International Civil Aviation Organization

WORKING PAPER

A42-WP/395
TE/158
19/8/25
(Information paper)
English only

ASSEMBLY — 42ND SESSION

TECHNICAL COMMISSION

Agenda Item 25: Other issues to be considered by the Technical Commission

AIRCRAFT FIRE SUPPRESSION – HALON REPLACEMENT

(Presented by the International Coordinating Council of Aerospace Industries Associations (ICCAIA))

EXECUTIVE SUMMARY

This information paper provides the detailed rationale for the discussion and actions proposed in A42-WP/74-TE/20.

Strategic Goals:	This paper relates to *Every Flight is Safe and Secure*, *The International Civil Aviation Convention and Other Treaties, Laws and Regulations Address all Challenges*, and A*viation is Environmentally Sustainable.*
Financial implications:	The activities referred to in this paper will be undertaken with the resources available in the 2026-2028 Regular Programme Budget.
References:	Annex 8 — *Airworthiness of Aircraft* Doc 10184, *Assembly Resolutions in Force,* Resolution A39-13: *Halon replacement* A42-WP/74, *The challenge of Halon replacement: balancing fire safety, environmental goals, and industry readiness* A41-WP/96, *Aircraft halon replacement*

1. INTRODUCTION

1.1 The aviation industry remains committed to environmental stewardship and compliance with international agreements, including the Montreal Protocol on Substances that Deplete the Ozone Layer. While Halon has been a highly effective fire suppression agent for decades, its classification as an ozone depleting substance (ODS) necessitates its replacement. International Civil Aviation Organization (ICAO) Assembly Resolution A39-13 acknowledges the complexities of this transition and encourages global collaboration.

1.2 Despite intensive research and development efforts spanning many years, finding a universally acceptable Halon alternative has proven exceptionally challenging across various aircraft zones, and in particular for cargo compartments. As current alternatives for use in cargo compartments face challenges in terms of acceptability[1], this paper provides the comprehensive justification for the specific actions proposed to the Assembly in A42-WP/74, *The challenge of Halon replacement: balancing fire safety, environmental goals, and industry readiness*, and expands on the working paper's 'Discussion' section.

2. DISCUSSION

2.1 The mandate for Halon replacement

2.1.1 Halon is identified as an Ozone Depleting Substance (ODS) and its production was phased out under the Montreal Protocol of the United Nations Environment Programme's (UNEP) Ozone Secretariat. The Montreal Protocol restricts the production and consumption of both recycled and newly manufactured ODS, including Halon 1301 as used for cargo compartment fire suppression, except for essential uses. Aviation fire protection has been deemed an essential use, allowing continued reliance on banked recycled Halon 1301.

2.1.2 Constraints on the use of Halon exist at two levels. The International Civil Aviation Organization (ICAO) has introduced "cut-off dates" in Annex 8 — *Airworthiness of Aircraft* , after which Halon 1301-based fire extinguishing systems should no longer be used for new-type certified aircraft (e.g., 2024 for aircraft cargo compartments). These deadlines do not apply to aircraft models already type certified nor to the existing fleet. The European Union has reflected these "cut-off dates" in its Ozone Regulation. Furthermore, the EU Ozone Regulation[2] goes one step further by setting "end-dates" (e.g., 2040 for Cargo and Engine/APU) after which Halon should no longer be used in existing fleets, prompting retrofit requirements. Until these deadlines, the use of recycled Halons is permitted and considered critical, provided appropriate licenses are obtained and obligations related to reporting, labelling, and emissions controls are carried out.

---

[1] The criteria for an "acceptable" Halon alternative in aviation are multifaceted. As guided by decisions of the Parties to the Montreal Protocol (Decision IV/25 and subsequent), an alternative must be: Commercially available, Technically proven to meet aviation safety and performance standards (e.g. MPS), Environmentally sound (low/zero Ozone Depleting Potential (ODP) and ideally low Global Warming Potential (GWP)), Economically viable and cost-effective, safe for aircraft occupants and maintenance personnel, and easy to service and maintain within the global aviation infrastructure.

[2] Regulation (EU) 2024/590 of the European Parliament and of the Council of 7 February 2024 on substances that deplete the ozone layer, https://eur-lex.europa.eu/eli/reg/2024/590/oj/eng (link validity: 22 July 2025)

2.1.3 The European Union Aviation Safety Agency (EASA) has issued the "Halon replacement in the aviation industry guide 2025"[3]. This guide has been jointly developed by the European Commission and EASA to support the aviation industry in complying with the requirements of the EU Ozone Regulation on halon replacement. It is mainly for the attention of applicants for type certificates, to help them to determine when their proposed new design needs to comply with the Ozone Regulation. The document provides, in particular, clarifications on the interpretation of the cut-off and end dates applicability, as well as information on the derogation process.

2.2 **Challenges of Halon alternatives for cargo compartments**

2.2.1 For existing aircraft (already type-certified) in lower deck cargo compartments (LDCC), the only potential Halon replacements that have been identified, after over twenty years of industry research, is either a blend of CO2 and 2-BTP, or inert gas (such as nitrogen).

2.2.2 Technical performance challenges

2.2.2.1 A major hurdle in identifying suitable alternatives for cargo compartments is meeting the stringent requirements defined in the Minimum Performance Standard (MPS) for aircraft fire suppression systems. This standard, developed by the Halon Replacement MPS task group of the International Aircraft Systems Fire Protection Forum (IASFPF), outlines specific fire test scenarios that candidate agents and systems must successfully suppress to demonstrate a level of safety equivalent to Halon 1301. For cargo compartments, these challenging scenarios include bulk-load fires, containerized-load fires, flammable liquid fires (surface burning), and aerosol can explosion simulations. A fifth fire threat, the "Multiple Fuel Fire Challenge" including lithium-ion batteries, is also being added to the MPS, further increasing the complexity.

