TP 14396E

PERFORMANCE TESTS OF SELECTED PLASTIC DRUMS

Prepared for
Transportation Development Centre
Transport Canada

by
Environmental Simulation Lab
Centre for Surface Transportation Technology
National Research Council Canada

FEBRUARY 2005

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Since some of the accepted measures in the industry are imperial, metric measures are not always used in this report.

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Un sommaire français se trouve avant la table des matières.

Transport Canada Transports Canada

PUBLICATION DATA FORM

1. Transport Canada Publication No.
TP 14396E

2. Project No.
5470-72

3. Recipient's Catalogue No.

4. Title and Subtitle
Performance Tests of Selected Plastic Drums

5. Publication Date
February 2005

6. Performing Organization Document No.

7. Author(s)
N. Richter, D. LeBlanc and L. Tighe

8. Transport Canada File No.
2450-FP740/2

9. Performing Organization Name and Address
Centre for Surface Transportation Technology
National Research Council Canada
U-89 Lester Road
Ottawa, Ontario
Canada K1A 0R6

10. PWGSC File No.

11. PWGSC or Transport Canada Contract No.

12. Sponsoring Agency Name and Address
Transportation Development Centre (TDC)
800 René Lévesque Blvd. West
Suite 600
Montreal, Quebec
H3B 1X9

13. Type of Publication and Period Covered
Final

14. Project Officer
A. Vincent

15. Supplementary Notes (Funding programs, titles of related publications, etc.)
Co-sponsored by Transport Canada's Transport Dangerous Goods Directorate

16. Abstract

This report details the work carried out to determine the performance level of 210 L plastic drums intended for the transport of dangerous goods. This will help in evaluating the effectiveness of quality control measures implemented as a result of a 1985 study.

Two types of tests were carried out for this study. Drop tests were conducted to find the average and lowest height from which the drums could be dropped without releasing any of the contained products. Pressure tests were also performed to determine whether the drums were able to meet the pressure ratings for which they were designed.

All of the drums tested in the study were found to be well within the drop resistance requirements established for shipment of dangerous goods. There were some slight discrepancies in the pressure tests where some drums in a sample did not meet the specified pressure requirement, but these may have been due to an incorrect torque value for the closure.

Recommendations include requiring at least one drop test in each orientation to ensure the most vulnerable condition has been tested, making the correct torque information readily available to users, and requiring training in the importance of proper torque.

17. Key Words
Bruceton Staircase, dangerous goods, drop orientation, drop testing, drums, drum closures, drum testing, package testing, packaging

18. Distribution Statement
Limited number of copies available from the Transportation Development Centre

19. Security Classification (of this publication)
Unclassified

20. Security Classification (of this page)
Unclassified

21. Declassification (date)
—

22. No. of Pages
x, 16, apps

23. Price
Shipping/ Handling

Transports Canada Transport Canada

FORMULE DE DONNÉES POUR PUBLICATION

1. N° de la publication de Transports Canada
TP 14396E

2. N° de l’étude
5470-72

3. N° de catalogue du destinataire

4. Titre et sous-titre
Performance Tests of Selected Plastic Drums

5. Date de la publication
Février 2005

6. N° de document de l’organisme exécutant

7. Auteur(s)
N. Richter, D. LeBlanc et L. Tighe

8. N° de dossier - Transports Canada
2450-FP740/2

9. Nom et adresse de l’organisme exécutant
Centre de technologie des transports de surface
Conseil national de recherches du Canada
U-89 Lester Road
Ottawa (Ontario)
Canada K1A 0R6

10. N° de dossier - TPSGC

11. N° de contrat - TPSGC ou Transports Canada

12. Nom et adresse de l’organisme parrain
Centre de développement des transports (CDT)
800, boul. René-Lévesque Ouest
Bureau 600
Montréal (Québec)
H3B 1X9

13. Genre de publication et période visée
Final

14. Agent de projet
A. Vincent

15. Remarques additionnelles (programmes de financement, titres de publications connexes, etc.)
Coparrainé par la Direction générale du transport des marchandises dangereuses

16. Résumé

Le présent rapport rend compte des travaux réalisés pour déterminer le niveau de rendement de fûts en plastique de 210 L destinés au transport de marchandises dangereuses. Ces travaux aideront à évaluer l’efficacité des procédures de contrôle de la qualité mises en place par suite d’une étude menée en 1985.

Deux types d’épreuves ont été exécutées – des épreuves de chute et des épreuves de pression. Les épreuves de chute visaient à déterminer les hauteurs moyenne et minimale desquelles les fûts pouvaient être lâchés sans rien laisser échapper de leur contenu. Quant aux épreuves de pression, elles servaient à déterminer la capacité des fûts de résister à la pression nominale pour laquelle ils avaient été conçus.

Tous les fûts testés ont amplement satisfait aux exigences de résistance au choc établies pour le transport de marchandises dangereuses. De légères lacunes ont été constatées aux épreuves de pression. Ainsi, quelques fûts d’un échantillon n’ont pas résisté aux pressions exigées, mais il se peut que cela tienne au fait qu’un couple de serrage incorrect avait été appliqué au système de fermeture.

Le rapport formule diverses recommandations, dont celle d’exiger au moins une épreuve de chute selon chaque orientation, de façon à être sûr que l’orientation la plus fragile soit mise à l’épreuve. Il est également recommandé de faire en sorte que les utilisateurs aient facilement accès aux données sur le couple de serrage, et d’obliger ceux-ci à suivre une formation sur l’importance de respecter les prescriptions touchant le couple de serrage.

