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An Acoustic Emission Test for Aircraft Halon 1301 Fire Extinguisher Bottles

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Final Report

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16. Abstract

An acoustic emission test for aircraft Halon 1301 bottles has been developed, a prototype acoustic emission test system constructed, and over 200 used bottles tested at the repair facilities of the two manufacturers of these bottles. The system monitors a bottle with six acoustic sensors while the pressure of the bottle is raised by heating it in an oven. The sensors are held in position, with a fixed relationship between them, by a special fixture. This fixture is designed to fit spheres with diameters between 5 and 16 inches. Results of the tests on used bottles indicate that over 95 percent of the bottles showed no indication of significant defects. The rest had some indication of flaws or corrosion. However, all bottles tested to date have passed the hydrostatic test required by the U.S. Department of Transportation. Based upon this data, the Air Transport Association (ATA) requested an exemption from the DOT to allow their members to use this acoustic emission test in place of the hydrostatic test. This exemption, DOT - E 11850, was granted to the ATA on December 11, 1997.

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PREFACE

This project was funded by the Federal Aviation Administration (FAA) William J. Hughes Technical Center with in-kind support from the Air Transport Association (ATA). The author would like to thank Michael Bucke of American Airlines and Steve Jeung of United Airlines for supplying the halon bottles used in the experiment. Kamran Ghaemmaghmi of Federal Express provided both aid and encouragement. Steve Erickson, formerly of the ATA, was instrumental in getting this project started. Steve Lamb and Junior Bunn of Walter Kidde enthusiastically conducted the tests of used bottles at their facility as did John McNeese at Pacific Scientific Corporation. Finally, Wayne Roney of Physical Acoustics Corporation (PAC) worked many extra long days to adapt the Sandia program to PAC hardware on schedule.

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EXECUTIVE SUMMARY

Many of the world's commercial jet aircraft use spherical bottles containing pressurized Halon 1301 (CF_3Br) to extinguish engine, auxiliary power unit, and cargo hold fires. The U.S. Department of Transportation (DOT) regulations require periodic testing of these bottles for structural integrity. The only test method previously approved by DOT regulations was a hydrostatic test for inelastic expansion of the bottles. To perform this test, the sealed bottles must be cut open, emptied, and then refilled and resealed after the test.

The production of Halon 1301 was banned in January 1994 by international agreement due to the ozone depleting properties of halon. At this time no substitute material exists which combines both Halon 1301's outstanding fire extinguishing effectiveness and low toxicity. The U.S. airline industry has been granted an exemption by DOT to continue using Halon 1301 through the year 2000. The cost of halon from existing stores has rapidly increased even though halon from the bottles undergoing a hydrostatic test is recovered, purified, and reused. A test of the bottle's integrity, which does not require the opening of the bottle, would save time and expense for the airline industry as well as eliminating one source of loss of the world's Halon 1301 supply.

The airlines, through the Air Transport Association (ATA), pursued the development of a nondestructive inspection (NDI) method for Halon 1301 bottles. The FAA's Airworthiness Assurance NDI Validation Center (AANC) operated by Sandia National Laboratories, with assistance from the ATA's Hydrostatic Task Force, developed an acoustic emission-based test for the bottles. Experiments showed that an acoustic emission test could potentially be an economical replacement for the hydrostatic test for aircraft halon bottles in the commercial air fleet.

During this program, an acoustic emission test for aircraft Halon 1301 bottles has been developed, a prototype acoustic emission test system constructed, and over 200 bottles tested at the repair facilities of the two manufacturers of these bottles. The system monitors a bottle with six acoustic sensors while the pressure of the bottle is raised by heating it in an oven. The sensors are held in position with a fixed relationship between them by a special fixture. This fixture is designed to fit spheres with diameters between 5 and 16 inches. Results of the tests on used bottles indicate that over 95 percent of the bottles show no indications of significant damage. Tests of the rest indicated the presence of flaws or corrosion. However, all bottles tested to date have passed the hydrostatic test required by the U.S. Department of Transportation. As such, it appears that the developed acoustic emission test can safely and effectively screen the majority of halon bottles.

Based upon this data, the ATA requested an exemption from the DOT to allow their members to use this acoustic emission test in place of the hydrostatic test. This exemption, DOT - E 11850, was granted to the ATA on December 11, 1997.

INTRODUCTION

BACKGROUND.

Many of the world's commercial jet aircraft use spherical bottles containing pressurized Halon 1301 (CF_3Br) to extinguish engine, auxiliary power unit, and cargo hold fires. The U.S. Department of Transportation (DOT) regulations require periodic testing of these bottles for structural integrity. The only test method currently approved by DOT regulations is a hydrostatic test for inelastic expansion of the bottles.

