DEVELOPMENT OF A 100% SOLID PROPELLANT BASED GAS GENERATOR FIRE SUPPRESSION SYSTEM

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ABSTRACT

ATK started the development of solid propellant based fire suppression technology systems in the summer of 2002. This project employed experiences learned in the 1990's during ATK's efforts to produce non-azide gas generants for use in the automobile airbag industry. The goals to produce low temperature, low toxicity gases for airbag inflation coincide well with requirements for clean agent, non-Halon based fire suppression. One gas generant developed for the airbag industry was particularly suited for fire suppression use. This generant produces a combination of nitrogen gas and water vapor with small amounts of carbon dioxide. This combination works efficiently to suppress fires by methods of oxygen depletion and reaction zone cooling due to water droplet vaporization-convection-condensation cycles (C_p of air is 1 J/g K, ΔH_{vap} of H_2O is 2256 J/g). Current gas generator fire suppression technology relies mainly on oxygen depletion and/or chemical suppression.

ATK's system is also suitable for use in occupied spaces due to low toxicity combustion products and elimination of chemical suppression agents. The combustion products from the generator have zero ozone depleting potential and zero halogen content.

Prototype generators have been developed, constructed and tested. The generators consist of a combustion chamber, an ignition system, a nozzle flow control system and heat management for gas cooling. Each generator is designed to protect a 250 ft^3 volume of room. These generators may then be spaced around rooms in any combination to provide coverage for larger volumes.

Current testing has been conducted in a 1000 ft^3 chamber containing four generators. Two heptane over water fires were placed within the chamber: one at ground level and one at 6 ft above ground level. Both fires were extinguished in less than 10 seconds. Temperatures, pressures and oxygen levels within the chamber were monitored during the test. Video coverage will be presented in the body of this paper.

INTRODUCTION

Early in 2002, ATK Thiokol was approached by N2 Towers Inc. with the concept of developing a patented inert gas generator based fire suppression system as a Halon 1301 replacement technology. Specifically the gases generated from the system were to have zero ODP, low GWP and low toxicity levels for use in normally occupied spaces.

Based on ATK developed technology for automobile airbag inflation systems and subsequent work on new gas generant formulations, the feasibility of such a system was deemed possible. Funding was obtained and development started in the summer of 2002.

BACKGROUND

Clean agent total flood fire suppression systems throughout the world have previously relied Halon 1301 to extinguish fires inside specific spaces. Halon 1301 is an ozone depleting compound and has global warming potential (GWP). HFC alternatives currently also have GWP concerns and are listed on the Kyoto Protocol Treaty.

There is a Halon 1301 alternative market need, for a compact, affordable, breathable, clean agent, inert gas generator total flood fire suppression system.

CONCEPT

The concept for this gas generator based fire suppression system was jointly developed by ATK and N2 Towers. The direction selected for the initial packaging was to build a gas generator to cover a room volume of 250 ft^3. These generators would then be housed in a tower distribution device in groups of four to cover rooms of 1000 ft^3. Multiple towers would then be used for larger volume spaces.

The target weight and space requirements for this system are to be equivalent or less than the requirements for other alternative total flood systems.

The system is to be compliant with the NFPA 2001 Standard and the UL 2127 test specification requirements for suppression of heptane and wood crib fires.

Data from inert gas only (N2, Ar) systems indicate that the room oxygen level must be dropped to below 14% in order to extinguish a fire. The NFPA 2001 Standard requires that an inert gas system must reduce oxygen levels inside a protected space to 12% by volume. Occupants must egress the protected space within 5 minutes, Therefore, the goal for this system is to meet this requirement or show that the specific combination of gases and water droplets from these generators will suppress fires at higher oxygen levels.

Other desired features would include that this be a pre-engineered system, which is rechargeable on-site (no pressurized cylinders), requires no discharge piping/delivery network, is suitable for normally occupied spaces and is environmentally friendly.

DEVELOPMENT

The initial development phase of this program consisted of selecting a baseline gas generant formulation, which could meet the concept design goals. Several years of ATK gas generant formulation experience in the air bag industry generated a wide variety of options. These generants were developed with application to the occupied space in the interior of an automobile. Therefore, all options were acceptable for the low toxicity and inert gas combustion products criteria.

