 2021. The specification gave the USFS discretion to require an OFE to determine the product's suitability during actual use. The USFS exercised that discretion for FR-200, conducting an OFE during the 2021 and 2022 fire seasons, which is discussed later in this section. Following successful completion of the OFE, the USFS granted FR-200 full qualification in December 2022.

For use in fixed-wing airtankers, the specification required uniform corrosion testing of 2024-T3 aluminum alloy, 4130 chromoly steel, UNS C26000 yellow brass, and AZ31B magnesium. Consistent with the testing specification, individual coupons were fully or partially submerged in wet concentrate and mixed retardant for 90 days at 70°F and 120°F, and their weight loss was used to calculate a uniform corrosion rate. For wet concentrate, the maximum allowable corrosion rate was 5.0 mils per year for aluminum, steel, and brass.[12] For mixed retardant, the maximum was 2.0 mils per year for aluminum and 5.0 mils per year for steel and brass.

The specification established no maximum allowable rate for magnesium when qualifying a product for fixed-wing airtankers. It also required microscopic

[12] One mil equals 0.001 inch.

examination of at least one 2024-T3 aluminum coupon from each mixed-retardant exposure and temperature, with no intergranular corrosion permitted. It did not, however, require testing of other materials commonly used in aircraft construction, such as 6061 and 7075 aluminum alloys, stainless steels, nickel alloys, and titanium alloys.

The specification also did not require testing of dissimilar materials electrically connected as they are in aircraft; fasteners and joints; or built-up structures, such as assemblies of skins, stiffeners, fittings, and fasteners joined to function as a structural unit. The specification also did not require evaluation of galvanic corrosion or the chemical and corrosion effects of contact between LTFRs with substantially different base chemistries, such as phosphate-based and $MgCl_2$-based retardant salts.[13]

FR-100 received interim qualification in October 2020 after the USFS NTDP determined that it satisfied accelerated stability-testing and other interim requirements in Appendix A of the specification; final laboratory results and an OFE were still required for full qualification. After completing all laboratory evaluation requirements, FR-100 received conditional qualification in May 2021. During the subsequent 2021 OFE, in which Aero Air and Neptune participated, airtankers equipped with coated metal tank structures and components carried both FR-100 and Phos-Chek LC95, an APP-based retardant. Contact between the products produced a thick, gel-like material when wet and a clay-like deposit when dry.

Operators reported that the deposits interfered with tank sensors, valves, flow meters, and seals; required mechanical removal; and were accompanied by corrosion of actuator hardware and breakdown of protective coatings inside the tanks. The resulting USFS report recommended testing aircraft materials—including stainless steels, aluminum alloys, magnesium, nickel, and titanium—using an aeronautical standard, such as ASTM F482-09, *Standard Practice for Corrosion of Aircraft Metals by Total Immersion in Maintenance Chemicals*. The report also recommended continued monitoring of the corrosive effects of $MgCl_2$-based FR-100, further study of the deposits and accelerated corrosion, and preventing contact between FR-100 and LC95 inside airtanker tanks.

Following FR-200's conditional qualification, the USFS evaluated the product during the remainder of the 2021 fire season and during the 2022 fire season using just one single-engine airtanker equipped with a fiberglass retardant tank (see figure 8). The evaluation produced no significant corrosion findings, and the USFS granted FR-200 full qualification in December 2022. However, because the evaluation used fiberglass tanks, it did not evaluate FR-200's corrosive effects on the combinations of metallic materials and built-up structures found in large airtankers.

[13] Galvanic corrosion is accelerated corrosion that can occur when dissimilar metals are electrically connected in the presence of an electrolyte, such as liquid retardant. The less corrosion-resistant metal generally corrodes preferentially.

The OFE report for FR-200 also acknowledged that continuing work could require additional operational safeguards and stated that isolating products to particular tanks and systems was the safest option given the remaining unknowns.



