

**A NON-INTRUSIVE METHOD TO DETERMINE THE INTERNAL PRESSURE OF
SEALED WASTE STORAGE CONTAINERS AND SUPPORT WASTE INVENTORY
ACCOUNTABILITY**

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ABSTRACT

This paper discusses the testing of a newly developed drum pressure alert device (DPAD), which can non-intrusively monitor internal pressure of waste drums and provide an external alarm if internal pressure develops. It also discusses an integrated automatic identification data collection (AIDC) "button" that supports waste life-cycle inventory management and provides a permanent, and resilient "tagging" method for waste containers, waste storage facilities, waste certification facilities and waste transport vehicles.

Since 1992, there have been approximately 150 recorded occurrences at U.S. Department of Energy (DOE) facilities associated with pressurized waste drums. These occurrences document the fact that many of the materials normally stored in drums can generate gasses, which can pressurize a waste storage container to unknown levels. Pressurized waste drums are a safety hazard that can lead to significant personnel injury and property damage caused by the expelled drum lid or fragments of the burst drum, as well as exposure to the radioactive or other hazardous contents. During the same period, it has become increasingly clear that manual inventory procedures currently being used at DOE sites to mark, track, and manage the vast amount of legacy and newly generated waste throughout the waste's life-cycle have become obsolete. Waste container-tracking issues, which have resulted in questionable waste inventory accountability, may unwittingly contribute to the occurrences associated with pressurized waste storage containers.

INTRODUCTION

Large industrial complexes at DOE sites across the country have produced nuclear materials and weapons to support United States national defense. There are over 100 of these DOE sites located in 30 states and Puerto Rico. Like many government and commercial industrial operations, these facilities generate (or have generated) waste materials, which can be hazardous and in some cases radioactive. Waste handling procedures traditionally mirror the regulatory and industrial standards of the time. As a result of over fifty years of radiochemical development and production operations at DOE sites, various radioactive and hazardous waste streams are stored in a variety of containers and storage facilities across the DOE complex, resulting in a risk to workers, the public, and the environment. The responsibility for waste management, environmental restoration, and nuclear material and facility stabilization at nuclear weapons sites was assigned to DOE's Office of Environmental Management (EM) in 1989. The DOE Office of Environmental Management document published in 1998, *Accelerating Cleanup: Paths to Closure* (DOE/EM-0362), escalated clean up efforts at these sites, while ensuring worker safety and health

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protection. As of 1998, approximately 60 sites have been cleaned-up, yet 53 sites consisting of approximately 353 remediation projects still required environmental and waste management. (DOE/EM-0362, 1998). Completion of the cleanup project is forecasted for the year 2070 with an estimated cost of \$147 billion (1998 dollars).

WASTE INVENTORY CONCERNS

DOE and its predecessor agencies has been packaging, categorizing, storing, shipping, receiving, and restoring waste containers at multiple sites for about 50 years. Inventory control, tracking, and accountability are critical components of proper waste management at nuclear sites. Facility managers are responsible for the safe storage and handling of nuclear materials and wastes, and are required to inventory actual amounts of nuclear material contained in these storage locations and compare the results with existing tracking systems. This labor-intensive manual effort is designed to insure that all inventory and configuration changes to nuclear material and waste inventories are correctly documented. All changes to the tracking and configuration requirements and inventories are required to be rigorously and systematically captured in facility basis documents and procedures. The waste characterization process is also a largely manual effort that controls the development of waste profiles, packaging, identification, certification and transportation of material for on-site storage or disposal. Official audit reports document the safety and significant inventory control problems associated with these processes

As the inventory of legacy and newly generated waste containers has grown, databases at the various DOE sites have proliferated in an effort to track and manage this waste. There are many different systems in use today, but few seem to interface with each other, and there is not a consistent DOE wide approach to waste tracking databases. As a result, the existing databases may not interface, and information needed for waste tracking, certification, transportation, and disposal may require the search of several databases in order to obtain the needed information. Over time, declining budgets and increased regulatory oversight have exerted pressures on the process and have stressed DOE's outdated logistics support system. The current waste tracking/information management system still relies heavily on labor intensive processes to collect data, convert it to electronic format, and transmit it to the appropriate database. The errors generated by this deceptively simple process are a major contributing factor to DOE's waste container inventory tracking problems. The manual conversion of printed information from identification plates, stencils, or stickers to an electronic format is a fertile environment for human error often resulting in error rates above 35%. Typical data entry errors include: accidentally transposing data, misinterpreting numbers or characters, and inadvertently entering incorrect data into the database.