To perform a hydrostatic test, the permanently sealed bottle is first cut open and the halon removed. The bottle is then hydrostatically pressurized to twice its marked service pressure in a water bath. The displacement of the water is measured both at the maximum pressure and after the release of the pressure. The elastic and inelastic expansion are determined from the data. If the inelastic expansion exceeds 10 percent of the total expansion, the bottle is rejected. After testing, the bottle is then refilled with Halon 1301, resealed, and returned to service. The test primarily detects thinning of the wall due to corrosion, not flaws in the bottle. Gross corrosion has not been a problem in recent years. The few bottles that have failed the hydrostatic test recently (aside from experimental error) exploded during the test. Thus the hydrostatic test has effectively become a go/no-go proof test. Another problem is that cutting open a bottle and then resealing it by welding removes metal and can introduce new weld defects.

The production of Halon 1301 was banned in January 1994 by international agreement due to the ozone depleting properties of halon. At this time no substitute material exists which combines both Halon 1301's outstanding fire extinguishing effectiveness and low toxicity. The U.S. airline industry has been granted an exemption by the DOT to continue using Halon 1301 through the year 2000. The cost of halon from existing stores has rapidly increased even though halon from the bottles undergoing a hydrostatic test is recovered, purified, and reused. A test of the bottle's integrity, which does not require the opening of the bottle, would save time and expense for the airline industry as well as eliminating one source of loss of the world's Halon 1301 supply.

In the past, the DOT has granted exemptions which allow acoustic emission (AE) testing in place of the hydrostatic test of gas cylinders for gas transportation trailers [1]. This procedure is now widely used throughout the United States. In this test, the cylinders are individually monitored by an acoustic emission system while being pressurized to 110 percent of their service pressure. This extra pressure is applied during the normal filling procedure and bled off after the test. An extensive testing program was conducted to determine the acoustic emission failure criteria for these cylinders. The extension to a similar acoustic emission test for aircraft halon bottles appeared to be a viable solution to the problems associated with the hydrostatic test.

PURPOSE.

The airlines, through the Air Transport Association (ATA), pursued the development of a nondestructive test method for Halon 1301 bottles. The FAA Aging Aircraft NDI Validation Center (AANC), with support from ATA, sponsored the development of an acoustic emission-based test for these bottles. Experiments showed that an acoustic emission test could be an effective and economical replacement for the hydrostatic test of aircraft halon bottles in the commercial air fleet.

PRINCIPLES OF ACOUSTIC EMISSION TESTING.

Acoustic emission techniques detect transient acoustic waves generated by a sudden change in the local stress field in a material [2]. Detectable waves are generated by stress changes in microscopic regions. The cracking of a single metallic grain or the interface between two such grains will generate a transient acoustic wave or acoustic emission. These waves contain a wide band of frequencies, extending from the low audio to around 1.0 MHz. The amplitude of each wave has some correspondence to the volume of the region generating it, but a single test will usually produce waves with a range of amplitudes exceeding three orders of magnitude. The exact time of generation of these waves is random; the occurrence of a fracture depends upon the magnitude and orientation of the local stress field and the strength and orientation of the individual grains. The use of acoustic emission in nondestructive testing (NDT) is based upon the fact that crack tips have high stresses and will grow, producing acoustic emission, at lower overall stress levels than necessary to introduce damage in the unflawed material. Flaws which are located in low stress regions will not grow or produce acoustic emission. Thus, flaws whose size, location, or orientation do not affect the strength of the structure under normal load will not produce acoustic emission during a small overload.

An acoustic emission is generated in the form of transient bursts of acoustic energy. Acoustic waves propagate through the material until they reach the surface where they can be detected by a piezoelectric sensor. In a thin sheet of material, the waves travel along the sheet, generally in one of two different modes of motion. The two modes are an extensional wave, where the particle motion is parallel to the propagation direction in the sheet, and a flexural wave, where the particle motion is perpendicular to the direction of propagation. Both of these modes have frequency dependent velocities and are thus dispersive. The flexural velocity is about half the extensional velocity and both modes are usually seen in an emission burst. The dispersion of the two modes results in the shape of the acoustic waveform continually changing over time. Both modes are detected by conventional piezoelectric sensors with the flexural mode usually having the largest amplitude.

As the burst signal propagates away from the source, the locus of maximum energy is an expanding circle in isotropic materials. The wave will excite the surface mounted sensors at different times as it passes under them. The measured time of arrival is proportional to the wave velocity and the distance from source to sensor. Knowing the wave velocity and the sensor locations, one can then use these arrival times to triangulate back to the source and thus calculate its location. Because the time of origin of the wave is not known, three sensors are needed for location on a surface and four for location in a solid.

In general, a single acoustic emission only indicates that something happened in the test object. The large number of possible generating mechanisms usually prevents the determination of the source mechanism for a single emission. On the other hand, several emissions from the same location usually is evidence of a growing flaw. Another significant piece of information is the occurrence rate of the detected emissions as a function of load. If the rate of emissions from one region increases more than linearly with respect to the load value, there is a strong probability that unstable crack growth is occurring and failure is not far away.

