



Environmentally-Friendly Fire Suppression System for Cargo using Innovative Green Technology

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Overview



- Background and scope of project
- Tests and acceptance criteria
- Experimental rig set up
- Results





Background and Scope



- EFFICIENT – (Environmentally Friendly Fire Suppression System for Cargo using Innovative
- Green Technology)
- Funded by the European Union Clean Sky 2 research program
- Collaboration of several Academic and Industrial partners



Background and Scope



Scope:

- To develop and mature potential fire suppression technology for eventual application in the cargo-cabin architecture of next generation aircraft
- Identify a suitable agent which will replace Halon 1301 and will be able to qualify the FAA MPS



Background and Scope



Objectives:

- Identify a suitable AGENT, or mixture of AGENTs, capable of providing the fire suppression specified in DOT/FAA/TC-TN12/11 MPS - not harmful to human health or the environment
- Develop the EFFICIENT Fire Knockdown System (EFKS) capable of delivering the AGENT(s) under a range of environmental conditions simulating those an aircraft would undergo
- Construct a suitable DEMONSTRATOR capable of showing that the EFKS will fulfil all requirements in terms of fire suppression performance



Background and Scope



Tasks accomplished by RISE

- Defined main requirements, boundaries and objectives
- Pre-select and characterize the candidate suppression agents
- Select the final suppression concept to be used in performance test required by MPS
- Perform risk and opportunity analysis

Tasks accomplished by LSBU

Small scale tests to determine the required nitrogen concentration for fire suppression

Tasks accomplished by Fraunhofer Institute

Second phase of project including the testing of the Low Rate Discharge system,



Tests and Acceptance Criteria

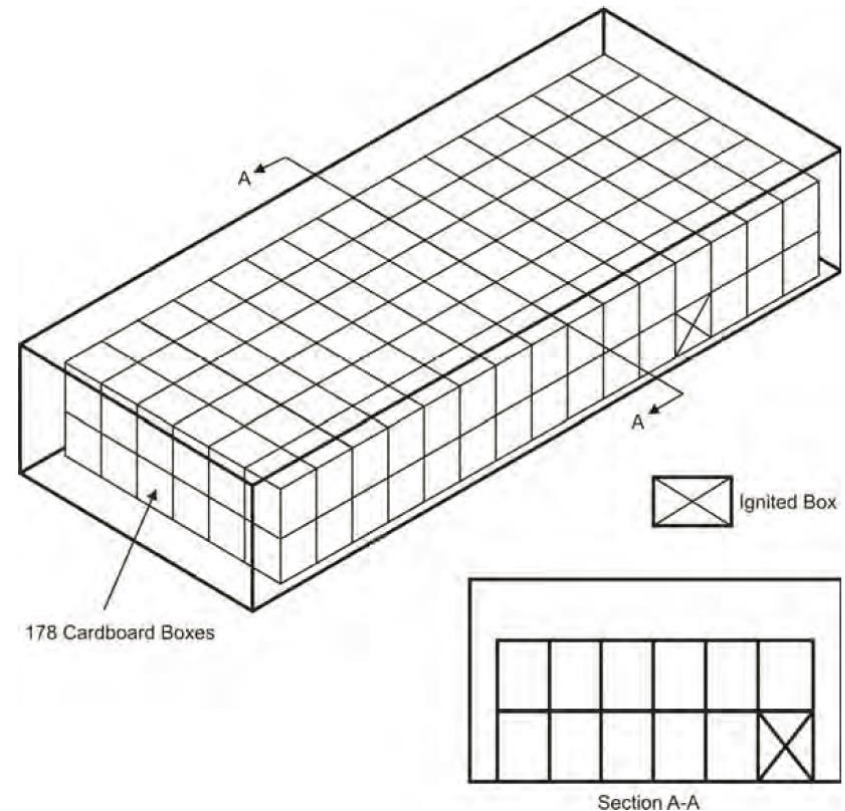


Four test scenarios:

1. Bulk - load fire
2. Containerized load fire
3. Aerosol can explosion (short version)
4. Surface burning fire

Bulk – load fire scenario

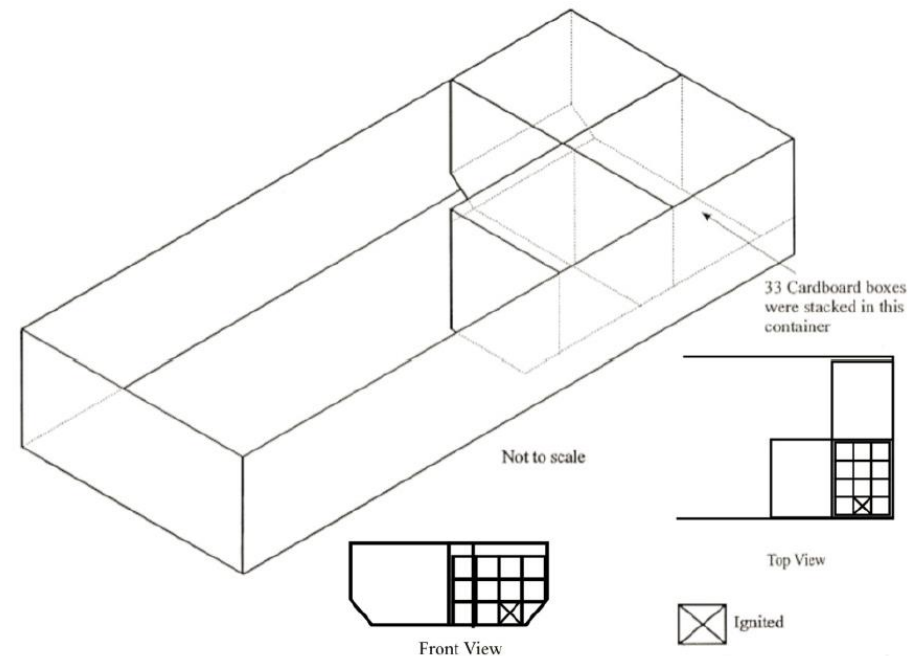
- 178 cardboard boxes filled with shredded paper
- Each box weighs 1.1kg net
- Ignition triggered through a specially perforated box
- Suppression triggered 1 min after ceiling temperature Reaches 93.3 °C
- Temperatures monitored for 28 minutes



Source: FAA MPS

Containerised – load fire scenario

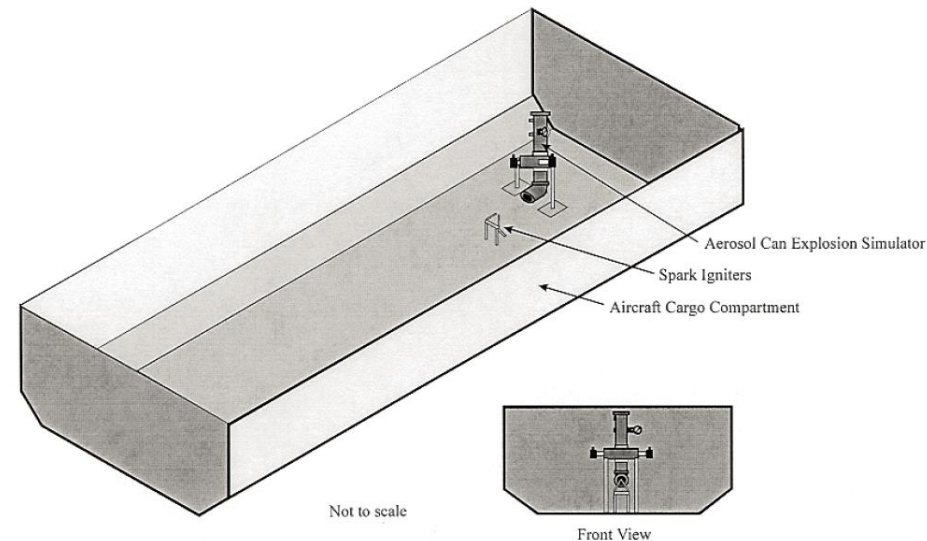
- 3 LD3 containers stacked inside the demonstrator
- One LD3 is filled with 33 boxes
- Ignition triggered through a specially perforated box
- Suppression triggered 1 min after ceiling temperature Reaches 93.3 °C
- Temperatures monitored for 28 minutes



Source: FAA MPS

Aerosol can explosion scenario

- Appropriate pressure vessel containing 20% liquid propane, 60% ethanol and 20% water
- Vessel heated to 240psi
Internal pressure
- Ignition electrodes 3 feet away are charged with 10,000V
- Mixture released within 0.1sec, 2 minutes after suppression activation



