DANGEROUS GOODS PANEL (DGP)
MEETING OF THE WORKING GROUP OF THE WHOLE

TWENTY-FIFTH MEETING

Delhi, India, 21 to 25 April 2025

Agenda Item 4: Managing safety risks posed by the carriage of energy storage devices by air *(Ref: Job Card DGP.003.05)*

UPDATE ON RESEARCH RELATED TO LITHIUM BATTERIES CONDUCTED BY THE EUROPEAN UNION AVIATION SAFETY AGENCY

(Presented by L. Calleja Barcena)

SUMMARY

The European Union Aviation Safety Agency (EASA) has been working on research related to lithium batteries in the last few years. The presentation provided in the appendix contains the most relevant information and updates of this work.

Fraunhofer EMI

Fraunhofer IBP

AIRBUS

LOKI-PED

ICAO Dangerous Goods Panel 2025, Delhi, India

Lia Calleja-Barcena, Simon Holz, Victor Norrefeldt

Lithium batteries in pOrtable electronic devices – risk of fIre and smoke

www.loki-ped.de

LOKI-PED: Lithium Batteries Fire/Smoke Risks in Cabin

Overview

Sponsor: European Union Aviation Safety Agency EASA

Partners

- Fraunhofer Institute for Highspeed Dynamics, Ernst-Mach-Institute, EMI
- Fraunhofer Institute for Building Physics, IBP
- Airbus Operations GmbH & Airbus SAS

including 20 experts, researchers and technicians.

Focus

- Cabin and cockpit
- Not cargo nor checked luggage

Tasks

- Characterization of the main hazards posed by PEDs
- Consequences of fire and smoke in cockpit and cabin
- Risk assessment regarding number and energy content of PEDs
- Assessment of emergency procedures
- Assessment of additional mitigation measures
- Identification of gaps in the regulatory provisions

Duration: 01/2023 – 01/2026

Happened since last meeting

Test of CO_2-spread from PED emulator in Flight Test Facility aircraft cabin mock-up

- 3D simulation model validation
- Spread radius deduction

Smoke and noxious gases correlation to CO_2-Emission

- Measurement of composition of the combustion gas
- Visibility reduction due to smoke

→ Assessment of potential exposure to smoke and contaminants

Mitigation means

- Fire tests of containment bags and fire extinguishers
- Handling tests by crew members

→ Sharing of experiences with bags

Correlation of noxious gases to CO_2 emission

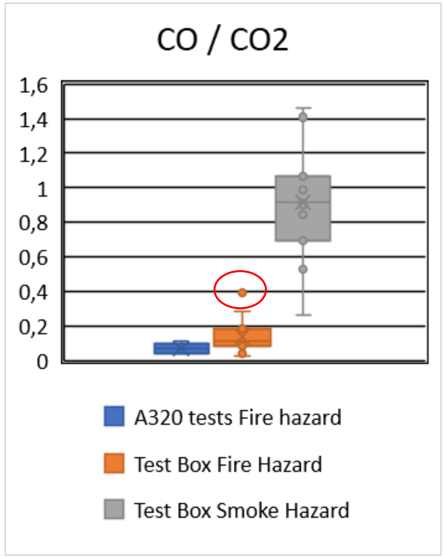
1. Deduction of peak CO_2 concentration vs. other peak concentration of other measured substances in
   - A320 mock-up for fire hazard
   - Test box for fire hazard
   - Test box for smoke hazard

$$f_i = \frac{c_{i,peak}}{c_{CO2,peak}}$$

2. Derivation of 10-min AEGL-2 (acute exposure guideline levels)
   - Serious or long lasting health effects or impairment to escape
   - Example: 10-min AEGL-2 for CO is 420 ppm

3. Derivation of critical associated CO2-level

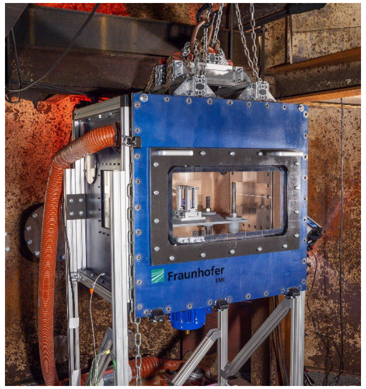
$$c_{CO2,crit} = \frac{c_{10minAEGL-2}}{f_i} = \frac{420ppm}{0.39} = 1078ppm$$



Worst case example: for 10l CO_2 produced in combustion, up to 3,9l of CO is produced

Note: During smoke event much lower volume of CO_2 is emitted and therefore less CO is emitted even though relative fraction is higher.

Test Box



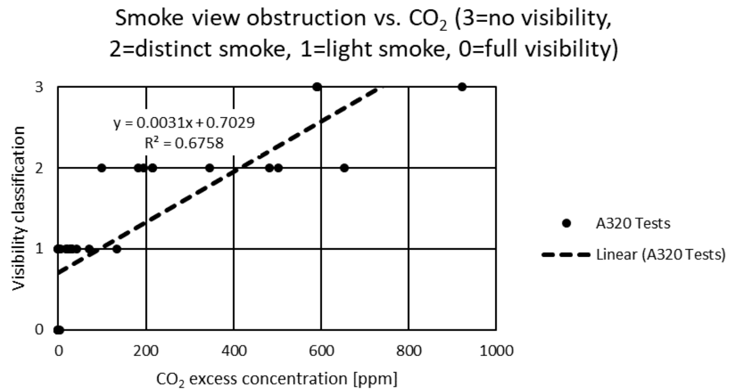
A320 mockup

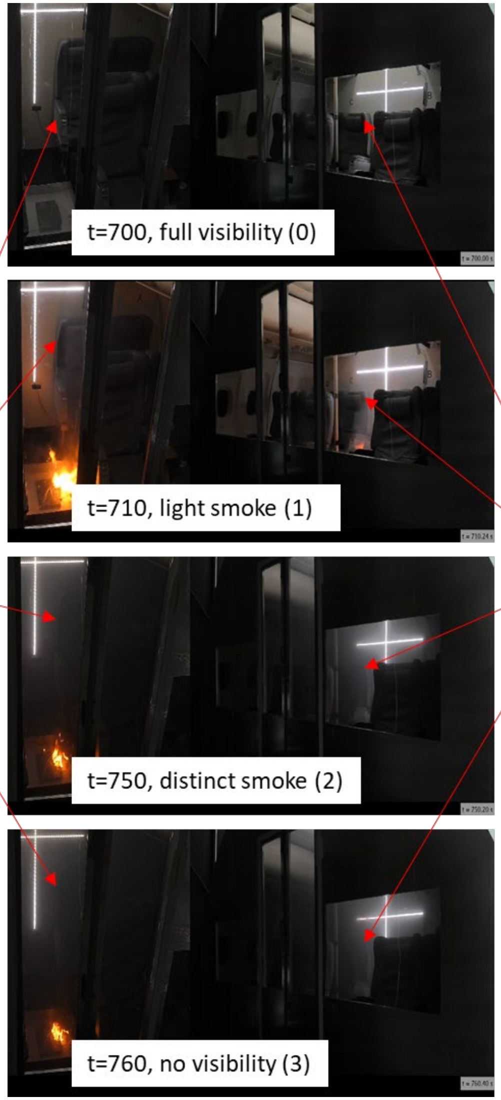
LOKI-PED

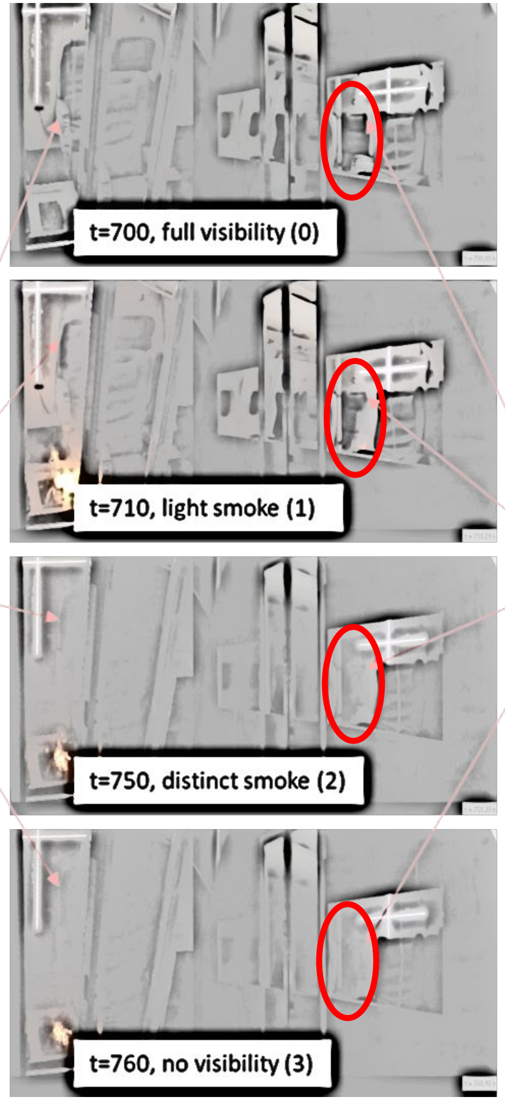
Fraunhofer

Correlation of smoke to CO_2 emission

1. Surveilling of videos from A320 mock-up burn tests
   - Visibility of rear row backrest as criterion for smoke density
   - 0: full visibility
   - 1: light smoke visible
   - 2: impaired visibility due to smoke
   - 3: no visibility
2. For each of the levels: read out CO2-concentration in exhaust gas measurement
3. Plot data visibility vs. CO2 concentration
4. Draw correlation line





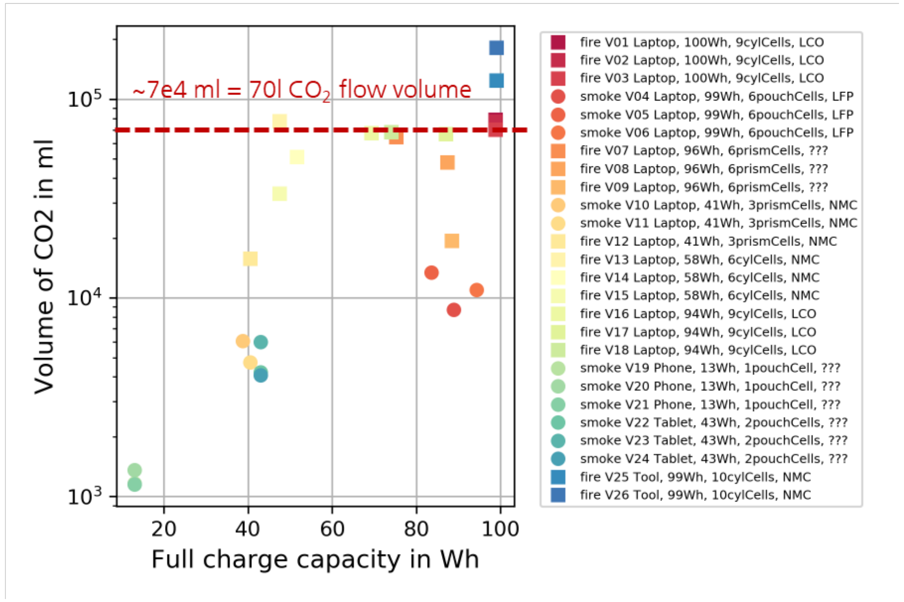


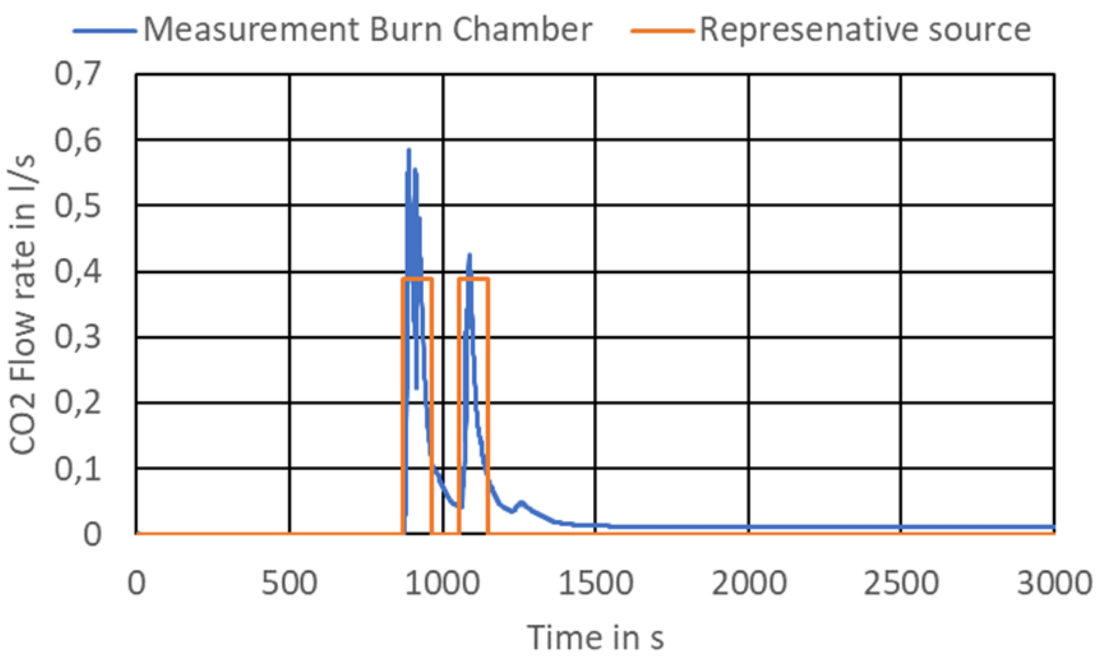
Derivation of characteristic CO_2-emission from PED fire