Due to concerns over high CO_2 levels inside an occupied space, it was decided to narrow the formulation choices to those having a low total carbon content. In addition, to maximize environmental aspects, the formulation should contain little or no halogen compounds. A candidate was selected which is based on a metal complex fuel and a metal oxide for an oxidizer. The combustion gases from this generant consist of mainly nitrogen and water. In previous experience with this generant, it had been shown to produce very low levels of other combustion byproducts. An additional benefit to selecting this formulation is that it has the property of forming a sinter from the solid products of combustion. This sinter (Figures 1 & 2) is very efficient at capturing and retaining solids, thereby reducing the amount of filtering necessary prior to exhausting the gasses into an occupied space.

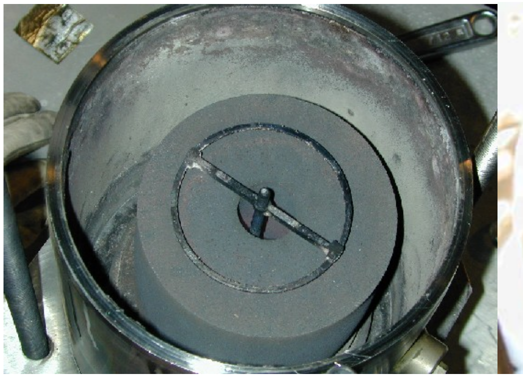

Figure 1 Pre-combustion Grain

Figure 2 Post-combustion Sinter

In the early stages of the development cycle, it was also decided that the generant would be formed into grains by high pressure consolidation in a mechanical press. This is a standard manufacturing process in the pyrotechnic industry. The grain geometry is calculated based on the desired mass flow rate and internal combustion pressure of the generator. The pressing of the selected formulation required that a small amount of polymeric binder be added to the generant in order to achieve acceptable mechanical integrity of the final grains.

Calculations and modeling estimated that ~10 pounds of this generant would be required to produce a sufficient gas volume to lower the oxygen level in a 250 ft^3 space to below 14%. Another early decision was made regarding the gas discharge time target for the system. The initial target was set at 10 seconds. The burn rate of this generant formulation was characterized and well known from previous work.

The major components required in any pyrotechnic gas generation include; a combustion chamber for containing the high temperature and high pressure burning process, an ignition system to quickly start the generant surfaces burning, and a nozzle to regulate the gas mass flow rate out of the generator.

Using the values calculated for gas discharge time, generant burn rate and the quantity of generant required, the remaining starting parameters were calculated using a combustion model. The combustion pressure was set at ~650 psig (nozzle), and the grain geometry and size were set.

Figure 3 Development Hardware Test Setup

Development hardware was manufactured to function under these starting parameters (Figure 3). Since many of these parameters are interactive, additional tuning was required. In an iterative process the initial development effort included determining these interactions and fine tuning the following: formulation fuel/oxidizer ratio, grain geometry for initial surface area and burn back profile, nozzle sizing, ignition methods and materials. All initial testing was performed on single gas generators, also no tower was employed at this stage.

The combustion products were monitored during the development cycle to demonstrate that this combination of the selected gas generant, hardware and ignition system would provide a non-toxic environment for occupied spaces. OSHA STEL (15 minute exposure) and IDLH levels were used as a guide (Table 1).

Table 1 Toxic Gas Measurements

Toxic Gases	Spring 2003	Summer 2003	Fall 2003	STEL (15 min)	IDLH
Carbon Dioxide (CO_2)	1.8%	0.2%	0.3%	3.0%	4.0%
Carbon Monoxide (CO) in ppm	2500	170	270	400	1200
Ammonia (NH_3) in ppm	<1	48	7	35	300
Nitrogen Monoxide (NO) in ppm	2470*	96	24	35	100
Nitrogen Dioxide (NO_2) in ppm	230*	9	<1	5	20

During the development, it was determined that a modification to the original approach for gas discharge time was necessary. Initially a few large grains were used to extend the gas discharge time to the 10 second target. Due to mechanical integrity issues with these grains, it was decided to use a larger quantity of small grains and decrease the gas discharge time to ~3 seconds. A rapid discharge time has the disadvantage of producing larger over pressures in the closed space. This could be compensated for with larger vents in the space. However, in this case it was decided to approach the over pressure problem by firing the four generators within a tower sequentially. Sequencing the generators at 2.5 second intervals allowed us to meet the initial total gas discharge target of 10 second without significantly increasing the space overpressure.