Figure 8. The single-engine airtanker equipped with a fiberglass retardant tank used in the OFE that supported the USFS's full qualification of FR-200. (Source: United States Department of Agriculture)

Following the 2021 FR-100 OFE, NTDP examined the compatibility of the Fortress $MgCl_2$-based retardants with several phosphate-based products. Laboratory testing found an immediate precipitation reaction when a $MgCl_2$ solution was mixed with a DAP solution.[14] After drying, the resulting solid was identified as likely struvite, or magnesium ammonium phosphate.[15] Mixing the $MgCl_2$ solution with an APP solution produced a more pronounced clumping reaction. NTDP then tested the formulated retardants using a ratio of 97% bulk product to 3% residual product, which it considered representative of conditions inside an airtanker tank fully depleted and then refilled.

Although the uniform corrosion rates measured on 2024-T3 aluminum testing coupons remained within the specification's 2.0-mils-per-year limit for aluminum with mixed retardant, some combinations produced intergranular corrosion requiring further study. NTDP concluded that the Fortress products were significantly

[14] A precipitation reaction occurs when substances dissolved in a liquid react to form an insoluble solid, called a precipitate, that separates from the liquid.

[15] Struvite is chemically identical to a type of mineral that forms in humans as kidney stones.

incompatible with the APP-based Phos-Chek LC95 products and recommended that they not be comingled.

In August 2022, prompted by these results from laboratory testing and by findings from the 2021 OFE of FR-100, large-airtanker operators met with USFS and advised that the existing testing did not account for the various alloys used in airtankers or the effects of exposing those materials to different retardants. They expressed particular concern about the corrosive effects of $MgCl_2$-based retardants, deposits produced when retardants interacted, and the potential consequences for aircraft structure and flight safety. The operators recommended delaying further field evaluations until appropriate tests had been developed, consulting airtanker operators and other corrosion experts, testing products on representative aircraft materials and assemblies, and evaluating interactions between products before granting conditional qualification. The USFS documented these concerns in an internal memorandum.

In December 2022, the USFS solicited additional information from operators, manufacturers, and other stakeholders about the operational risks associated with LTFRs. Respondents again identified corrosion and product-interaction hazards and recommended testing the materials, joints, built-up structures, and components found in actual aircraft under representative operating conditions. In that same month, NTDP also began testing the effects of alternating among different retardants on aluminum tank-level sensors. By July 2023, while the I-OFE was underway but before its second phase, this testing had documented substantial residue accumulation and operational problems with some combinations of phosphate- and $MgCl_2$-based retardants. The NTSB's investigation found no evidence that the stakeholder recommendations or the results of prior testing were incorporated into the I-OFE before the USFS proceeded with the second phase.

Postincident Testing

At the NTSB's request, the NIST examined components removed from Tankers 02 and 106 and samples of FR-200 and MVP-Fx. NIST found that some components had experienced galvanic corrosion where steel and aluminum alloys were electrically connected in the presence of liquid retardant. Other components had corroded after their protective surface treatments deteriorated in the presence of liquid or residue left after the retardant dried. NIST also identified a likely chemical interaction between the proprietary nitrogen-based corrosion inhibitors used in the two retardants. These mechanisms were consistent with the concentration of corrosion around fasteners, joints, dissimilar-metal connections, and areas where retardant or dried residue had accumulated.

Based on the NIST findings, NTDP conducted additional tests using 2024 and 6061 aluminum alloys electrically coupled to 4130 steel and exposed to individual

retardants. The aluminum coupons exposed to FR-200 developed visible pitting, with more severe corrosion on the 6061 alloy, while the steel coupons generally exhibited greater corrosion when exposed to MVP-Fx. Although the calculated uniform corrosion rates for the 2024-T3 aluminum and 4130 steel coupons did not exceed the corresponding limits in the specification, the specification provides no limit for 6061-T6 aluminum, and NTDP cautioned that the existing acceptance limits were not likely valid for this galvanic testing. Additional testing with different relative surface areas confirmed that galvanic coupling could induce substantially more extensive corrosion than was observed on isolated coupons.

Testing of galvanically coupled materials in a 97%–3% mixture of FR-200 and MVP-Fx did not produce corrosion significantly different from that produced by the individual retardant constituting 97% of the mixture. However, a 50%–50% mixture was more acidic than either retardant alone and produced moderate-to-severe pitting on the coupled aluminum coupons, with corrosion rates significantly exceeding the specification's limits. These results demonstrated that FR-200 could promote galvanic corrosion of aluminum alloys when used alone and that interaction with a phosphate-based retardant could intensify the corrosion under some conditions. They also demonstrated that the existing uniform-corrosion tests could permit a product to satisfy the specification despite corrosive behavior under conditions representative of aircraft construction and operation.