2.2.2.2 Many potential agents have failed the MPS tests for cargo compartments because they could not effectively extinguish or suppress the specific fire types within the required parameters, or they introduced unacceptable risks such as excessive compartment pressure increase upon discharge at concentrations below fire suppression levels. For instance, single-component vaporizing liquid agents like HFC-125, 2-BTP (2-bromo-3,3,3-trifluoropropene), and FK-5-1-12 have been shown to cause undesired pressure increases during the exploding aerosol can test, rendering them unacceptable under the current MPS requirements.

2.2.2.3 Finding agents that can match Halon's effectiveness, low weight, and minimal toxicity profile under these conditions while passing all MPS criteria has been exceptionally difficult, and no acceptable "drop-in" alternative has been identified, necessitating extensive aircraft system redesigns. In addition to passing the MPS test, all aircraft integration, safety/reliability, supply chain, and weight aspects have to be taken into account.

2.2.2.4 After approximately two decades of research and development, two candidate technical solutions have passed the MPS testing. One of them, a 2-BTP/CO2 blend, has reached TRL6[4]. The other technical solution which has passed the MPS test is a water mist / nitrogen inerting system which imposes additional system complexity and weight, explained in 2.2.3.

[3] https://www.easa.europa.eu/en/document-library/general-publications/halon-replacement-aviation-industry-guide-2025 (link validity: 22 July 2025)

[4] TRL: Technology Readiness Level. TRL 6 demonstrates that the technology is technically viable and can perform its intended functions in conditions that are highly similar to its eventual real-world application.

2.2.2.5 The MPS is intended to cover all “fires likely to occur”. Just as the aerosol can test was a necessary response to a perceived "likely to occur" fire type in the early 2000s, the inclusion of lithium-ion cells into the multi-fuel fire test is the direct consequence of their escalating presence in air cargo and the unique, severe hazards they pose.

2.2.2.6 The evolution of the MPS, spearheaded by the FAA and collaborative bodies like the IASFPF, is ongoing. It ensures that any certified Halon replacement system can genuinely address the full spectrum of "fires likely to occur" in modern cargo compartments, including the most challenging and rapidly growing threat: lithium-ion battery thermal runaway. Meeting this revised multi-fuel test, including Li-ion cells, represents the pinnacle of current cargo fire suppression development and is essential for maintaining and enhancing aviation safety.

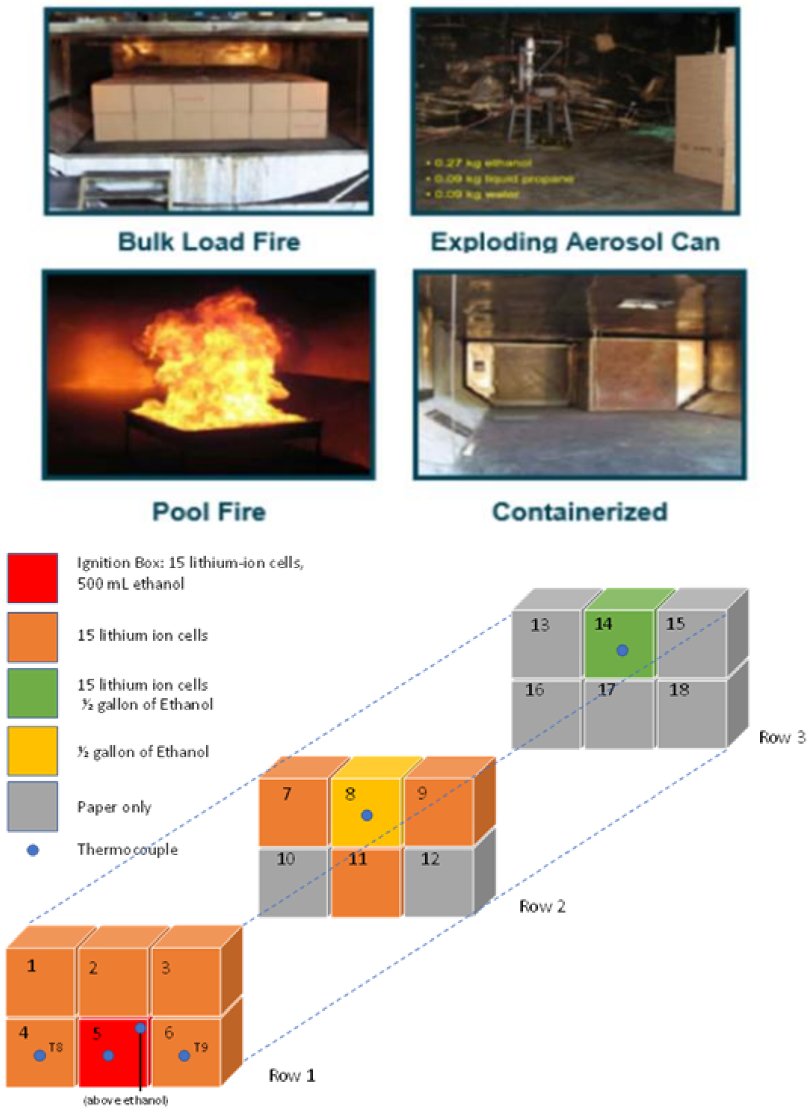

Figure 1. Fire scenarios to be suppressed by an aircraft cargo compartment fire suppression agent (minimum performance standard (MPS) test) including the most recently introduced multi fuel fire including lithium-ion cells and ethanol

2.2.3 System layout and complexity challenges

2.2.3.1 The system layouts of each alternative bring additional complexity and as such potentially increase weight and consequently fuel burn and CO2 emissions.