CO_2 emission results from burn chamber tests
- Selection made to consider laptop fire
- Approx. 70l CO_2 emission for a PED thermal runaway

Typical CO_2-Emission profile during two consecutive ignitions
Deduction of representative CO_2-source for simulations

CO2 volume from battery and combustion





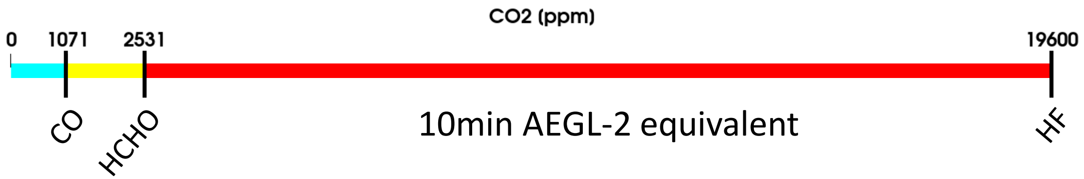
S7_A - 4F newspaper holder - Cabin fresh air

Simulation of CO_2 spread in cabin

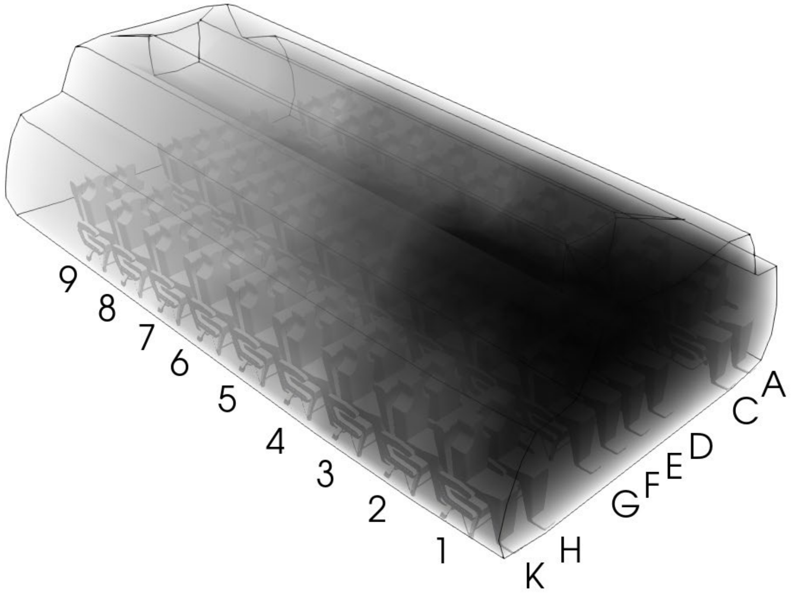
- CO_2 injection according to characteristic profile
- Assessment of peak concentration vs. hazardous substances concentration limit
- Assessment of transient decline vs. hazardous substance time limit
- Deduction of smoke density

Result

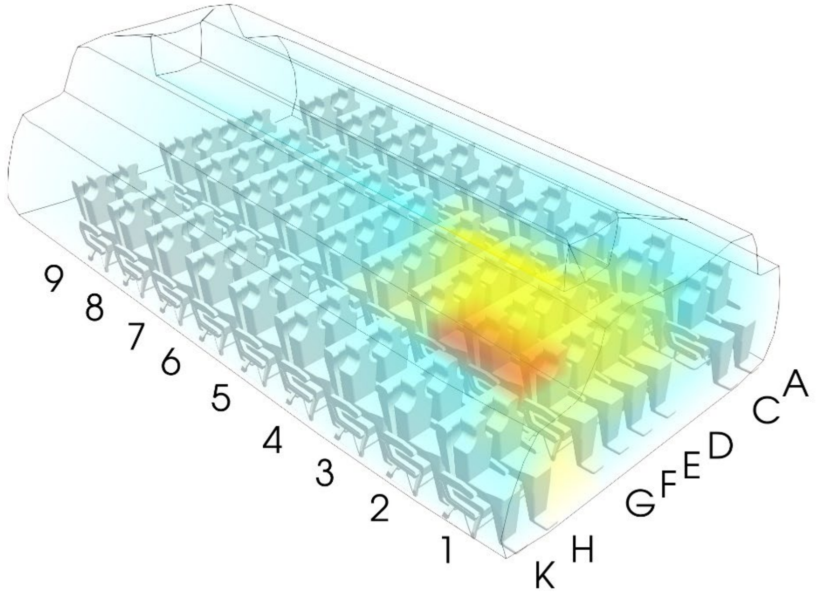
- Short-term excess of 10min AEGL-2 for HCHO in emission zone
- Short-term excess of 10min AEGL for CO in approx. ±2 seats from emission
- No reaching of 10min AEGL2 for HF and other substances assessed (HCl, Acetaldehyde, Methanol)



Peak smoke spread



Peak concentration in the emission zone



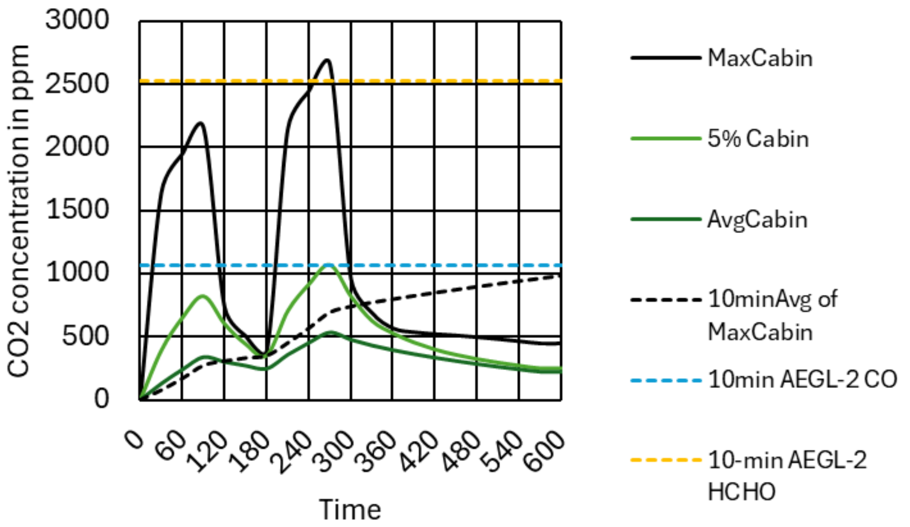
Transient concentration evolution

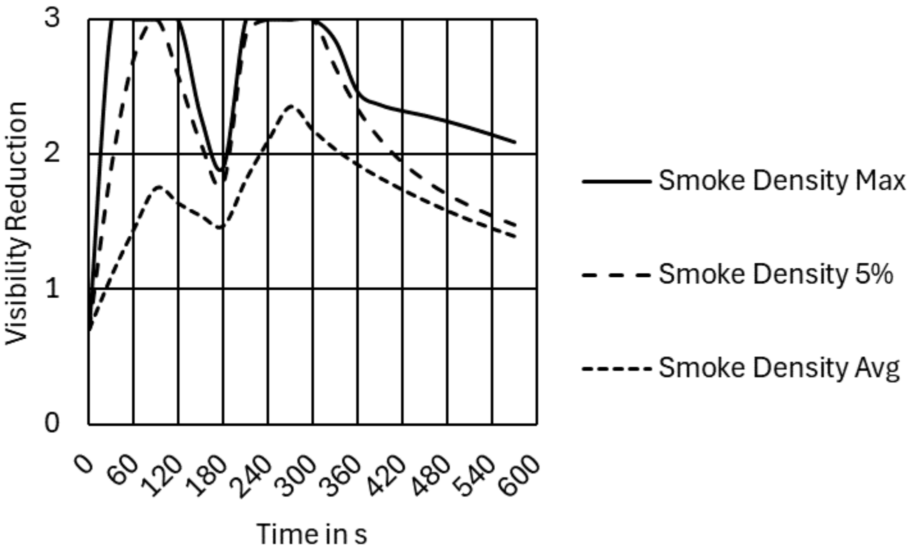
Evaluations
- Maximum concentration in entire cabin
- 5% highest concentrations in entire cabin
- Average concentration in cabin

Results for Exposure
- Maximum concentration has short-term exceedance of 10min AEGL-2 for CO and HCHO, but 10min average remains below
- Only 5% of cabin volume temporarily exceeds 10min AEGL-2 for CO, i.e. 95% remain below

Results for smoke
- First incident:
  - 5% of cabin have short-term no visibility (approx. 1 minute)
  - Average cabin sees between light and distinct smoke
- Second incident:
  - Average cabin sees distinct smoke that clears within approx. 1-3 minutes

→ Action should be taken to prevent thermal runaway propagation





Additional Mitigation Means

Identified PED fire mitigation means

- Baseline procedure (similar to FAA video)
- Dedicated fire extinguishers
- Containment bags

Test of extinguishers and bags for effectiveness

- Extinction after provoking thermal runaway
- Storage in bag when runaway is provoked

Test of bags for handling

- Invitation of crews in the Flight Test Facility
- Observation of baseline procedure and bag handling during an emulated PED fire or smoke (emission of theatre smoke)
- Post-test crew interview

PortableElectronicDeviceFireTrainingFlightDeck : FAA Fire Safety

Cool down capability of extinguishers
Summary

Tested extinguishers

- Manufacturers from Europe and US
- 3 of 3 especially for lithium battery fires
- 3 of 3 do not contain halon
- 3 of 3 commercially available
- 2 of 3 in service on aircraft

Test conditions

- Laptop with 9 cylindrical cells (100 Wh)
- One cell heated to enforce thermal runaway
- Ext. in operation when flames are observed until it is empty
- Ext are empty after 15s to 45s

Findings

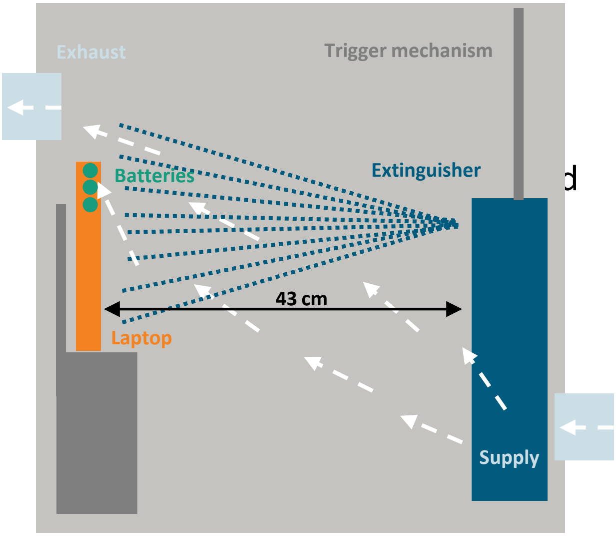
- 1 of 3 supressed thermal propagation
- 3 of 3 suppressed flames during operation

Cooling

Battery Test Center

Temporal characteristics

- Duration of operation varies
- Multiple events possible
- 2 to 5min from first to next