17. Mots clés
Méthode de l’escalier de Bruceton, marchandises dangereuses, orientation de chute, épreuve de chute, fûts, système de fermeture de fût, épreuve de rendement de fût, épreuve de rendement d’emballage, emballage

18. Diffusion
Le Centre de développement des transports dispose d’un nombre limité d’exemplaires.

19. Classification de sécurité (de cette publication)	20. Classification de sécurité (de cette page)	21. Déclassification (date)	22. Nombre de pages	23. Prix
Non classifiée	Non classifiée	—	x, 16, ann.	Port et manutention

EXECUTIVE SUMMARY

This project featured a series of drop tests and internal pressure tests carried out to evaluate the performance of selected plastic drums used for the transport of dangerous goods. A previous study was done by Transport Canada in 1985 (TP 7423E) that covered many types of packaging and several types of tests. As a result of that study, Transport Canada implemented quality control provisions to address some deficiencies found in drums used in the study. In order to evaluate how well these provisions were working, Transport Canada instituted a study of 210 L steel drums. Those results were presented in report TP 14093E, published in April 2003.

The current study continued the work of the 2003 study by performing similar tests on 210 L plastic drums. This study differed from the previous study in that the procedure for drop tests was streamlined slightly, and a series of internal pressure tests was included for the plastic drums.

Sample sets of 50 drums were purchased from two manufacturers in Canada, two manufacturers in the United States, and one each in the United Kingdom, Continental Europe and Asia. Two orientations were tested. In the six o'clock orientation, the drum is dropped diagonally on its top circumferential edge so that the point closest to the large closure strikes the target. The eight o'clock orientation is similar except that the drum is rotated so that the large closure is in the centre of the "crush pattern" that forms when the drum hits the target. Several different combinations of closure styles were used in the tested drums, and these are noted in the report; however, no particular analysis was done to compare closure styles due to the large variety of styles supplied.

Preliminary testing was done on each set of drums to determine the most severe drop orientation and the starting height. That orientation and starting height were then used in the actual drop tests. This was a significant change from the procedure used in the steel drum study, in which a full series of drop tests were conducted in both orientations. It was also where a difference in the results was found. Whereas in the steel drum study, the lowest mean failure height was always in the 8 o'clock orientation, in this study it was found that plastic drums from different manufacturers behaved differently, with several sets of drums failing earlier in the 6 o'clock orientation.

An Up and Down *Bruceton Staircase* procedure was used to mathematically establish a mean failure height and standard deviation for each set of drums. The drums were filled with water to 98 percent of their maximum capacity and then subjected to the drop test as required for transport of dangerous goods. After each drum was tested it was evaluated to see whether there were leaks (failure). If there were, then the next drum was tested at a 0.2 m lower height. If not, the next drum was dropped from a 0.2 m higher height. This was continued until all 20 drums had been tested in the selected orientation, after which the data was analyzed to arrive at an estimate for the mean and standard deviation for each series.

Five drums from each manufacturer were tested for their ability to withstand internal pressure without leakage. Each drum was pressurized in increments either until they leaked or until a pressure equal to 150% of the drum's rated pressure was reached.

The study found that there was a wide variation in the failure heights between manufacturers, but good consistency between drums from the same manufacturer. All of the drums tested were more than capable of surviving the standard drop test required for transport of dangerous

goods. Most of the drums withstood more than their rated internal pressure. Some sets had one or more samples that leaked just below the rated pressure, but this may be attributable to not having the correct torque for securing the closures.

There was a greater variety of failure modes demonstrated by the plastic drums than was the case during the steel drum study. This probably reflects the fact that there is a much greater variation in the design details between different plastic drum manufacturers, whereas steel drums are much more standardized.

Recommendations include requiring at least one drop test in each orientation to ensure the most vulnerable condition has been tested, making the correct torque information readily available to users, and requiring training in the importance of proper torque. Similar studies are recommended for other types of packaging, including 20 L pails and combination packages.

SOMMAIRE

Le projet a consisté en une série d’épreuves de chute et d’épreuves de pression interne qui avaient pour but d’évaluer le rendement de divers fûts en plastique utilisés pour le transport des marchandises dangereuses. Transports Canada a déjà réalisé, en 1985, une étude (TP 7423E) qui couvrait de nombreux types d’emballages et d’essais. Par suite de cette étude, Transports Canada a mis en place des procédures de contrôle de la qualité pour prévenir certaines défectuosités décelées dans les fûts étudiés. Pour évaluer l’efficacité de ces procédures de contrôle de la qualité, Transports Canada a lancé une étude sur les fûts en acier de 210 L. Les résultats obtenus sont présentés dans le rapport TP 14093E, publié en avril 2003.

La présente étude est la poursuite de l’étude de 2003. Des fûts en plastique de 210 L ont été soumis aux mêmes épreuves que les fûts en acier, si ce n’est que le protocole de l’épreuve de chute a été légèrement simplifié. De plus, les fûts en plastique ont également été soumis à une série d’épreuves de pression interne que n’avaient pas eu à subir les fûts en acier.

Des ensembles d’échantillons de 50 fûts ont été achetés à deux fabricants du Canada, deux fabricants des États-Unis, un fabricant du Royaume-Uni, un fabricant d’Europe continentale et un fabricant asiatique. Les épreuves de chute ont été exécutées selon deux orientations. Dans l’orientation «6 h», le fût est lâché sur son bord périphérique supérieur de sorte que son point le plus près de la grande fermeture frappe la cible. L’essai selon l’orientation «8 h» est similaire, sauf que l’on fait subir une rotation au fût de sorte que sa grande fermeture coïncide avec le centre de la zone de déformation résultant de l’impact sur la cible. Plusieurs combinaisons différentes de systèmes de fermeture équipaient les fûts essayés; on trouve cette information dans le rapport. Mais aucune analyse comparative n’a été faite de ces systèmes de fermeture, en raison de leur trop grande diversité.