Source: FAA MPS

Surface – burning scenario

- Appropriate steel pan containing 0.385l gasoline, 1.9l kerosene and 9.5l water
- Pan located at disadvantaged location
- Ignition electrodes are charged with 10,000V
- Temperatures monitored 2 minutes after suppression activation (60 s after 93.3 °C) for 3 minutes

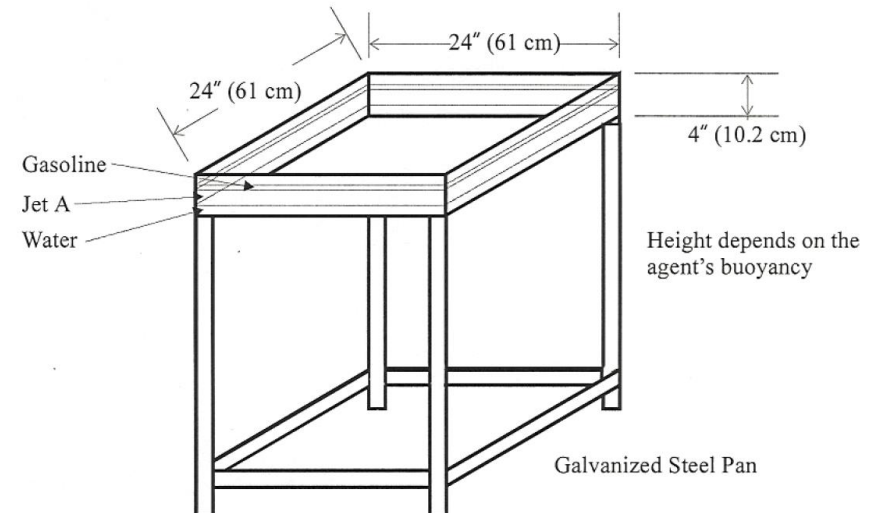


Figure 7. Surface-Burning Fire Pan

Source: FAA MPS

Tests and Acceptance Criteria



Fire Scenario	Maximum Temp. °F (°C)	Maximum Pressure psi (kPa)	Maximum Temp-Time Area °F-min. (°C-min.)	Comments
Bulk Load	710 (377)	Not Applicable	9850 (4974)	Use the data that are between 2 and 30 minutes after suppression system activation.
Containerized Load	650 (343)	Not Applicable	14520 (7569)	Use the data that are between 2 and 30 minutes after suppression system activation.
Surface Fire	560 (293)	Not Applicable	1190 (608)	Use the data that are between 2 and 5 minutes after suppression system activation.
Aerosol Can Explosion Simulation	Not Applicable	0.0	Not Applicable	There shall be no evidence of an explosion. No enhancement of explosion at below inert concentrations.

Synopsis of acceptance criteria - Source: FAA MPS



Experimental Rig Set Up



- Demonstrator manufactured to exact dimensions of wide body aircraft FWD cargo hull (57m³)
- 33 K type thermocouples installed on ceiling and side walls
- Ports for cargo hull door leakage simulation designed according to MPS – Electric fan extracts air at rate of 23l/s
- Adjustable ventilation system installed



Cargo hull demonstrator



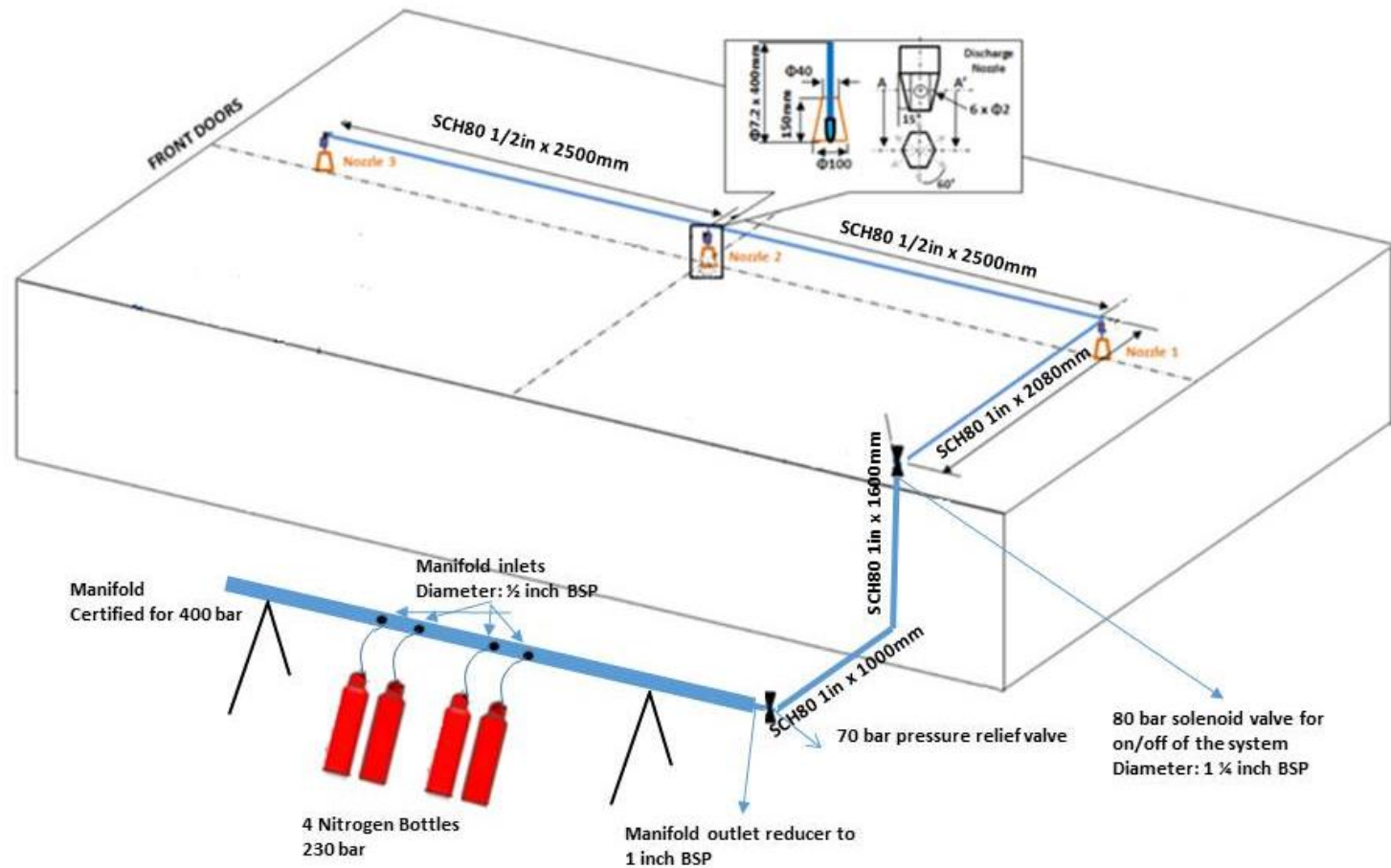
Interior of demonstrator



Leakage simulator



Ventilation and regulation



Schematic representation of nitrogen supply for EKFS

Experimental Rig Set Up



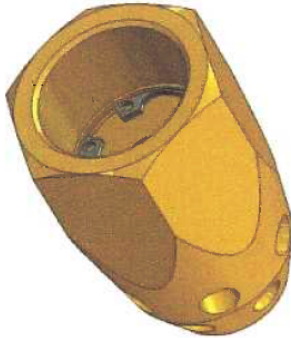
Galvanised steel pipes
1 inch

Spray Nozzles x3

Galvanised steel pipes
 $\frac{1}{2}$ inch

Pressure transducers x3

Nitrogen distribution for EKFS



ASSEMBLY	ORIFICE	Height	A/F	DN	Design Flow rate	Max Flow rate
Part No	RANGE	mm	mm	mm (inch)	Kg/min	Kg/min
NF35150	1.6-10mm	44	24	15 (½")	23	33
NF35200	7-14mm	55	32	20 (¾")	45	66
NF35250	10-18mm	67	41	25 (1")	90	133
NF35320	12-23mm	82	54	32 (1-¼")	118	175
NF35400	15-26mm	93	63	40 (1-½")	158	235