Containment capability of bags

Preliminary summary

Tested bags

- Manufactures from Europe and US
- 2 of 8 bags in early design stage
- 6 of 8 commercially available
- 3 of 8 in service on aircraft

Test conditions

- Laptop with 9 cylindrical cells (100 Wh) packed in bag
- One cell heated to enforce thermal runaway
- Adopted from UL 5800 standard

Hazards observed

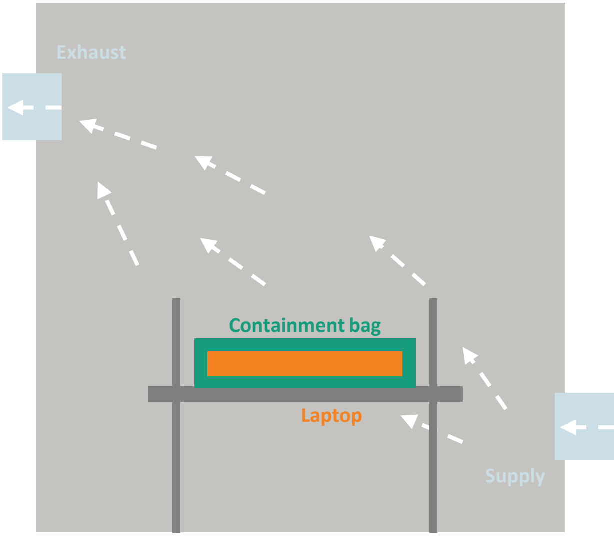
- Thermal propagation from cell to cell: 8 of 8
- Venting of smoke: 8 of 8
- Venting of hot particles: 8 of 8
- Venting of flames: 5 of 8
- Opening of bag closure: 2 of 8
- Destruction of bag: 2 of 8

Temporal characteristics

- Duration highly variable
- Multiple events possible
- 1h from first to last event observed

Containment

Battery Test Center



Crew test conduct

Investigation of

- Baseline procedure
- Pure storage bags
- Kits with extinguishing means and bag
- Bags involving water
- Bags with additional smoke bag around containment bag (not part of fire testing effort)

Crew was allowed to use PBE at own choice

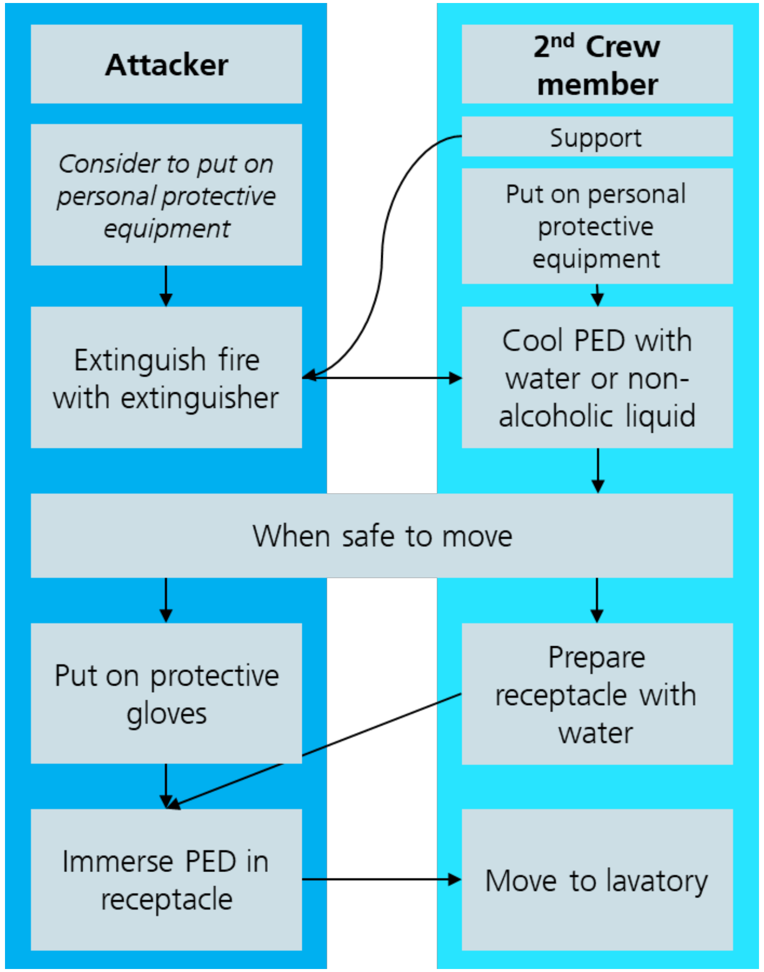
Presented scenario

- Smoke + fire for suppression means and storage tests
- Only short smoke emission for pure storage bag tests

Test statistics

- 11 bags, each 3-4 times in use
- 9 airlines participated with 1-3 crew members
- 5 consecutive days of test

Baseline procedure



Crew feedback on baseline procedure

Crew feedback ☹
- Tradeoff between quick action and self-protection difficult
- Involves many steps, extensive training required
- Bottle cooling
  - Small bottles impractical, opening bottles challenging with gloves
  - Obstruction of the aisle by bottles
  - Long action close to PED required
- Receptacle
  - Obstruction of the aisle
  - Difficult to judge when PED can be moved
- Coordination (hearing) difficult due to cabin noise and PBE (if used)
- Equipment in test was stored close to the fire → should be in safe space

Crew feedback ☺
- Attacker can immediately react and guarantees quick fire extinction
- Opening bottles was possible with gloves
- Once trained easy to coordinate

Recommendations for improvement
- Uncertainty on PBE use
  - Information wished on potential crew exposure
  - Information wished on the threat of smoke/fire during delay time posed by PBE preparation
- Procedure modification
  - Clearly state that unprotected PED extinction must be minimized to the acute fire fighting. Attacker shall asap. leave afterwards
  - Provide clearer definition of roles, evtl. with pictograms
  - Ensure PED remains attended during whole procedure
  - Provide information on the effect of water on cabin / galley / cockpit floor and health concerns (crew is reluctant to pour water)
- Receptacle
  - Provide examples of suited receptacles depending on PED size
  - Extend procedure with specification that water is poured onto PED in receptacle (ensures better immersion and avoids floating)
  - Some airlines carry dedicated plastic boxes
- Some airlines carry dedicated (larger) water bottles

Crew feedback on bags

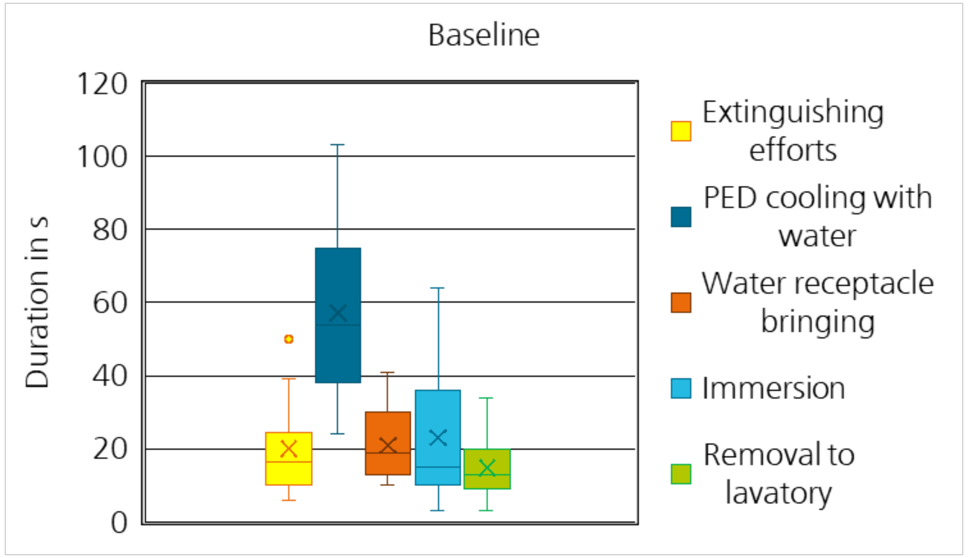
Bag recommendations

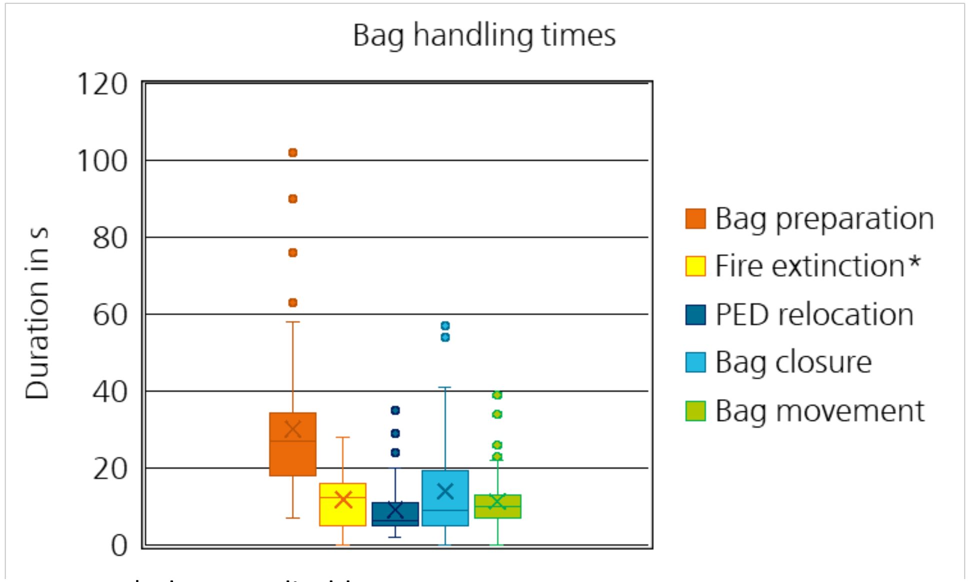
- Bag packaging should easily open
- Bags should be ready to use (no additional mounting)
- Bags should be intuitive and e.g. not require 90° rotation from packaging to opening
- When opened, bag should not close by itself but remain open
- Bags should be large enough to host typical PEDs; analogous for smoke containment bags
- PEDs should fit both ways (long and short side)
- Zippers
  - Should have handle to ease operation with gloves
  - Should not block
- Bucklets more difficult than zipper
- Unalignment of Velcro closure should not occur (make Velcro strips wide enough to align)
- Bag openings should be indicated by visual element
- PED should be secured in bag to not fall out during handling
- Handle on bag for transport preferable

Recommendations for procedures

- **Two-person operation of bags usually required** → consider having two pairs of gloves with the bag instead of one
- Available space in cabin aisle should be considered
- Good and visual documentation of bag procedure should be available including
  - When shall bag be used
  - How shall it be used
  - What to do when PED is in bag
- Bag should not add workload in pre-flight check; each component's state should be visible