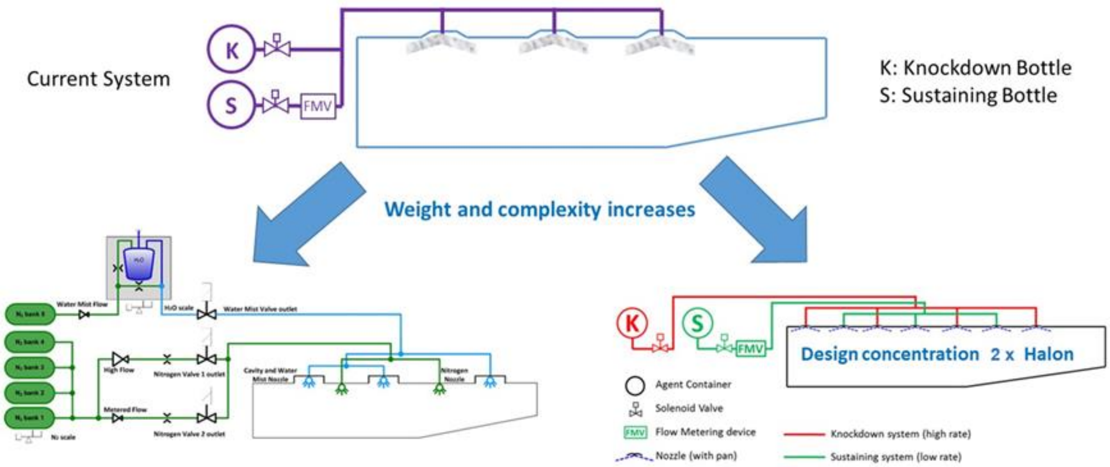

Figure 2. Current system architecture to date and technical solutions that have passed MPS testing

2.2.3.2 As illustrated at the top of Figure 2, the typical Halon 1301 system for cargo compartments utilizes a "Knockdown Bottle" (K) for initial suppression and a "Sustaining Bottle" (S) with a Flow Metering Valve (FMV) for prolonged fire control to compensate for leakages caused by the pressure differential between the aircraft pressure vessel and the ambient pressure at flight altitude. This system's inherent simplicity and low weight have made it a preferred solution for decades.

2.2.3.3 The lower right image of Figure 2 depicts the architecture of the 2-BTP/CO2 blend system. The major drawbacks are:

a) double amount of agent required to reach the same fire suppression performance compared to Halon;

b) double the number of pipes required compared to a halon 1301 system, which adds weight, volume, and complexity to the system; and

c) an overall weight increase from 100 kg for regional aircraft and up to 500 kg for long haul aircraft.

2.2.3.4 The lower left image of Figure 2 depicts the architecture of a combined water mist (for initial fire suppression)/nitrogen (for continuous compartment inerting) system. The major drawbacks are:

a) complex valve and control system;

b) 5-6 times amount of weight compared to a Halon system; and

c) additional systems like water freezing protection required.

2.2.3.5 Replacing Halon with non-ozone depleting substances increases both weight and complexity. A higher weight leads to an increase of fuel consumption and an associated increase in CO2 emissions. Higher complexity due to additional system components can lead to a decrease of system reliability.

Specific Challenges With Nitrogen Systems for Cargo Compartments

2.2.3.6 While inert gases like nitrogen are well-understood fire suppression agents, the aerospace industry has not prioritized their further development as a primary Halon alternative for cargo compartments due to several critical limitations. Although the basic materials and tools for nitrogen systems exist, expanding their use for aircraft cargo fire suppression presents significant practical challenges.

2.2.3.7 The significant weight and volume constraints of nitrogen systems would make them particularly unsuitable for smaller aircraft or regional jets, where available space and payload capacity are even more critical.

2.2.3.8 The larger equipment footprint and different operational characteristics of nitrogen systems would introduce new complexities for maintenance, servicing, and global infrastructure support.

2.2.3.9 The possibility of leveraging existing aircraft inerting systems, such as the Onboard Inert Gas Generation System (OBIGGS) used for fuel tank inerting for cargo fire suppression with nitrogen has been considered. However, this approach faces significant challenges. OBIGGS is designed to produce a continuous flow of nitrogen-enriched air to inert fuel tanks during flight. It is not typically designed to instantaneously deliver the high flow rates and concentrations of nitrogen required for rapid fire suppression in a cargo compartment. Furthermore, the operational availability and dispatch conditions of OBIGGS are primarily tied to fuel tank safety, not cargo fire suppression, introducing potential conflicts or limitations. Finally, not all aircraft, especially regional jets, are equipped with OBIGGS

2.2.4 Health and safety challenges

2.2.4.1 Due to the higher toxicity of the 2-BTP/CO2 blend compared to Halon, industry has conducted human health risk assessments to evaluate the potential health and safety implications. This assessment considered potential risks to both aircraft occupants and workers.

2.2.4.2 The primary health effect of concern from acute inhalation of 2-BTP is cardiac sensitization, with a No Observed Adverse Effect Level (NOAEL) identified at 0.49 per cent and a Lowest Observed Adverse Effect Level (LOAEL) at 1.0 per cent. For CO2, the primary health effect of concern is asphyxiation, with an Immediately Dangerous to Life and Health (IDLH) level identified at 4 per cent.

2.2.4.3 Potential exposure scenarios evaluated included aircraft occupant exposure during in-flight cargo fire events and on-ground emergency evacuations, as well as worker exposure during on-ground 2-BTP/CO2 blend discharge in or around the cargo compartment.

2.2.4.4 Exposure testing was conducted using a wide body aircraft with a lower deck cargo compartment. For aircraft occupants, testing simulated in-flight discharge with the ventilation system in cargo fire mode and on-ground discharge during a simulated emergency evacuation with ventilation shut off. Results from these tests indicated that 2-BTP and CO2 concentration levels in the passenger cabin and flight deck remained negligible and well below the identified toxicity thresholds (NOAEL for 2-BTP and IDLH for CO2) throughout the test durations. Concentrations measured outside the airplane during on-ground evacuation also remained low.