An additional issue to the human error factor in waste tracking/information management when dealing with databases, is the inadvertent loss or destruction of the of the waste identification data found on the waste containers, generally in the form of metal plates, stencils, and barcode stickers. This identification data ties back to the sites databases, which may include waste container configuration data, and container operating history, container inventory, waste certification information, etc. Loss of this important information inhibits identification/tracking of the waste container and contributes to low inventory validity, potential loss of control of the container, and generally degrades database integrity. There are safety and budgetary issues associated with the loss of this information; a waste container with a damaged or lost identification tag potentially requires new waste certification to determine the contents and classification of the waste, resulting in lost time, increased costs, potential exposure of the workers performing the recertification

WASTE CONTAINER SAFETY ISSUES

The carbon and stainless steel drum has been the container of choice for packaging relatively small quantities of radioactive and hazardous wastes for more than 50 years. Hundreds of thousands of these legacy waste containers are in existence, and as waste is generated, more drums are packaged and stored. Some existing containers have been buried in subsurface trenches on DOE sites, but most still require inventory management while being held in long-term storage in buildings, bunkers, vaults, and other facilities while awaiting final disposal.

Since 1992, the DOE *Operating Experience Weekly Summary Report* has identified more than 150 incidents associated with pressurized drums. This proactive safety report documents operational problems and promotes safety by encouraging operational experience feedback among nuclear facilities. It also encourages general exchanges of information and feedback based on hands-on experience that is deemed appropriate for all. The report may include incidents that involve personal injury, near misses, and contamination of personnel, equipment and facilities. It also describes inconsistencies in waste inventory accountability and loss of control. Analyses of the relationship between incidents that involve pressurized waste drums and waste inventory inconsistencies suggest a correlation to safety issues effecting workers who package, transport, and store wastes, and a potential danger to the health/general welfare of the public and the environment. While each event is investigated and categorized, corrective action to prevent recurrence has proved to be elusive. Pressurized waste drums present several personnel hazards including:

potential injury from ejected material, a pressure release, or burst drum fragments;

exposure to radioactive or hazardous contents of the drum; and

exposure to pyrophoric, flammable, or combustible materials which can ignite and burn.

The following incident was taken directly from the *Operating Experience Weekly Summary Report* 99-34, August 20 through August 26, 1999. "On August 13, 1999, at the Savannah River Technology Center, an engineer participating in a research project received a laceration to the forehead when he was struck by a lid propelled from a pressurized drum. He and a technician were pumping approximately 30 gallons of sludge from an experimental tank to a nearby 55-gallon drum, using a positive displacement pump, when he noticed that the flow had stopped. Workers had installed a valve and pipe on the side of the drum near the bottom for the sludge transfer. They left the lid on the drum to eliminate splashing during the transfer. The engineer shut the pump off and determined that the pump had pressurized the drum to 15-20 psig. The lid propelled from the drum as he attempted to release pressure by loosening the locking ring. The sludge had a pH of approximately 5 and contained traces of mercury. Responders transported the injured employee to the site medical facility, then to a local hospital, and from there to a plastic surgeon who closed the wound. This event is significant because the sudden release of pressure from pressurized drums can cause severe personal injury, expose personnel to contamination, or release hazardous or toxic contents to the environment (ORPS Report SR--WSRC-LTA-1999-0030)."