Estimated duration of operation steps





*where applicable

PBE usage interview

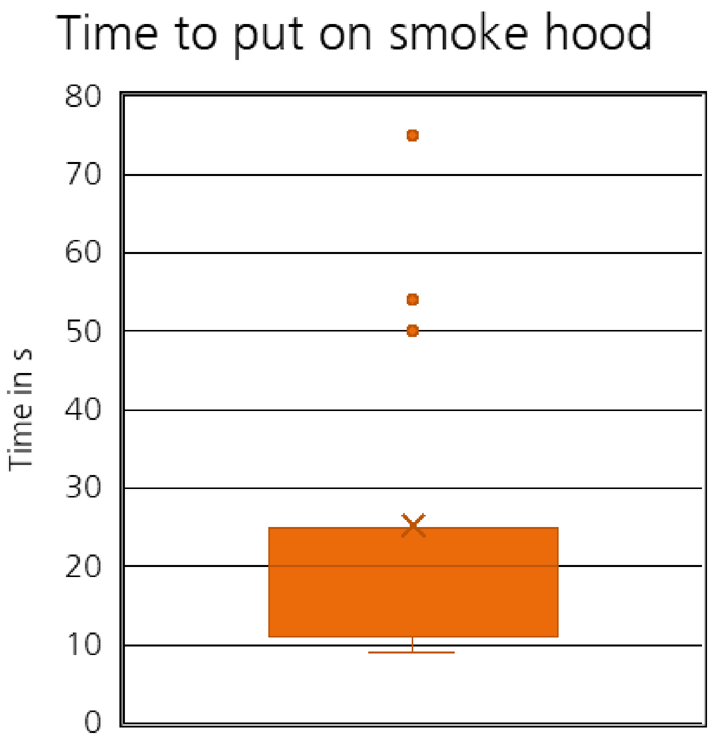
Reasons for crew to wear PBE

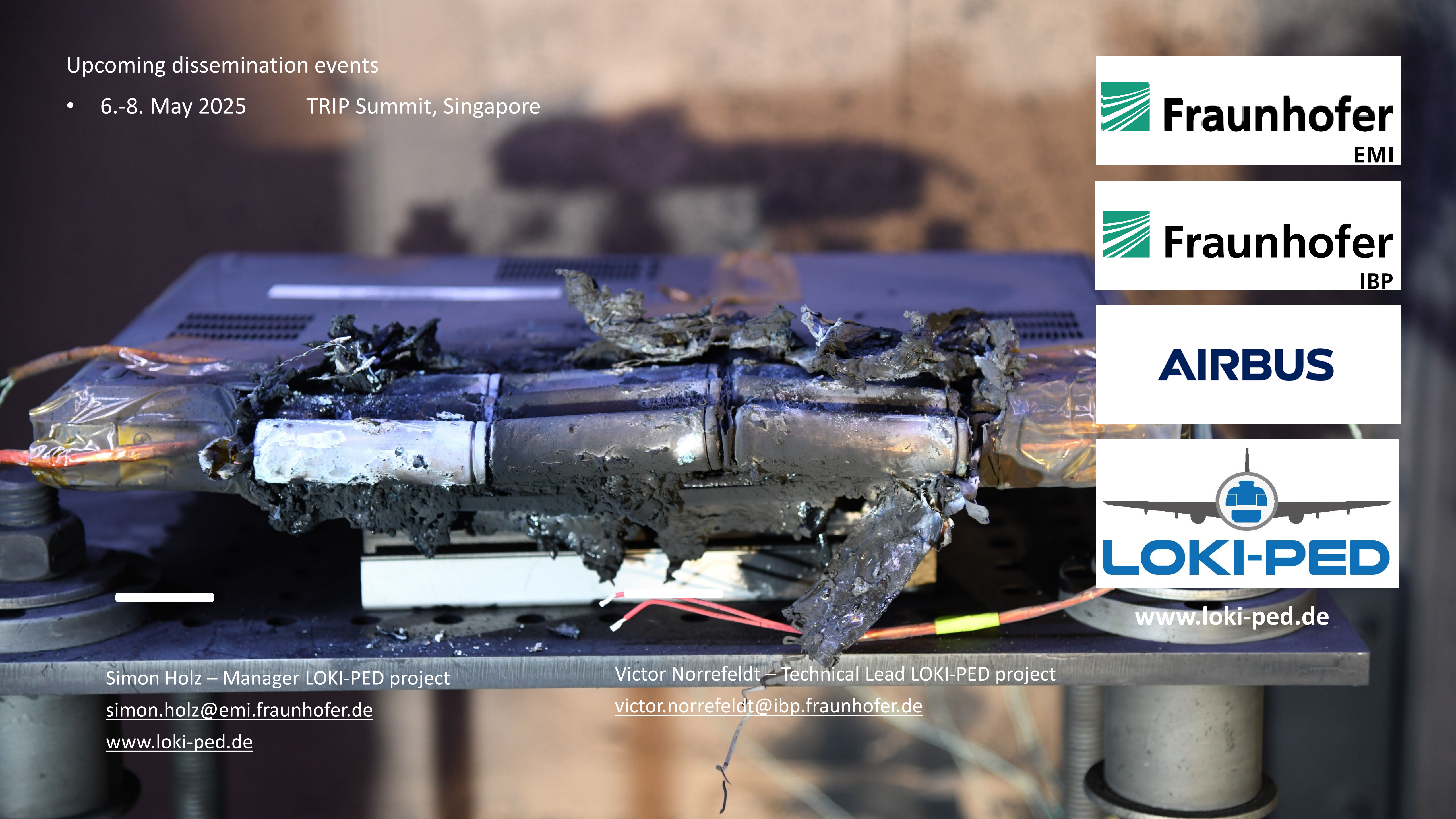
- Crew is trained to use as soon as smoke is visible
- Impaired sight, large amount of smoke
- When hard to breathe
- Smell event
- Feeling of need to protect oneself

Reasons for crew to take off PBE

- Individual judgement
  - When hard to breathe or uncomfortable
  - When operation is done, and crew returns to galley
  - When out of area and crew returns to galley
  - Smoke is gone and situation cleared
  - If communication requires
- Objective
  - After time taking (1 airline only mentioned this)
  - Red flash indication on some smoke hoods

Time was taken when crew used smoke hood





Upcoming dissemination events

- 6.-8. May 2025 TRIP Summit, Singapore

www.loki-ped.de

Simon Holz – Manager LOKI-PED project
simon.holz@emi.fraunhofer.de
www.loki-ped.de

Victor Norrefeldt – Technical Lead LOKI-PED project
victor.norrefeldt@ibp.fraunhofer.de

EASA update on AIRPED research project

Enzo Canari
Cabin Safety Expert
21 April 2025

Your safety is our mission.

An Agency of the European Union

EASA research

AirPED

Research project EASA.2020.HVP.12
based on the Horizon 2020 Work Programme Societal Challenge 4
'Smart, green and integrated transport'

- Lithium battery fires in cargo compartments:
  - PEDs in checked baggage
  - Bulk shipment of lithium batteries
- Budget: 600.000 €
- Project started in September 2021
- Report to be published in Q2 2025

vito

AIRBUS

DLR Deutsches Zentrum für Luft- und Raumfahrt
German Aerospace Center

AirPED

Objectives

- To evaluate the effectiveness of cargo fire suppression systems (Halon-based and Halon-free) in case of thermal runaway events originating from battery-powered devices in checked baggage
- To generate data to support the revision of the MPS for Aircraft Cargo Compartment Halon Replacement Fire Suppression Systems : validation of the definition of a new cargo fire test scenario involving lithium batteries
- To perform additional tests with the same setup as Task 4 of the Sabatair project (external fire scenario, with FCCs protecting the batteries/cells)

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TASK 1 – EVALUATE THE BASELINE PERFORMANCES OF THE SELECTED FIRE TEST CHAMBER FOR MPS TESTS

- The test chamber should meet the definition given in DOT/FAA/TC-TN12/11 (Minimum Performance Standard for Aircraft Cargo Compartment Halon Replacement Fire Suppression Systems (May 2012 Update)), considering the changes currently under development by the IASFPF Cargo MPS Task Group.
- Compliance in volume and shape, materials and, as one of the most important performance influencing parameters, the leakage and the way it is imposed.
- Perform full-scale fire tests to prove the performance of the chamber.
- Introduce any design change necessary to ensure that the test chamber is suitable to perform testing as per the MPS.

AirPED

TASK 2 – DEVELOP THE TEST PLAN AND PROTOCOLS

TASK 3 – PERFORMANCE OF FIRE TESTS

Test Scenario
Unsuppressed Surface Burning
Unsuppressed Bulk Load
Unsuppressed Containerized
Unsuppressed Multiple Fire Test

Test Scenario
Surface burning & Halon 1301
Bulk Load & Halon 1301
Containerized & Halon 1301
Multiple Fire Test & Halon 1301
Multiple Fire Test & Halon replacement agent
Surface Burning & Halon replacement agent
Bulk Load & Halon replacement agent
Containerized & Halon replacement agent

Test Scenario
Calibration of baggage
Compartment floor
Compartment ceiling
ULD container
Involvement of a bulk shipment of cells/batteries in an external fire event

AirPED

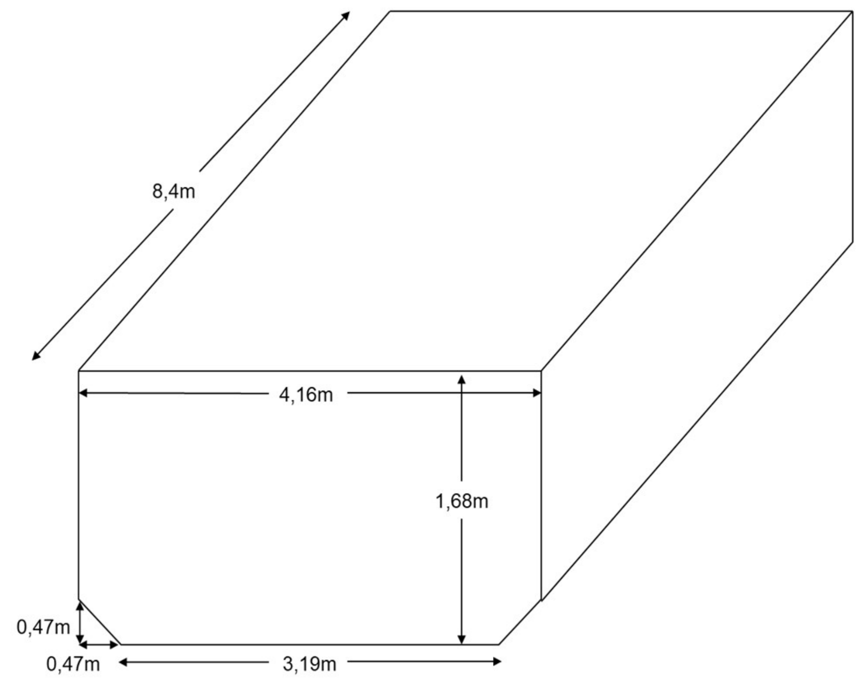
TASK 4 – ASSESSMENT OF TEST RESULTS AND AIRCRAFT FIRE PROTECTION EFFECTIVENESS

TASK 5 – PROJECT CONCLUSIONS, RECOMMENDATIONS AND PRESENTATION TO AVIATION STAKEHOLDERS

- The objective of Task 4 and Task is the assessment of the effectiveness of a state-of-the-art fire protection means of a Class C cargo compartment in suppressing a fire involving lithium batteries. This assessment will be done based on test data from the different test scenarios carried in the previous tasks and will include:
  - the evaluation of the level of performance of the tested aircraft fire protection systems in the tested cargo fire scenarios
  - recommendations for improvements of the MPS test protocols, with particular reference to the definition of the new Multiple Fuel Fire scenario involving lithium batteries.
- The final project report will also identify recommendations and further work on open issues that were not deeply investigated during this project.

AirPED

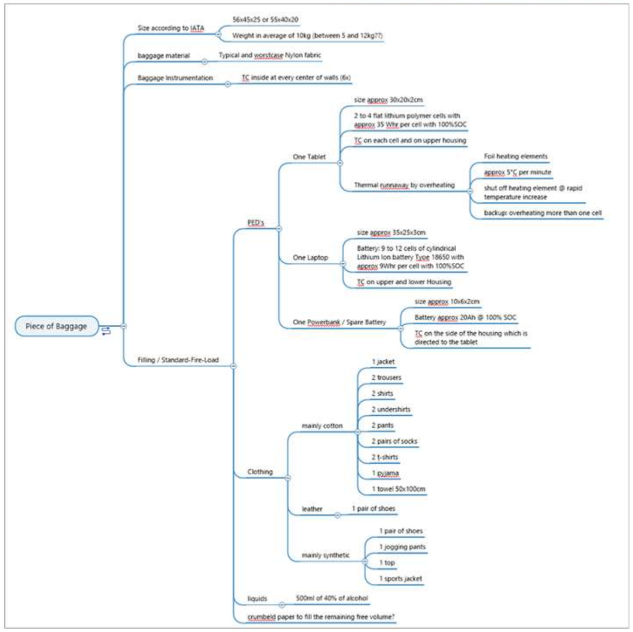
All tests are conducted in the cargo compartment Halon replacement MPS test chamber at DLR (Trauen, Germany)



AirPED

SCENARIO 1: Baseline – Calibration of baggage

- The objective of this test is to define a representative single baggage configuration to be used for the thermal runaway test scenarios that will address possible fire events in representative check-in baggage of passenger aircrafts.
- Different baggage configurations including PEDs, power banks and/or spare batteries, together with other representative checked-in baggage content (e.g. clothes, permissible liquids and/or aerosol cans) will be tested until PEDs in thermal runaway are able to create a sustained internal fire that may propagate outside the baggage



EASA

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SCENARIO 2: Compartment floor

- The objective of this test is to investigate the scenario in which fire starts from a piece of baggage that is not directly exposed to the extinguishing agent discharged in the compartment.
- The thermal runaway occurs inside the baggage located on the floor in the middle of the compartment and which is fully hidden below other baggage items with similar PED battery loadings.
- The extinguishing agent shall be released inside the compartment after a timeframe that is established with the objective to simulate the sequence of events that would occur in an actual cargo fire scenario, from the time at which fire detection occurs and a warning is provided to flight crew to the implementation of the cargo fire emergency procedure.