2.2.4.5 For aircraft workers, testing simulated a worst-case scenario with 2-BTP/CO2 blend bottles discharged on the ground while workers might be present in or around an open cargo compartment with aircraft ventilation shut off. Results showed that 2-BTP concentrations inside the cargo compartment and at the cargo door exceeded the 2-BTP NOAEL for approximately 2-3 minutes following discharge. Similarly, CO_2 concentrations in these areas exceeded the CO_2 IDLH for approximately 2-3 minutes. Concentrations of both agents measured outside the cargo door remained well below their respective thresholds.

2.2.4.6 The findings indicate that while there are no potential health risks to cabin occupants during a standard cargo fire system discharge (both in-flight and on-ground evacuation), there are significant health risks to workers inside the cargo compartment from concentrations of 2-BTP and CO_2 exceeding toxicity thresholds during ground discharge. This highlights the need for appropriate exposure mitigations for workers in such scenarios, which will require extensive industry coordination and design changes to ensure that the mitigations are appropriate, sufficient, and standardized across the industry to ensure personnel safety.

2.2.5 Environmental impact challenges

2.2.5.1 While the primary driver for Halon replacement is stratospheric ozone layer protection, it is crucial to consider the holistic environmental impact of alternatives. Substituting Halon eliminates its ODP and GWP impact, but candidate Halon alternatives, particularly for cargo compartments, have lower mass efficiency, requiring a greater quantity of agent and heavier system components to achieve the same level of fire suppression. This leads to an increase in aircraft weight, estimated at 100 to 400 kg per aircraft depending on type and configuration.

2.2.5.2 This increase in aircraft weight directly translates to higher fuel burn and, consequently, increased CO_2 emissions over the aircraft's operational life. Based on industry analysis for the Airbus fleet, substituting Halon with a 2-BTP/CO_2 blend would lead to increasing emissions by around 600 000 metric tons of net CO_2 equivalent every year.

2.2.5.3 This consideration underscores the potential for tradeoffs when substituting Halon with currently identified agents for cargo fire suppression applications. While the substitution may address ozone layer protection, it is crucial to recognize that such actions could inadvertently lead to negative consequences. This highlights the need for a comprehensive assessment of environmental impacts, acknowledging the dynamic interplay of ecological systems. A holistic approach is important.

2.2.6 Regulatory challenges

2.2.6.1 A previously identified risk[5] related to anticipated PFAS regulations has recently emerged as more serious. These substances are under regulatory review in several countries due to their persistence in the environment and potential health effects.

2.2.6.2 The Organisation for Economic Co-operation and Development (OECD) published a definition of PFAS in 2021[6], which is widely referenced by regulatory bodies. This definition is broad, encompassing any fluorinated substance that contains at least one fully fluorinated methyl or methylene carbon atom.

---

[5] Aircraft Halon Replacement - Working Paper the 41st ICAO Assembly, ref. A41-WP/96

[6] Reconciling Terminology of the Universe of Per- and Polyfluoroalkyl Substances: Recommendations and Practical Guidance, OECD Series on Risk Management No. 61, 09 July 2021, https://www.oecd.org/en/publications/reconciling-terminology-of-the-universe-of-per-and-polyfluoroalkyl-substances_e458e796-en.html (link validity: 22 July 2025)

2.2.6.3 The leading candidate alternative agent identified by the industry for cargo compartments is based on 2-BTP.

2.2.6.4 2-BTP is considered to fall within the scope of the OECD and dependent regulatory definitions of PFAS due to its chemical structure (containing fully fluorinated carbon atoms). Depending on the outcome of pending PFAS regulations, there is a significant risk that use of 2-BTP may be restricted.

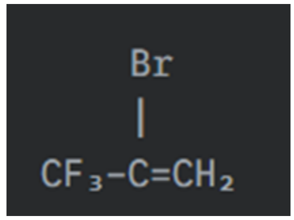

Figure 3: Chemical Structure of 2-BTP

2.2.6.5 The following table gives an overview of the globally varying definitions of 2-BTP as PFAS:

Organization/ Jurisdiction	Definition of PFAS	2-BTP Included	Reason for Inclusion/Exclusion	Official Source/Reference
OECD (2021)	"Any substance that contains at least one fully fluorinated methyl (CF_3-) or methylene (-CF_2-) carbon atom (without any H/Cl/Br/I attached to it)." This is a very broad, inclusive, and widely accepted scientific definition.	YES	2-BTP contains a -CF_3 group, which is a fully fluorinated methyl carbon atom. This directly satisfies the OECD definition.	Reconciling Terminology of the Universe of Per- and Polyfluoroalkyl Substances: Recommendations and Practical Guidance, OECD Series on Risk Management No. 61, 09 July 2021
ECHA (EU PFAS Restriction Proposal)	Aligns with the OECD 2021 definition: "Any substance that contains at least one fully fluorinated methyl (CF_3-) or methylene (-CF_2-) carbon atom (without any H/Cl/Br/I attached to it)." This proposal aims to restrict a wide range of PFAS.	YES	Similar to the OECD, the presence of the -CF_3 group in 2-BTP directly meets this definition. Regulatory bodies and industry groups confirm its inclusion under this proposal.	ECHA 2023, "Proposal for a restriction on PFAS," (See Annex XV Restriction Report for full details).
United States EPA (TSCA Reporting Rule)	PFAS means any chemical substance or mixture containing a chemical substance that structurally contains at least one of the following three sub-structures: (1) R-(CF_2)-CF(R′)R″, where both the CF_2 and CF moieties are saturated carbons. (2) R-CF_2OCF_2-R′, where R and R′ can either be F, O, or saturated carbons. (3) $CF_3C(CF_3)R'R''$, where R′ and R″ can either be F or saturated carbons.	NO	As 2-BTP contains only a single fully-fluorinated carbon, it falls outside the scope of the EPA's PFAS reporting requirements under TSCA	United States EPA, "Toxic Substances Control Act (TSCA) Reporting and Recordkeeping Requirements for Per- and Polyfluoroalkyl Substances," 40 CFR Part 705.
United Sates (e.g., Maine, Minnesota)	PFAS means a class of fluorinated organic chemicals containing at least one fully fluorinated carbon atom." Maine further clarifies "fully fluorinated to mean a carbon	YES	2-BTP contains a -CF_3 group, where the carbon atom is fully fluorinated (all attached atoms are fluorine). This directly matches the broad and	Maine Department of Environmental Protection, "Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS) Definition," (Refer to relevant state legislation, e.g.,