In order to accommodate this change, a new set of prototype hardware (Figure 4) was designed and tested. After again tuning the system, fixed sets of parameters were obtained for continuing into the next phase of testing. Figure 5 shows a combustion pressure curve for a gas generator.

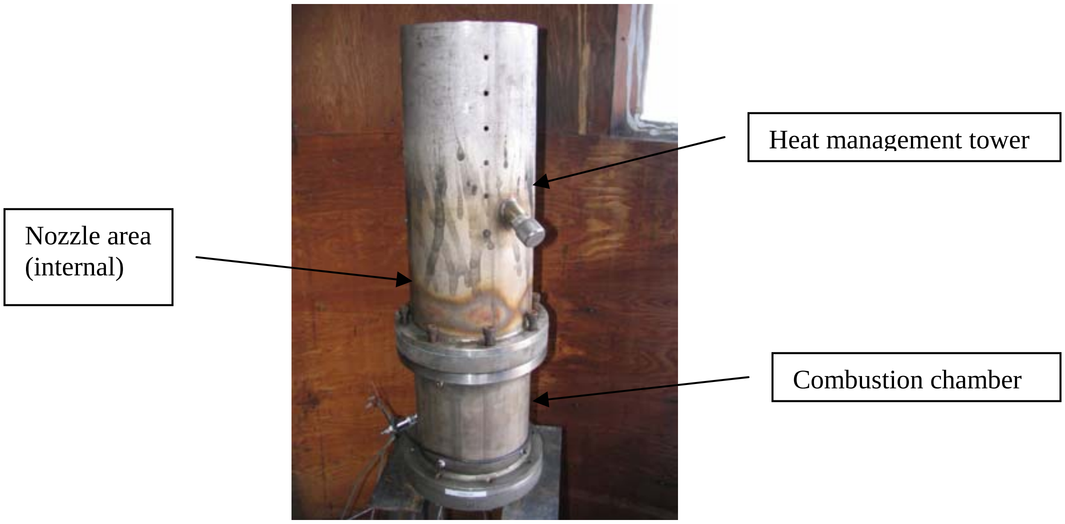

Figure 4: Prototype Hardware with Heat Management System

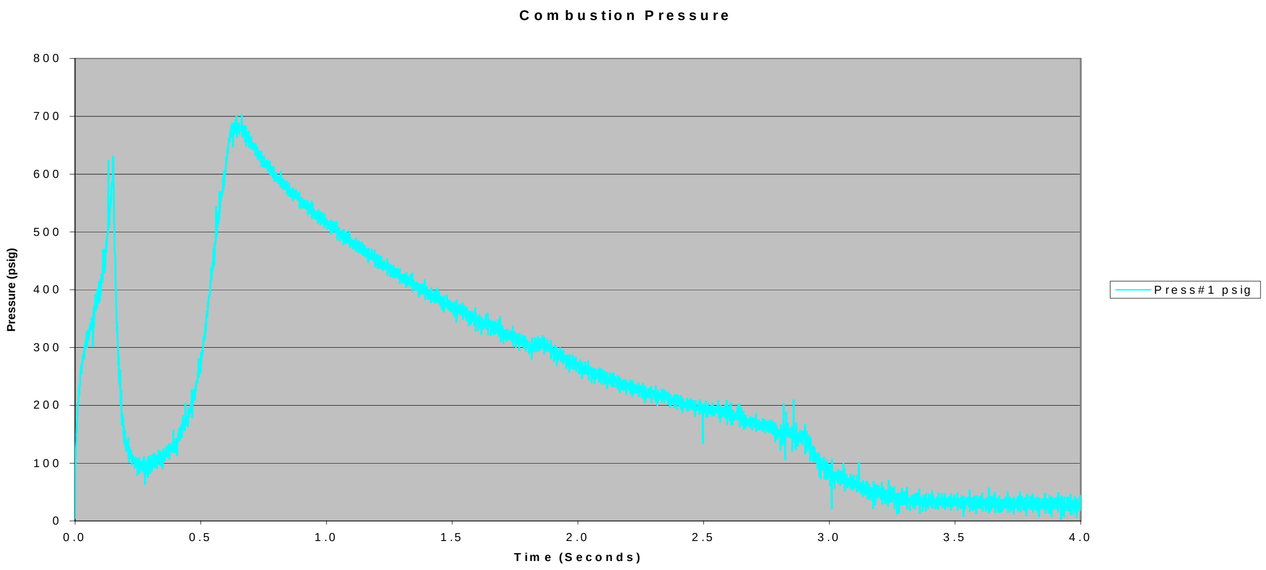

Figure 5 Typical Pressure - Time Curve for Generator

The NFPA 2010 Standard contains additional criteria that the discharge gas temperature from the distribution system must be <167 ºF. Since the combustion temperature of this gas generant can reach ~3000 ºF, a significant amount of cooling is required. This was accomplished through the design of a heat management system at the gas generator exhaust. Figure 