Unfortunately, even new, empty drums can present a hazard due to pressurization caused by changes in altitude. This kind of an occurrence happened at the DOE Los Alamos National Laboratory (LANL) and Processing Facility, in New Mexico on January 28, 1999. Shipping and receiving employees were opening empty 208 L (55 gal) drums, when the lid of one drum forcibly ejected without warning. The empty containers had been shipped from ORNL, located at approximately sea level, to LANL, with an elevation of approximately 2,194.5 m (7,200 ft). The change in elevation caused internal drum pressure to build to approximately 20.7 kPa (3 psig). When a 208 L (55 gal) drum lid is pressurized to 20.7 kPa (3 psig), a total force of 518.0 kg (1,142 lbs) is generated, which can cause serious injury and property damage. Research at LANL quantified the amount of deformation that a 208 L (55 gal) drum

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experiences at various pressures with a statistical analysis on the mean failure pressure. The collected data was sufficient to support the development of a device for estimating the internal pressure of a waste drum because of the similarities between pressure and the deformation curves of a drumⁱ

On May 17, 1995, a drum lid blew off in Grand Junction, Colorado when a technician attempted to remove it. Incident investigators believe the pressurization was caused because of differing ambient conditions between the locations where the drum was sealed and opened. There were no visual clues (i.e. deformation) to indicate the drum was pressurized. As this example indicates, workers may have few visual clues that they are at risk. Interviews with workers who handle drums on a routine basis indicated that one of their greatest fears deals with handling potentially pressurized drums because visual deformations are not always obvious. There is a potential for sealed drums to develop an internal pressure of 6.9-13.8 kPa (1-2 psig) or more, which presents a definite risk to the workers if the drum lid explodes.

The cost of pressurized drum incidents can be high; resulting in financial losses, and a loss of worker and public good will. In addition to the potential personal injury and property damage that can result from a pressurized drum incident, there is also a great potential for contamination of personnel, the work space, equipment, facilities, and the environment. Costly corrective actions for the Grand Junction event included:

Re-evaluating and amending the existing drum handling procedures to insure safe venting of all new drums before use;

Creating new procedures to insure that the existing drum inventory and all newly received drums were safely vented;

Evaluating and revising the applicable training courses to include the warnings of potential drum pressurization;

Creating a standard operating procedure that requires all drums, including new drums, to be treated as if they are pressurized until they are vented; and

Creating and implementing instructions and procedures that require potentially pressurized drums that show no signs of deformation to be safely vented.

THE DRUM PRESSURE ALERT DEVICE/WASTE INVENTORY TRACKING (DPAD/WIT) SYSTEM

During the past year, research at the Oak Ridge National Laboratory (ORNL) has produced a prototype drum pressure alert device (DPAD), which is a magnetic pressure sensor that can measure the internal pressure of a waste storage drum, without intrusion into the drum. Realizing that the drums contents, the interaction of the contents during storage, and a change in the drums location and temperature can contribute to a drums internal pressurization, ORNL personnel combined AIDC technology with the magnetic pressure sensor to establish a verifiable safety audit trail and life-cycle waste inventory tracking (WIT) system for waste containers. The integrated DPAD/WIT system is composed of fully tested, commercially available, off-the-shelf technologies that provide a real time method to determine internal drum pressure, and verify the drums contents at the waste storage facility. This information can be passed electronically from a hand-held electronic reader/recorder, to an existing waste inventory database without introducing potential data entry errors.



Figure 1. The pressure sensor consists of a magnet and bellows attached to the inside of a drum bung or drum lid.

barometer and thermometer to support a software algorithm for calculating gas law equations when temperatures and pressures are recorded at different times or locations. Since the drum's volume is constant once sealed, a calculation of the change in drum pressure can be made by measuring and comparing the temperature and elevation of the drums location at the time of inspection, to the temperature and elevation when the drum was packaged and sealed. When the drum is initially packaged and sealed, its internal pressure (barometric pressure multiplied by 0.4897) and the ambient temperature are permanently loaded into the memory button, which provides a permanent and tough electronic container identification tag with the ability to read/write on contact. Other electronic data, such as the drums contents, container serial number, originating site, packing date, waste certification information, etc., can also be electronically downloaded to the memory button and permanently stored. The associated memory button reader insures that the internal pressure reading are accurate