	atom on which all the hydrogen substituents have been replaced by fluorine. Minnesota's definition is identical.		inclusive definitions adopted by these states.	Maine's 38 M.R.S. § 1614). Minnesota Pollution Control Agency, "PFAS in Minnesota: Chemical definition and properties."
General Scientific/ Media	Often described as "forever chemicals" or "highly fluorinated compounds" that are persistent in the environment due to the strength of the carbon-fluorine bond. This is more of a descriptive term emphasizing environmental concerns rather than a strict chemical definition.	YES (concept ually)	While not a chemical structure definition, 2-BTP contains strong C-F bonds that contribute to environmental persistence, fitting the conceptual understanding of "forever chemicals." Its use as a fire suppressant further ties into the context where PFAS are discussed in media and scientific circles.	No single official source; reflects common usage in scientific literature and news reports discussing PFAS impacts.

2.3 **Maintaining aircraft safety by securing fire suppression**

2.3.1 Development and Certification Timelines for Cargo Compartment Fire Suppression Systems

2.3.1.1 Developing and certifying a new aircraft fire suppression system is a complex process, contributing significantly to the inability to meet the current Halon replacement deadline. This process involves multiple phases:

a) *Fundamental Research*: Identifying potential candidate agents and understanding their chemical and physical properties.

b) *Laboratory Testing*: Initial small-scale fire tests and toxicity assessments.

c) *MPS Testing*: Large-scale fire testing in representative aircraft environments to prove the agent's effectiveness against specific fire threats under various conditions. As highlighted in section 2.2, many agents fail at this stage, particularly for cargo compartments.

d) *System Design and Integration*: Designing the complete fire suppression system, including containers, distribution piping, nozzles, and control systems, and integrating it within the complex aircraft structure while meeting weight, volume, and safety constraints. This is particularly challenging for cargo compartments due to the high weight/volume penalty of current alternatives. This phase also includes procurement of supplied equipment, which requires time for supplier development and qualification testing.

e) *Aircraft Level Testing*: Testing the integrated system on an aircraft platform to verify performance and safety in a realistic environment.

f) *Certification by Airworthiness Authorities*: A formal and extensive process involving detailed review of all test data, design documentation, and safety assessments by regulatory bodies such as the FAA and EASA. This requires demonstrating compliance with all applicable airworthiness standards.

g) *Production and Entry into Service*: Scaling up manufacturing of the agent and system components and integrating them into aircraft production lines. As described in section 2.2.3, the higher human health risks for aircraft workers in a production or maintenance environment will require development of new and appropriate safety mitigations.

2.3.1.2 Industry experience consistently shows that the typical timeline for developing and certifying a completely new fire suppression system, from initial concept to entry into service on a new aircraft type, can take a decade or more. This is due to the iterative nature of development, the need for extensive testing under various conditions, the time required for regulatory review and approval, and the need to ensure the highest levels of safety and reliability for aviation applications. The need for design iterations due to failed MPS testing or other challenges like investigations into health and safety impacts further extend these timelines.

2.3.1.3 After its charter in 2013 to develop a timeline for Halon replacement, the ICCAIA Cargo Compartment Halon Replacement Advisory Group developed a typical development schedule for a potential cargo compartment Halon replacement, depicted in Figure 4. This schedule is still valid to date, assuming no major technical shortfalls / root cause analyses are required during the development process. The sector has reached TRL6 in 2024 after approximately 10 years of development for the 2-BTP/CO2 blend. However, multiple factors have delayed TRL7 several years beyond the projected timeline.

2.3.1.4 The current deadline of November 28, 2024, which has passed, is therefore technically unattainable for new aircraft type certifications for cargo. This directly supports the Assembly's acknowledgment that the current deadline is no longer feasible.

2.3.2 Revising the cargo compartment cutoff date:

2.3.2.1 The proposal to revise the cutoff date for new aircraft type certifications for cargo compartments is supported by the industry commitment to achieving a sustainable solution. The original 2024 target, established in 2016, was based on the then-available technical understanding and progress in identifying candidate agents. Within that context, the industry made significant strides towards developing suitable alternatives, demonstrating the feasibility of the initial eight-year timeframe for technical development. However, due to the significant challenges described in this paper, and the passing of the existing cutoff date, a revised cutoff date for Halon replacement in cargo compartment fire suppression systems needs to be established, taking account of all relevant data.

