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Development and Testing of the Blanton Clamshell Closure for use on Radioactive Material Packaging Drums

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Abstract
This paper provides a brief history of the U.S. Type B 6M specification container, its introduction into U.S. Code of federal regulations and its scheduled elimination three decades later. The paper also presents development, testing and deployment by the Department of Energy (DOE) of an enhanced drum closure called the "Blanton Clamshell" (patent pending) that was designed to replace the standard open-head C-ring closure for the 55- and 85-gallon drums described in the 6M specification to extend their safe use. Nuclear Filter Technology has the Exclusive License for Clamshell production.

Drum packages utilizing the standard C-ring closure have been a main-stay for over a half of a century in the national and international nuclear industry for shipping radioactive materials and will remain so in the foreseeable future. Drum package use in the U.S. increased heavily in the 1950's with development of the Weapons Complex and subsequently the commercial nuclear reactor industry.

Early Packaging Hardware

Following the 1966 Atomic Energy Commission adoption of Radioactive Material Packaging requirements in 10CFR71 a Dow Chemical Corporation 10-gallon container, Model 1518, is referenced as the first United States drum packaging approved for shipping radioactive material.[1] These federal requirements emphasized the development of performance based standards for radioactive material packaging and formed the baseline of today's U.S. packaging regulations. The International Atomic Energy Agency (IAEA) published a similar set of regulations that were initiated by the United Nations governing the international transportation of Radioactive Material. While principally similar, International and U.S. regulations differ in key areas due to variations in Domestic and International policy (not a subject of this paper). However, from their establishment in the 1960's, the U.S. and IAEA regulations have steadily progressed toward alignment.

Model 1518 approval in 1967 was issued by the Atomic Energy Commission. By some accounts, this container was recognized as the first "6M" specification packaging. By the end of 1968, the Department of Transportation had codified Type B radioactive material specification containers into Title 49 Part 173 of the Code of Federal Regulations. The DOT specification covered drum containers ranging in size from 10- to 110-gallons and is known today in the nuclear industry as the DOT "6M Specification" for radioactive material packaging.[2] The Specification packaging idea was not adopted by the IAEA. Containers fabricated to this specification were authorized to ship a wide variety of Type B quantities of radioactive material and were widely used in the U.S. because of their license-exempt status and inexpensive fabrication. Around 1983, the DOT raised a concern about the safety of their continued use. A task force was convened by DOE to evaluate their safety and recommended that DOT not eliminate them from 49 CFR as an approved Type B container. With NRC's adoption of the IAEA Hypothetical Crush test in the 1995 Rule Making, the issue of continued 6M viability was raised again and debate continued through 2001. In 1998 the Environmental Management office of DOE restricted the allowable 6M contents. In 2001, the National Nuclear Security Administration recommended a phased elimination of the 6M hardware from service within the Office of Secure Transportation.[3]

In 2002, the DOT Rule Making proposed a phased elimination of the 6M Specification from 49 CFR 173. Shortly, afterward, drop testing of the NRC approved ABB-2901 utilizing the standard C-ring drum closure produced similarly unsatisfactory results, further validating the proposed elimination.[4] Note that the drum closure failures were not the only basis for removing the 6M specification from U.S. Regulations. The inability to measure and verify containment and proper QA of package fabrication and materials were other issues that ultimately led to its removal from 49 CFR 173.

Clamshell Closure Concept

Prior to the EM and NNSA actions and recommendations, drop testing of some DOE drum-type packages, including the DT-18, DT-22 and 9974 resulted in failure of the standard open-head C-ring closure.[5]

During the time DOT and DOE were debating the viability of the 6M Specification, results of a 9975 30-ft drop test by the Savannah River Site in 1999 showed a C-ring drum-closure failure, Figure 1.[6]