6 shows a typical exhaust temperature profile from a gas generator. The temperature reaches ~185 ºF. This can be further adjusted by the quantity of heat management material used. However, it is expected that the tower surfaces will provide additional heat sink capacity in the future.

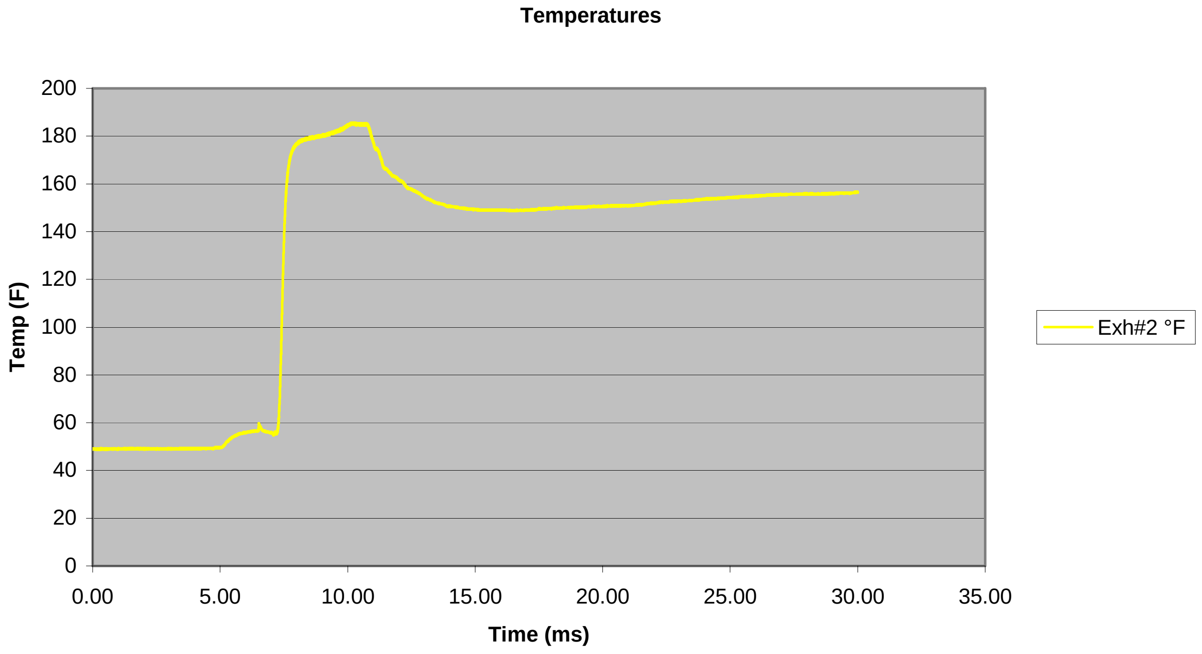

Figure 6 Typical Exhaust Temperature of a Gas Generator

As a consequence of this cooling requirement, the water vapor in the combustion products will start to condense. Since the condensing water has a much lower volume than the vapor, the oxygen dilution capacity in the protected space is lower. Modeling of this effect, predicted that the system would now reduce oxygen levels to ~15% instead of the target of <14%. In order to compensate for this, the generant mass would need to be increased.