Nitrogen spray nozzles specification

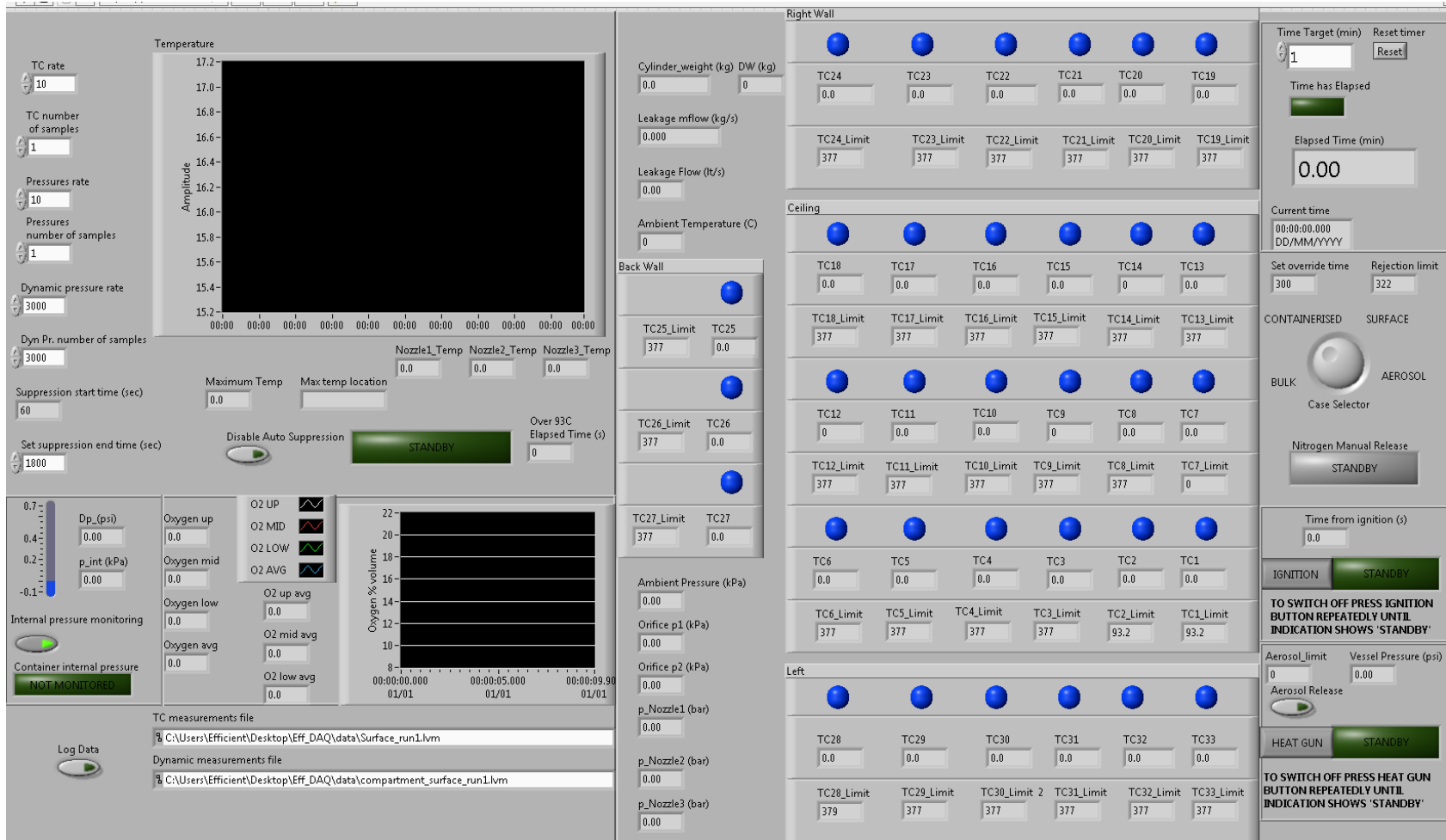


Nitrogen spray nozzle and nitrogen supply arrangement



No	Instrument/ sensor	Type	Measurement	Sensor Type	Range	Accuracy	Sampling	Output	Units	Usage
1	Thermocouples Type K	Thermocouples with standard head and process connection and weather protection	Temperature	K chrome/alumel	1300 C	1C	10 Samples /s	Low Voltage	35	Temperature measurement inside the demonstrator – One for Ambient temperature measurement
2	Pressure Transducer	OMEGA PXM409	Pressure	Differential Pressure	0-5 psid	0.08%	10 Samples/s	10VDC	2	Pressure drop across orifice plate for leakage simulation flow rate measurement
3	Pressure Transducer	OMEGA PXM409	Pressure	Gauge Pressure	0-70bar psig	0.08%	10 Samples/s	10VDC	3	Static pressure of nitrogen before each spray nozzle
4	Pressure Transducer	Kulite XCQ-093	Pressure	Sealed gauge	0-15 psig	0.1%	3000 Samples/s	100mV	1	Overpressure inside the demonstrator
5	Oxygen analyser	XZR-B2-C2	Oxygen Concentration (v/v)	Zirconium oxide	0-25%	0.55%	10 Samples/s	10V DC	3	Agent concentration,
6	One Weight industrial scale	HFC12	mass (kg)	Load cells – digital output	0-1500kg	0.2kg	10 Samples/s	RS232	1	Mass reduction of nitrogen cylinders during suppression

