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Publisher's version / Version de l'éditeur:

Fire Suppression & Detection Research Application Symposium: Proceedings: February 24-26 1999, Orlando, Florida, pp. 196-206, 1999

Fire Suppression Testing of Inert Gas Agents in a 120 m^3 Enclosure

Fire Suppression & Detection Research Application Symposium

Orlando, FL, 24-26 February 1999

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ABSTRACT

A series of full-scale fire suppression tests were conducted to evaluate pure argon and an inert gas mixture in applications where total flooding of an area is required. The tests were conducted in a 120-m^3 compartment. The design concentration of the agents used in most of the tests was 40%. The test fires simulated electronic-cabinet fires, wood-crib fires, liquid-pool fires and spray fires. Information on discharge characteristics and fire suppression performance of the inert gas agents was obtained.

IG-541 was uniformly distributed throughout the compartment during the tests. The distribution of argon became non-homogeneous as time evolving – its concentration became low in the top part of the compartment but high in the bottom part of the compartment. Argon is,

therefore, good at protecting an enclosure where potential fire sources are most likely located on the floor or at the lower part of an enclosure. On the other hand, IG-541 is a better choice of the two if potential fire sources are randomly located.

Both agents extinguished the test fires by reducing the oxygen concentration in the compartment. Small fires were challenging for the inert gas agents to extinguish. Although large fires were easy to extinguish by the inert gases, the oxygen concentration in the compartment fell to below 10% in some tests, which can cause asphyxiation if personnel are trapped in a confined space. An early fire detection system should be an integrated part of the inert gas fire suppression systems so that a fire can be extinguished before it is getting large; otherwise, enough time should be allowed for evacuation before discharge.

1 INTRODUCTION

Most commercialized halon replacements (i.e., halocarbon agents) have a global warming potential. They may be subject to regulation in future developments to the Kyoto Protocol. The most environmentally safe agent is logically made from the natural ingredients of the atmosphere.

The National Research Council of Canada (NRC) completed a series of full-scale tests to evaluate inert gas agents for fire suppression applications. Pure argon and an inert gas mixture (IG-541: 52% N_2 + 40% Ar + 8% CO_2 by volume) were evaluated in the total flooding mode. This paper describes full-scale fire testing and provides test results.

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2 FULL SCALE TEST SET-UP

A series of full-scale tests were conducted to evaluate the performance of argon and IG-541, respectively. The design concentrations of gaseous agents for fire suppression systems were often based on the Cup Burner tests. General practice was to use the Cup Burner extinguishing concentration plus a safety factor as the minimum design concentration for an agent. In the Cup Burner tests, the concentration of IG-541 for extinguishing heptane flame is 29% by volume; the concentration of argon is 38% for extinguishing heptane flame and 27% for extinguishing toluene flame [1, 2]. In NRC full-scale tests, the two inert gas agents were tested at a concentration of 40% for the heptane fuel; argon was also tested at 34% for the toluene fuel.

2.1 Test Compartment

Full-scale suppression tests were conducted in a 121 m^3 compartment, which simulated Radar Room No. 2 on the Canadian Navy Halifax Class frigates, as shown in Figure 1. The rectangular test compartment had dimensions of 9.7 m in length, 4.9 m in width and 2.9 m in height. The test compartment was relatively airtight. Fan pressurization tests indicated that the compartment had an equivalent leakage area of 0.014 m^2.

Since a rapid injection of a large quantity of the inert gases into the compartment could cause sudden over-pressurization to occur, a pressure relief vent (0.5 m by 0.5 m) was used to prevent damage to the enclosure during the discharge of the agent. During initial 10 s of the discharge, the louvres of the pressure relief vent were kept open.

Three thermocouple (TC) trees were placed in the compartment to monitor the compartment temperature during the tests. Each TC tree was 2.8 m high and contained six thermocouples. Nine pressure taps were installed on the west wall at three elevations (0.29, 1.47 and 2.67 m) and connected to pressure gauges to monitor the compartment pressure during the tests.

CO_2/CO and O_2 analyzers were used to measure the concentrations of CO, CO_2 and O_2 in the test compartment during the fire tests. The analyzers were connected to two sampling ports mounted on the west wall. The sound level in the compartment was measured using a broadband sound meter. Video cameras were set up at three observation windows to obtain visual records.