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SCENARIO 3: Compartment ceiling

- The objective of this test is to evaluate the scenario in which the fire starts in a point as close as possible to the ceiling level and as far as possible from the fire suppression system nozzle(s). This scenario is critical for the effectiveness of the fire suppression system considering the stratification of Halon 1301.

- The thermal runaway occurs inside a baggage located in one corner of the mock-up as close as possible to the ceiling considering the typical limitations to the maximum loading height for cargo compartments of large aeroplane (ref. paragraph 12 of AMC 25.851(b)).

AirPED

SCENARIO 4: ULD (container)

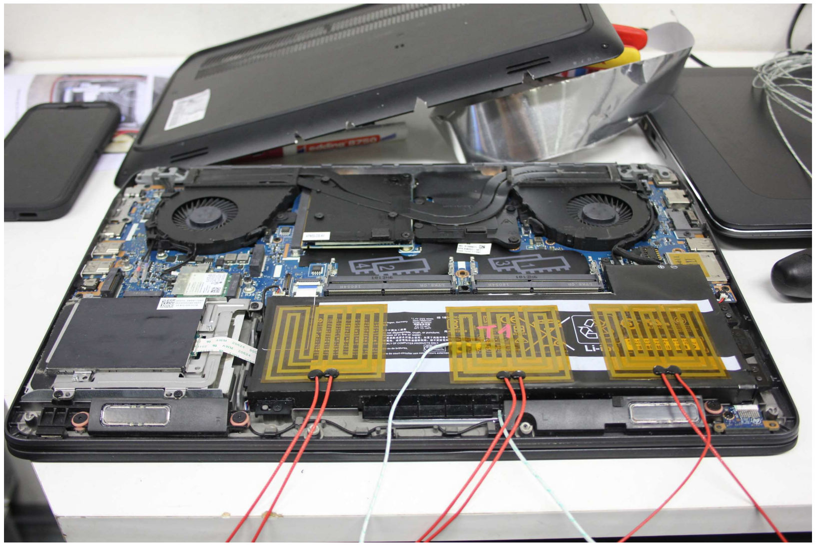
CANCELLED

- The objective of this test is to investigate the scenario in which fire starts from a piece of baggage that is not directly exposed to the extinguishing agent because it is placed inside a standard ULD container.

- Three LD-3 containers will be used for this test and arranged like the containerized scenario in the MPS. A minimum set of 6 baggage units having the configuration determined in scenario 1 will be placed inside the middle container. Dummy load will be used to fill up the whole container.

AirPED Baggage Calibration (Fire Scenario 1)

→ The objective of this test is to define a representative single baggage configuration to be used for the thermal runaway test scenarios that will address possible fire events in representative check-in baggage of passenger aircrafts.



Baggage Calibration (Fire Scenario 1)

AirPED

- Final baggage configuration based on using an artificial fire source based on the UL5800 definition (9 cells, 18650, total capacity 100 Wh)
- No aerosol cans in the initiation baggage
- Fire Scenarios 2 and 3 run with aerosol cans inside bags located in the periphery of the fire load.
- The objective of the tests is to demonstrate that Halon 1301 can stop fire propagation from the initiation baggage

AirPED Baggage content (fire scenarios 2 and 3)

Ignition Case
Suite Case STRATIC modell STRONG 40 x 20 x 55 cm
1x Notebook HP ZBook 15 G3, 90 WHr batterie with at least 80 % SoH and 100 % SoC
2x Flashlight Walther Tactical 250 incl. 2x CR123A li-ion batteries
1x PE bottle with 125 ml acetone
1x PE bottle with 125 ml ethnaol
~200 g (± 10 g) Cotton fabrics
~100 g (± 10 g) synthetic fabrics

Standard Case
Suite Case STRATIC modell STRONG 40 x 20 x 55 cm
1x Notebook HP ZBook 15 G3, 90 WHr batterie with at least 80 % SoH and 100 % SoC
1x Flashlight Walther Tactical 250 incl. 2x CR123A li-ion batteries
1x PE bottle with 125 ml acetone
1x PE bottle with 125 ml ethnaol
~630 g (± 10 g) Cotton fabrics
~305 g (± 10 g) synthetic fabrics
2x single shoes or flip flops ~600 g (± 100 g)

AirPED Baggage content (fire scenarios 2 and 3)

Standard Case with aerosol sprays
Suite Case STRATIC modell STRONG 40 x 20 x 55 cm
1x Notebook HP ZBook 15 G3, 90 WHr batterie with at least 80 % SoH and 100 % SoC
1x Flashlight Walther Tactical 250 incl. 2x CR123A li-ion batteries
1x PE bottle with 125 ml acetone
1x PE bottle with 125 ml ethnaol
~630 g (± 10 g) Cotton fabrics
~305 g (± 10 g) synthetic fabrics
2x single shoes or flip flops ~600 g (± 100 g)
1x Aerosol can hairspray 250 ml
1x Aerosol can deospray 150 ml

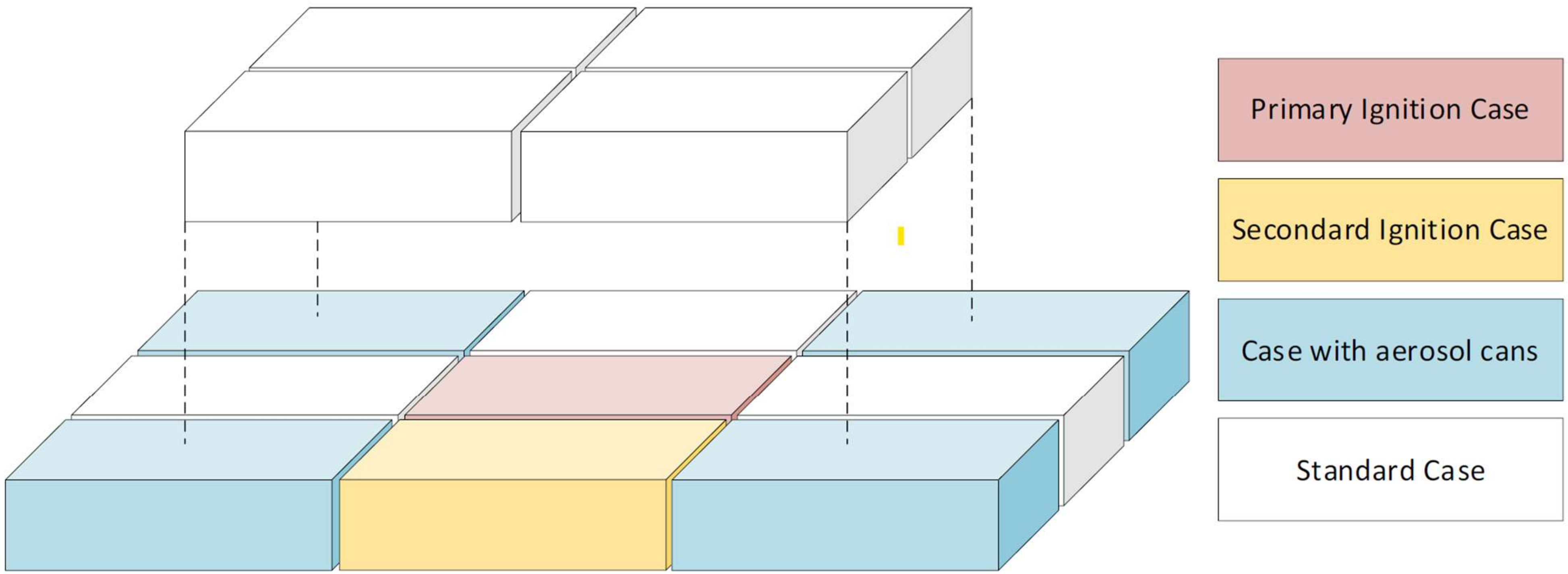
AirPED

Test procedure (fire scenarios 2 and 3)

1. Set cargo hold leakage rate to 23.3 sl/sec (1400 slpm) according to current leakage calibration procedure (with forced ventilation).
2. Activate heating of the artificial battery fire source inside the primary ignition case. The initiation cell in the artificial battery fire source should be heated with a rate of 5-10 °C/min.
3. As soon as the fire starts propagating from the primary ignition case, wait 1 minute before activating the halon knock-down. The start of the propagation of the fire can be either confirmed visually with the infrared camera or from the readings of the external thermocouples on each side the case. If any thermocouple reads at least 200°C for at least 5s, then it is assumed that the start of the fire propagation has occurred.
4. If no evidence of fire propagation from the primary ignition case is observed after 60 minutes from the activation of the heating of the artificial battery fire source, then activate the heating of the artificial battery fire source inside the secondary ignition case, following the same procedure as in steps 2 and 3 above.
5. Test end is at 30 minutes after activation of the halon knock down.
6. After the end of the test, either inert the cargo hold with nitrogen overnight or open cargo hold doors and initiate active extinguishing measures.

AirPED

Compartment floor (fire scenario 2)



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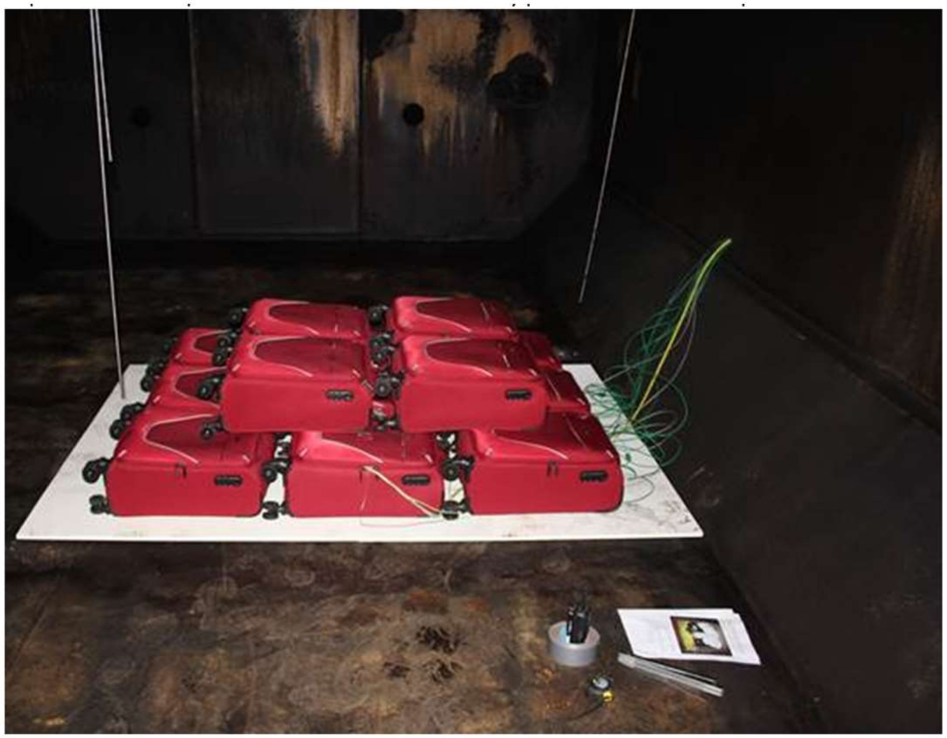
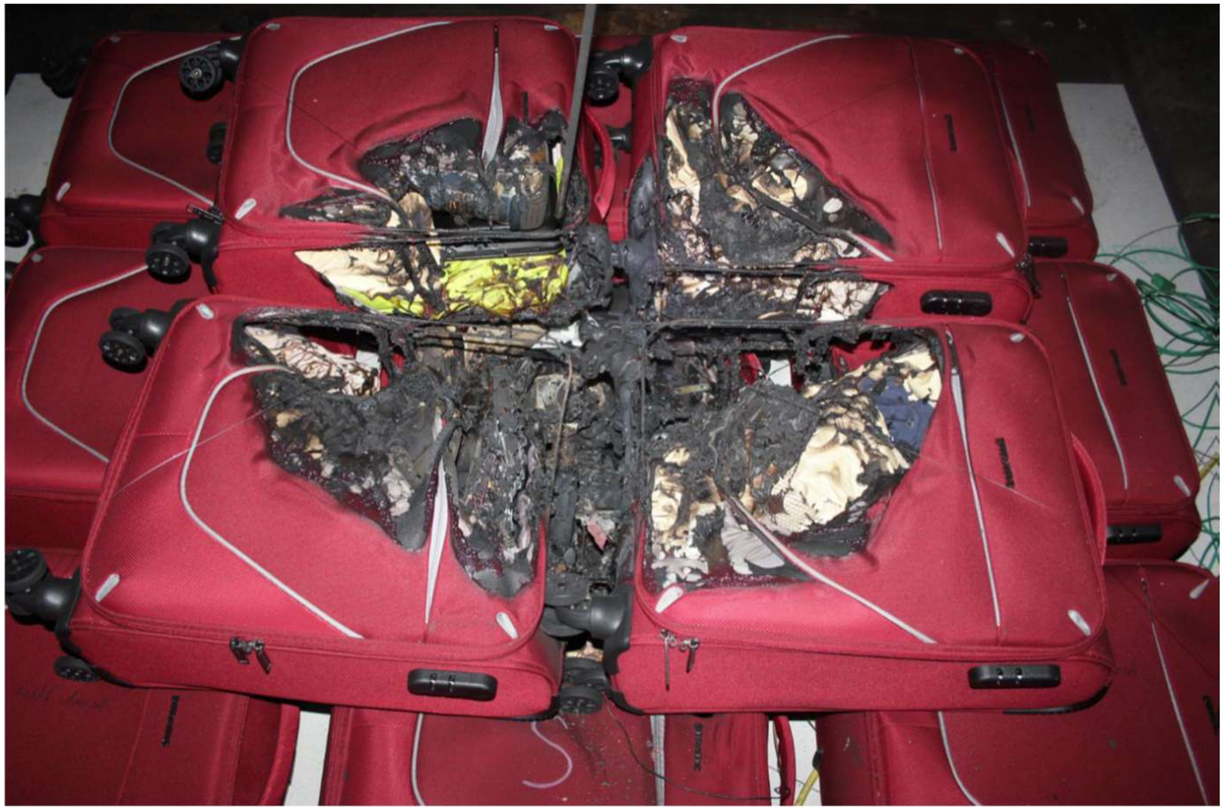
Compartment floor (fire scenario 2)