DESIGN OF THE ACOUSTIC EMISSION TEST

The application of acoustic emission techniques to the testing of pressure vessels is fairly simple. Increasing the pressure in a vessel increases the stress field in the walls. A crack will start to grow when the local stress exceeds the local strength of the material at the flaw. A crack produces a stress concentration at its tip. When an applied stress causes a crack tip to advance, this will usually cause a decrease in the local stress field and crack growth will stop. As the applied pressure is increased, the crack will grow intermittently. Each advance of the crack is accompanied by acoustic emission. The waves are detected and the rate of emission and the locations of the source are determined. An increasing rate of emission from a source is a warning of flaw growth while the absence of emission is the sign of a good bottle. Obviously, one has to know that the system is working to declare that little or no emission indicates a good pressure vessel.

The main problem in the design of a safe, practical acoustic emission test for halon bottles was how to apply an overpressure in the sealed bottles. The most viable method to increase the pressure appeared to be heating the bottle and its contents. The bottle is filled with a measured charge of Halon 1301 and then charged with dry nitrogen gas to a pressure of 360, 600, or 800 psi. Most of the halon bottles currently in use have been restricted by their manufacturers to temperatures below 160°F. Theoretical curves such as the one shown in figure 1 show that a temperature of approximately 145°F will produce a pressure in most halon bottles about 30 percent over the bottle pressure at 110°F. This is a temperature which industry members have estimated that a bottle will seldom exceed in normal commercial service. Therefore, heating a halon bottle to 145°F will exceed the 110 percent criteria developed for gas trailer bottles and should provide a valid test.

A completely quiet acoustic emission test of a pressure vessel is a rarity. Acoustic emission can be generated by the spalling or cracking of oxides or other corrosion products. Grit in threads can fracture with a change in the overall strain in the bottle. There are also different types of electrical interference which can be detected as emissions. Therefore, a source location test was chosen since sources caused by corrosion or grit will not repeat themselves and thus do not show several emissions at the same location. A growing crack will usually show a cluster of sources around one location.

Most of the Halon 1301 bottles in commercial aircraft are spheres. The mathematics for the location of a point on a spherical surface have long been known. If the sensors are positioned on the ends of the same spherical radii for different size spheres, the only parameter which has to be changed in a location calculation is the value of the radius. Therefore, a fixture which ran the sensors in or out at the tip of a rod located on a radii would allow the use of the same mathematics for a variety of sphere sizes. Such a fixture, shown in figure 2, was designed to hold spheres from about 5 to 16 inches in diameter and to fit in an industrial oven.