Basic instrumentation



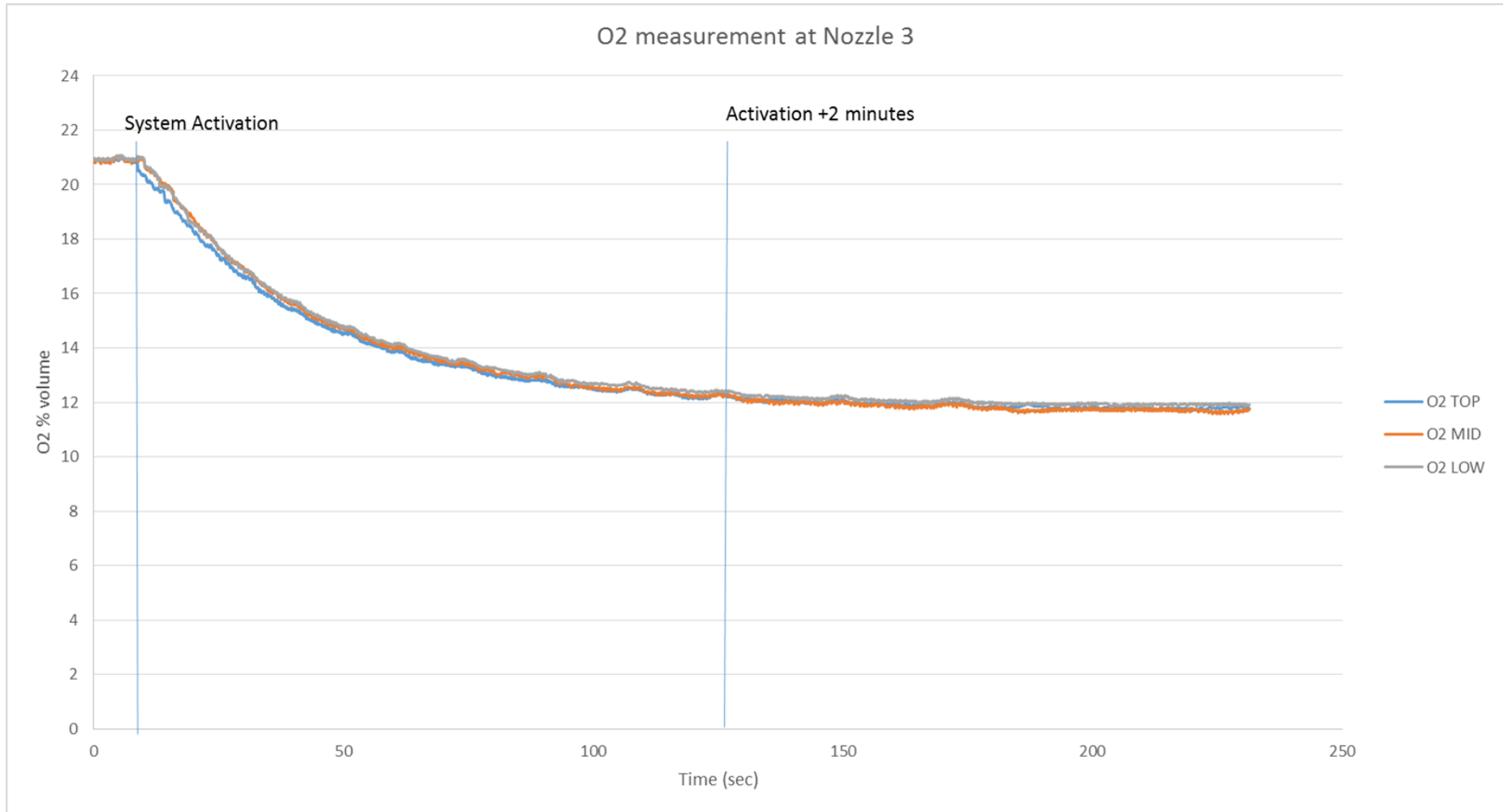
Experiment control interface



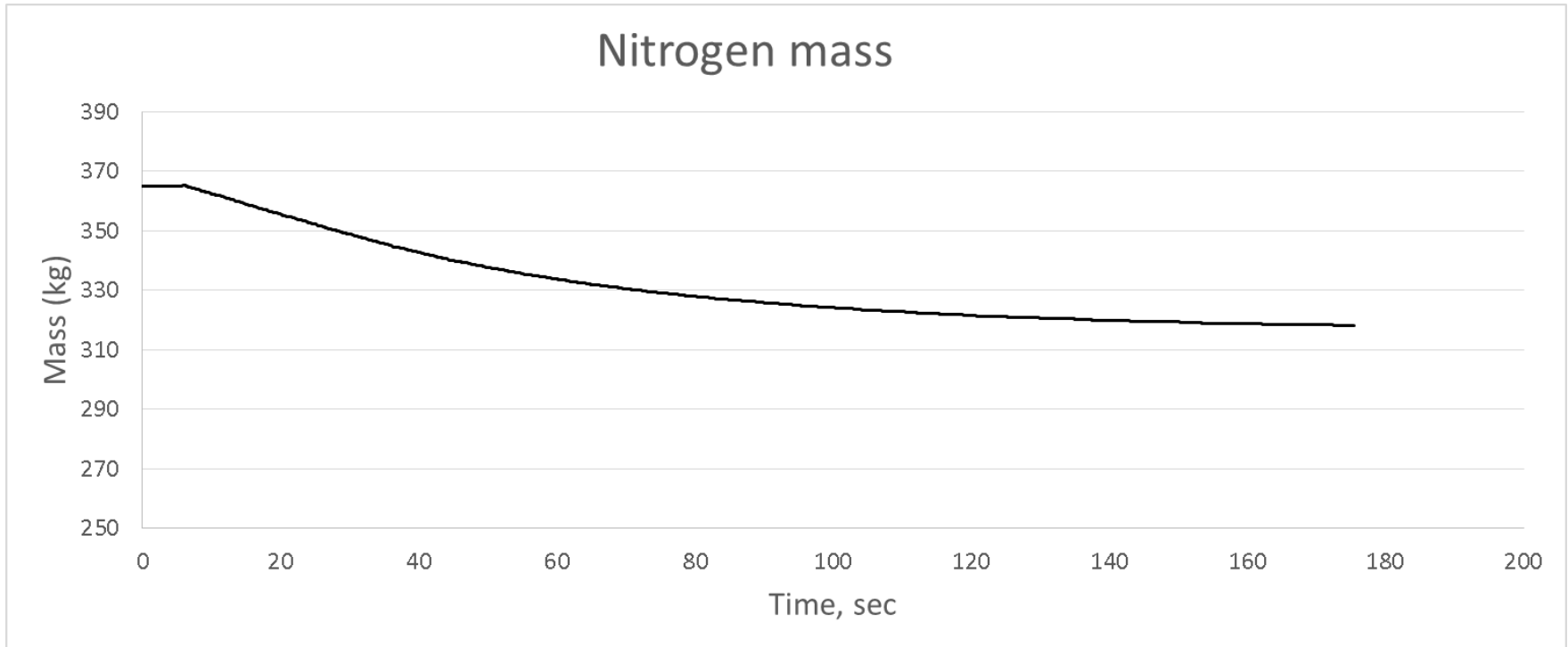
Experimental Rig Set Up



- Baseline nitrogen concentration tests for EKFS
- Nozzles configured at orifice diameters 5mm, 8.5mm and 8.5mm respectively
- Pressure of nitrogen distribution system regulated at 50bar
- Approximately 45kg of nitrogen consumed
- Peak pressure increase inside chamber at 0.4psi
- Oxygen concentration reduced below 12% volume within 2 minutes



Oxygen concentration reduction



Nitrogen mass consumption during EKFS

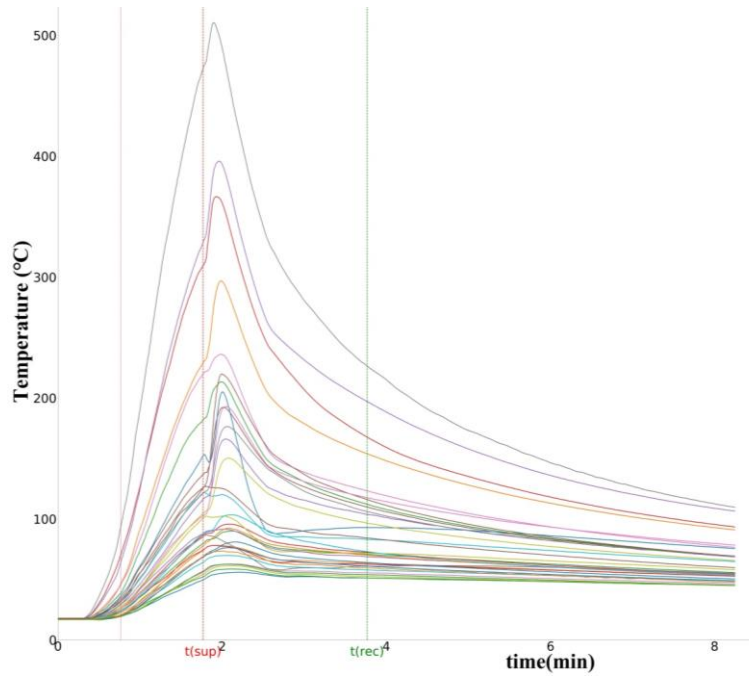


Location of Surface Burning pan

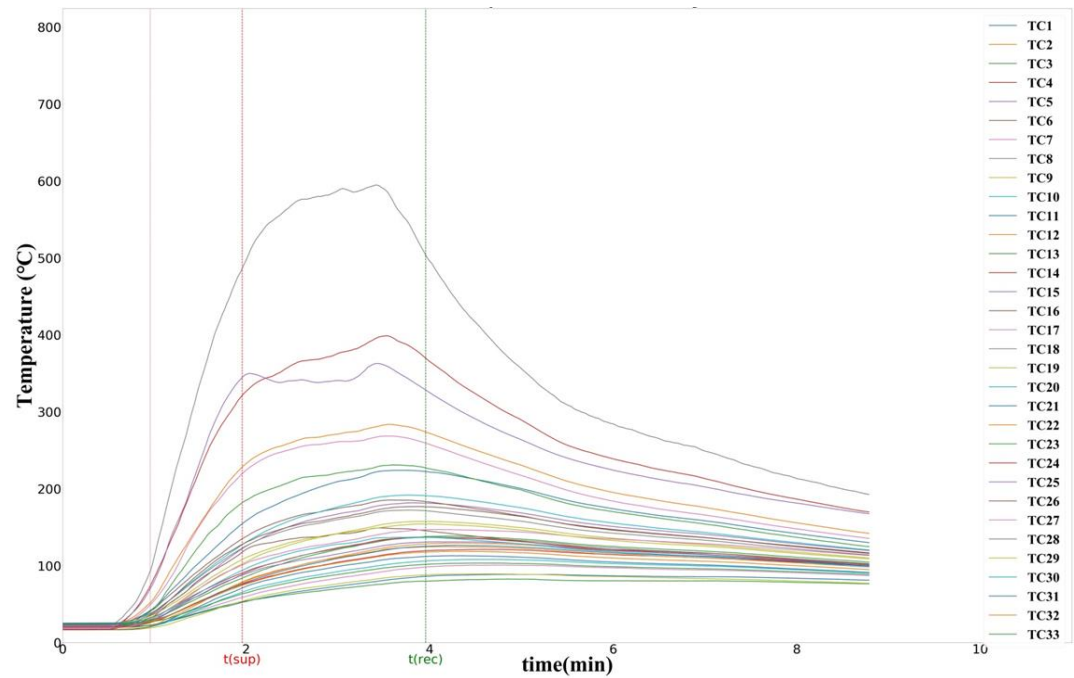
Cylinder_weight (kg)	TC1	TC23	TC22	TC21	TC20	TC19
117.8	20.2	19.8	19.7	19.8	19.4	25.1
Leakage mflow (kg/s)	TC4_Limit	TC23_Limit	TC22_Limit	TC21_Limit	TC20_Limit	TC19_Limit
NaN	93.2	93.2	93.2	93.2	93.2	93.2
Leakage Flow (kg/s)	Ceiling					
NaN	TC17	TC16	TC15	TC14	TC13	
Ambient Temperature (C)	TC17_Limit	TC16_Limit	TC15_Limit	TC14_Limit	TC13_Limit	
26.4	22.1	21.2	21.6	20.2	20.9	
Back Wall	TC17	TC16	TC15	TC14	TC13	
TC25_Limit	TC17_Limit	TC16_Limit	TC15_Limit	TC14_Limit	TC13_Limit	
93.2	93.2	93.2	93.2	93.2	93.2	
TC26_Limit	TC11	TC10	TC9	TC8	TC7	
93.2	21.3	21.1	22.7	23.8	22.8	
TC27_Limit	TC11_Limit	TC10_Limit	TC9_Limit	TC8_Limit	TC7_Limit	
93.2	93.2	93.2	93.2	93.2	93.2	
Ambient Pressure (kPa)	TC5	TC4	TC3	TC2	TC1	
88.85	22.3	22.8	22.8	22.4	25.1	
Office p1 (kPa)	TC5_Limit	TC4_Limit	TC3_Limit	TC2_Limit	TC1_Limit	
88.84	93.2	93.2	93.2	93.2	93.2	
Office p2 (kPa)	Left					
88.83	TC28	TC29	TC30	TC31	TC32	TC33
p_Nozzle1 (kPa)	21.6	21.3	21.3	22.2	21.6	22.3
p_Nozzle2 (kPa)	TC28_Limit	TC29_Limit	TC30_Limit 2	TC31_Limit	TC32_Limit	TC33_Limit
88.8	93.2	93.2	93.2	93.2	93.2	93.2
p_Nozzle3 (kPa)						
88.8						