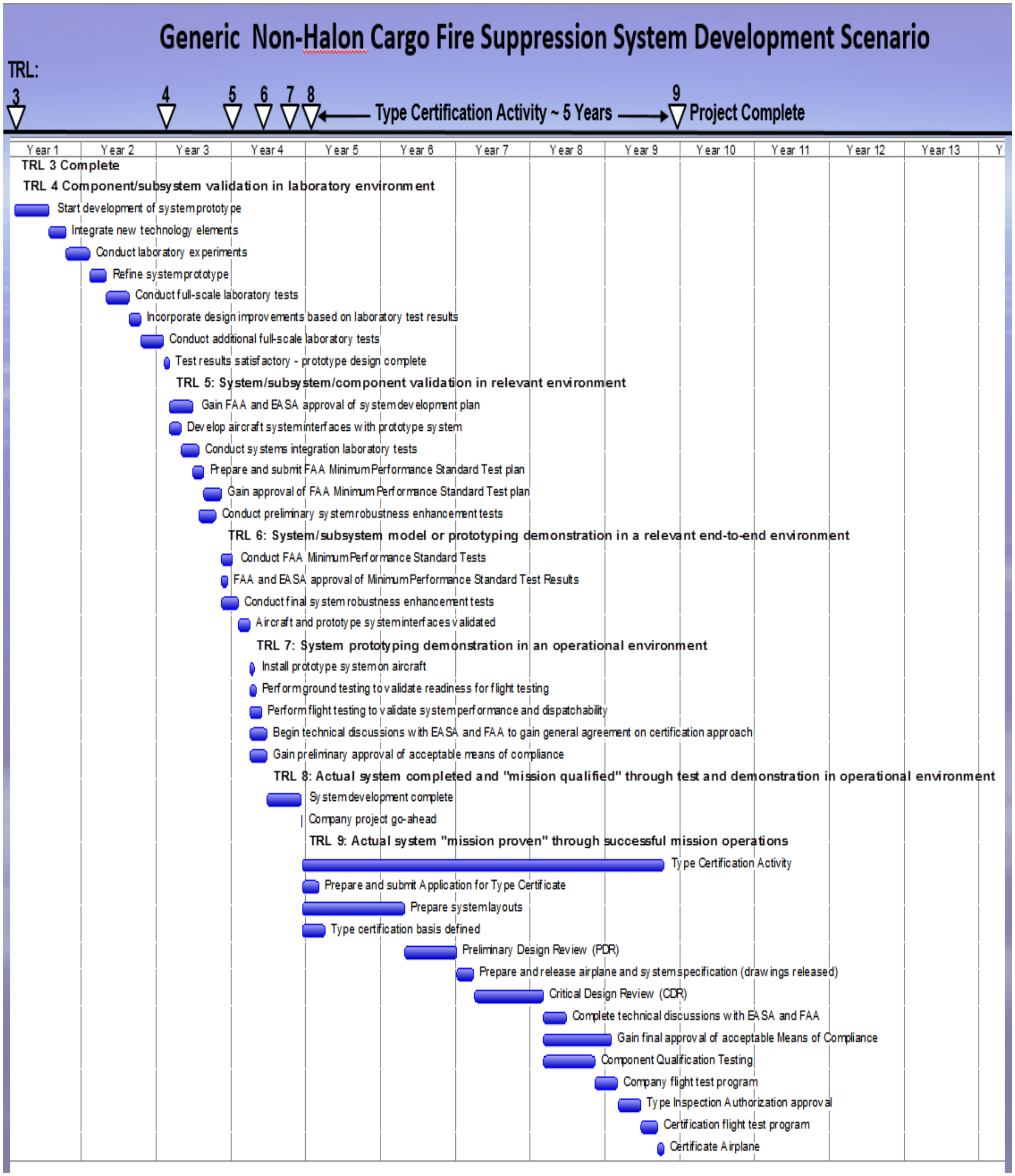

Figure 4. Typical development lifecycle timeline for a cargo compartment fire suppression agent

2.3.3 Securing Halon supply through essential use nomination

2.3.3.1 Global reserves of recycled Halon are finite. The United Nations Environmental Programme Technology and Economic Assessment Panel Fire Suppression Technical Options Committee (UNEP TEAP FSTOC) 2022 Assessment Report[7] provides projections on the availability of Halon reserves. The report indicates that the quantity and quality of Halon available to meet the demand for critical applications like aviation cargo compartments may become insufficient potentially starting around 2030. The report will be updated in 2026, and its data should be used for a thorough evaluation of a potential Essential Use Nomination (EUN) under the Montreal Protocol to ensure a sufficient global supply of Halon.

2.3.3.2 The Montreal Protocol includes provisions for EUNs, which allow Parties (countries) to request exemptions from the phase-out of ODS production and consumption for uses deemed essential.

2.3.3.3 A use qualifies as essential if:

a) it is necessary for health, safety, or critical for the functioning of society (including cultural and intellectual aspects); and

b) there are no available technically and economically feasible alternatives or substitutes that are acceptable from an environmental and health standpoint.

2.3.3.4 Production and consumption for essential uses are permitted only if:

a) all economically feasible steps have been taken to minimize the essential use and associated emissions; and

b) the controlled substance is not available in sufficient quantity and quality from existing banked or recycled stocks, considering developing countries' needs.

2.3.3.5 The industry is committed to researching the need for an EUN based on these requirements to determine if an EUN is warranted and with what scope. The process to be followed is laid out in the Montreal protocol Handbook on essential use nomination[8].

2.3.3.6 The short and mid-term actions to assess the need and scope for an EUN and the associated allowance for production and consumption can be achieved by following the process depicted in Figure 5.