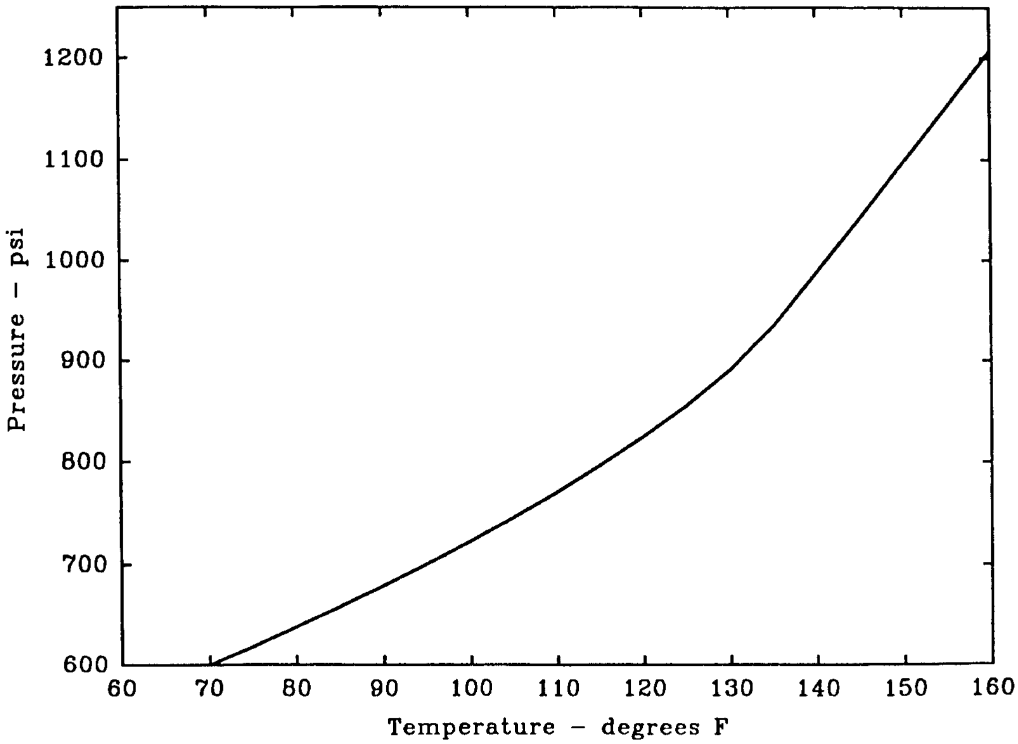


FIGURE 1. PRESSURE-TEMPERATURE CURVE FOR A HALON BOTTLE

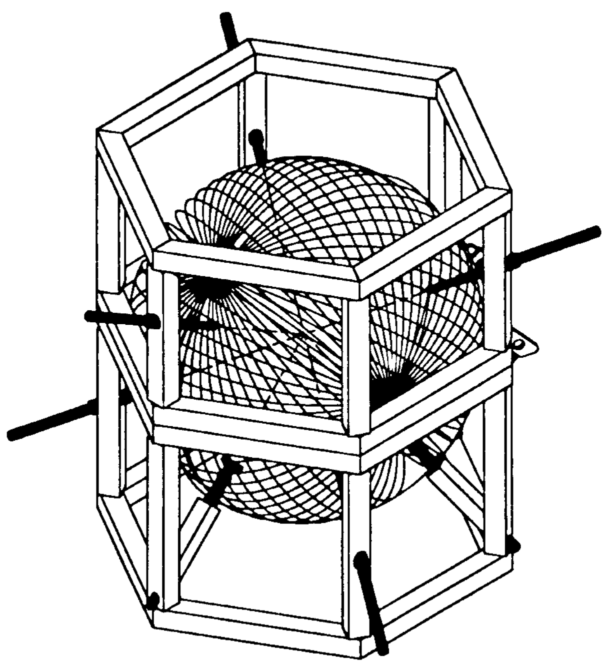


FIGURE 2. DRAWING OF THE FIXTURE

DESCRIPTION OF THE PROTOTYPE TEST SYSTEM

The acoustic emission system uses the Physical Acoustics Corporation (PAC) AEDSP 32/16 digital acoustic emission board. Three boards are mounted in a 66-MHz 486 computer. These boards each contain two separate channels, each containing a digital processor with a 16-bit word and a maximum digitization frequency of 8 MHz. The large dynamic range of the 16-bit word (up to 90 dB) allows triggering at a very low signal level without losing high amplitude data. The system is triggered at a 25-dB level (17 microvolts out of the sensor). The boards use dedicated signal processing chips to calculate various acoustic emission (AE) signal parameters in real time from the digital record. In this application, we record the following parameters for each AE hit: the test time to within 1/4 of a microsecond, the AE count, the peak signal amplitude, the signal rise time, the signal length, the area under the voltage time curve (called variously signal strength, energy, or marse), and finally, the digitized waveform for each hit. This digital record contains 2048 words digitized at a 4-MHz rate and is recorded for every hit on each sensor. This allows a test engineer to examine the data in great detail, including the acoustic waveforms, when the test results are not clear. The detectors are PAC nanno 30 sensors with a response peak between 300 and 350 kHz. The 40-dB preamplifiers have a frequency band pass set at 250 to 1200 kHz. This restriction to higher frequencies is necessary to reduce the effect of low frequency sound waves reverberating through the halon inside the bottle.

The prototype test system (figure 3) combines the acoustic emission described above with a Russell industrial oven having a cubic yard volume. The oven has a slide-out shelf which supports the test fixture. The fixture supports the bottle and positions the sensors on it. The shelf with the fixture is shoved back into the oven and the door closed to heat the bottle. The oven has encased heating elements with a surface temperature limit of 800°F. This will prevent thermal decomposition of the Halon 1301 in the event of an accidental release. The oven air temperature is limited to a maximum of 200°F. Relays are installed in the oven to allow the computer to operate the heaters and circulation fan. The computer reads the skin temperature of the bottle using a thermocouple taped to the bottom of the bottle.

Initially, the system was controlled by the operator, who conducted all operations from the keyboard or the oven controller. This required a relatively skilled operator to run and to constantly monitor the system. Since it was intended that the system be run by aircraft mechanics in maintenance facilities, it was decided to automate as much of the system as possible. Therefore, a computer program was developed to control the operation of the acoustic emission system and oven and to provide a decision to the operator regarding the health of the bottle based on the data collected. The operator is required only to mount and dismount the bottle and to enter information about the bottle into the computer. This turnkey system was used for the second half of a series of tests conducted at Walter Kidde and for all of the Pacific Scientific tests.

The system operates as follows. The operator first loads the bottle into the fixture and attaches the thermocouple to its lower skin. Next the bottle's identification number is entered into the computer with the keyboard. When this is verified, the computer starts an auto sensor test. Each sensor is excited several times with a voltage pulse. This generates an acoustic burst which is