Figure 1 9975 30-ft Drop C-Ring Lid Closure Failure

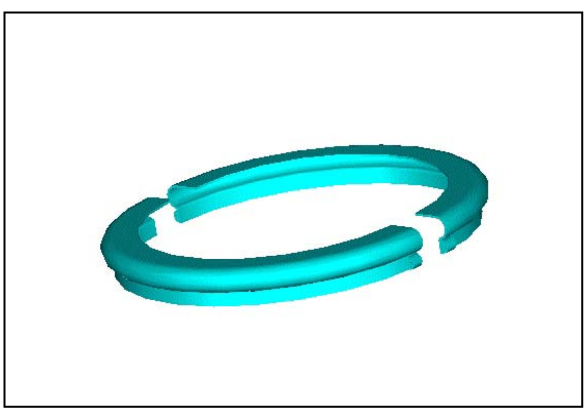
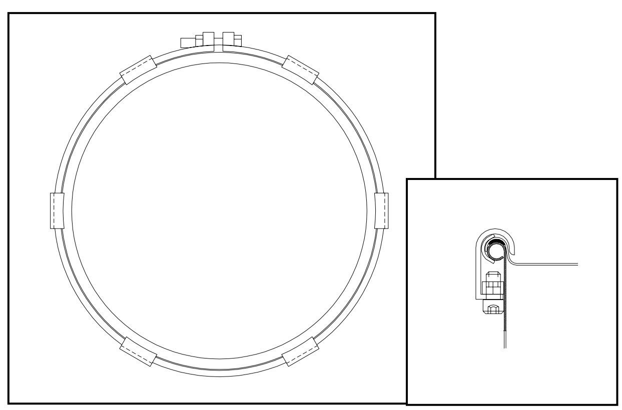
The SRNL testing provided further confirmation of the potential failure mode of the C-ring drum closure. Though the 9975 drum-lid breach shown in Figure 1 was not as significant as some other drum-closure failures that completely expelled closure lids from their drums, it was significant enough during the 9975 Regulatory review process to result in a closure lid redesign. Based on the 9975 lid breach, the Savannah River Packaging Technology Group (SRPT) developed ten concepts in March 2000 for replacement or enhancement of the standard C-ring closure apparatus. Of the ten concepts, two were selected for further evaluation, a bolted flange closure and a clamshell style arrangement. This was the first suggested use of a clamshell type closure. The bolted flange closure was implemented in the 9975 for the following reasons. Given that other DOE drum packages had experienced similar lid failures, were redesigned with a bolted flange closure, and certified, the retrofit of a bolted flange closure to the 9975 was deemed significantly less risky than further development of the Clamshell. At this time no further evaluation was performed on the Clamshell concept.

A series of events from 1999 to 2003 lead the NNSA to direct SRPT to develop an enhancement to the standard C-ring drum closure. These events were:

- NNSA Certification Office recommendation to phase out 6M (2001),
- DOT Proposed Rule Making to eliminate the 6M specification packaging from 49CFR173 (2002), and
- Failure of the drum closure of the NRC Licensed Model ABB-2901 Fuel Pellet Shipping Package (2002)

In May of 2003, based on a SRPT proposal to develop an enhancement to the drum-closure, the NNSA directed the SRPT to develop and test a modification to the drum closure which could be reliably implemented within the existing 6M fleet, permitting its continued use until DOE had a certified a new packaging design to replace the 6M Specification Hardware or until the DOT 6M Specification Hardware was prohibited from service (October 1, 2008), whichever occurred first.[7]

The request for a replacement/fix for the standard C-ring drum closure resulted in reevaluation of the conceptual designs considered for the 9975 drum-closure redesign effort. Two designs selected for further evaluation were the Clamshell and a J-hook. The Clamshell design replaces the standard C-ring closure while the J-hook supplements the C-ring drum closure. Figure 2 illustrates the two design concepts.

Clamshell Rendering J-Hook Top and Side View Details

Figure 2 Clamshell and J-Hook Drum-Closure Preliminary Enhancement Concepts

The clamshell and J-hook designs showed the greatest potential for performance success and were believed to be the most efficient to fabricate and implement within the 6M fleet. Concurrent with closure redesign, 6M package testing was initiated to determine the failure threshold for the C-ring drum closure. Results from testing would become the basis for assessing candidate closure improvements. Within a few months, prototypes of the modified closure designs were constructed and tested on 6M packaging. As the J-hook is not the subject of this paper, no further discussion of its design or its testing follows.

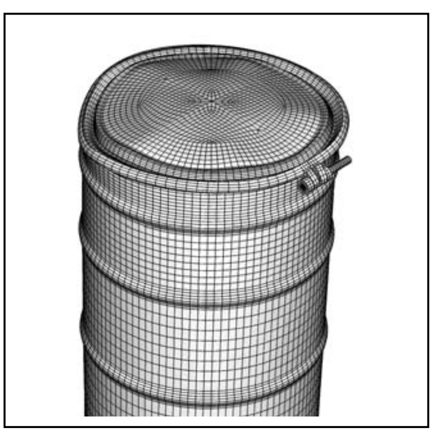
Clamshell Closure Design

The following functional performance requirements were considered in the clamshell development.