Taken together, the evidence showed why FR-200 could satisfy the existing qualification requirements yet cause significant corrosion when used in large airtankers. The specification evaluated uniform corrosion on a small number of isolated material coupons, and the field evaluation preceding full qualification used only one single-engine airplane equipped with a fiberglass retardant tank. Neither step systematically evaluated FR-200 on the numerous alloys, protective coatings, fasteners, joints, built-up structures, and electrically connected dissimilar materials found in large airtankers.

Therefore, the NTSB concludes that FR-200 received full qualification for use on fixed-wing airtankers without adequate evaluation of its corrosive effects on the materials and built-up structures used in large airtankers because the USFS-required laboratory testing used a limited number of isolated material coupons, and the qualification-stage OFE used one single-engine airtanker equipped with a fiberglass retardant tank.

The potential consequences extend beyond increased maintenance and component replacement. Corrosion reduces the thickness and strength of metallic aircraft structure and, if undetected or uncorrected, can result in structural failure. In this incident, corrosion developed during a single fire season and affected primary wing structure, internal fuselage structure, flight control cables, electrical connectors, tank components, and engines. Without adequate testing before an LTFR enters operational use, aircraft throughout the USFS contract fleet, including large

airtankers, single-engine airtankers, and helicopters, could be exposed to corrosion hazards that were not identified during qualification.

The USFS is responsible for determining which fire retardants may be carried and dispensed during its aerial firefighting operations. The Federal Aviation Administration approves an aircraft for the aerial-dispensing function but does not approve the particular liquids selected by the USFS for dispensing. Specification 5100-304d is therefore the principal means of ensuring that an LTFR is compatible with the aircraft on which the USFS permits it to be used.

An adequate corrosion-testing program must evaluate more than uniform material loss from isolated coupons. It should evaluate each retardant individually on the range of alloys and other materials typically used in aircraft construction and should account for localized corrosion, intergranular corrosion, galvanic coupling, protective coatings, fasteners, joints, and built-up structures. Testing should also reproduce relevant operating conditions, including repeated wet-and-dry exposure, retained residue, and contact between LTFRs with different base chemistries. Acceptance criteria must be capable of identifying harmful localized or galvanic corrosion even when the calculated uniform corrosion rate remains within the specification's allowable limits.

After the corrosion was discovered, the USFS suspended the qualifications of FR-100 and FR-200 on May 5, 2024, pending further evaluation. On October 25, 2024, it issued an interim amendment to Specification 5100-304d that again limited acceptable retardant salts to MAP, DAP, APP, or combinations of those phosphate-based salts. Although characterized as interim, the amendment specified neither an expiration date nor conditions under which the restriction would end. The USFS subsequently removed FR-100 and FR-200 from the QPL on December 5, 2024. These actions ended the immediate operational use of the $MgCl_2$-based products identified in this investigation.

The USFS began developing broader corrosion testing before the NTSB investigation commenced. At a December 2023 tanker briefing, the USFS reported that it had contracted with Aeronautica, a private aerospace engineering services firm, to develop testing intended to represent the airtanker operating environment. Aeronautica subsequently developed a cyclic-immersion test plan covering 20 materials commonly used in aircraft construction and a wicking test plan covering built-up assemblies incorporating multiple materials and common aircraft fasteners. Although those plans had been finalized and testing had begun, the results are not yet available.

The USFS also contracted with Assured Testing, a specialized commercial testing company accredited by the American Association for Laboratory Accreditation, to conduct modified salt fog testing of several aluminum alloys under alternating spray-and-dry conditions. Preliminary results indicated that the

uniform-corrosion rates for FR-200 and MVP-Fx remained within the specification's limits, but no final salt-fog report was available. These contract programs were separate from the NTDP galvanic-corrosion studies discussed previously, which had produced results relevant to the investigation.