Chaque ensemble de fûts a été soumis à des essais préliminaires, afin de déterminer l’orientation la plus susceptible d’entraîner une défaillance ainsi que la hauteur de chute initiale. Les épreuves de chute ont ensuite été exécutées selon l’orientation et la hauteur de chute ainsi déterminées. Cette méthode différait passablement de celle utilisée pour les fûts en acier, laquelle prévoyait une série complète d’épreuves de chute dans chacune des orientations. C’est d’ailleurs sur le plan de l’orientation qu’une différence a été constatée dans les résultats. Ainsi, alors que dans l’étude sur les fûts en acier, la hauteur moyenne minimale la plus probable de défaillance correspondait toujours à l’orientation «8 h», dans la présente étude, les fûts en plastique provenant de différents fabricants se comportaient de façon différente. En effet, plusieurs ensembles de fûts présentaient une défaillance plus rapidement dans l’orientation «6 h» que dans l’orientation «8 h».

Les chercheurs ont employé la méthode de l’*escalier de Bruceton* pour établir mathématiquement une hauteur moyenne de défaillance et un écart type pour chaque ensemble de fûts. Les fûts ont été remplis d’eau à 98 p. 100 de leur capacité, puis soumis à l’épreuve de chute exigée pour l’usage de transport de marchandises dangereuses. Après essai, chaque fût a été contrôlé pour la présence de fuites (assimilées à une défaillance). Le cas échéant, le fût suivant était lâché à une hauteur inférieure de 0,2 m. Si aucune fuite n’était décelée, le fût suivant était lâché à 0,2 m plus haut. Les essais se sont poursuivis ainsi jusqu’à concurrence de 20 fûts, selon l’orientation choisie, après quoi l’analyse des données a permis d’établir la hauteur moyenne et l’écart type pour chaque série d’essais.

Cinq fûts de chaque fabricant ont été soumis à des épreuves de pression interne. La pression à l'intérieur des fûts était augmentée par incréments jusqu'à ce qu'une fuite se produise ou jusqu'à ce que la pression soit égale à 150 p. 100 de la pression nominale du fût.

Les chercheurs ont constaté une forte variation des hauteurs de défaillance entre les produits des différents fabricants, mais une bonne uniformité entre les fûts provenant d'un même fabricant. Tous les fûts mis à l'essai ont obtenu des résultats plus que satisfaisants à l'épreuve de chute standard exigée pour le transport de marchandises dangereuses. La plupart des fûts ont résisté à une pression interne supérieure à leur pression nominale. Dans certains des ensembles de fûts, on a constaté une fuite dans un ou plusieurs des échantillons juste au-dessous de la pression nominale, mais une telle défaillance pourrait être attribuable à l'application d'un couple de serrage incorrect au système de fermeture.

Par rapport à l'étude sur les fûts en acier, les fûts en plastique ont présenté une plus grande variété de modes de défaillance. Cela tient probablement au fait que les détails de conception des fûts en plastique varient beaucoup d'un fabricant à l'autre, tandis que les fûts en acier sont passablement normalisés.

Le rapport formule diverses recommandations, dont celle d'exiger au moins une épreuve de chute selon chaque orientation, de façon à être sûr que l'orientation la plus fragile soit mise à l'épreuve. Il est également recommandé de faire en sorte que les utilisateurs aient facilement accès aux données sur le couple de serrage, et d'obliger ceux-ci à suivre une formation sur l'importance de respecter les prescriptions touchant le couple de serrage. Enfin, il est recommandé de soumettre d'autres types d'emballages à des études semblables, notamment les seaux de 20 L et les emballages combinés.

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1. INTRODUCTION

This report describes a comprehensive performance evaluation of selected plastic drums used for the transport of dangerous goods. A previous study [1] was done by Transport Canada in 1985 using larger sample sizes and covering many types of packaging, including 210 L drums. As a result of that study, Transport Canada implemented quality control provisions to address some deficiencies found in drums used in the study. A follow-up study [2] was carried out in 2003 to evaluate the effectiveness of these provisions. Since the time of the 1985 study, the use of plastic drums for transport of dangerous goods has grown significantly, and the current study is meant to evaluate how well plastic drums do in meeting the requirements.

A total of 350 drums were purchased from manufacturers in Canada, the United States, the United Kingdom, Continental Europe and Asia. Each sample set consisted of 50 drums, the first few of which were used for preliminary testing to determine the starting drop height in the six o'clock and eight o'clock orientations for that particular set. Twenty were used for drop tests in whichever orientation was identified as being the most failure prone for that drum set. Another five drums were used for internal pressure tests.

The principal objective of this test sequence was to evaluate the performance of plastic drums from various manufacturers around the world. An Up and Down *Bruceton Staircase* procedure was used to mathematically establish a mean failure height and standard deviation for each set of drums.

The secondary objective was to assess the merits of the two different drop orientations. Some countries require testing in only the six o'clock orientation, while others require the eight o'clock orientation. The latter is more time consuming because six o'clock drops must be done first to establish the correct angle for the eight o'clock drops.

Unlike steel drums, which all are made with the same closure configuration and one of two closure brands, plastic drums come with a wide variety of closure types, sizes, thread styles, and gasket types. Given the number of variations and the limited scope of the study, it was not possible to fully evaluate which closure types perform better. The closure types are described in this report but no conclusions are drawn as to their merits. However, the closure type may be a moot point as it relates to drop impact, since relatively few failures occurred as a result of closure leaks.

Throughout this report, drum manufacturers or countries of origin are referred to only by letter designation and not by name in order to maintain confidentiality when disseminating the report.

2. TEST PROCEDURE

Drums were ordered through a third party supplier to ensure a random sample. They were ordered from two manufacturers chosen at random from those in Canada, two in the U.S., and one each from France, the U.K. and India. A test plan was developed [2] and approved by Transport Canada. The test method was based on the Canadian General Standards Board standard [3] that deals with packaging for the transport of dangerous goods, and the two previous studies [1] and [4].