Nearest thermocouples

Surface Burning scenario pan location



Suppressed



Unsuppressed

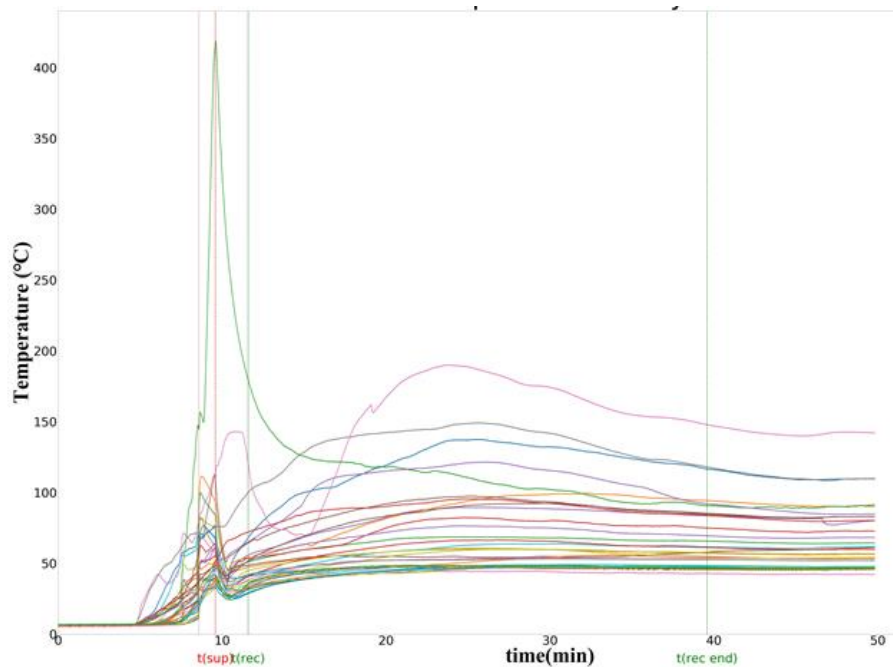
Temperature distribution for Surface Burning scenario

Containerised Load Results

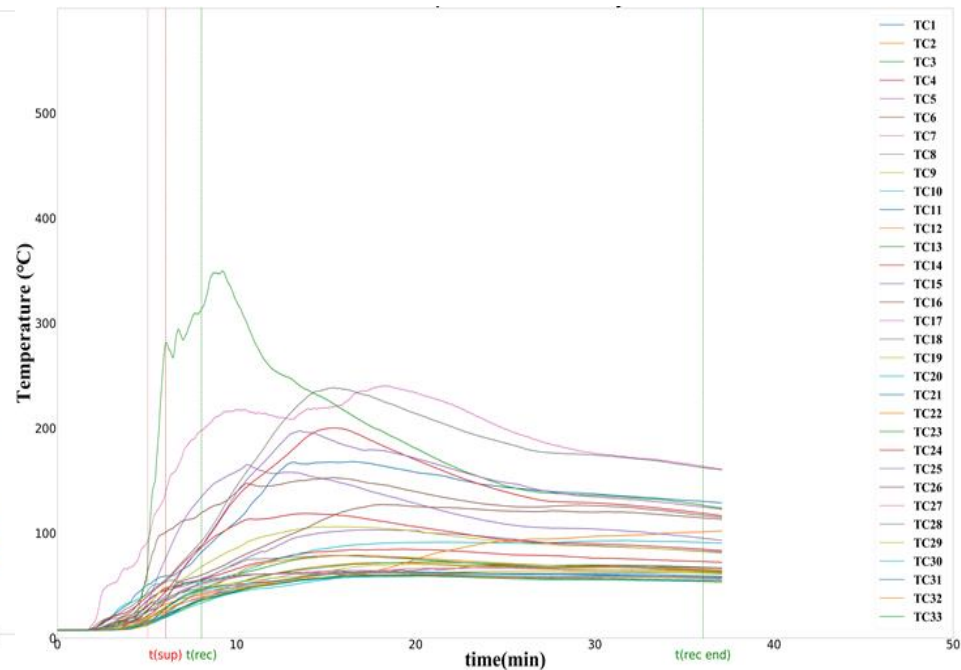


Containerised Load scenario configuration

Containerised Load Results



Suppressed



Unsuppressed

Temperature distribution for Containerised Load scenario



Bulk Load scenario configuration



Aftermath of testing

Bulk Load Results



RUN 2, 29 JAN 2020

LOWER LAYER						UPPER LAYER					
6	5	4	3	2	1	12	11	10	9	8	7
18	17	16	15	14	13	24	23	22	21	20	19
30	29	28	27	26	25	36	35	34	33	32	31
42	41	40	39	38	37	48	47	46	45	44	43
54	53	52	51	50	49	60	59	58	57	56	55
66	65	64	63	62	61	72	71	70	69	68	67
78	77	76	75	74	73	84	83	82	81	80	79
90	89	88	87	86	85	96	95	94	93	92	91
102	101	100	99	98	97	108	107	106	105	104	103
114	113	112	111	110	109	120	119	118	117	116	115
126	125	124	123	122	121	132	131	130	129	128	127
138	137	136	135	134	133	144	143	142	141	140	139
150	149	148	147	146	145	156	155	154	153	152	151
162	161	160	159	158	157	168	167	166	165	164	163
174	173	172	171	170	169	178	177	176	175	174	173

RUN 4, 07 FEB 2020

LOWER LAYER						UPPER LAYER					
6	5	4	3	2	1	12	11	10	9	8	7
18	17	16	15	14	13	24	23	22	21	20	19
30	29	28	27	26	25	36	35	34	33	32	31
42	41	40	39	38	37	48	47	46	45	44	43
54	53	52	51	50	49	60	59	58	57	56	55
66	65	64	63	62	61	72	71	70	69	68	67
78	77	76	75	74	73	84	83	82	81	80	79
90	89	88	87	86	85	96	95	94	93	92	91
102	101	100	99	98	97	108	107	106	105	104	103
114	113	112	111	110	109	120	119	118	117	116	115
126	125	124	123	122	121	132	131	130	129	128	127
138	137	136	135	134	133	144	143	142	141	140	139
150	149	148	147	146	145	156	155	154	153	152	151
162	161	160	159	158	157	168	167	166	165	164	163
174	173	172	171	170	169	178	177	176	175	174	173