The NTSB notes that although these actions are encouraging, restricting the permissible retardant salts does not correct the underlying deficiency in the qualification process. A future LTFR formulated with a substantially different chemical composition could satisfy the same limited uniform-corrosion requirements without being adequately evaluated under representative aircraft conditions. Further, although the USFS's additional testing may provide the technical basis for improved procedures, those procedures will not govern future qualification decisions unless they are formally incorporated into the specification.

Therefore, the NTSB concludes that the corrosion-testing requirements in USFS Specification 5100-304d are inadequate because they principally evaluate uniform corrosion on a limited number of isolated material coupons and do not evaluate the range of materials and built-up structures used in aircraft construction, galvanic coupling, or the chemical and corrosion effects of retardant comingling, thereby allowing an LTFR capable of causing damaging corrosion under representative aircraft conditions to satisfy the specification and receive full qualification.

Developing representative testing procedures will require expertise extending beyond retardant performance and wildland-firefighting operations. Airtanker operators can identify the materials, assemblies, exposure pathways, and maintenance conditions that should be represented; aircraft corrosion experts from government and industry can select appropriate test methods and acceptance criteria; and retardant manufacturers can provide necessary information about product formulations and chemical interactions.

Therefore, the NTSB additionally concludes that developing representative corrosion test procedures requires the participation of aircraft corrosion experts from industry and government, airtanker operators, and retardant manufacturers.

The NTSB recommends that the USFS work with aircraft corrosion experts from industry and government, airtanker operators, and retardant manufacturers to develop robust corrosion test procedures that address the range of materials typically used in aircraft construction, built-up structures incorporating those materials, galvanic coupling, retardant comingling, and possible chemical interaction effects.

Furthermore, the NTSB concludes that because USFS Specification 5100-304d governs LTFR qualification, future LTFRs cannot be adequately evaluated unless improved, representative test procedures are incorporated into the specification.

The NTSB therefore recommends that the USFS revise the requirements for LTFR qualification contained in Specification 5100-304d, *Long-Term Retardant, Wildland Firefighting*, to incorporate the procedures developed in response to Safety Recommendation A-26-66. The revised specification must require future qualification decisions to be based on testing representative of the materials, structures, and exposure conditions encountered in aerial firefighting operations, reducing the likelihood that an LTFR capable of causing harmful corrosion will enter operational use before its effects on aircraft airworthiness have been adequately evaluated.

Conclusions

Findings

1. FR-200 received full qualification for use on fixed-wing airtankers without adequate evaluation of its corrosive effects on the materials and built-up structures used in large airtankers because the United States Forest Service-required laboratory testing used a limited number of isolated material coupons, and the qualification-stage operational field evaluation used one single-engine airtanker equipped with a fiberglass retardant tank.
2. The corrosion-testing requirements in United States Forest Service Specification 5100-304d are inadequate because they principally evaluate uniform corrosion on a limited number of isolated material coupons and do not evaluate the range of materials and built-up structures used in aircraft construction, galvanic coupling, or the chemical and corrosion effects of retardant comingling, thereby allowing a long-term fire retardant capable of causing damaging corrosion under representative aircraft conditions to satisfy the specification and receive full qualification.
3. Developing representative corrosion test procedures requires the participation of aircraft corrosion experts from industry and government, airtanker operators, and retardant manufacturers.
4. Because United States Forest Service Specification 5100-304d, *Long-Term Retardant, Wildland Firefighting*, governs long-term fire retardant (LTFR) qualification, future LTFRs cannot be adequately evaluated unless improved, representative test procedures are incorporated into the specification.

Recommendations

New Recommendations

As a result of this investigation, the National Transportation Safety Board makes the following new safety recommendations.

To the United States Forest Service:

1. Work with aircraft corrosion experts from industry and government, airtanker operators, and retardant manufacturers to develop robust corrosion test procedures that address the range of materials typically used in aircraft construction, built-up structures incorporating those materials, galvanic coupling, retardant comingling, and possible chemical interaction effects. (A-26-66)

2. Revise the requirements for long-term fire retardant qualification contained in Specification 5100-304d, *Long-Term Retardant, Wildland*

Firefighting, to incorporate the procedures developed in response to Safety Recommendation A-26-66. (A-26-67)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

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THOMAS CHAPMAN
Member

JOHN DELEEUW
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Report Date: November 2, 2026

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