All drop tests were performed at the Centre for Surface Transportation Technology (CSTT) Environmental Simulation Laboratory (ESL) in Dartmouth, Nova Scotia. Data analysis was carried out using the Bruceton Staircase method as described in Natrella [5]. Most of the drop testing was carried out on a thick concrete pad outside the lab building, since preliminary testing indicated more height would be needed than could be reached indoors. The floor in the ESL building is 0.12 m thick over very well compacted fill. The outdoor drops utilized a concrete pad measuring approximately 3 m by 3 m by 0.2 m thick.

2.1 Drop Orientations

Two orientations were tested for each drum set, six o'clock and eight o'clock. The six o'clock orientation is so named because, when the drum is lying on its side, the large closure is positioned at the bottom, or six o'clock position. The bottom of the drum is then raised so that a vertical line passes through the two opposite edges and the centre of gravity. When the drum is released from this position, it impacts on the edge of the chime directly below the large closure. At the end of the impact, the drum usually has a new flat face running at an angle to the top and sides, with the large closure near the centre of the flat. See Figure 1.

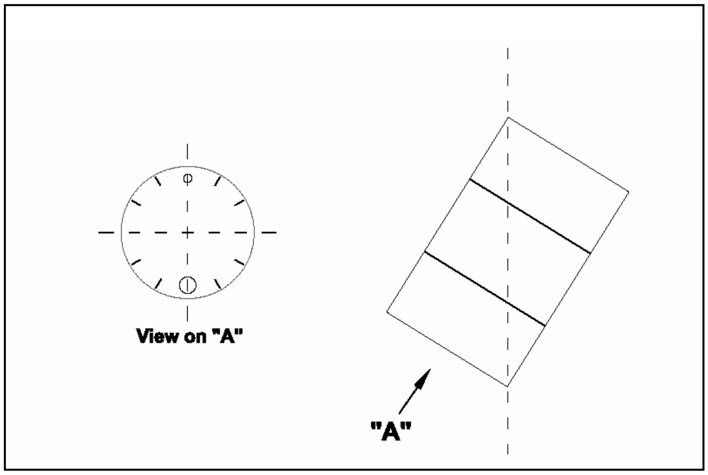

Figure 1: Six O'clock Drop Orientation

The eight o'clock orientation is similar except that when the drum is lying on its side, the drum is rolled so that the large closure will be offset from the six o'clock position. See Figure 2. This orientation is intended to be the worst-case scenario, since it is expected that, following the impact, the edge of the distortion pattern will pass through the large closure. The name is somewhat of a misnomer then, because the actual orientation required to accomplish this may be more or less than eight o'clock, depending on how large the distortion pattern is. For this reason it is necessary to first do a few six o'clock drops to establish the correct angle to ensure that the distortion pattern edge coincides with the closure.

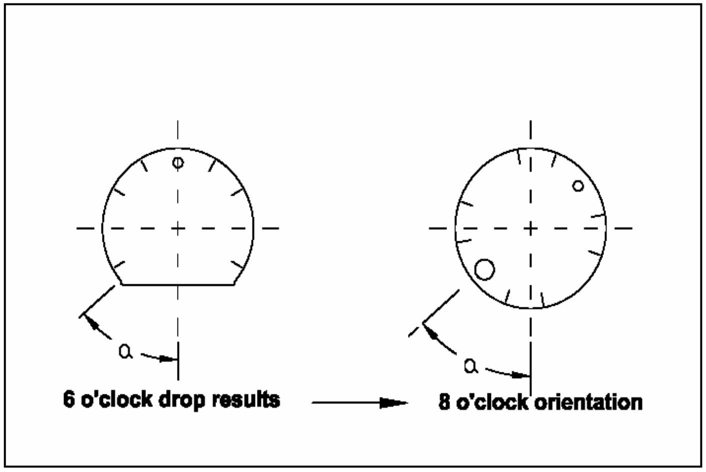

Figure 2: Eight O'clock Drop Orientation

In this test program, approximately five six o'clock drops were carried out for a set of drums first, to estimate a starting height for drops in that orientation. Then the size of the pattern was determined and the true angle established for the eight o'clock orientation. The process of estimating the starting drop height was repeated in that orientation. Finally, the orientation that appeared to give the lowest start height was chosen, and 20 drums were tested in that orientation. In some cases, the difference between the two orientations was quite pronounced, but in others, the difference was quite minor, and either orientation may have given similar results.

2.2 *Drum Specifications*

As stated in Section 1, 50 drums were ordered from each manufacturer with the following minimum specifications:

- Certified and marked UN 1H1/Y1.5/200

  Which means
- Plastic, tight-head drums (1H1)
- For substances of a medium hazard class of up to 1.5 specific gravity (Y1.5)
- Capable of withstanding pressures of 200 kPa

However, some manufacturers were unwilling to set up a separate run, given the small size of the order, and most drums arrived with one or more specifications at a different level than were requested. Therefore, when assessing the compliance to the standard, it is important to do so with a view to the actual specifications, and not those listed above. Table 1 lists the "as received" specifications of the drums.