2.2 Piping System

The real frigate room was installed with a two-nozzle Halon 1301 piping system. The existing Schedule 80 distribution pipes were used in the tests, as shown in Figure 1. The main distribution pipe started with an inside diameter of 38 mm for 6.48 m and branched to two smaller diameter pipes at a side-opening reducing tee. The through-branch (32 mm inside diameter) of the tee continued for 1.68 m to a down-turned elbow. The side-branch (32 mm inside diameter) of the tee continued for 2.7 m to a down-turned elbow. Special discharge nozzles, agent cylinders and manifold connecting cylinders to the distribution pipes were provided by Ansul Inc. (for the IG-541 tests) and by Control Fire Systems Ltd. (for the argon tests). Pressure transducers and thermocouples were installed along the pipe to monitor the flow inside the pipe during discharge.

For the IG-541 tests, two discharge nozzles were used. A nozzle, shown in Figure 2, was installed at each down-turned elbow at the ceiling of the compartment. The nozzles were cylindrical with 8 holes around the nozzle axis. The discharge orifice was 15.5 mm in diameter for the south nozzle and 14.7 mm for the east nozzle, respectively. Five cylinders (0.28 m in diameter and 1.57 m in height) were used in each test and IG-541 was pressurized at a pressure of 150 bar. The discharge valve for the cylinders was activated manually.

For the argon tests, four discharge nozzles were used. Two sprinkler-like nozzles, shown in Figure 3, were installed at each down-turned elbow at the ceiling of the compartment. The discharge orifice was 11.0 mm in diameter for the south nozzles and 10.3 mm for the east nozzles, respectively. Argon was pressurized in cylinders at a pressure of 150 bar. Six cylinders (0.23 m in diameter and 1.48 m in height) were used to achieve the 40% concentration and five cylinders were used to achieve the 34% concentration in the compartment. The discharge valve was activated electrically.

2.3 Fire Scenarios

The test fires simulated electronic-cabinet fires, wood-crib fires, liquid-pool fires and spray fires, creating different fire scenarios. Liquid fuel was heptane or toluene.

Figure 4 shows Fire Scenario 1. It included tell-tale (TT) fires and square-pan (SP) fires. Each TT was a 75 mm diameter can containing 20 mL of liquid fuel. The TTs were placed strategically throughout the compartment. Each SP (0.3 m x 0.3 m) contained 425 mL of liquid fuel. Two SPs were placed on the floor at the southeast corner and the northwest corner. Another SP was placed midway up the wall in the southwest corner. (Each SP was placed 50 mm away from the walls.) Ignition of the test fires started 30 s before discharge. The TT and SP fires were sequentially ignited using torches.

Figure 5 shows Fire Scenario 2. It included TT fires, SP fires and a large round-pan (RP) fire. The RP (0.7 m in diameter) contained 2 L of heptane fuel, producing a fire with an estimated heat release rate of 400 kW. The RP was placed on the floor at 1.32 m to the east wall and 1.45 m to the south wall. The TTs and SPs were placed at the same locations as in Scenario 1. Ignition of the test fires started 30 s before discharge. The TT fires were first ignited, and then the SP fires and finally the RP fire were sequentially ignited using torches. The total heat release rate was estimated to be 600 kW.

Figure 6 shows Fire Scenario 3. It included simulated electronic-cabinet fires and Class A wood-crib (WC) fires. An electronic switching gear cabinet (SGC, 0.75 m x 0.61 m x 2.1 m) was placed against the east wall near the door. This metal cabinet had ventilation grilles on the sides. A tell-tale can was placed at the bottom of the metal cabinet. A 0.4-m long cable bundle in a PVC slotted cable ladder was mounted vertically in the upper portion of the metal cabinet. Three other mock-up cabinets (MC, 0.81 m x 0.81 m x 1.0 m) were made of polycarbonate plastic sheets, each with two small grille openings. MC-1 and MC-2 had an opening ratio of 5% (ratio of the opening area over the total surface area of the cabinet) and were placed one on top of the other. MC-3, with an opening ratio of 2%, was placed on the floor. Each mock-up cabinet had a tell-tale can inside. The wood crib was made of pine sticks (40 mm x 40 mm x 600 mm) in 6 layers, with a size of 0.6 m x 0.6 m x 0.24 m, and was placed in the southwest corner on the floor. The wood crib was ignited 120 s before discharge in order to have a fully developed fire. Ignition of the in-cabinet fires started 30 s before discharge. The heat release rate was estimated to be 400 kW.