However, information published in a prior HOTWC conference, indicates that a combination of water fog and reduced oxygen levels in the 16-18% range is very efficient in extinguishing fires [1]. Therefore, it was decided to proceed with testing using the current design.

FIRE SUPPRESSION TESTING

The next phase in development consisted of designing and building a test chamber for demonstrating the capability of this system to suppress a fire. A 1000 ft^3 chamber was designed to accommodate four gas generators in order to simulate the tower concept. The generators were not housed in a tower for these tests. The four generators were spaced evenly around the chamber as shown in Figure 7. Figure 8 shows the outside of the actual chamber.

The overall chamber ceiling height was set at 11 feet. Heptane fires were placed at center ground level and at the 6 foot level, 1 foot from a wall. Two roof vents provided a total vent area of 289 in^2. The chamber was instrumented with two video cameras for viewing the fires, three chamber temperature probes at top, middle and bottom, two temperature probes for gas generator exhausts, one chamber overpressure probe, an oxygen level monitor and combustion pressure transducers for the four generators.

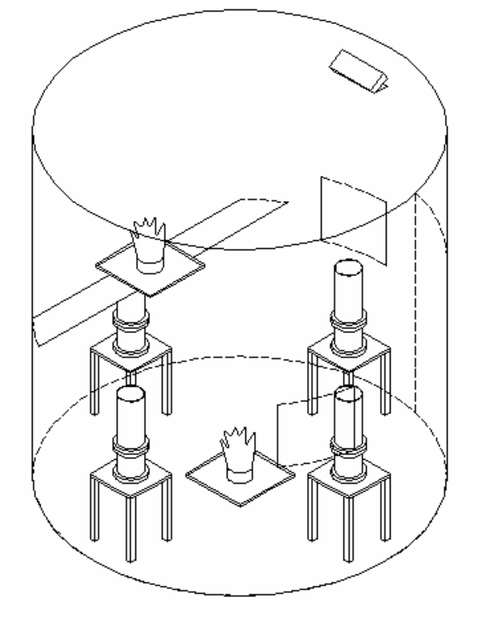

Figure 7 Test Chamber Diagram

Figure 8 Actual Test Chamber

Three full-scale demonstrations were performed with the four generators fired sequentially at 2.5 second intervals. In all three tests, the heptane fires were extinguished in less than 10 seconds from the time the first generator was initiated. The combustion pressures in the tests were nominal and consistent.

Figure 9 charts the results from one of theses tests. It shows a generator exhaust temperature of ~185 ºF as seen in previous tests and a maximum room temperature of ~120 ºF. The room overpressure (Figure 10) is below 1 in H2O in all instances.