- Structural - Will it ensure lid retention after a 30-ft drop impact?
- Operability - Is it compatible with existing manufactured drums?
- Fabrication Expense – Is production cost effective?
- Testing Requirements - Can it be proven with minimal testing?
- Certainty of Success – Will the DOT approve a replacement for the existing drum closure?
- User Community Impact - Can it be easily implemented?

The design expected to meet the functional performance requirements would have to be evaluated rigorously through analytical analysis and testing. Both design and prototype manufacturing of the Clamshell were "fast-tracked". Finite element analysis (FEA) and rapid-prototyping technology were used to evaluate design performance and operability prior to fabrication of prototype hardware.

To better understand the functional requirements that the Clamshell design must meet, FEA was performed to simulate the response of a 55-gallon drum closure to both 10CFR71 Normal Condition of Transport (4-ft) drop, and Hypothetical Accident Condition (30-ft drop).[8] Review of the graphical FEA results provided quick insight into how the clamshell would have to perform during regulatory drop events. Figure 3 presents deformed geometry results from 4-ft and 30-ft drop analyses. No discernable damage is observed for the 4-ft drop, however, the drum closure failed in the 30-ft drop. Analysis determined the limited friction load achievable with the C-ring band is a factor in the ability of the drum to retain its lid.



4-Foot Drop Analysis **30-Foot Drop Analysis**

Figure 3 Deformed C-Ring Drum Closure following a 4-ft and 30-ft Drop Event Analyses

The clamshell design quickly progressed from paper to prototype hardware with the help of rapid prototyping machinery. Rapid prototyping permitted trial fit up of subscale hardware components before more time and money were spent on producing actual prototype hardware. Figure 4 shows two of the rapid prototype components produced to verify functionality. The ability to go from paper to a rapid prototype item in a single day significantly increases the efficiency of design and development. One of the parts represents a smooth clamshell and the other a scalloped clamshell. During discussions, the die-manufacturer expressed concern that the opposing vertical and horizontal flanges may produce scalloping of the horizontal flange during rolling to the diameter of a 55-gallon drum. Based on a sketch from the die-manufacturer, the part was drawn and a rapid prototype part was produced. Though analysis determined that the scalloped section would still function as needed it was not as aesthetically pleasing as the desired smooth walled design.

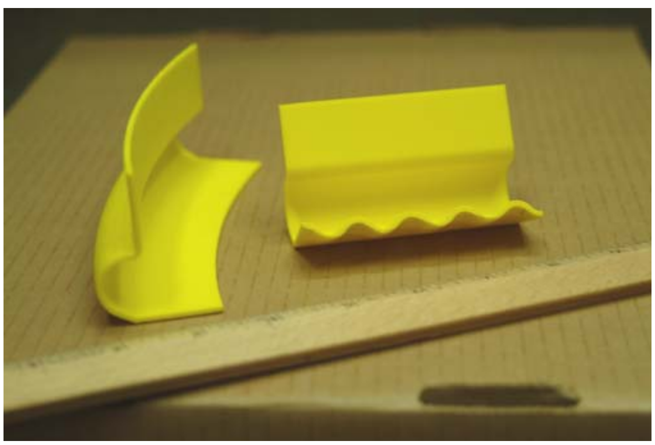


Figure 4 Rapid Prototype Sections of the Clamshell Design.

Clamshell Closure Prototype Fabrication

The first clamshell prototype was fabricated by halving a standard carbon steel C-ring closure and welding on an opposing pair of lugs; the clamshell was completed by welding stock to the half-rings. The bottom flanges were from 12-gauge strip and the top flanges were cut from 12-gauge sheet. Figure 5 shows one of the first clamshell prototypes fitted to a UN1A2 drum. In each figure the welds are visible between the C-ring and flanges. The opposing lugs ensure application of a more consistent friction load along the curl of the drum during bolt tightening. The vertical flange extending downward from the C-ring was designed to fit securely under the drum curl. The horizontal flange extends the top surface area of the C-ring over the edge of the drum closure. The combination of these three changes has been shown by testing to prevent drum closure failure during 10CFR71 30-ft Hypothetical Accident Condition drop event. Figure 7 pictures the damage imparted to a 6M packaging using the clamshell closure. Various package weights and drop orientations were tested for the retrofitted UN1A2 drums.