Figure 7 shows Fire Scenario 4. It included a RP fire and a spray fire. Both fires were shielded. The circular RP was covered with a box made of perforated sheet steel. The meshed metal sheet had an opening ratio of 33% for the sides of the box and an opening ratio of 6% for the top of the box. The liquid fuel was sprayed from a fuel nozzle at an operating pressure of 5.8 bar for the IG-541 tests or 8.3 bar for the argon tests. A metal table (1 m wide x 1.36 m long x 0.61 m high) was used to cover the fuel nozzles and shield the spray fire. Ignition started 20 s before discharge. The RP fire was first ignited, and then the spray fire was ignited.

To determine fire extinguishment times, thermocouples were placed at each fire location. To minimize oxygen consumption by the fires, the compartment door was kept open during the pre-burn. For each fire scenario, the ignition sequence was the same and the pre-burn time was the same in different tests. The door was closed when the discharge started. After extinguishment had been achieved, re-ignition of the fuel pans or spray was attempted using electrical heating ignitors. Table 1 shows a matrix of the parameters used in the tests.

Table 1. Test Matrix and Fire Extinguishment Time

Agent	Agent Concen-tration	Fuel	Discharge Time (90% complete)	8 TT's	8 TTs 3 SPs (Scenario 1)	8 TTs 3 SPs RP (Scenario 2)	WC Cabinets (Scenario 3)	Spray RP (shielded) (Scenario 4)
IG-541	40%	heptane	45 s	5-25 s	5-15 s 15-46 s	5-10 s 10-37 s 35 s	27 15-30	23 s 40 s
Argon	40%	heptane	45 s	8-37 s	2-91 s 190-207 s	2-27 20-31 30	41 10-48	30 35
Argon	34%	toluene	—	—	2-37 84-97 s	—	—	48 38

3 RESULTS AND DISCUSSIONS

The compartment remained visible during the discharge. Figures 8 and 9 show discharge characteristics for IG-541 and argon, respectively. Based on the measured oxygen concentration during the discharge tests, the concentration of the agent in the compartment achieved the design values for both agents. For both agents, the discharge time to release 90% of the agent from the cylinders was approximately 45 s, which was determined using the time profiles of pipe pressure and temperature and compartment sound level.

During the discharge, the maximum pipe pressure was 52 bar for the argon tests and 58 bar for the IG-541 tests. The pipe temperature dropped by 20 to 40°C, depending on position, as a result of agent expansion.

The maximum sound level measured inside the compartment was 128 dB during the IG-541 tests and 85 dB during the argon tests. (In previous halocarbon tests conducted by NRC in the same compartment, the maximum sound level was 122 dB). It appeared that the lower sound level during the argon tests was due to the increased number of nozzles used.

When the agents were discharged into the compartment, the compartment temperature generally decreased and the compartment pressure had a positive pulse. The magnitude of the temperature and pressure changes depended on the agent quantity and compartment conditions. When the fire size was getting larger, the agent cooling effect became less obvious and the positive pressure pulse became larger in the compartment. The largest pressure pulse in the compartment was 540 Pa for the IG-541 tests and 580 Pa for the argon tests, which was bearable for most of building structures.

IG-541 and argon extinguished the test fires by reducing the oxygen concentration in the compartment to a level that no longer supports combustion. Therefore, they did not produce any by-products during fire suppression. All the gas products generated during the suppression tests came from the combustion of the fuels.