Table 1: "As received" specifications

Manufacturer	A	B	C	D	E	F	G
Grade	Y/1.9	Y/1.9	Y /1.9	Y /1.9	Y /1.9	Y /1.5	Y/1.9
Pressure Rating	150	150	150	250	200	100	200
Closure *	c ,e	a, b	a, b	b, b	c, c	c, c	c, b
Gaskets **	1	1	1	2	1	2	2

<u>Note:</u>

* Closure type
- a: 2 in. NPS thread
- b: 2 in. buttress thread, with ¾ in. threaded blind hole with knockout diaphragm in the centre
- c: 2 in. buttress thread
- d: 2 in. buttress thread, with ¾ in. threaded hole and bung in the centre
- e: 2 in. NPS thread, with ¾ in. threaded blind hole with knockout diaphragm in the centre

** Gasket type
- 1: Rectangular section, soft rubber
- 2: Round section, hard plastic

2.2.1 Drum Closures

Whereas the type of closure on steel drums is fairly uniform, with only a couple of variations on the design of the actual closure, types of closures for plastic drums are much more varied. The most common system on the drums bought in North America consisted of two closures: a 2 in. NPS threaded bung and a 2 in. buttress thread bung on the opposite side. Some of the drums purchased overseas came with both bungs having 2 in. buttress threads. Some of the 2 in. bungs also had a ¾ in. bung in the centre (Photo 32). Others had a ¾ in. threaded recess with a "knock-out diaphragm" but no bung. (Photo 33)

The type of gaskets used with the bungs also varied considerably, with some using a soft rubber-like rectangular section gasket, and others using a round section gasket of a harder plastic material. (Photo 31)

It was not always straightforward to know what torque to apply to the closures. The North American drums either had the closing torque moulded into the drum, or readily available on the company's web site. Many manufacturers also indicated the closing torque on the packing slips that came with the drums. However, for the overseas drums, either the torque values were not available or, if available, only a wide range of values was given.

This was particularly difficult for closures with the hard plastic gaskets. The torque of 27.1 J (20 ft-lb) that worked for closures with soft rubber gaskets was entirely inadequate for closures with hard plastic gaskets. After several attempts to contact the manufacturers, it was decided to try increasing the torque until a value was found that appeared to work. Often a value of 40.7 to 47.5 J (30 to 34 ft-lb) would seal, but 54.2 J (40 ft-lb) would cause the threads to be stripped, while lower values would result in a leaking closure at very low pressures.

2.3 Specimen Preparation

Each drum was labeled with a prefix, indicating the set the drum belonged to, along with a number (e.g., A1, A2, A3 … A50).

The tare and 100% capacity masses were established for the drums. A drum was filled with water until the meniscus of the water rose above the opening to obtain the 100% mass. Two percent of the total mass of the water was then subtracted to obtain the 98% fill-mass of the drum.

All drums were filled with water and allowed to settle at ambient temperature. All closures were manually tightened.

2.4 Drop Testing

A pair of grips, a sling and a quick-release latch were used to lift and drop the drums. The quick-release latch was actuated with the quick jerk of a rope to minimize any rotation on the drum upon release. The impacting surface used for all drops was concrete. The height was measured using a surveyor's telescoping aluminum rod. Photos of the test setup and methods are shown in photos 1 to 4 in Appendix A.

The worst-case orientation and starting drop height was determined through a preliminary drop test of approximately 10 drums. Based on the tester's experience and the apparent quality of the drums in question, a first drop height was chosen arbitrarily and one drum dropped from that height using the 6 o'clock orientation. Based on the results, the drop height was adjusted upward or downward for the next drops, so that a rough level of starting height could be determined. The size of crush pattern from the last few drops was then used to establish a rough starting height for the 8 o'clock orientation. Usually, by this time, one orientation or the other was clearly inferior to the other (failures occurring at a lower height) and that orientation was then used for the official drop tests. If the results were similar for the two orientations, a few more drops were performed in both orientations until a pattern could be ascertained.

An additional variable is introduced into the question of drop height orientation with plastic drums: which of the 2 in. closures should be facing downward during the drops? This was not an issue when testing steel drums, since they have only one 2 in. closure. It is also not an issue for plastic drums if both closures are the same type. However, in cases where both closures were the same size but different types, it wasn't clear which would be the most vulnerable and some extra preliminary drops had to be carried out to decide this.

It was found that, in cases where the failure occurred at a closure, it was nearly always the 2 in. NPS thread closure that leaked, but the failures occurred earlier when the drop impacted the buttress-thread closure. In cases where the failures did not involve a closure, it made no difference which closure was impacted. Therefore, all official tests were carried out with the 2 in. buttress thread closure down.

Once the minimum failure height was established, it was used as the starting height for the corresponding set of 20 drums. The Bruceton Staircase approach was then used to increase/decrease the drop height by 0.2 m, depending on whether the previous drop was a pass or failure.

Free flowing drops of water from the body of the drum within five minutes after impact represented a failure. A splash of water upon impact was permitted, as long as it was not followed by a continuous flow. If no leaks were immediately apparent, a small hole was drilled in the drum to relieve any pressure differential after the drop, allowing for leaks to be exposed and evaluated more consistently.

The preliminary drops were not included in the calculation of mean and standard deviation, because the preliminary drop heights were varied more for some drum sets than others, and more preliminary drops were required for some sets compared to others.

The data for each drum set, along with the corresponding statistical analysis, is attached in Appendix B.

2.4 Pressure Testing

Five drums from each set were used for pressure testing. These were new drums, not used for any other tests. A 1/8 NPT hole was drilled and tapped in the top of the drums in the thickest part of the top, but far removed from any closure, mold parting line or feature that could act as a stress riser. The drum was filled with water and pressurized slowly, pausing for a minute at every 6 kPa increment. A pressure regulator connected to city water was used to apply the pressure, except when higher pressures were needed. In the latter case an air-operated pressure pump supplied the regulator.

The pressure was increased until either a leak was observed or the pressure reached 1.5 times that for which the drum was rated.

3. DROP TEST OBSERVATIONS

Appendix A includes photos of a representative sample of each drum set, showing the most prevalent failure modes or any unusual observations. Appendix B contains detailed data, including calculations and plots for each set of drums.