Figure 5 Prototype Clamshell Closure Fitted to a UN1A2 drum

Drum Closure Testing of 6M Specification Hardware

Concurrent with the clamshell closure development 6M containers were procured and subject to 10CFR71 NCT and HAC drops. The 6M 55-gallon drums were dropped from a range of 15 to 30 feet at varying angles while varying gross drum weight from 325 lb to 640 lb[9]. The latter being the maximum gross weight permitted by the 6M specification. Thirty feet is the regulatory drop height. Lesser drop heights down to 15 feet were included in an attempt to determine the minimum drop height that would fail the standard C-ring drum closure. Test results showed that C-rings failed about the same for the lesser weight packaging dropped from 15 feet as the maximum gross weight packaging dropped from 30 feet. Figure 6 shows some of the closure failures seen for the 6M specification packaging testing. Following these drop tests 6M drums were fitted with the Clamshell or J-clip and subjected to similar drop testing.

Center of Gravity over Corner (CGOC) | **Shallow Angle Drop Damage**

Figure 6 Typical Impact Results from a 6M packaging dropped from 30-Feet.

On close inspection of high-speed film footage of the drop events the common form of closure failure, i.e., lid ejection from the drum, appeared to be due to the variability of spring-back among the deformed drum closure parts (lid, drum body and C-ring). Drum lid retention during a drop or even when under an internal static pressure is based on the C-ring's contact surface area between the lid and drum curl and the applied friction generated when the C-ring is tightened i.e., bolted together. The circumferential distribution of applied friction in this joint is greatly dependent on how friction is relieved in the joint during the closure process. Hammer blows during tightening help distribute contact friction. FEA confirmed that how the friction load was applied was a determining factor in lid retention.

On rebound, the drum body remains close to its original impact deformed shape, however, the C-ring and drum lid spring back much more and rapidly, with the C-ring responding much like a hula-hoop that's been forced into an oval shape. The combination of rapid spring-back of the C-ring and the deformed drum shape relieves the friction load locally between the drum curl and C-ring. This allows the lid to spring away from beneath the C-ring. As the lid escapes locally, the C-ring hoop loosens further, further releasing the drum lid. On close inspection of the high-speed footage, it is evident that upon impact C-ring closure, drum body and drum lid deform as one; the lid becomes detached from the drum during the resulting rebound. The Clamshell and J-hook were specifically designed to prevent this mode of drum closure failure.

Clamshell Closure Validation Tests on 6M Specification Packaging

The impact driven response of the Clamshell design differs significantly form the standard C-ring drum closure. The addition of vertical and horizontal flanges strengthens the closure the C-ring. Gross damage to the drum during the initial impact is indistinguishable from that associated with the standard closure. However, upon rebound the Clamshell does not deliver the "hula-hoop" reaction of the standard C-ring. The Clamshells' horizontal flange buckles during the drop impact which prevents the C-ring portion from returning to its original shape, i.e., prevents the "hula-hoop" effect. Since the Clamshell does not spring back independent of the drum, the Clamshells' vertical flange remains with the drum. The lid may spring back during rebound, however, the combination of original friction load (achieved by tightening the opposing lugs) and the Clamshell's glove-like match to the deformed shape of the drum prevents lid loss. Figure 7 illustrates drum damage with a Clamshell following the 30-ft drop impact. Inquiry for additional information can be sent to the SRNL Author.

Center of Gravity over Corner Drop

Shallow Angle Drop

Figure 7 6M 30-ft Impact Damage with the Blanton Clamshell Closure.

Clamshell Closure Production Manufacturing

Clamshell production activities followed concurrence by the DOT that the Clamshell closure met the requirements of the closure design standard given in 49 CFR 178.352-5.[10] Greater than a thousand Clamshell closures have been produced since 2004 and are in service within the DOE Complex for shipment of 6M packaegs.

The standard method for C-ring closure manufacturing is automated, and thousands are produced daily for various drum manufacturers. Forming machinery incorporates a few dies to form strip-steel into the C-ring shape of the standard drum closure. The process is fast and repeatable.

However, the Clamshell's geometry requires multiple dies to form its shape in an automated process. The Clamshell is manufactured by Drum Parts-MidWest located in Thornton, IL who is also a major supplier of drum C-ring closures. Clamshell production is licensed to Nuclear Filter Technology of Golden Colorado. Drum Parts Mid-West worked with their die-manufactures to develop a series of rolling-dies that would automate fabrication of the Clamshell shape using a multi-stage rolling process pictured in Figure 8. Following the forming process, the lugs are welded in place by hand using a jig. The manufacturer plans to automate the lug welding process as is currently done with standard C-ring production. Following lug welding, the Clamshells are cleaned and painted. The current process can produce hundreds of Clamshells per day. Completely automating the process and employing multiple rolling machines would significantly increase capacity. Quality Control is implemented throughout all stages of production to ensure accuracy and consistency. Figure 8 presents a snap shot in time of the Clamshell production process.