For the IG-541 tests, all unshielded tell-tale fires were extinguished in 5-25 s after the start of the agent discharge and all in-cabinet fires were extinguished in 15-30 s. The extinguishment of the SP-3 fire in Fire Scenario 1 took 46 s, the longest extinguishment time among all for the IG-541 tests. Larger fires were extinguished more quickly than this SP-3 fire since larger fires consumed more oxygen, which accelerated fire extinguishment. The large round-pan fire was extinguished in 35 s in the test with no shielding and 40 s in the test with shielding, respectively. The shielded spray fire was extinguished in 23 s and the wood crib fire was extinguished in 27 s. The IG-541 concentration (40%) used in the tests was 1.4 times the Cup Burner value for the heptane fuel. All the fires were extinguished well before discharge was completed.

The 40% concentration of argon used in the tests was 1.2 times the Cup Burner value for the toluene fuel; the 34% concentration was 1.05 times the Cup Burner value for the heptane fuel. In the tests with Fire Scenarios 2, 3 and 4, all fires were extinguished within 48 s after the start of the discharge; in general, extinguishment times were shorter for the unshielded fires. Since Fire Scenario 1 had a relative small fire size, this scenario also resulted in the most challenging fires for argon to extinguish by means of oxygen depletion. The extinguishment of the three SP fires took place later than the completion of the discharge.

When the fire size was small (tell-tale fires alone or Fire Scenario 1), the oxygen concentration in the compartment was above 12% after the discharge of the two agents, respectively. However, when the fire size became large, the oxygen concentration in the compartment fell to below 10%. Even for the design concentration of 34% argon, the oxygen concentration dropped to 9.5% during the test using the shielded toluene RP and spray fires. Such low oxygen concentrations can cause asphyxiation if personnel are trapped in a confined space in a fire event. This implicates that an early fire detection system must be an integrated part of the inert gas fire suppression systems so that a fire can be extinguished before it is getting large. Otherwise, enough time should be allowed for evacuation before discharge.

After fire extinguishment, several re-ignition attempts were made. In the absence of ventilation, both agents were effective in preventing re-ignition to occur. As shown in Figure 8, the measured O_2 concentration indicates that the IG-541 concentration was maintained and uniformly distributed at different heights in the compartment for an extended period of time. The measured O_2 concentration, as shown in Figure 9, indicates that the argon distribution became non-homogeneous as time evolving during the test. Argon is heavier than air. This induced a hydrostatic pressure difference between the inside and the outside of the compartment, causing a gradual air exchange between the inside and the outside through cracks along the door, windows, etc. The argon concentration became low in the top part of the compartment but high in the bottom part of the compartment. Argon is, therefore, good at protecting an enclosure where potential fire sources are most likely located at the lower part of the enclosure. However, if potential fire sources are randomly located, IG-541 is a better choice of the two since it can distribute homogeneously throughout the compartment for an extended period of time.

4 CONCLUSIONS

During the discharge of both inert gas agents, there was a positive pressure pulse in the compartment, which increased with increasing fire size. By the use of a pressure relief vent, the largest pressure pulse was 540 Pa for the IG-541 tests and 580 Pa for the argon tests, which was bearable for most of building structures. It appeared that increasing the number of nozzles could reduce the discharge sound level.

IG-541 and argon extinguished the test fires by reducing the oxygen concentration in the compartment. Most of the fires were extinguished well before discharge was completed. In general, extinguishment times were shorter for the unshielded fires than that for the shielded fires. Small fires were challenging for the inert gas agents to extinguish and large fires were easy to extinguish by the inert gases. However, when the fire size became large, the oxygen concentration in the compartment fell to below 10% in some tests, which can cause asphyxiation if personnel are trapped in a confined space. An early fire detection system must be an integrated part of the inert gas fire suppression systems so that a fire can be extinguished before it is getting large. Otherwise, enough time should be allowed for evacuation before discharge.

IG-541 was uniformly distributed throughout the compartment during the tests. IG-541 is, therefore, a better choice of the two if potential fire sources are randomly located. Argon is heavier than air and the argon distribution became non-homogeneous as time evolving during the tests. Argon is good at protecting an enclosure where potential fire sources are most likely located on the floor level. To maintain the agent concentration, an enclosure must be sufficiently airtight and the ventilation system should be shut down.

ACKNOWLEDGEMENTS

The Department of National Defence Canada funded this research project. The authors wish to thank for their support to this study.