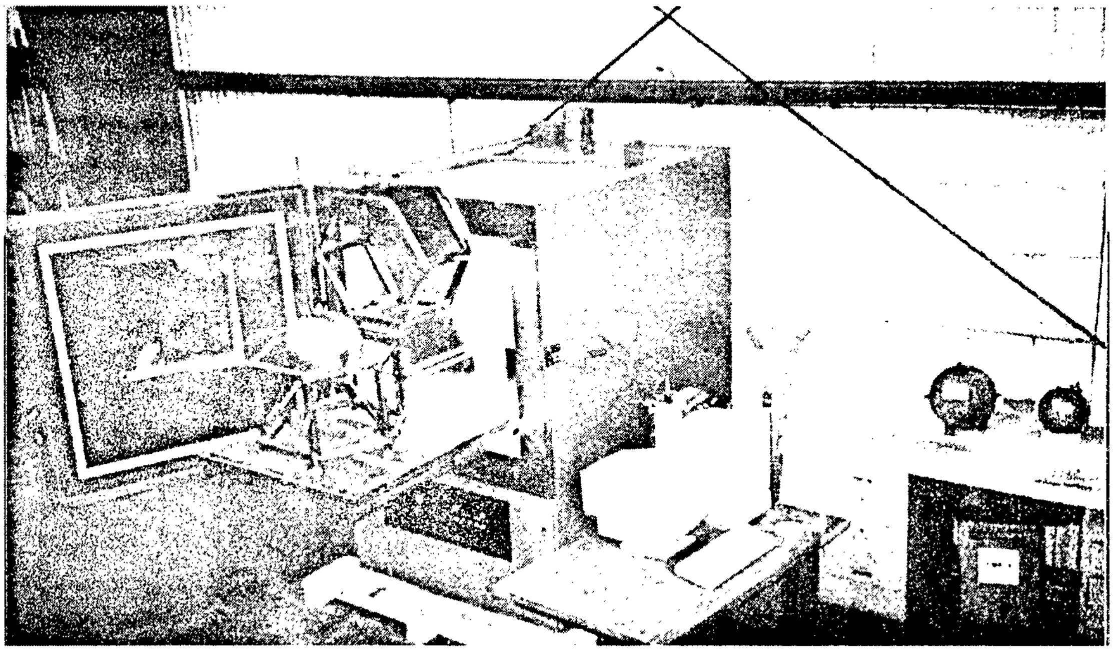


FIGURE 3. PHOTOGRAPH OF THE PROTOTYPE SYSTEM

received at each of the other five sensors. The peak amplitude of each received signal is measured. If the average of the peak amplitudes of all signals received by each sensor lies within + 4 dB of the average of all signals received by all sensors, the test is passed. This shows that all the electronics are working and that each sensor has good acoustic coupling to the bottle. If the test fails, the operator is instructed to reseat the sensors and try again. After the auto sensor test is passed, the system turns on the oven and the circulation fan and starts taking data. When the bottle wall temperature reaches 150°F, the heaters and fan are turned off and the bottle sits for 5 minutes to allow the halon inside to reach equilibrium with the bottle wall. The equilibrium temperature is usually between 145 and 150°F. Throughout the test, the computer calculates the locations of every event. It checks each located event to see whether it is a member of a cluster or whether to start a new cluster. If a cluster size exceeds a preset criteria, the computer will conclude that the bottle has failed the test and may be close to structural failure. It will shut off the heater and circulating fan and signal the operator. The operator will then open the door to allow the bottle to cool before removing it from the oven. At the end of a test, the auto sensor test is again performed to insure that all sensors are still working. A brief report is printed after the test identifying the bottle and stating either that it has passed or failed the acoustic emission test.

DISCUSSION OF ANALYSIS

While the mathematics of location of points on a spherical surface are not new, the problem is complicated because halon bottles are not smooth spheres. Fill ports, discharge ports, and mounting lugs are welded onto the bottle. These cause distortions of the acoustic waves traveling along the bottle wall. The largest amplitude signals are usually flexural waves which are easily distorted as they pass under a mounting or positioning lug or through the base of a port.

The lugs are often mounted on a doubler plate which is fillet welded to the surface of the sphere. At the relatively low signal amplitudes (35 to 50 dB) seen in these spheres, the distortion of the waves can produce triggering on either the extensional or the flexural portion of the wave, making the calculation of the exact source position difficult. To achieve reasonably accurate location of the source of the detected signals, only overdetermined data sets are used in the calculation (an event where the emitted acoustic wave excites four or more sensors). A nonlinear least squares program was written in FORTRAN to calculate the most probable location of the event on the sphere. It was then modified by PAC for their hardware. This location program first tries the extensional wave velocity (0.205 inch/microsecond). If that does not produce a good fit to the data, the flexural velocity (0.118 inch/microsecond) is tried. The computer ignores the event if it cannot locate the source position with a relatively good fit to the data by using one of these two wave velocities. Approximately 80 percent of all the events are located. This percentage approaches 100 percent as the peak amplitude of the wave exceeds 316 microvolts (50 dB) out of the sensor.

To estimate the significance of the events, an algorithm was written which searches for spatial clusters of event sources. A cluster is arbitrarily defined here as all events which fall within a circle on the surface of the sphere. The radius of this circle is 15 degrees of the arc of a great circle on the bottle. The 15 degree radius corresponds to a circle about 3 inches in diameter on a 11-in-diameter sphere. This cluster radius was based on data from a flawed bottle. Extended testing indicates that it is a reasonable choice for the spherical halon bottles used in the air fleet.

Analysis of data collected at Pacific Scientific showed that the usual AE signal parameters (ringdown count, signal strength, signal energy, or signal length) are not ideal indicators for the cluster severity. The acoustic impedance ratio between the Halon 1301 and the bottle wall is different for different metals. This changes the damping of the acoustic wave which affects these parameters. For example, an acoustic emission signal for a titanium bottle has an acoustic emission count about 50 percent greater than the same amplitude signal for one made of ferrous alloys. Therefore, it was decided that a failure criteria should be based solely on the density of the located emissions in the cluster and the change in slope of the AE curve with temperature (pressure). The program keeps a record of the location coordinates and the temperature for each member of a cluster. From the data, it was determined that bottles with identified flaws showed most of the located events above a temperature of 130°F. In addition, it was noticed that the slope of the event versus temperature curve for bottles with known flaws increased by a factor of 3 or more when calculated over the ranges of 110 to 130°F and 130 and 150°F. This established one failure criterion.