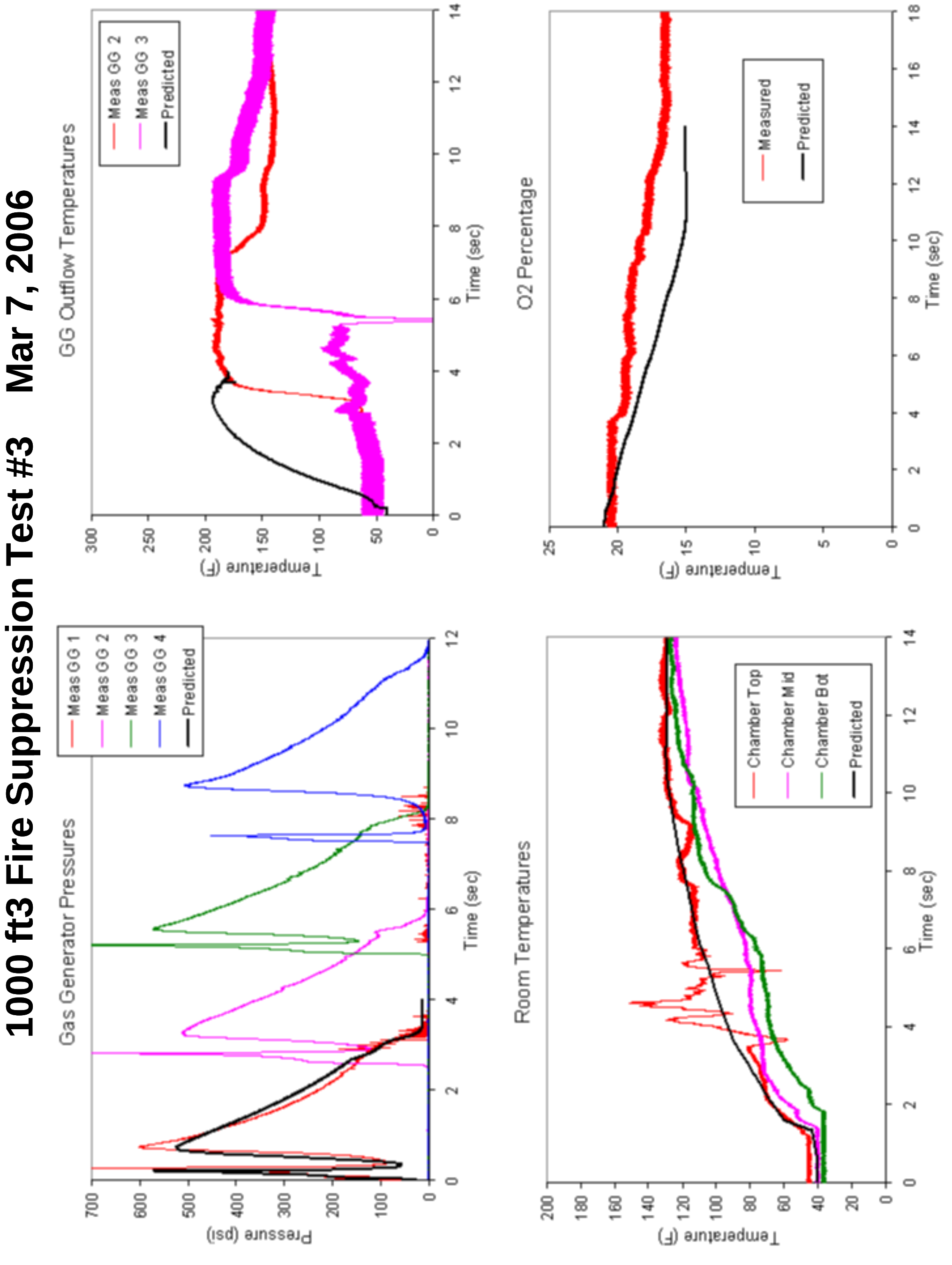

Figure 9 Data from Full Scale Fire Suppression Test

The oxygen level was reduced to ~15.7%. Predicted values were 15%. This is most likely due to additional water vapor condensation from lower ambient temperatures encountered during the testing. However, it is evident from the tests that the condensing water vapor is aiding in the suppression of the fires. The combination of lower oxygen level and water content works efficiently to suppress fires by methods of oxygen depletion and reaction zone cooling due to water droplet vaporization-convection-condensation cycles (C_p of air is 1 J/g K, ΔH_{vap} of H_2O is 2256 J/g).