The DPAD consists of a bellows, which is a sealed metal cylinder with deeply convoluted sides, topped with a permanent magnet. The sensor can be inserted into a bellows guard to avoid contact with the waste and attached to a drum bung (plug), which is inserted into the bung hole of a tight head type drum lid. It can also be attached to the underside of an open head drum lid. Changing pressure inside of a drum causes an expansion or contraction of the bellows, which results in a variation of the magnetic field (flux density lines of the magnet). The variation of the magnetic field provides an external, passive, and non-intrusive method to correlate the pressure/force exerted internally on the drum by using a Hall Effects gaussmeter. A passive contact memory button (part of the AIDC family) is attached to the outside of the drum directly above the DPAD to support this internal pressure monitoring method. An audio/visual alarm can also be attached to the outside of the drum in "high risk" scenarios to provide workers an instantaneous indication of an over-pressurized waste drum.

The memory button and associated button reader are key components of the DPAD/WIT system. The button reader incorporates a Hall Effects gaussmeter,



Figure 0. Demonstrating the memory button, associated button reader, and customized software.

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and provides a means of verifying the gaussmeter readings by performing a simple calculation based on the ambient temperature at the time of the drum pressure reading. Once the pressure is determined and verified, and any other information required for the inspection is obtained, the date, time, and name of the person performing the inspection can be written to the memory button. This read/write "electronic tag" can be linked to existing waste management databases and its data can be verified via the unique serial number assigned to each electronic button (tag). All of this information can be held in the button reader and then electronically passed to the database without error, providing an audit trail of the inspection, and validation of the container pressure, contents, and location.

The DPAD/WIT system can provide a waste management safety and inventory audit trail that can help to improve safety and prevent "loss of control" of waste containers. A waste drum's pressure data, waste inventory, and inspection data is maintained permanently on the memory button attached to the waste container. The memory button can also be permanently attached to waste storage facilities, waste transport vehicles, etc., and loaded with the information about the individual waste containers contained within, to provide an accurate waste inventory/container verification in the field, or during waste transport.

The DPAD/WIT system can significantly reduce risks associated with hazardous waste drum management and has significant value for the waste tracking/inventory process associated with the safe management of waste storage containers. The turn-key non-intrusive DPAD/WIT system includes the following.

- Magnetic sensors, which indicate the change in the waste containers internal pressure.
- Memory buttons that can read/write on contact to store pressure, waste inventory, and other required waste management information.
- A contact memory button reader/recorder with an integrated gaussmeter, barometer, and thermometer, which can measure any changes in the magnetic flux of the magnetic sensors inside the drum, and retrieve information from and update the memory button. The reader/recorder also provides the downloading link to existing waste management databases.
- Customized software which is integrated with existing waste management databases for electronic inventory control, and also includes algorithms to verify the internal pressure readings in the field.

The DPAD can operate remotely and provide a remote alarm, which may consist of flashing lights, audio signals, or a combination to indicated elevated drum pressure levels. The utilization of these remote alarms becomes a function of the risk associated with waste containers that may have the potential to become pressurized during storage. High risk scenarios would include alarms on all of the waste drums to provide an instant alert of dangerous drum pressure. Medium risk scenarios may not include the alarms, but would include all other equipment. Low risk scenarios may only include the memory button, which would be loaded with the temperature and pressure at the time the waste container is packaged and sealed. The algorithms included in the software and used to verify the gaussmeter readings of the magnetic sensor would be used to provide an indication of any internal pressurization in low-risk situations.

LABORATORY TESTS

The edge welded, opposed ripple type bellow was selected for use in the DPAD due to its superior linear deformation characteristics. The design specification called for an operating stroke of 0.250 in. at 3 to 5 psi, and a free length of 1.10 in. +/- 0.005 in. with a diameter of 1.900 in. +/- .005 in.. The bellow material was specified to be 316L stainless steel with ambient air inside. The ambient air provides a quality control check during contraction and expansion of the bellows during operation. Two types of tests were performed on the prototype bellows by Robertshaw, an independent laboratory in Tennessee. Five (5) bellows were tested for leak rate, spring rate and hysteresis, stroke and pressure, stroke and temperature, and life cycle. Magnets were permanently attached to 4 of the 5 bellows, which were then submitted to further testing to determine the change in magnetic flux resulting from a controlled increase in internal drum pressure caused by heating and cooling the drum. The results of the tests and conclusions follow.