While corrosion has not appeared to be a problem in recent years, some of the bottles showed high cluster densities with event rate curves typical of corrosion. Even in stainless steel bottles, a small amount of liquid impurity, such as water, sitting on the bottom of the sphere for long periods of time could cause corrosion in a small area if the Halon 1301 decomposed in the liquid. It was decided that a second failure criterion based upon cluster density might be appropriate, depending upon the results of the bottle tests at the commercial repair stations.

RESULTS OF BOTTLE TESTS

Both current manufacturers of these halon bottles maintain test and repair facilities. It was arranged to perform the acoustic emission test on used Halon 1301 bottles as they were returned to these facilities for repair or testing. The test was run on the arriving bottles before emptying them for the hydrostatic test. The prototype system was first installed in the Walter Kidde testing facility in Wilson, NC. Because these bottles were owned by customers and some had tight scheduling requirements, not all of the desired nondestructive testing could be performed on those questionable bottles found by the acoustic emission tests. However, all bottles tested with the acoustic emission system subsequently passed the hydrostatic test. A total of 147 bottles were tested at the facility while the prototype system was there. The system was then moved to Pacific Scientific Corporation in Duarte, CA. Here another 60 bottles were tested. This gave a data set of 207 bottles. Table 1 shows the number of the tested bottles by material.

TABLE 1. BOTTLES TESTED VERSUS COMPOSITION

Material	Number
Nitronic (21-6-9)	125
Almar	40
4130 Steel	26
Titanium	7
300 series Stainless	9

Table 2 shows the number of the tested bottles as a function of size. A majority of the bottles were made of Nitronic steel and had a volume of 630 cubic inches, but a wide selection of bottles were tested.

TABLE 2. BOTTLES TESTED VERSUS VOLUME

Bottle Volume (Cubic Inches)	Number Tested
72	1
150	1
224	23
378	24
420	3
536	14
630	123
800	13
1400	5

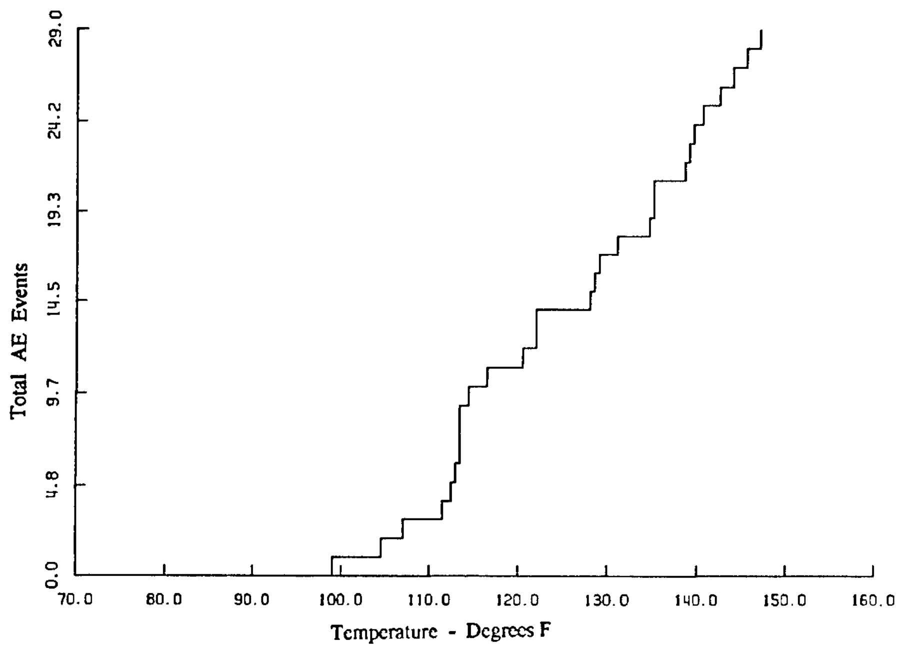
The acoustic emission results are given in table 3. Seven bottles gave no emission at all, 56 bottles had emission but no located events, and another 77 had located events and possibly small clusters which contained less than 5 events. Thus, about 68 percent of the bottles showed no significant acoustic emission. The rest had clusters of moderate to large numbers of events.

TABLE 3. SUMMARY OF ACOUSTIC EMISSION DATA FOR THE 207 BOTTLES TESTED

7 bottles	No acoustic emission (AE) seen.
56 bottles	Random AE hits but no located events.
77 bottles	AE hits and one or more located events but no clusters with more than four events.
54 bottles	AE hits and located events. Clusters with 5 to 20 located events.
13 bottles	AE hits and located events. At least one cluster containing 21 or more located events.