There was quite a variety of failure modes observed throughout the study, with each drum set tending towards one or two failure modes, and very few modes being common to more than one or two sets. This is in contrast to what was observed during the earlier steel drum study, where most sets tended to fail the same way. The difference is probably due to the wider variation in construction details used in plastic drums as opposed to steel drums. Steel drums have been made for a longer time, and most manufacturers' products look pretty much alike. However, the plastic drum is newer and still evolving, with different manufacturers using different types of ribs (and some none at all), different methods of joining the top and bottom to the body, different methods of forming the body (extruded, blow-molded, etc.) and even differences in the overall size and shape. Plastic materials properties will also change from batch to batch and will be modified to different degrees during the various molding processes used.

Determining the deflection pattern to establish the 8 o'clock orientation is not as easy with plastic drums as it is for steel drums, because the plastic drums do not keep their deflected shape, but return to near their original shape. However, there is usually a slight stress line marking the extent of the deflected plastic that can be discerned on close examination.

During the steel drum study, it was observed that in almost all cases, the 8 o'clock orientation resulted in lower failure heights. In this study, however, it was found that the 6 o'clock orientation often gave lower failure heights. In only one case it was found that drums failed earlier in the 8 o'clock than in the 6 o'clock orientation. In two cases, the two orientations had failure heights quite similar to one another, so the choice of 6 o'clock was a bit arbitrary. In the other four cases, the difference between the two orientations was pronounced, with 6 o'clock giving considerably lower heights.

3.1 Drum Set A (Photos 5 and 6)

Drops in Set A reached heights of approximately 5 m before failure. During the preliminary drops, the drums appeared to be able to withstand higher drops in the 8 o'clock orientation as opposed to 6 o'clock orientation. The difference was not as pronounced as in some other sets, but in the limited number of samples available for preliminary testing there appeared to be enough of a difference to choose the 6 o'clock orientation for the official drops. The mean drop height was calculated to be 4.88 m with a standard deviation of 0.77 m.

Out of all the failures, most were due to splitting of the top cover along the mold part line. A few drums split where the cover joined the body. There were no failures of either closure observed during the official series but one NPS closure leaked and another popped off during the preliminary tests.

3.2 Drum Set B (Photos 9 and 10)

All of this set failed at 5 m or over, with several surviving drops well over 6 m. During the preliminary drops, failures occurred earlier for the 6 o'clock, buttress thread down orientation, so that was chosen for the official drops. However, later in the official drop series, failure heights were experienced at or above those observed during 8 o'clock preliminary drops. The small number of drums available for preliminary testing made this scenario a possibility. Nevertheless, both orientations resulted in failure heights well above the rated heights.

The mean failure height was 5.93 m with a standard deviation of 0.70 m. Most failures occurred at the 2 in. NPS thread closure, even though the impact was on the buttress thread closure. Usually the failure was in the form of a steady drip from the closure, and two of the closures popped off altogether.

3.3 Drum Set C (Photos 11 and 12)

This set was also tested in the 6 o’clock, buttress thread down orientation, although the difference between 6 o’clock and 8 o’clock orientations was not pronounced. All drops were carried out from heights of over 5 m.

Set C was one of two that used a separate, pressed on ring to form the spill containment reservoir around the top. These sometimes came off when the drum was dropped, and the failure sometimes occurred around the recess into which this ring was pressed.

The mean was calculated to be 5.2 m with a standard deviation of 0.16 m. There were no closure leaks. Most failures were as a result of splitting at the mold line running across the top.

3.4 Drum Set D (Photos 15 to 18)

Set D drums had separate molded rings pressed onto the top and bottom edges, forming the chimes and a containment reservoir on the top. The two rings seemed to aid in stability of the drums and to make handling easier. They sometimes flew off when impacting the ground following a particularly high drop.

This set had the highest drop test results of all the drums tested. All drops were from over 6 m, with a few going over 7 m. The drops were done in the 6 o’clock orientation with the buttress thread down, although the difference was not pronounced and either orientation could have been used.

The mean and standard deviation were calculated to be 6.64 m and 0.66 m, respectively. Even at these extreme heights, there were no catastrophic failures, with most failures consisting of a slight leak at the closure or a small pin-hole at a fold.

3.5 Drum Set E (Photos 20 to 22)

This set was the one exception in that the 8 o’clock orientation was definitely the most vulnerable, and so it was the one used for the official test series. The difference was quite distinct, with the drums passing when dropped from as high as 5.6 m in the 6 o’clock orientation, but failing at least 1 m earlier when dropped in the 8 o’clock orientation.

The mean and standard deviation for the 8 o’clock drops were calculated to be 3.76 m and 0.6 m, respectively. Most of the failures were due to a leak at one of the buttress thread closures. A few, mainly from the higher drop heights also split along the top, usually adjacent to the closure.

3.6 Drum Set F (Photos 23 to 25)

Set F was an interesting one as the construction was quite unlike any other set tested. It appeared to use an extruded body, unlike the other sets which all had blow-molded bodies. This method would not facilitate rolling ribs, and probably for this reason, the slightly overhanging tops and bottoms served the function of rolling ribs. This set also used some sort of filler / reinforcement in the plastic material, which tended to delaminate slightly on impact.

The difference between drop orientations was definite, with the 6 o'clock orientation being the more vulnerable of the two. The mean and standard deviation were calculated to be 3.4 m and 0.28 m, respectively, for the six o'clock drops. The failure mode was either by fracturing along the sidewalls, or the top fracturing in the vicinity of the closure. No failures were by closure leakage.

3.7 Drum Set G (Photos 27 to 29)

With set G, the 6 o'clock drop orientation was again the most vulnerable. The preliminary drums were able to survive drops from as high as 4.6 m, while almost all of the drums tested in the 6 o'clock orientation failed below 4 m.

The mean and standard deviation were calculated to be 3.64 m and 0.27 m, respectively, for the six o'clock drops. The failure modes were about evenly divided between closure leakage, and the top fracturing in the vicinity of the closure. A few drums also failed by longitudinal fractures along the body sidewalls.