Bellow Tests

Leak Test

The 5 bellows were placed in a pressure vessel. Nitrogen gas was applied to the pressure vessel, resulting in more than 34.5 kPa (5 psi) and less than 48.27 kPa (7 psi) of pressure applied to the 5 bellows. After a period of two hours, the bellows were removed from the pressure vessel, immediately submerged in isopropyl alcohol, and inspected under magnification for escaping air. No leaks were detected.

Spring Rate and Hysteresis

The 5 bellows were placed individually on a spring tester, which was preloaded to the same height {approximately .68 kg (0.5 lb) force}, with the load cell zeroed. From the preload height, the bellows were compressed, beginning at 0.1 inches, increasing to 0.13 inches, and decreasing back to 0.1 inches. Both the spring rate and hysteresis dropped during the test, showing an improvement. The spring rate dropped around 8% after running approximately 77,000 pressure cycles as part of the life test. The hysteresis also improved. This suggests that there is a "run in" phenomenon and that the parts stabilize over time.

Stroke at 34.5 kPa (5 psid)

The 5 bellows were placed on a dial indicator test stand in a pressure vessel. The atmospheric pressure was increased to 134.452 kPa (19.2 psia). This resulted in a stroke variance of 0.005 of an inch between all 5 bellows.

Stroke vs. Temperature Results

The 5 bellows were not evacuated and contain ambient air. The bellows displayed "thermostating" qualities, since with an increase in temperature of 70[®]F, the bellows increased in length by 0.177 cm (0.070 in.). This corresponds to a 0.001 in/[®]F rate.

Life Cycle Tests

The 5 bellows were placed in a pressure vessel and the atmospheric pressure was cycled from ambient pressure to plus 34.5 kPa (5 psid). Leak tests were performed about every 25,000 cycles by submerging the bellows in alcohol and then depressing them to increase the inside pressure. There were no leaks

detected after 77, 595 cycles. The 5 bellows were tested for a total 141,149 cycles with no leaks or failures identified.

Tests Of Bellows With Attached Magnets

Four (4) bellows with magnets attached were tested to determine magnetic flux density strength while inserted in test drums of heated and cooled air and water. Test procedures were developed and implemented to ensure the accuracy of the test results.ⁱⁱ Three tight head drum type bung plugs made from poly vinyl chloride (PVC), nylon, and delran materials respectively were fitted with 3 of the 4 bellows with the attached magnets. The last bellow assembly was attached to the underside of a 208 L (55) gal, stainless steel, open head type, drum lid. Memory buttons were attached to the external surfaces of the bung plugs and on the stainless steel drum lid directly over the bellows assembly to complete the DPAD assembly and provide a uniform surfaces for conducting measurements. Two 208 L (55) gal drums were used in the tests; one was sealed with ambient air, and the other was filled with potable water and sealed. Each drum was incrementally heated and cooled to specific temperatures to create a range of internal drum pressures. The drum lids were outfitted with a dial pressure indicator and a thermometer to provide verification of the temperature and the resulting pressure change. A hand held Hall Effects Gaussmeter was used to measure the strength of the magnetic flux line densities, which changed with the increase or decrease of the internal drum pressures resulting from the controlled drum temperature changes.



Figure 2. Tests of bellows with attached magnet and pressure alarm.

Heat Variation Test Results with Carbon Steel Drum Lid and Ambient Air

This test was designed to determine if the strength of the DPAD's magnetic flux lines increased or decreased as a result of changes to the drum temperature and pressure. Each bung plug was screwed into a tight head drum lid after the locking ring had been torqued. The drum restraint was secured and the ambient air in the drum was controlled and heated through a temperature range of 70[®]F to 120[®]F. The tests of all three DPADs attached to the various bung plug materials failed to produce a change in the magnetic flux lines. It was determined that this was due to leaks in the drum lid gasket even though the lock ring was repeatedly tightened to the maximum torque values. Further testing was suspended in order to test the stainless steel lid PAD. Although the test failed to produce the desired results, it is assumed that drum gaskets "seat" over time, and that temperature changes can induce a leak tight seal, which can result in a pressurized drum. The gasket material is closed-cell rubber and glued into the lid. The gasket operating range is -40[®]F to +158[®]F.