Based on the data from Walter Kidde tests, it appeared that the bottles could be graded according to whether acoustic emission clusters contained low or high numbers of events. However, 25 percent of the Pacific Scientific bottles showed clusters containing 18 or more events, although none failed the hydrostatic test. A more thorough examination was then made of the data. Most pressure vessels which fail an acoustic emission test show a distinct knee in the data where a relatively steady rate of emission as a function of the load suddenly starts to increase. This is indicative of continuous crack propagation which ends in the failure of the vessel if the loading is not at least stopped, if not reversed. Of the 19 bottles with 18 or more located events in a cluster, 15 of them showed a relatively constant rate of emission between 110°F and the end of the test at 150°F. Only four of them showed a much higher emission rate between 130 and 150°F than between 110 and 130°F. However, 5 of the remaining 15 had 35 or more located events in a cluster. This high density in a cluster with a constant slope of the event versus temperature curve was probably due to the cracking or spalling off of corrosion products at a localized region inside the bottle. After discussions with the DOT technical staff, it was decided to set two failure criteria. First, any bottle with a cluster containing 35 or more located events would fail the acoustic emission test. Second, any bottle with a cluster containing 18 or more events and which had a significantly increased acoustic emission rate above 130°F would also fail the acoustic emission test. The actual criteria used in the computer program was to divide the number of events in the cluster which occurred at temperatures above 130°F by the number of cluster events which occurred in the range between 110 and 130°F. If this ratio is 3.0 or higher, the bottle will fail the test. Of the 207 bottles tested, two failed both criteria, two failed the slope criteria, and five failed the cluster density criteria.

Location diagrams and event versus temperature data are shown in figures 4 and 5. In figure 4, a serious appearing cluster containing 29 events is shown on the location plot. However, the event rate is constant as the temperature, and thus the pressure, increases. In contrast, figure 5 shows a



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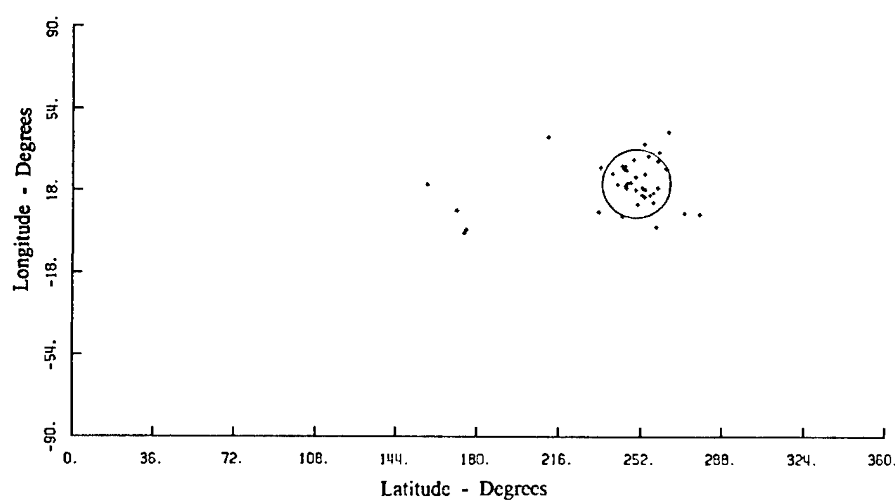

FIGURE 4. EVENT VERSUS TEMPERATURE CURVE AND LOCATION PLOT. The slope of the event curve for the cluster is constant with increasing temperature.

cluster containing 20 events, but 18 of the 20 events occurred above 130°F. The cluster in figure 5 is located partially over a doubler plate on the bottle. An x ray of this plate showed a tungsten inclusion in the fillet weld holding the plate on the bottle. The fact that the emission did not start until a relatively high temperature and the rapid emission rate above 148°F is strong evidence that a crack is propagating in the weld, starting from the tungsten inclusion. Because