RUN 5, 19 FEB 2020

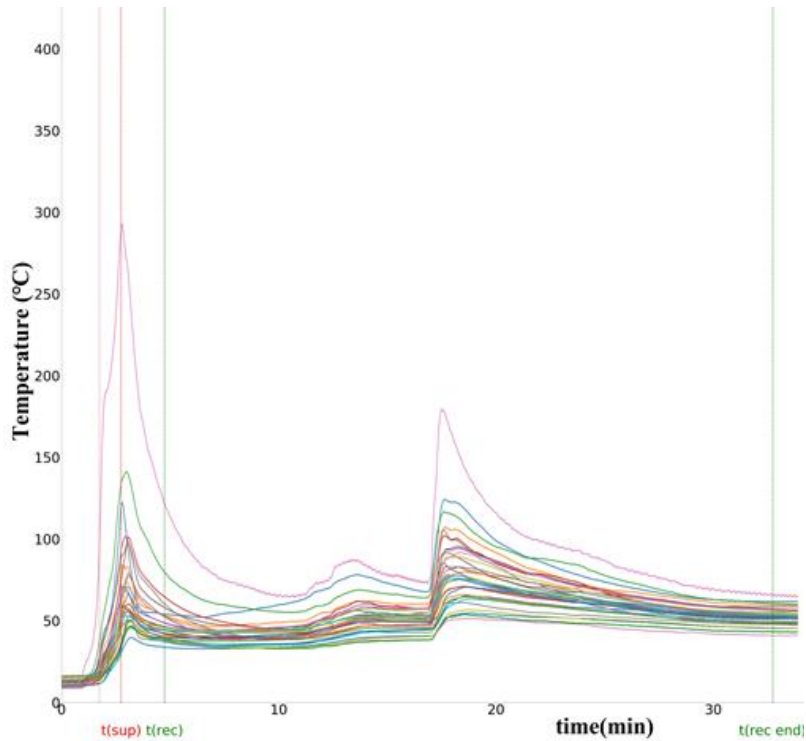
LOWER LAYER						UPPER LAYER					
6	5	4	3	2	1	12	11	10	9	8	7
18	17	16	15	14	13	24	23	22	21	20	19
30	29	28	27	26	25	36	35	34	33	32	31
42	41	40	39	38	37	48	47	46	45	44	43
54	53	52	51	50	49	60	59	58	57	56	55
66	65	64	63	62	61	72	71	70	69	68	67
78	77	76	75	74	73	84	83	82	81	80	79
90	89	88	87	86	85	96	95	94	93	92	91
102	101	100	99	98	97	108	107	106	105	104	103
114	113	112	111	110	109	120	119	118	117	116	115
126	125	124	123	122	121	132	131	130	129	128	127
138	137	136	135	134	133	144	143	142	141	140	139
150	149	148	147	146	145	156	155	154	153	152	151
162	161	160	159	158	157	168	167	166	165	164	163
174	173	172	171	170	169	178	177	176	175	174	173

LEGEND

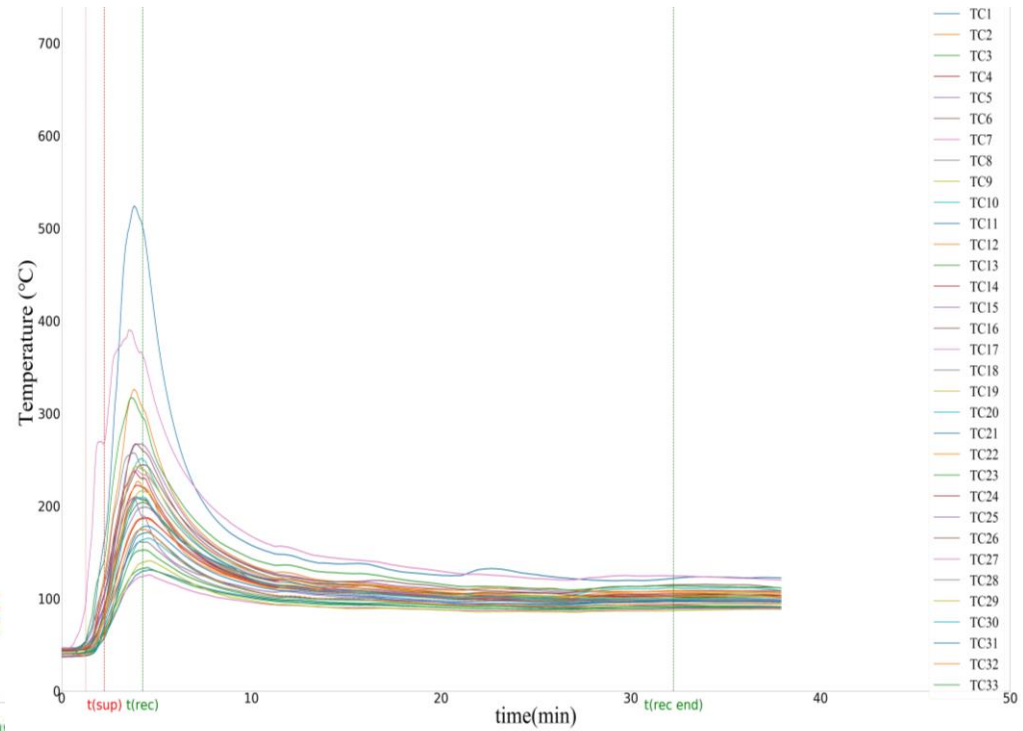
	Intact Boxes
	Partially Burned Boxes
	Totally Burned Boxes
	Not Installed

RED NUMBERS : IGNITER BOX

Burnt cardboard boxes pattern



Suppressed



Unsuppressed

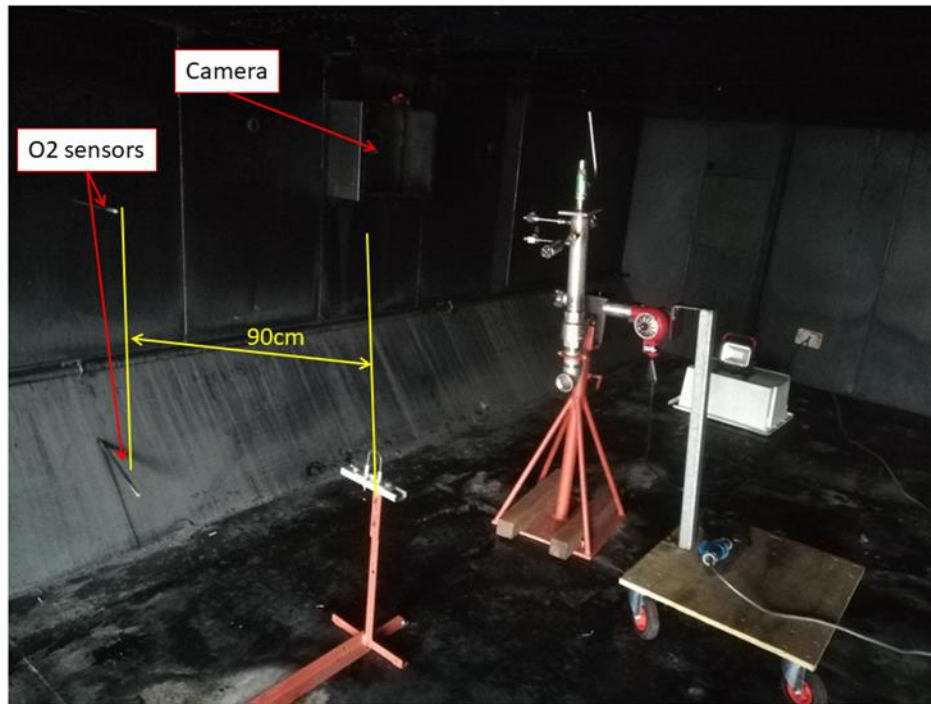
Temperature distribution for Bulk Load scenario