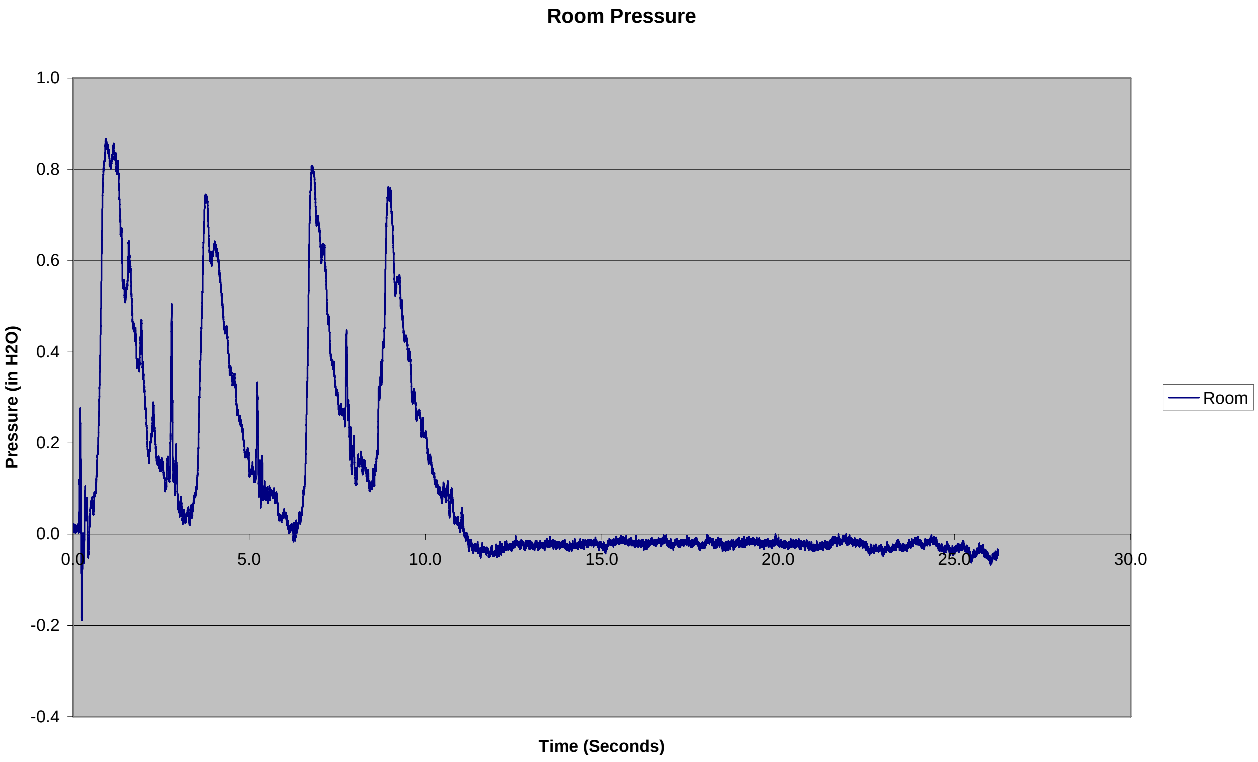

Figure 10 Chamber Overpressure

This gas generator technology has demonstrated excellent performance in applications with space and weight requirements equivalent to those of Halon 1301 and is a clean agent total flood alternative.

FUTURE DEVELOPMENT

The near term development efforts will be focused on the testing of the system to verify the ability to suppress other types of fires, e.g. wood crib, outlined in the UL 2127 test specification.

The next steps in the development of this system is to progress into production intent hardware, design and test the four generator tower arrangement, optimize all parameters and test the system to the NFPA 2001 Standard.

Concepts of the tower and protected space distribution arrangements are shown in Figures 11 & 12.