---

[7] UNEP Report Of The Fire Suppression Technical Options Committee, 2022 Assessment Report https://ozone.unep.org/system/files/documents/FSTOC-2022-Assessment.pdf (link validity 22 July 2025)
[8] Handbook on essential use nominations, https://digitallibrary.un.org/record/450087?v=pdf (link validity 22 July 2025)

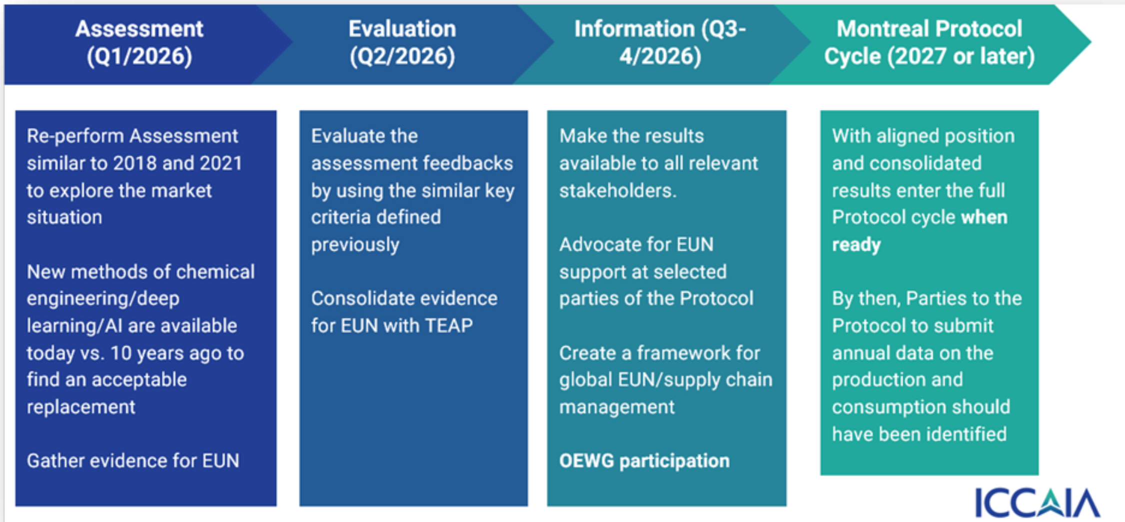

Figure 5. Major process steps to be followed to achieve an Essential Use Nomination under the Montreal Protocol

2.3.4 2025 Open-ended Working Group of the Parties to the Montreal Protocol on Substances That Deplete the Ozone Layer

2.3.4.1 During the forty-seventh meeting of the open-ended working group (OEWG), on 9 July 2025, during the Presentations by the Technology and Economic Assessment Panel on its 2025 progress report[9] the topic addressed in the ICAO Working Paper was already addressed, submitted by Australia, Canada, the European Union, New Zealand, Norway, Switzerland, the United Kingdom of Great Britain and Northern Ireland, and the United States of America.

2.3.4.2 It was agreed at the OEWG that the Thirty Seventh Meeting of the Parties (MOP) will decide:

a) To request that the Ozone Secretariat liaise with the secretariat of the International Civil Aviation Organization on the matter of fire suppression agents controlled under the Montreal Protocol on Substances that Deplete the Ozone Layer and facilitate the exchange of information between the Technology and Economic Assessment Panel, through its Fire Suppression Technical Options Committee and the relevant International Civil Aviation Organization technical committees and working groups to allow the Panel to:

   1) Better assess the future use of and needs for halons in civil aviation, making use of, inter alia, available data on the locations and quantities of halon used by the maintenance, repair and overhaul operations authorized to service halons, data on future fleet evolution and estimates on aircraft in operation with different types of halon fire protection systems;

---

[9] REPORT OF THE TECHNOLOGY AND ECONOMIC ASSESSMENT PANEL MAY 2025 https://ozone.unep.org/system/files/documents/TEAP-May2025-Progress-Report-vol1.pdf (link validity: 22 July 2025)

2) Submit a report on halon availability and the global distribution of halon banks, based on the above-mentioned activities, to the parties in advance of the forty-eighth meeting of the Open-ended Working Group of the Parties to the Montreal Protocol;

b) To encourage parties, to liaise, through their national ozone officers, with their national civil aviation authorities to gain an understanding of how halons and their alternatives are being used and supplied to air carriers to meet ongoing civil aviation needs;

c) To encourage all parties to reassess any national import and export restrictions other than licensing requirements with a view to facilitating the import and export of recovered, recycled, or reclaimed halons and other controlled substances used for fire suppression, with the aim of enabling all parties to meet their remaining needs, taking into account the requirements of the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal, where applicable;

d) To request parties to submit to the Ozone Secretariat, by 31 March 2026, information regarding the development of alternatives suitable for use as substitutes for in fire suppression, and to request the Secretariat to forward the information received to the Technology and Economic Assessment Panel for its consideration and for inclusion in its 2027 progress report.

2.3.4.3 The text of the decision is included in Appendix A of this paper.

2.4 Halon Alternatives for other aircraft applications (engine/APU, lavatory, and cabin hand-held)

2.4.1 While the primary focus of this paper is on the significant challenges in cargo compartment Halon replacement, it is important to acknowledge the status and hurdles in other aircraft fire suppression zones.

2.4.2 For engine/auxiliary power unit (APU) fire suppression, candidates like sodium bicarbonate [NaHCO3] Solid Aerosol and CF3I liquid/gas are being explored and are at lower technology readiness level (TRL) on sector level. The challenges here include demonstrating effectiveness against the specific fire dynamics within engine nacelles and APU compartments, often involving high airflows and complex geometries. While some agents have been successfully tested to the MPS for these applications, including CF3I, demonstrating effectiveness against live-engine fires under realistic operating conditions has proven difficult for some candidates. Additionally, some potential agents like CF3I have faced challenges related to potential ODS and CMR (Carcinogenic, Mutagenic, Reprotoxic) concerns. These have been addressed, and current assessments suggest that alternatives for Engine and APU applications are expected to offer global environmental benefits and therefore are anticipated to be implemented in time to comply with the EU regulatory timeframe.