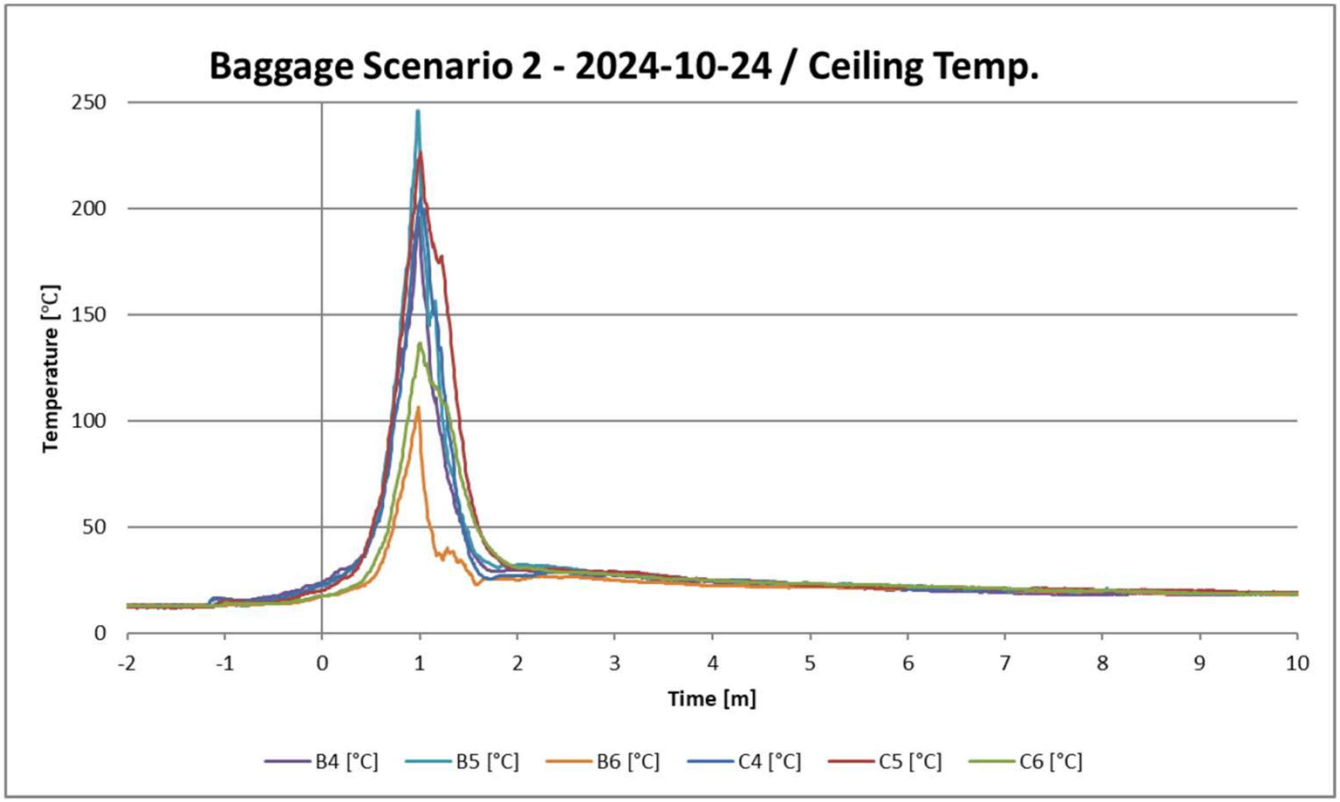
AirPED

Compartment floor (fire scenario 2)



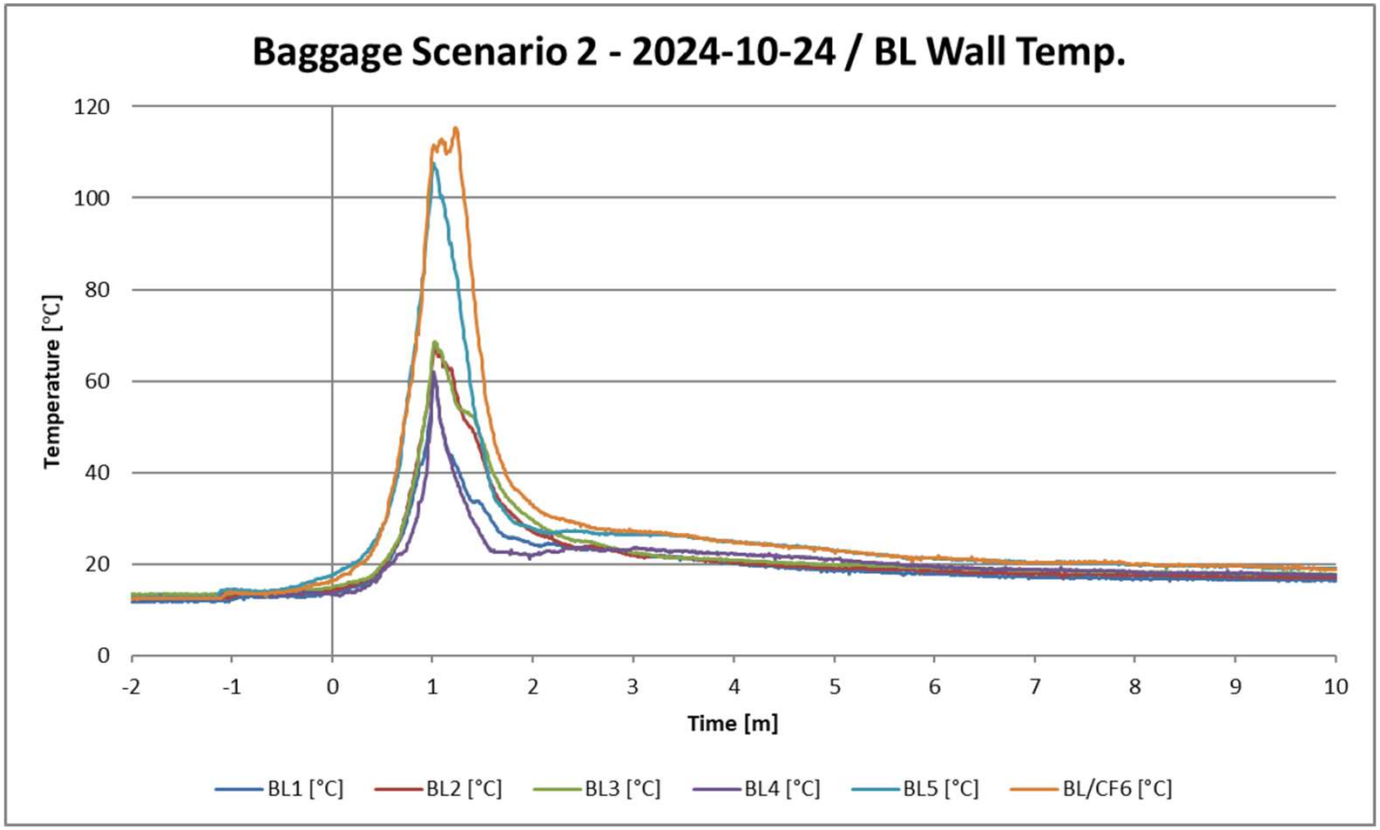
EASA

Compartment floor (fire scenario 2)



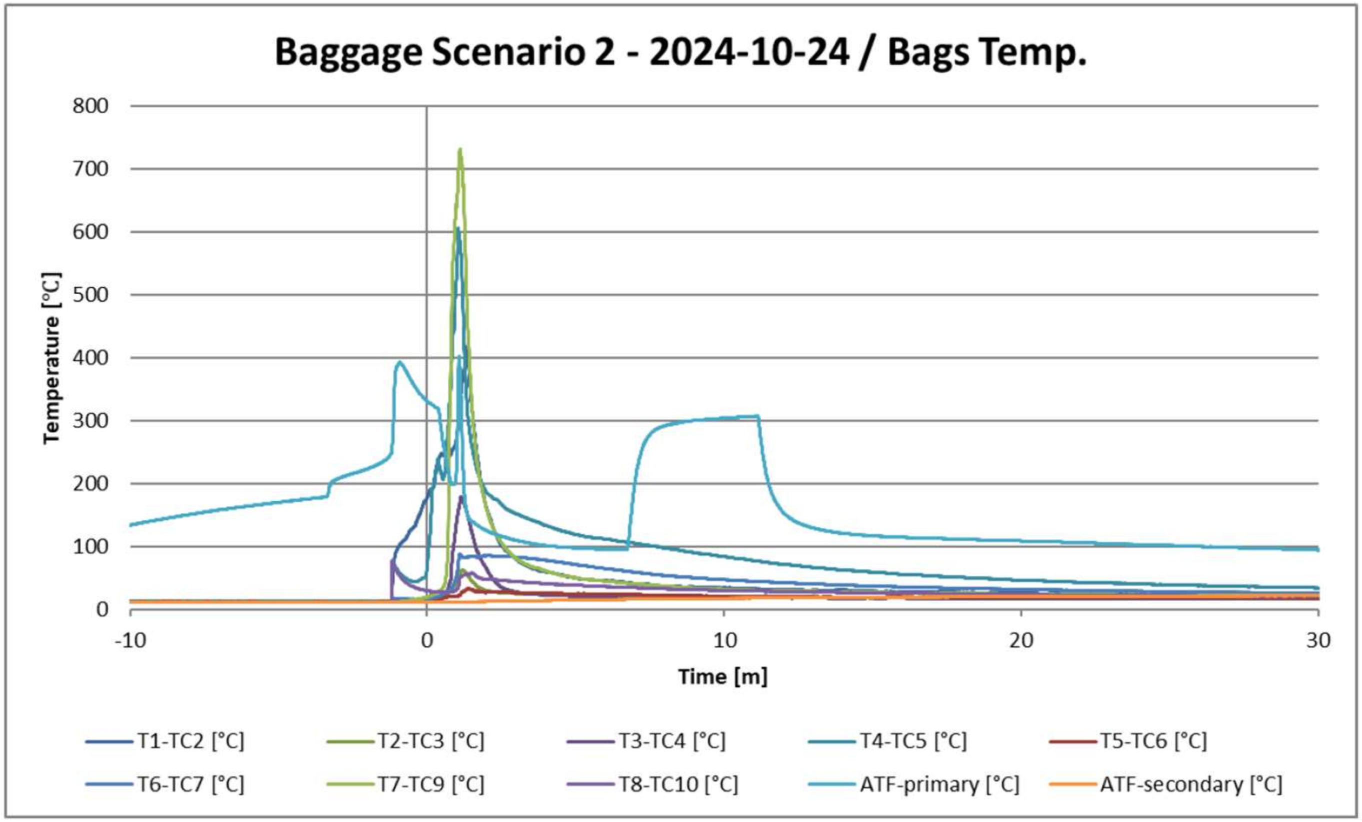
AirPED

Compartment floor (fire scenario 2)