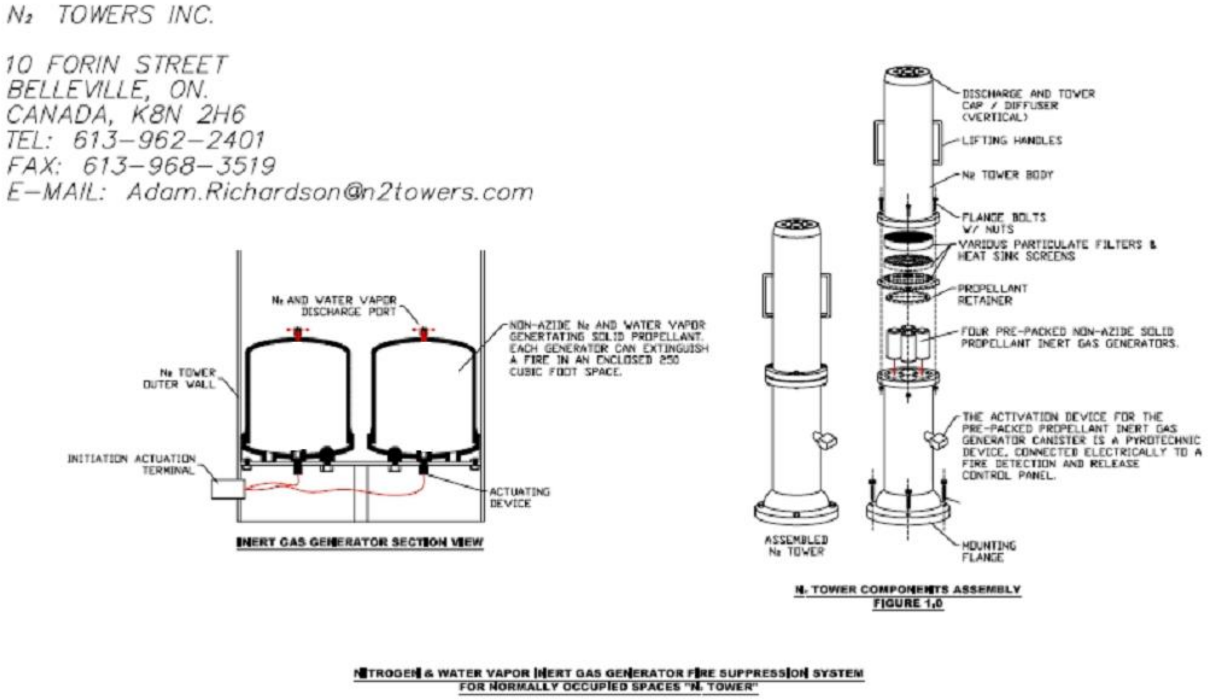

Figure 11 Tower Concept

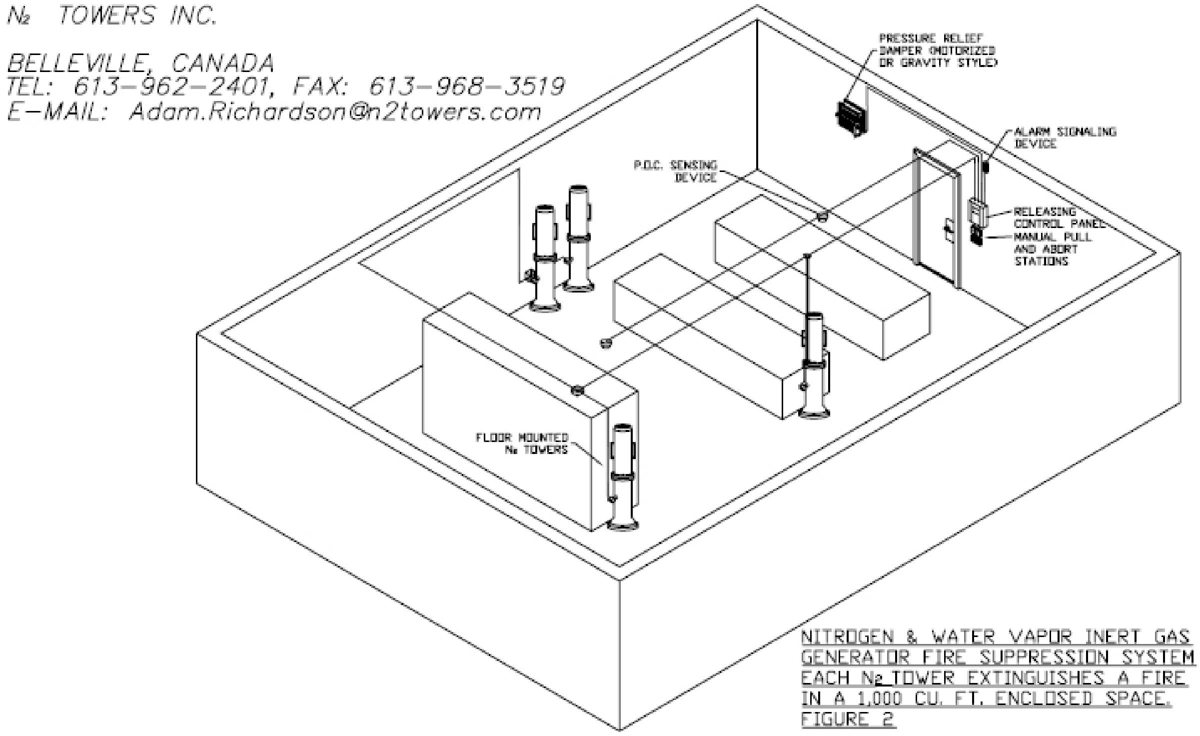

Figure 12 Protected Space Distribution Concept

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