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Legends to Figures

Figure 1. Plan View of Test Compartment, Instrumentation and Piping System.

Figure 2. Nozzle for IG-541.

Figure 3. Nozzle for Argon.

Figure 4. Fire Scenario 1.

Figure 5. Fire Scenario 2.

Figure 6. Fire Scenario 3.

Figure 7. Fire Scenario 4.

Figure 8. Discharge Behaviour of IG-541.

Figure 9. Discharge Behaviour of Argon.

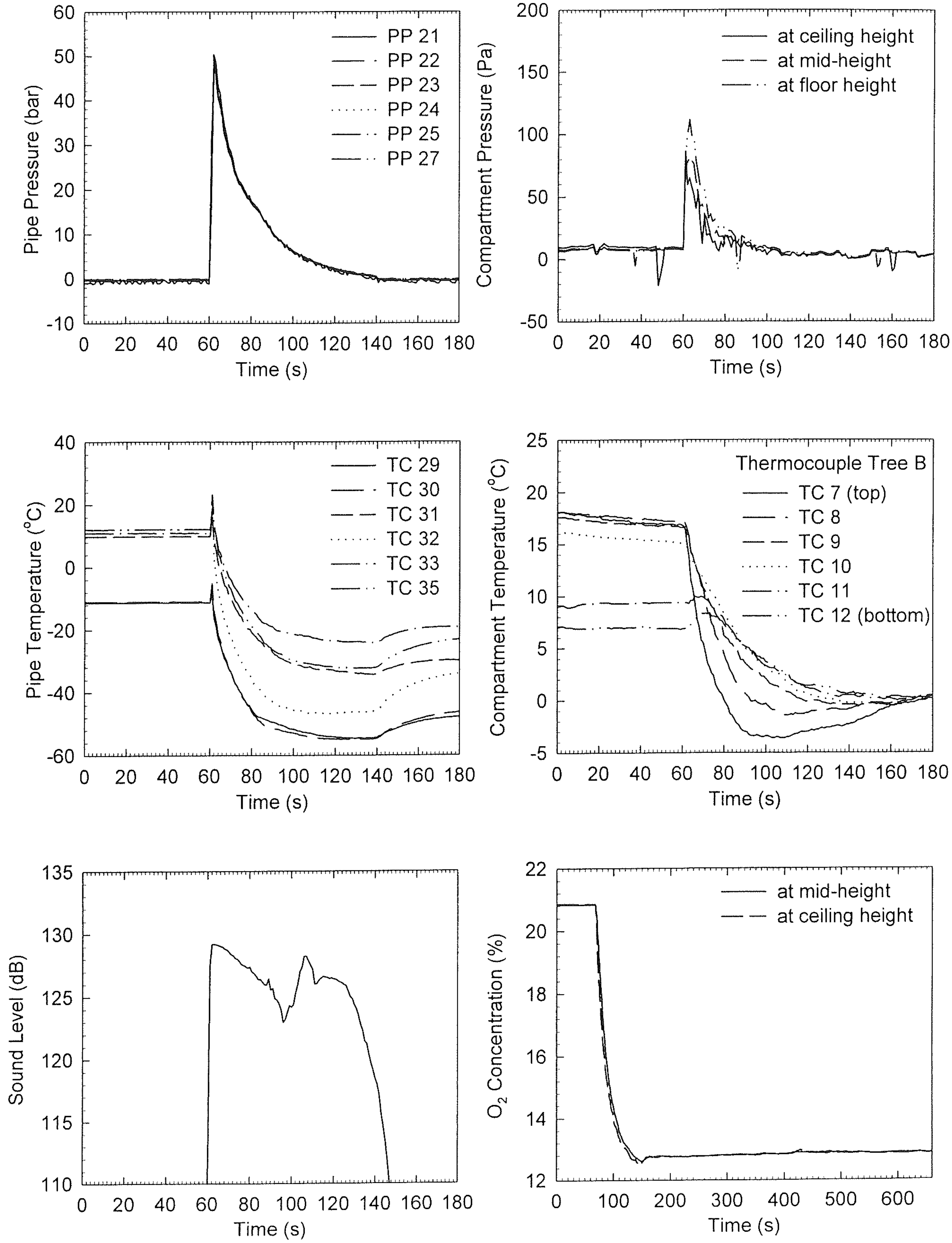

Figure 8. Discharge Behaviour of IG-541.