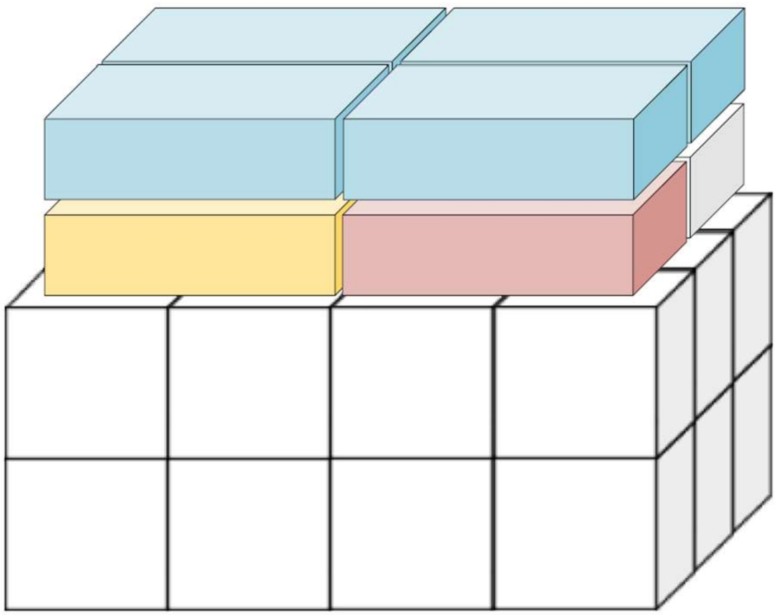


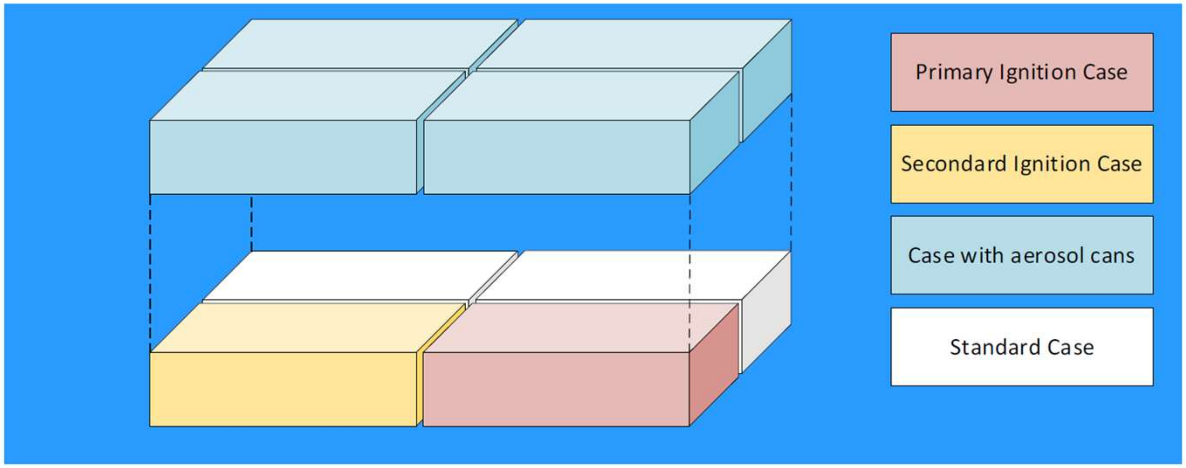
EASA

Compartment floor (fire scenario 2)



Compartment ceiling (fire scenario 3)





AirPED

Compartment ceiling (fire scenario 3)

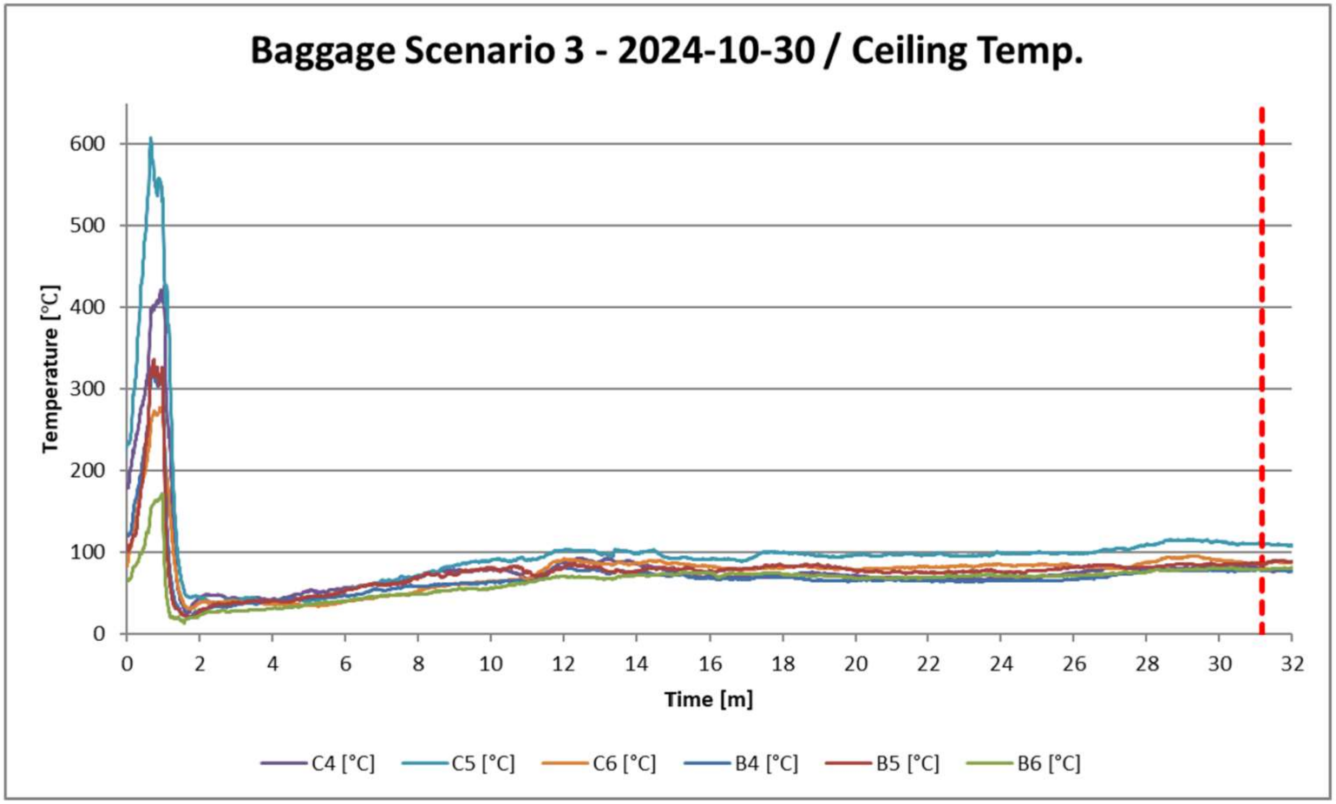
EASA

AirPED

Compartment ceiling (fire scenario 3)

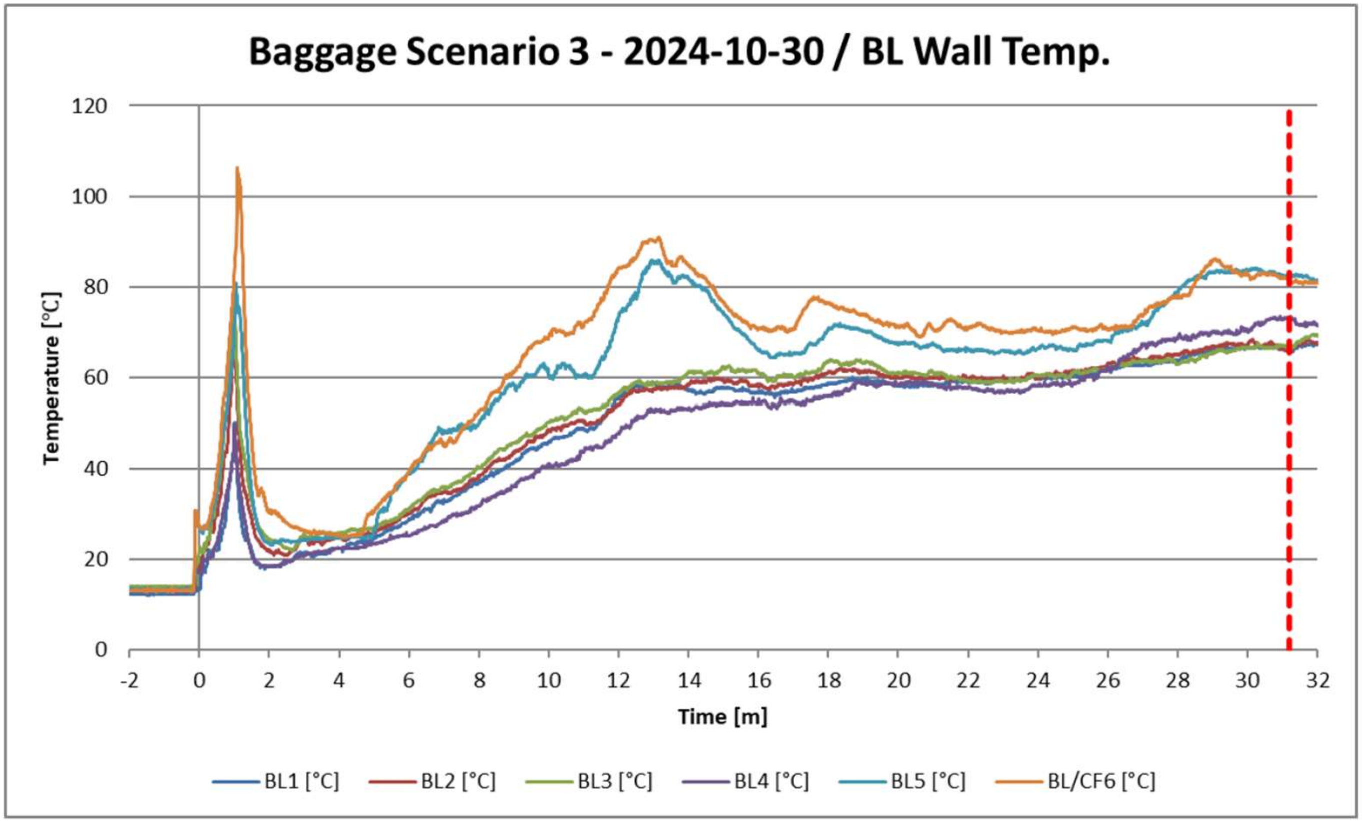
EASA

Compartment ceiling (fire scenario 3)