2.4.3 For lavatory waste compartment extinguishers, HFC-236fa (FE-36) and HFC-227ea (FM-200) are used in-service. For cabin handheld extinguishers, 2-BTP is used in-service. These agents have been demonstrated to be safe for use in occupied spaces and effective against a range of fire types (Class A, B, and electrical fires). However, HFC-236fa, HFC-227ea and 2-BTP face significant regulatory risks, derived from their potential identification as PFAS. While already implemented, the high

GWP of HFCs and potential PFAS identification of both HFCs and 2-BTP could classify these in retrospect as regrettable substitutions from a regulatory standpoint. For cabin/cockpit handhelds, no other acceptable substitute is currently identified with a low likelihood to find an acceptable alternative in the mid-term, and the only solution foreseen today to avoid PFAS for this use would be reversion to Halon 1211. For lavatory built-in extinguishers, no other acceptable replacement has been identified so far and industry is engaging to research and evaluate potential new alternatives for this application.

2.5 **Outlook: methodology for basic research**

2.5.1 New methodologies for basic research, which use computer programs for chemical engineering and genetic algorithms to discover new molecules, have recently become available and open up opportunities which were not available even 5 years ago.

2.5.2 The new methodologies and tools and their suitability and efficacy to accelerate the identification of Halon replacement agents will be discussed and evaluated in industry groups like the CCHRAG and the IASFPF.

2.5.3 Considering that no other Halon alternative for a cargo fixed fire suppression system has been identified to date, some OEMs have started internal feasibility studies on this new approach.

3. CONCLUSIONS

3.1 Despite intensive research and development efforts spanning many years, finding a universally acceptable Halon alternative has proven exceptionally challenging across various aircraft zones, particularly for cargo compartments. As current cargo compartment alternatives face challenges in terms of acceptability, this paper provides comprehensive justification for the specific actions proposed to the Assembly in A42-WP/74 with a specific focus on:

a) the requirements of the Minimum Performance Standards (MPS) for cargo compartment Halon replacement and the resulting challenges in alternative agent development and certification;

b) the impact of anticipated legislation on PFAS (per- and poly-fluoroalkyl substances) on the leading candidate Halon alternative;

c) the environmental footprint implications of current alternatives, which poses conflicts between ozone layer protection and climate change due to increased aircraft weight and CO2 emissions;

d) safety risks, including findings from a health risk assessment of the leading candidate Halon alternative; and

e) the development and certification processes and timelines for new fire suppression systems.

— — — — — — — —

APPENDIX A

UNEP/OZL.PRO.WG.1/47/CRP.6

Open-ended Working Group of the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer

Forty-seventh meeting

Bangkok, 7–11 July 2025

Agenda item 4 (d)

Presentations by the Technology and Economic AssessmentPanel on its 2025 progress report and discussions on: any other issues

United Nations Environment Programme

9 July 2025

Halon 1301 and its continuing use in the aviation industry, and management of other controlled substances used for fire suppression

Submitted by Australia, Canada, the European Union, New Zealand, Norway, Switzerland, the United Kingdom of Great Britain and Northern Ireland, and the United States of America

The Thirty Seventh Meeting of the Parties

Taking note of the 2025 progress report of the Technology and Economic Assessment Panel and its update on the potential long-term use of halon 1301 in the aviation sector;

Noting that some controlled substances, including halons and HCFC-123, continue to have a meaningful role in fire suppression,

Noting with concern that the long-term supply of halon 1301 is uncertain given its continuing use in key sectors, difficulties in transboundary shipment of recovered, recycled or reclaimed halon 1301, its deliberate destruction for carbon credits and some users of halon 2402 switching to halon 1301,

Noting that the International Civil Aviation Organization may consider changes to the mandatory 2024 date by which an application for a type certificate submitted to the State of design shall not use extinguishing agents listed in the Montreal Protocol on Substances that Deplete the Ozone Layer,

Noting also that considerable work has been carried out on evaluating alternatives to halon 1301 in cargo compartments for new aircraft designs, and that at least one alternative candidate might soon be available,

Recalling the ongoing communication between the International Civil Aviation Organization and the Fire Suppression Technical Options Committee of the Technology and Economic Assessment Panel, Recalling also the long-standing decisions XXX/7, XXIX/8, XXVI/7, XXII/11 and XXI/7, and most recently, decision XXXVI/7 on measures to support the sustainable management of recovered, recycled or reclaimed halons,

Decides:

1. To request that the Ozone Secretariat liaise with the secretariat of the International Civil Aviation Organization on the matter of fire suppression agents controlled under the Montreal Protocol on Substances that Deplete the Ozone Layer and facilitate the exchange of information between the Technology and Economic Assessment Panel, through its Fire Suppression Technical Options Committee and the relevant International Civil Aviation Organization technical committees and working groups to allow the Panel to:

(a) Better assess the future use of and needs for halons in civil aviation, making use of, inter alia, available data on the locations of the maintenance, repair and overhaul operations authorized to service halons, data on future fleet evolution and estimates on aircraft in operation with different types of halon fire protection systems;

(b) Submit a report on halon availability and the global distribution of halon banks, based on the above-mentioned activities, to the parties in advance of the forty-eighth meeting of the Open-ended Working Group of the Parties to the Montreal Protocol;

2. To encourage parties, to liaise, through their national ozone officers, with their national civil aviation authorities to gain an understanding of how halons and their alternatives are being used and supplied to air carriers to meet ongoing civil aviation needs;

3. To encourage all parties to reassess any national import and export restrictions other than licensing requirements with a view to facilitating the import and export of recovered, recycled, or reclaimed halons and other controlled substances used for fire suppression, with the aim of enabling all parties to meet their remaining needs, taking into account the requirements of the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal, where applicable;

4. To request parties to submit to the Ozone Secretariat, by 31 March 2026, information regarding the development of alternatives suitable for use as substitutes for in fire suppression, and to request the Secretariat to forward the information received to the Technology and Economic Assessment Panel for its consideration and for inclusion in its 2027 progress report

— END —