4. PRESSURE TEST OBSERVATIONS

Only five samples of each drum set were subjected to pressure testing, and the main objective was to see whether the drums met their rated pressure capacity, not to find the actual failure pressure. To this end, if no failure was detected at 150% of the rated pressure, the test was stopped. This was the case with many of the drums tested.

Some sets had one or more failures at pressures slightly below their rated pressure when first tested, but no set failed consistently or at levels very far below the rating. Further, as all the failures that were observed were by slight leaking around the closures, it is possible that the closure torque being used was not correct. The difficulty of obtaining the correct torque value was discussed in section 2.2.1.

So, in cases where there was a doubt, the test was repeated on a new drum with higher torque. It was found that the closures with a hard plastic gasket required at least 47.5 J (35 ft-lb) torque to seal them, so this value was used in any repeated tests. However, it was also noted that torques much above 54.2 J (40 ft-lb) would sometimes cause this type of gasket to be cut, or the closure threads to strip, so there is little margin for error in installing the closure.

4.1 Drum Set A (Photos 7 and 8)

All of set A drums leaked at pressures ranging from 154 kPa to 229 kPa. These are all above the rated pressure (150 kPa) but without much margin of error. In each case, the 2 in. NPS closure leaked, and on two occasions the buttress thread closure leaked as well.

4.2 Drum Set B

Set B drums leaked at pressures ranging from 193 kPa to 256 kPa. The drums are rated at 150 kPa so all leaks occurred well above that. All drums leaked at the NPS thread closure, and one also leaked at the buttress thread enclosure.

4.3 Drum Set C (Photos 13 and 14)

Drums in set C were rated at 150 kPa and none leaked below 276 kPa or 150% of rated pressure. In fact, one drum was pressure tested at 303 kPa (greater than 200% of rated pressure) still with no leaks.

4.4 Drum Set D (Photo 19)

Set D drums had a 250 kPa rating, and none of the samples leaked below 150% of that.

4.5 Drum Set E

Set E drums were rated for 200 kPa, and none of the drums tested leaked below 300 kPa.

4.6 Drum Set F (Photo 26)

Set F was one of the sets for which no closure torque was supplied, and attempts to obtain the value from the manufacturer brought no reply. So, the first pressure test was attempted at lower torque values that have worked with other closures. When the drums leaked at low pressures, the torque was increased to 54.2 J (40 ft-lb). While this worked, it sometimes caused the threads to strip or the gasket to be destroyed, so the torques for later tests was reduced to 47.5 J (35 ft-lb).

The drums were rated for 100 kPa. Once the torque values were adjusted, the closures leaked at values from 125 kPa to 175 kPa. These are all above the rated pressure, but without very large safety margins.

4.7 Drum Set G (Photo 30)

No torque values were supplied for drums in Set G, as discussed in section 2.2.1. The drums were rated 200 kPa, but the test results varied considerably from there. Three of the drums tested did exceed the rated pressure, and one exceeded 150% of rated. Others leaked at pressures ranging from 105 to 190 kPa.

This was one of the drums that had a ¾ in. plug in the centre of the 2 in. closure. During the setup, no attention was paid to this smaller closure, since it was assumed it had a knock-out diaphragm like many other drums. However, it turned out that they were an actual port, with a separate gasket. Since two of the drums leaked around this small port, it is again possible that the torque value was not correct.

5. SUMMARY OF RESULTS

5.1 Drop Test Results

Table 2 summarizes the findings of the drop test program. Figure 3 shows these results graphically for comparison. In addition to the average failure heights, the minimum and maximum heights are shown to give a sense of the consistency of the data. More detailed results are given in Appendix B.

Table 2: Drop Test Results Summary

Set	Orientation used for test	Results		Comments
		Avg. Ht. (m)	Std. Dev.	
A	6 o'clock	4.88	0.77	Most failures were fractures in top cover, at mold part line.
B	6 o'clock	5.93	0.70	Mainly leaked at NPS closure.
C	6 o'clock	5.20	0.16	Most failures from fracture to cover, or at folds in chime.
D	6 o'clock	6.64	0.66	Leaks at NPS closure, or fracture in top, close to the closure.
E	6 o'clock	3.83	0.57	Failures mainly due to fractured top cover, near the closure.
F	8 o'clock	3.40	0.28	Failures were from fracture of sidewalls, or top cover, around closure. Some delamination of reinforced material after all impacts, including "passes"
G	6 o'clock	3.64	0.27	Failures from closure leaks, fractured top cover, or fractured cover/sidewall joint.

Figure 3 shows the minimum, maximum and mean failure heights along with the certified rating. From Figure 3 it can be seen that all the drums tested demonstrated fairly consistent failure heights, within each set, and that all of them quite comfortably exceeded their required drop test heights.