Summary of Fire Tests Results

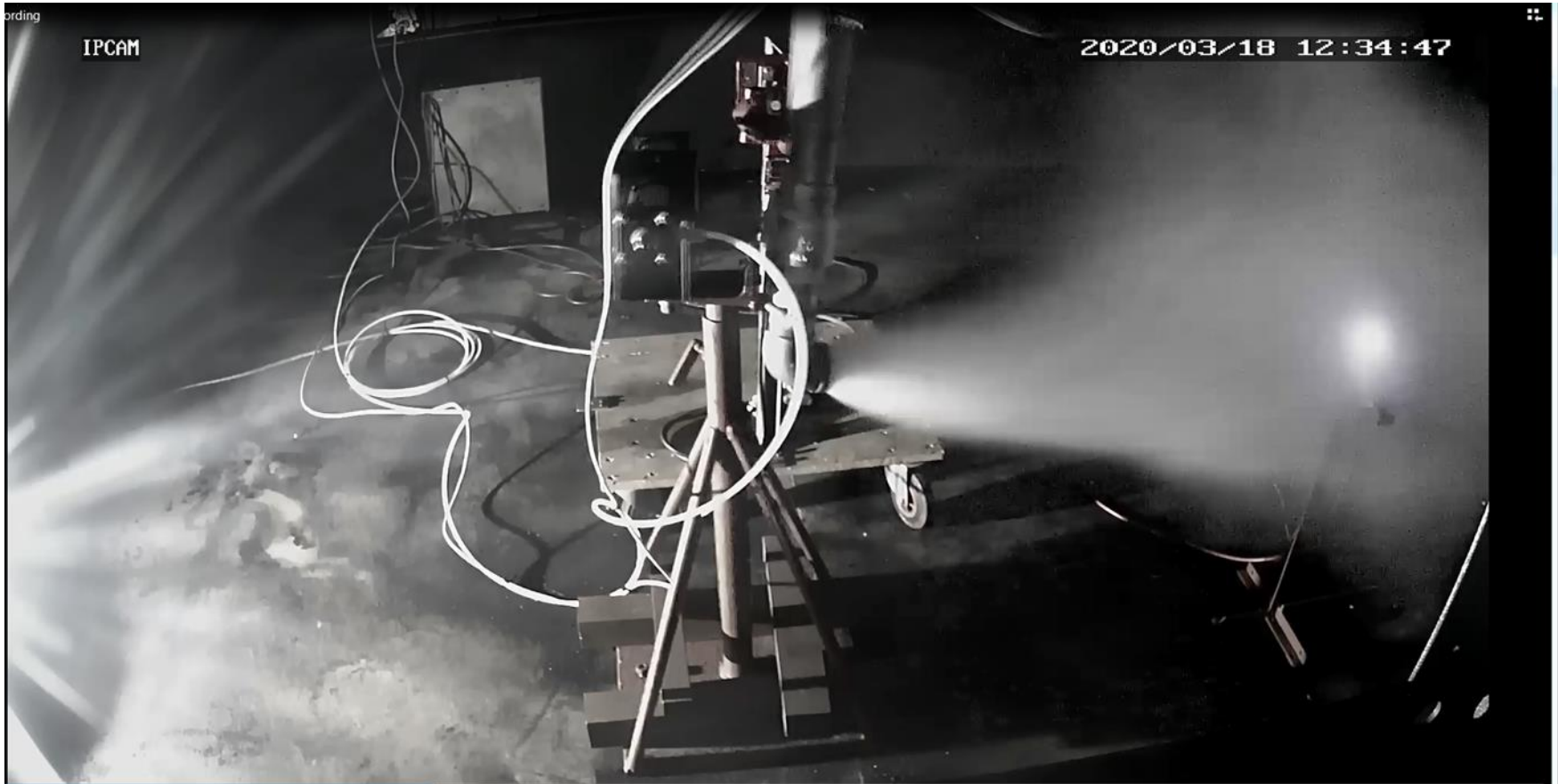


Test Scenario	T/C Location of Max temp	Averaged Max temp (°C)	Max temp limit (°C)	Averaged Max temp – time area over time (°C - min)	Max temp - time area Limit (°C - min)	Result
Surface Burning	TC18	219	293	498	608	PASS
Containerised Load	TC17/18	210	343	4711	7569	PASS
Bulk Load	TC11/17	255	477	2949	4974	PASS

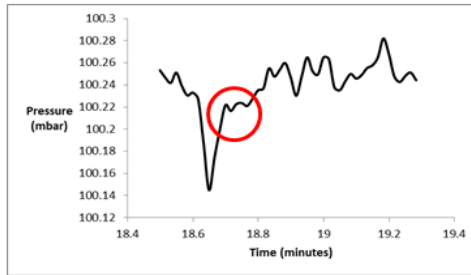
The values shown are the average values of the results of the 5 suppressed runs for each scenario



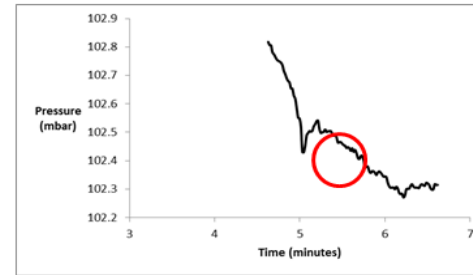
Arrangement for Aerosol Explosion test runs



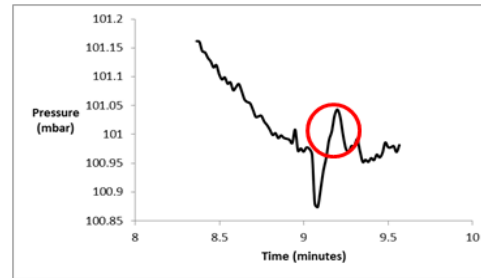
Pressurised mist discharge



Run 2



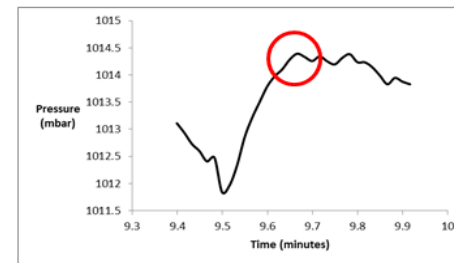
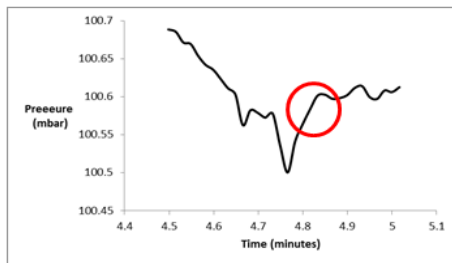
Run 4