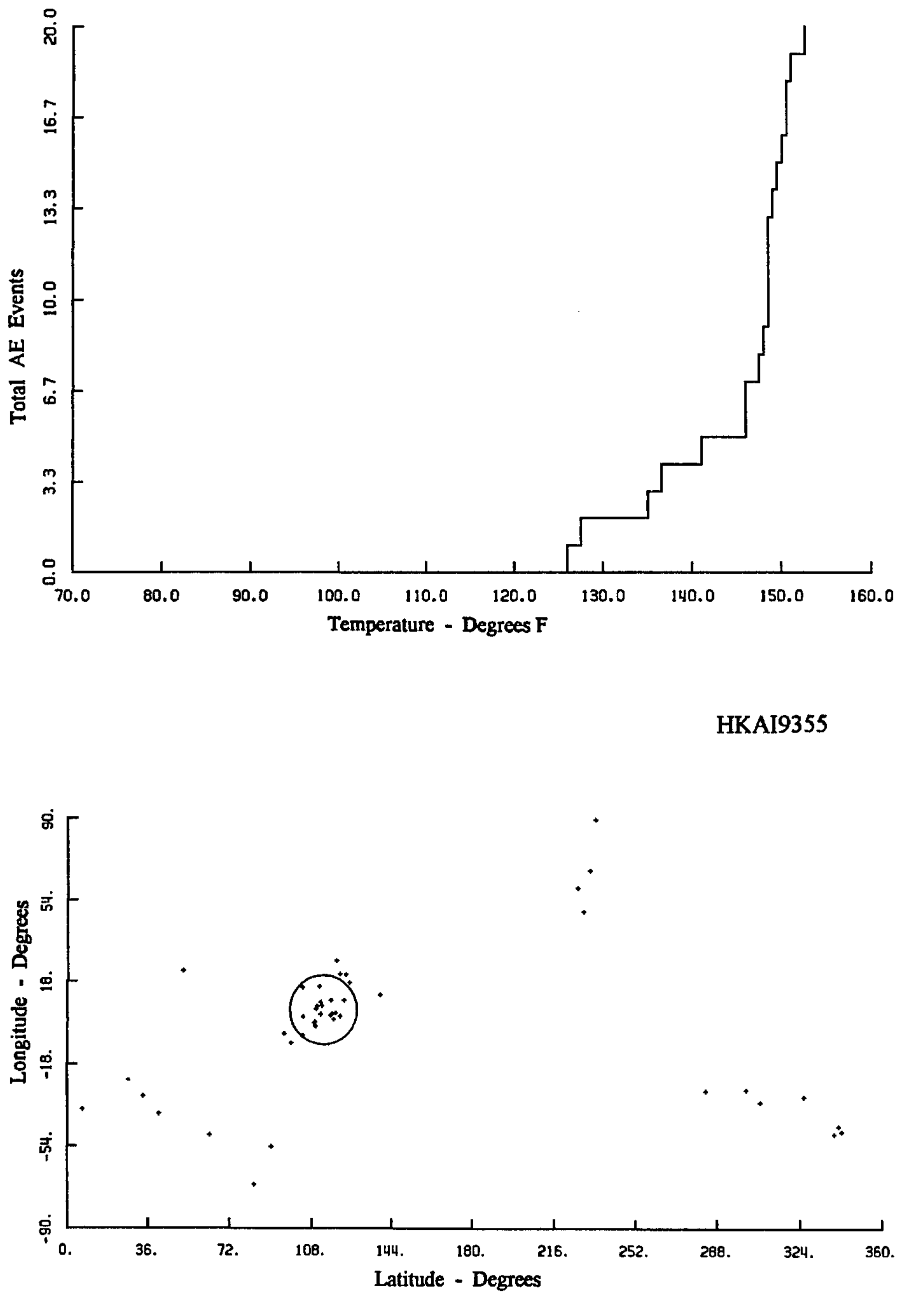

FIGURE 5. EVENT VERSUS TEMPERATURE CURVE AND LOCATION PLOT. The slope of the event versus temperature curve for the cluster shows a significant increase at high temperatures.

the bottle passed a hydrostatic test, the crack is probably not in the vessel wall but instead is propagating within the doubler plate fillet weld parallel to the wall. Thus, it is a real flaw but one which may not result in the failure of the bottle.

Four of the 207 bottles in the data set produced emission data which indicated the possibility of serious flaws. Five more of the bottles had cluster densities which indicated the possible presence of areas with at least moderate corrosion products inside the bottles. All nine bottles passed the hydrostatic test which primarily means that they did not blow up at pressures twice the nominal pressure at 70°F. The other 198 bottles passed the acoustic emission test based on the failure criteria described above. It was noticed that two sets of identical bottles with closely grouped serial numbers contained the majority of moderate to high density clusters. It is not known whether these belonged to two distinct batches of old bottles, whether they had been somehow mistreated by their owners, or whether this observation was just a statistical anomaly.

The failure criteria determined from this set of bottles are admittedly conservative. No bottle has actually failed during the acoustic emission test or the following hydrostatic test. These criteria will be reexamined after a sufficient data set has been accumulated by the use of commercial acoustic emission Halon 1301 testers.

The time that it takes to run a test on a bottle depends upon the size of the bottle, its surface condition (paint slows down the heat transfer), and the condition of the oven. Total test times including the 5-minute hold at the end, ranged from 15 minutes to over an hour. The first test of the day is always longer due to the heating of the mass of the oven. Handling the 150°F bottles is no problem assuming gloves and long sleeves are used. The turn around time between tests is quite short, even when the fixture has to be reset for a new bottle size. At Walter Kidde, the average time was about 25 minutes per bottle. This data indicates that an average test time of around 30 minutes per bottle should be quite feasible.

CONCLUSIONS

The acoustic emission tester has shown its ability to detect small flaws in Halon 1301 bottles. None of the flaws seen yet has caused the rejection of a bottle by the hydrostatic test. A conservative acoustic emission rejection criteria has been set for commercial use of the system. The test data reported in this report show that over 95 percent of the tested bottles passed this criteria. There was no indication that any specific bottle design or construction was more prone to failure than the rest of the test set.

Based on the data presented here, the ATA applied for an exemption which would allow its members to use the acoustic emission Halon Bottle tester described here in place of the hydrostatic test. This exemption [3] was granted on December 11, 1997. The system is now available commercially from Physical Acoustics Corporation of Princeton, NJ.

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