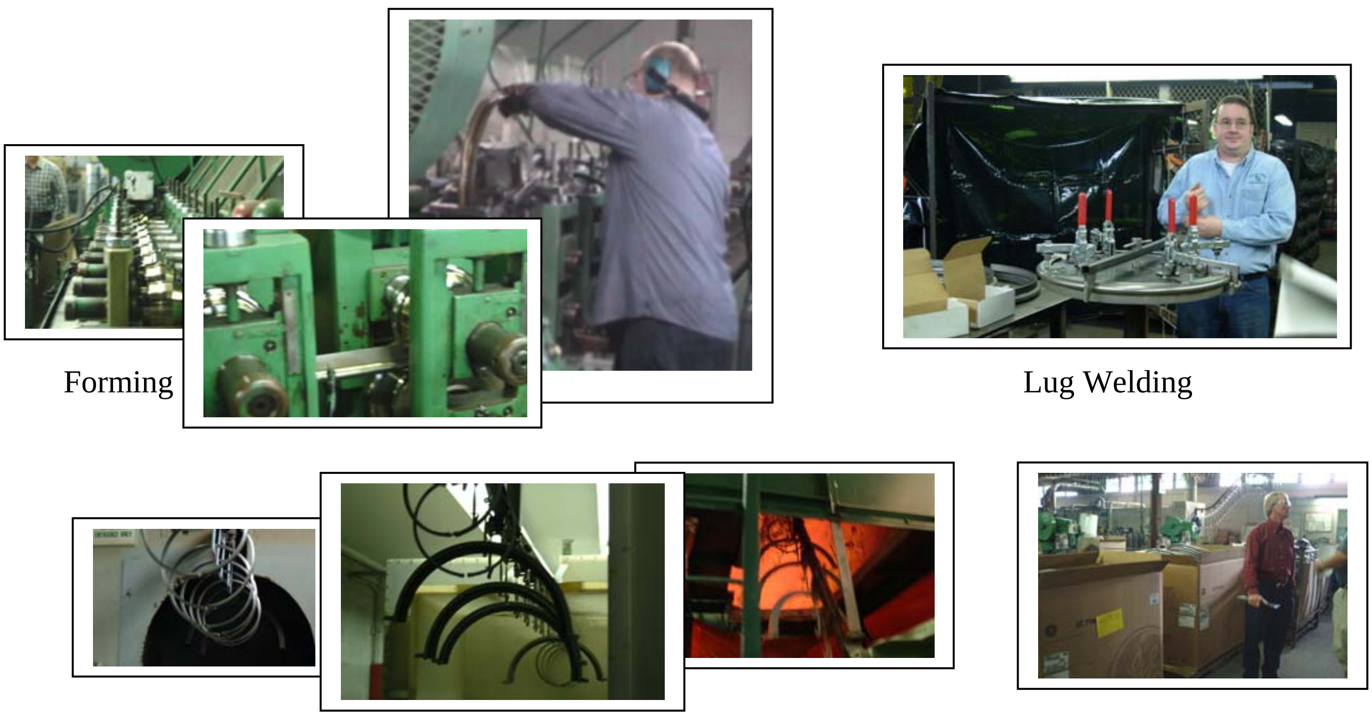


Figure 8 Clamshell Production Process

Clamshell Closure Installation and Operability

The closure is installed in about the same time frame as the standard C-ring closure. The two halves are positioned opposite each other and pressed or hammered together with a rubber mallet. Once the clamshell halves are in position the bolts are tightened to 40-ft lbs. No special handing or constraints are required to ship a drum closed with the Clamshell closure. Figure 9 depicts the first production clamshell closure, witnessed by the designer/author installed on a 55-gallon drum.

Figure 9 Production Version of a Blanton Clamshell Closure Installed on a 55-gallon Open Head Drum.

Conclusions

The Blanton Clamshell was developed as a replacement for the standard C-ring closure that is used on the majority of UN1A2 open head drums. Its closure strength is superior to the standard C-ring closure as proven by testing and repeated use over the last three years as a working substitute for the standard closure. It is currently deployed within the Department of Energy as a replacement for the standard C-ring used on 6M specification 55- and 85-gallon drum packages. Although designed for radioactive material packagings the Clamshell can provide robust closure of other open-head drums in various applications where improved lid retention capability is desired. The “Clamshell” closure was designed by the SRNL and is licensed for use by Nuclear Filter Technology, Golden, Colorado.

Disclaimer

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