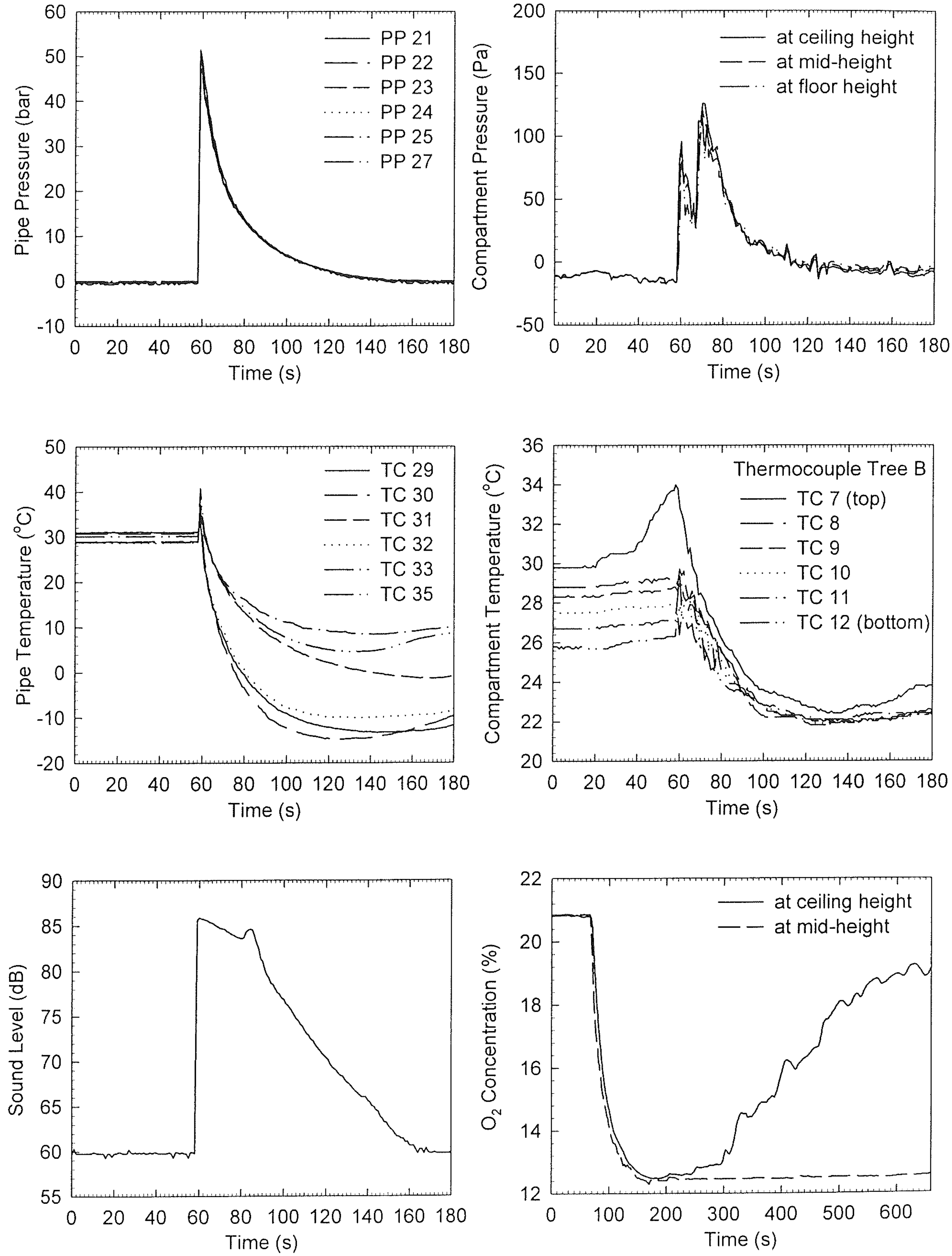

Figure 9. Discharge Behaviour of Argon.