Figure 2. Test setup for the heat variation tests at Oak Ridge National Laboratory.

Heat Variation Test with Carbon and Stainless Drum Lids and Water

Due to the failure to produce an internal drum pressure with the initial test, an air pump was used to induce pressure in a drum filled with water. Using the revised drum configuration for the tests, each bung plug was tested through temperature ranging from 30[®]F to 120[®]F and measured in 10 degree intervals. A pressure from 0 to 5 psi was introduced at each 10[®]F temperature interval and the strength of the magnetic flux densities were measured. The test was repeated four times for each type of the bung plug material to ensure accurate results.

The increase and decrease in the strength of the magnetic flux density lines for each bung plug material type was different, although the measurements were consistent for the individual materials. This suggests the magnetic flux line strength is a function of the material it passes through. In each of the three bung plugs the precision and accuracy of the flux density lines was consistent with the test pressure and temperature parameters. The DPAD attached to the stainless steel drum lid was subjected to the same test and the accuracy and precision of the magnetic flux density lines was consistent with the bung plugs measurements.

Cold Variation Test with Carbon and Stainless Steel Drum Lids

As internal drum temperature decreased, a negative pressure occurred, thus eliminating the potential for a pressurized drum. The lowest temperature the bung plugs and stainless steel drum lid was subjected to was 30[®]F, however, only the nylon bung plug was subjected to a 2 in. of mercury negative pressure in order to measure the magnetic flux density lines in a cold environment. During this test the drum lid "snapped" inward violently and the DPAD was dislodged from the bung plug. The balance of planned

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tests were canceled due to the increase risk of injury and damage (permanent deformation) of the test platform.

CONCLUSIONS

An assessment and comparison was performed on the results of all the tests. This assessment indicated that the “thermostating” condition identified by the Robertshaw tests did not present a problem for the bellows application since the 0.001 in./[°]F variation in the bellows stroke is easily overcome in the selection of the strength of the magnet. The Ideal Gas Law (internal pressure in the bellows versus internal pressure in the drum) concern is negligible, because even with a small variation in the bellows stroke, a change in the strength of the magnetic flux can still be measured to indicate an internal pressure buildup inside the drum.

The linearity of the DPAD measurements during the temperature and pressure variations was compared with the spring rate and hysteresis test results. Due to fact that there is little to no variation in the magnetic flux density line measurements during the temperature and pressure variation tests, and that the spring and hysteresis test indicate that the DPAD materials become more stable over time, the comparison suggests that the DPAD will perform its intended functions of indicating an increase in drum pressure.

The tests indicate that the DPAD by itself is reliable, and when integrated with a memory button, button reader, and associated software to form the DPAD/WIT system, the results indicate that this system not only provides an accurate and reliable method to identify and potentially control pressurized waste drums, but also provides a bridge that could potentially link existing DOE waste inventory databases. The use of this integrated system will allow a means to effectively maintain and verify a waste containers contents, pressure, location, originating site, etc. in the field. Using the memory button as the permanent “electronic tag” on waste containers, and the associated button reader to upload the field inspection data into the existing databases will help to reduce the human error factor, and provide a means of integrating the multitude of information contained in the existing DOE waste management databases. The DPAD/WIT system can facilitate life-cycle tracking of the large waste inventories at DOE sites, and help to reduce the risk to waste management workers associated with the surveillance, maintenance, and transport of waste containers at waste storage facilities. The combined system could potentially have far reaching effects and applications in the waste management industry, and can help to reduce the risk to the workers, public, and the environment posed by pressurized waste containers and inaccurate waste inventories.

FOOTNOTES

ⁱ M.D. Larranaga, D. L. Voltz, and F. N. Bolton, *Pressure-Deformation Correlation in Waste Containers*, Los Alamos National Laboratory, 1998

ⁱⁱ *Field Test Procedure-Pressure Change Detection from Thermal Variations with a Pressure Alert Device (PAD)*, Procedure No. T-1 Revision No. 1, November 17, 1999, Advanced Integrated Management Services, Inc. and Tellico Technical Associates.

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