Run 5

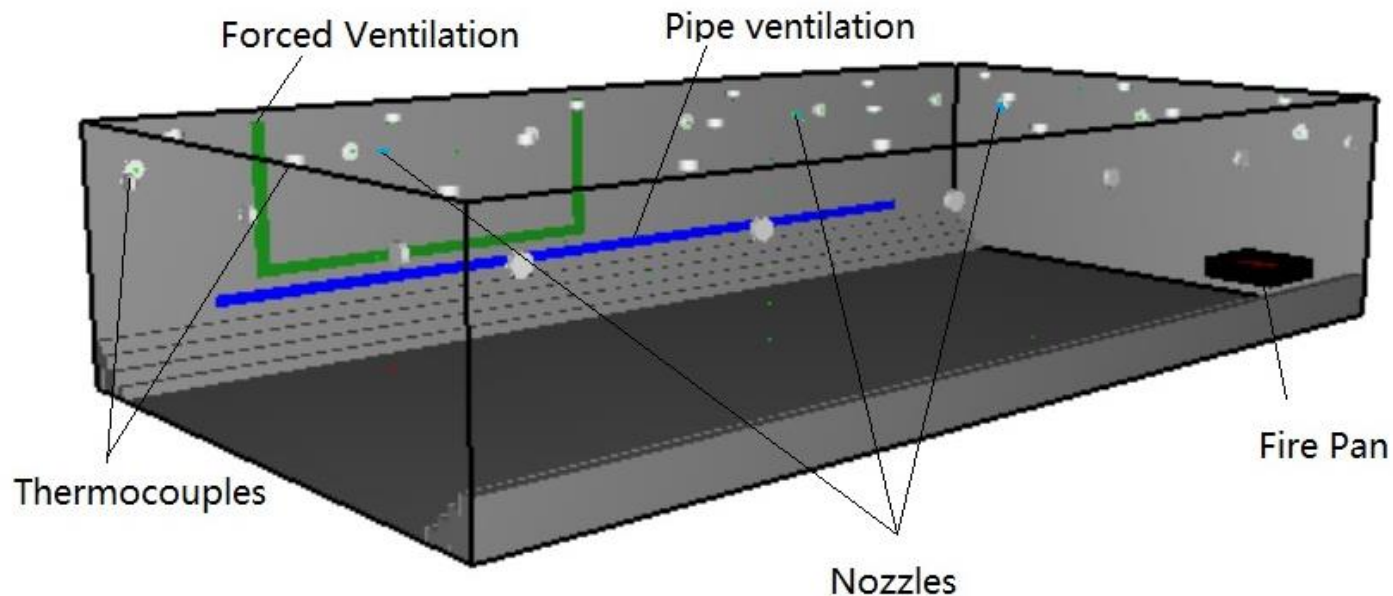
Run 6

Run 3



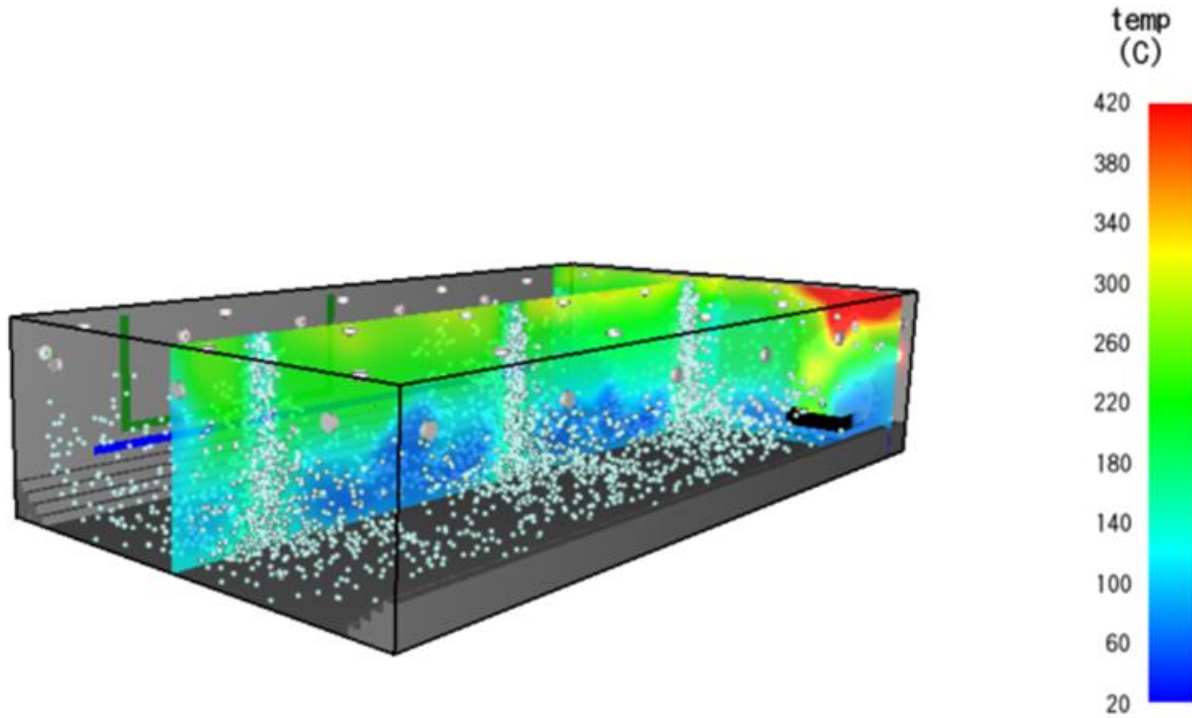
Compartment pressure rise during mist discharge –
Rise between 0.51 - 2.55 mbar

- Gas Expansion Predictive (GEP) model developed with CFD
- Capable of assessing flow features in single and multiphase flows
- Fire simulated with Pyrolysis model and then with tanh growth rate applied
- CFD results validated against experimental data

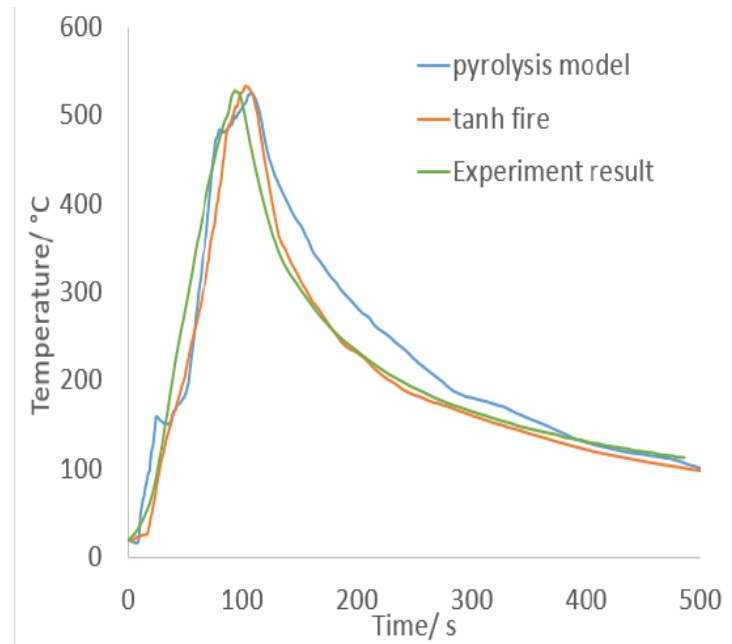
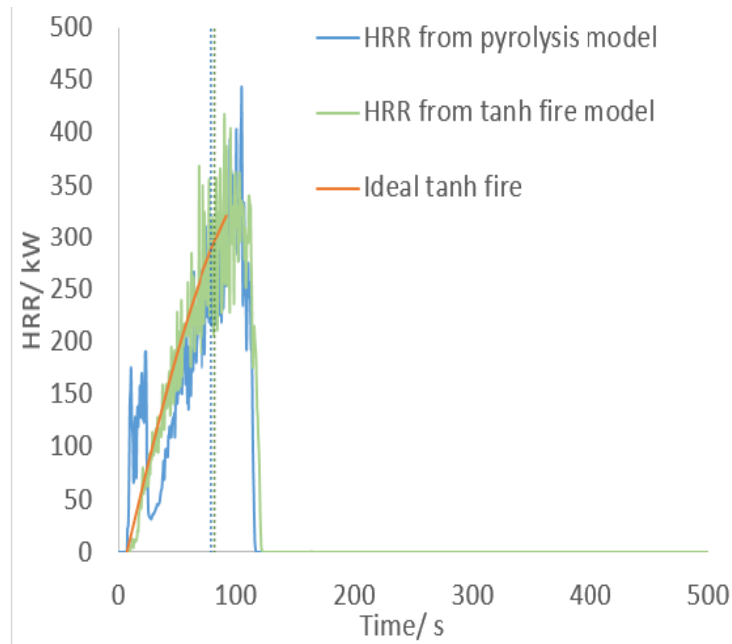


CFD geometry for Surface Burning scenario

Additional Work



Visualization of CFD model for Surface Burning scenario



Comparison of CFD models results and experimental data for Surface Burning scenario

- All tests competed with excellent safety record
- Preliminary design of Nitrogen Knock Down system function satisfactory
- All 4 test scenarios passed the MPS criteria
- Surface burning test runs highly consistent between runs
- Randomness observed in temperature profiles of Bulk Load and Containerised cases
- No explosion or overpressure observed in Aerosol Explosion runs
- CFD prediction model obtained satisfactory simulation of actual fire events



Relevant Publications

1. Performance evaluation of nitrogen for fire safety application aircraft
Journal publication – Reliability Engineering and System Safety (2020) 202. Issue 107044. Doi:
<https://doi.org/10.1016/j.ress.2020.107044>
Authors: A Dinesh, CM Benson, PG Holborn, S Sampath, Y Xiong
2. Numerical assessment for aircraft cargo compartment fire suppression system safety Journal
publication – Journal of Fire Sciences (2021). Doi: 0.1177/07349041211003208/ ID: JFS-20-0147.R2
Authors: Y Xiong, M Diakostefanis, S Sampath, A Dinesh, T Nikolaidis
3. A fast-convergence algorithm for reliability analysis based on the AK-MCS, Journal publication -
Reliability Engineering & System Safety, Volume 213, 2021, 107693,ISSN 0951-8320
<https://doi.org/10.1016/j.ress.2021.107693>.
Authors: Y Xiong, S Sampath
4. Environmentally-friendly fire suppression for aircraft cargo safety Journal Publication – Journal of Fire
Sciences (2021).
<https://doi.org/10.1177%2F07349041211034456>
Authors: M Diakostefanis, S Sampath, A Dinesh, R Beurman, A Malkogianni



Relevant Publications

5. Environmentally-Friendly Fire Suppression System for Cargo using Innovative Green Technology
Conference presentation - Ninth Triennial International Aircraft Fire and Cabin Safety Research Conference. Presented by: Michael Diakostefanis (October 2020)
Authors: M Diakostefanis, A Dinesh, S Sampath
Location: Atlantic City, New Jersey, USA
6. Challenges for the development of EFFICIENT – An Environmentally Friendly Fire Suppression System for Cargo using Innovative Green Technology
Conference presentation – Institute of Fire Engineers RE16
Presented by: Fernandez-Cerezo (Nov 2016)
Authors: G Fernandez-Cerezo, CM Benson, PG Holborn, D Mba
Location: Birmingham, UK
7. Fire Suppression systems in aircraft : Their past, present and future
Journal publication – Fire Investigation (2016) 1(3) pp 34-41
Authors: CM Benson, G Fernandez-Cerezo, PG Holborn, D Mba
8. Article on MPS published by CORDIS, Cranfield University
(https://cordis.europa.eu/article/id/429163-safe-and-environmentally-friendly-solutions-for-fire-suppression-in-aircraft-cargo-holds?WT.mc_id=exp)
9. CFD investigation of halon-free agent for aircraft propulsion fire suppression system
Conference paper – ISABE 2022
Authors: A Dinesh, M Diakostefanis, S Sampath, N Powell
Location: Ottawa, Canada



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