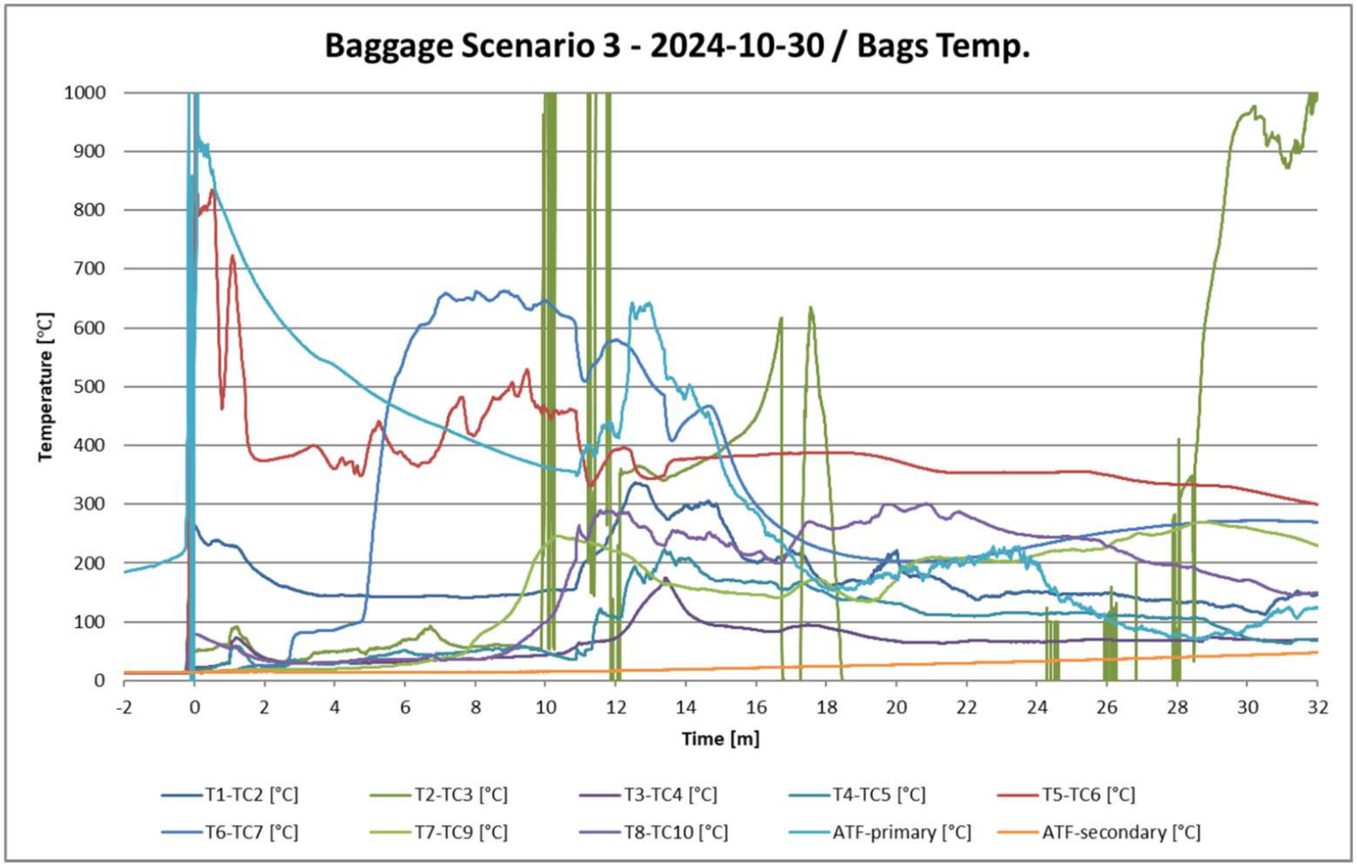


AirPED

Compartment ceiling (fire scenario 3)



Compartment ceiling (fire scenario 3)



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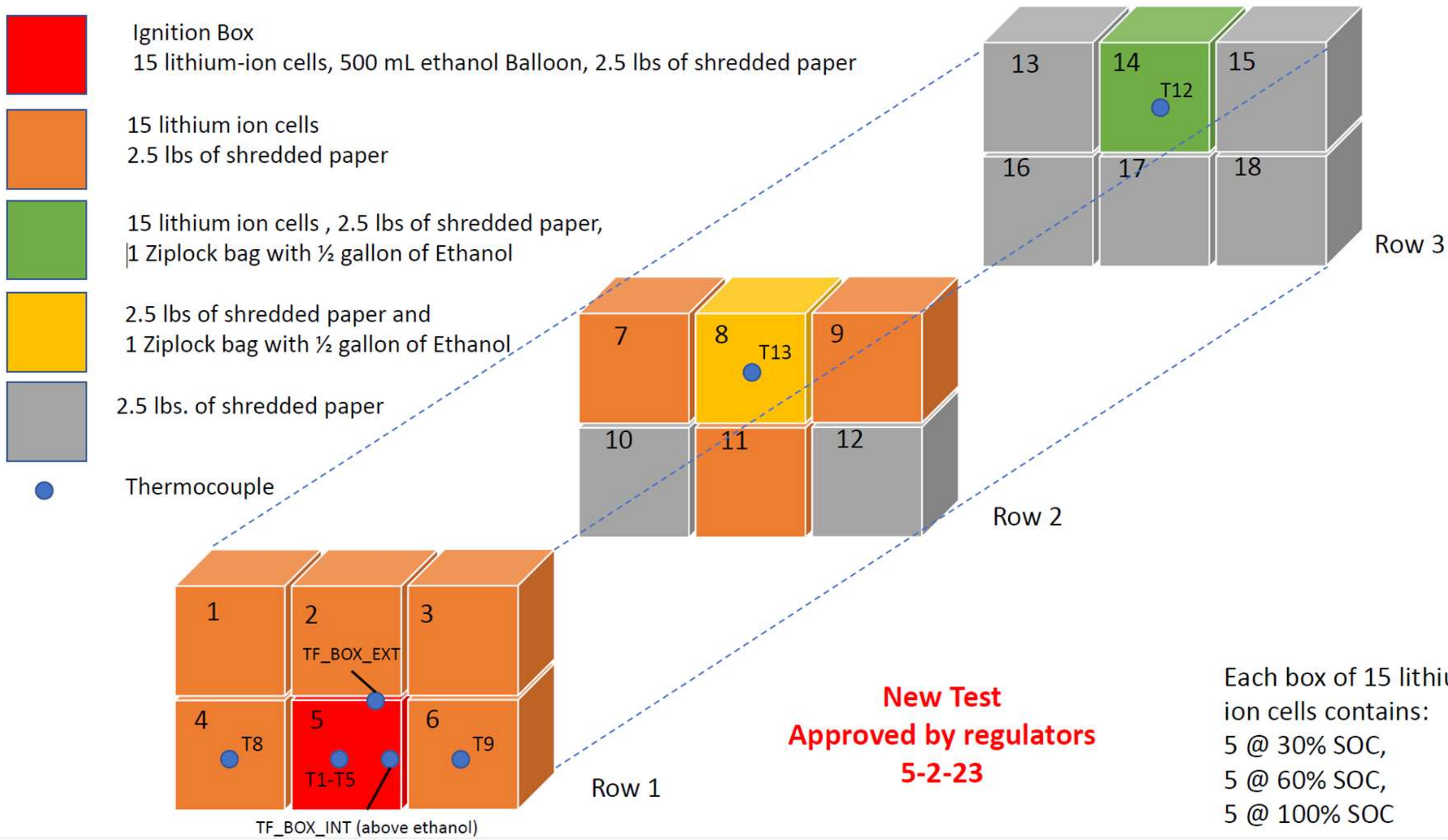
Test results (fire scenarios 2 and 3)

- The results of the tests are still under evaluation: interpretations and recommendations will be included in the final report of the research project.

- Preliminary observations:
  - No significant propagation and damage in fire scenario 2 (compartment floor)
  - Appreciable propagation and damage in fire scenario 3 (compartment ceiling)

Multiple Fuel Fire (MFF) Test

SCENARIO 5: Multiple Fuel Fire Scenario

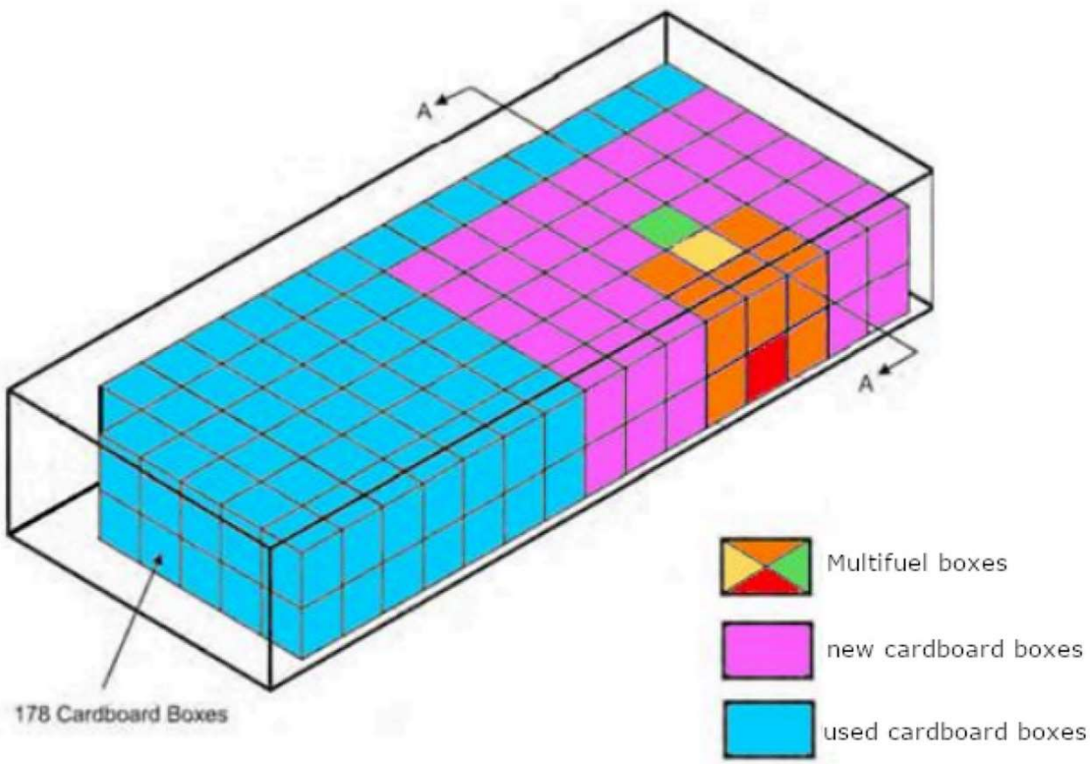


New Test
Approved by regulators
5-2-23

Each box of 15 lithium ion cells contains:
5 @ 30% SOC,
5 @ 60% SOC,
5 @ 100% SOC

Multiple Fuel Fire (MFF) Test

SCENARIO 5: Multiple Fuel Fire Scenario



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MPS update

- Impact on the Cargo Compartment Halon replacement MPS (to be further discussed with the MPS Task Group):
  - Conducting unsuppressed tests should be required by the MPS
  - Define minimum conditions for the acceptance of the results of unsuppressed fire tests
  - allow testing in conditions that are more severe than the ones specified in the MPS to increase the level of severity of the unsuppressed fire events

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SCENARIO 6: Halon Replacement

→ Show that a candidate replacement agent can pass the cargo MPS, including the Multiple Fuel Fire scenario.

Only MFF with Nitrogen

Test Scenario
Surface burning & Halon 1301
Bulk Load & Halon 1301
Containerized & Halon 1301
Multiple Fire Test & Halon 1301
Multiple Fire Test & Halon replacement agent
Surface Burning & Halon replacement agent
Bulk Load & Halon replacement agent
Containerized & Halon replacement agent

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SCENARIO 7: Involvement of a bulk shipment of cells/batteries in an external fire event

CANCELLED

- The objective is to perform a series of tests to assess the external fire threat on the packaging solutions used for the transport as cargo of lithium cells/batteries (other than 18650 cells).
- Assess fire suppression and non-propagation aspects with and without additional mitigating measures (e.g. FCCs) protecting the cell/batteries.

Project Status

AirPED

- Task 1 completed
- Task 2 completed
- Task 3 completed
- Activities performed since January 2024:
  - unsuppressed fire test scenarios (issues with the Multiple Fuel Fire scenario)
  - Halon 1301 fire suppression system calibration tests
  - MFF test with Halon
  - Baggage calibration test
  - Fire scenarios 2 (baggage fire on the floor)
  - Fire Scenario 3 (baggage fire close to the ceiling)
  - Fire scenario 6 (replacement agent): test with N_2 only the MFF scenario
- Final report and project deliverables due by the end of Q2 2025

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Any Questions ?

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An Agency of the European Union