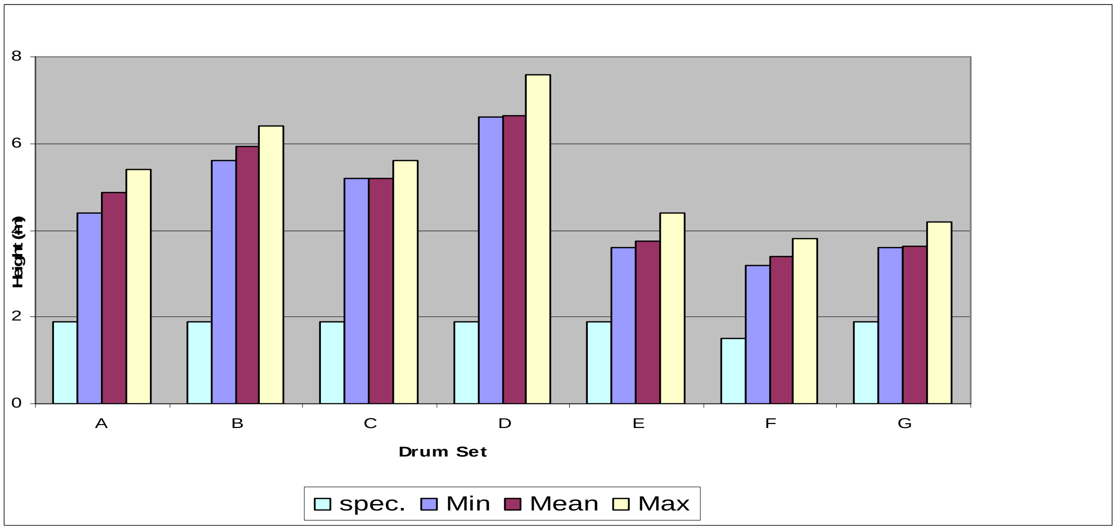

Figure 3: Summary of Drop Heights

5.2 Pressure Test Results

Table 3 summarizes the pressure test results. As explained in section 4, the test was normally stopped if no failures were detected after the pressure reached 150% of the rated pressure. That fact and the small sample size make statistical analysis of the results of little value. The average pressure achieved is shown as a quick way to compare the results to the rated pressure, but in cases where the tests weren't continued to failure, the value shown is simply a lower bound, and the true pressure carrying capability is greater than that shown.

Table 3: Pressure Test Results Summary

Set	A	B	C	D	E	F	G
Rated Pressure, kPa	150	150	150	250	200	100	200
Average Pressure achieved, kPa	201	223	>276	>375	>300	>150	220
Comments	No failures	No failures	No leaks	No leaks	No leaks	No leaks	Some failures

6. DISCUSSION

6.1 General Results

The drums for this study were intended to all have the same test specifications, to facilitate comparison of results. Specifically, it was intended to test drums with a rating of "Y/1.5/200", meaning one able to survive a drop from 1.2 m drop test with liquids having specific gravity of up to 1.5, and able to withstand pressures up to 200 kPa. However, few manufacturers made a drum with those exact specifications, so one with the closest specifications to those was accepted.

All drums received were for hazard class "Y", but some had different specific gravity and pressure test ratings. As it turned out, the majority of drums received were designated Y/1.9, with only one manufacturer unable to supply anything higher than Y/1.5. The pressure ratings varied considerably more, being anywhere from 100 to 250 kPa.

In general, all the drum sets tested for this program more than met their specified drop test requirements. The quality control used by the various manufacturers seems to be effective as all drum sets gave quite consistent results, without much spread between the highest and lowest failure heights. During the steel drum study [4], it was stated that the standard deviations calculated might not be very reliable because of the small sample size and the fact that some sets had quite low average failure heights. In the current study, no sets had particularly poor results, and the consistency of the data does suggest a more or less normal distribution, although the sample size is still quite small.

The certification tests in CAN/CGSB-43-150 require a drop height of 1.2 m for a Grade Y drum, which all of the tested drums were designated. If the drum is intended for liquids of higher specific gravity than 1.2, then the drop test height is to be increased for testing with water. Therefore, drums designated up to "Y/1.2" should pass 100% of drops from 1.2 m. However, one designated "Y/1.9" would have to be tested with water at a height in metres equal to the maximum specific gravity, i.e., 1.9 m.

Table 4 calculates the required test height for each drum set at maximum fill density, and compares these to the minimum failure height obtained during this test program. For a normally distributed sample, about 99.7% of the responses should fall within a range of three times the standard deviation above or below the mean. Therefore, if that range is above the required test level, one can be reasonably certain that any random sample chosen will pass. This appears to be the case with all the drum sets tested for this study.

Table 4: Minimum Drop Heights Compared to Requirements

Manufacturer	A	B	C	D	E	F	G
Designated drop height (m)	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Designated specific gravity	1.9	1.9	1.9	1.9	1.9	1.5	1.9
Adjusted drop height (m) for testing with water	1.9	1.9	1.9	1.9	1.9	1.5	1.9
Minimum drop height (m) obtained	4.4	5.6	5.2	6.6	3.6	3.2	3.6
Mean failure height less 3 standard deviations	2.13	3.5	4.72	4.66	2.12	2.56	2.83

In all cases, the minimum failure height is well above the required test height. Further, in all cases, the mean less 3 standard deviations is also above the required test height, giving us confidence that if we tested any random sample from these manufacturers, we should achieve a 100% pass rate.

6.2 Importance of "Venting"

Though less frequent during this study than in the steel drum study, it was noticed in a few cases that a leak did not appear immediately after a drop test, but became apparent once the drum was vented (a small hole drilled in the drum to release stored vacuum). It is therefore essential to vent the drum before deciding whether it is a pass or fail. Any standards or regulations pertaining to the drop testing of drums should require this step as part of the evaluation.

6.3 Effect of Drop Orientation

It was somewhat surprising to find that most drum types tested in this study failed at lower heights when dropped in the 6 o'clock orientation than when dropped in the 8 o'clock orientation. This is the opposite of what was observed during the steel drum study. Part of the reason may be that there were relatively few drum types that failed mainly through leaks at closures, which would be expected to be the type of failure most dependent on drop orientation. Nevertheless, the two sets that did fail from a significant number of closure leaks seemed more vulnerable in the 6 o'clock orientation.

It also must be stated that the difference between drop orientations was often not pronounced, and had a full sample been tested in each orientation, the opposite orientation may have been seen to be slightly more vulnerable. The scope of work in this study did not allow for this, and a judgment had to be made on the strength of a few drops in each orientation. This worked well if the difference was pronounced, but if the true difference were within the "scatter" of the data, it is possible that the decision on orientation based on these few preliminary drops did not result in the correct choice of the most vulnerable orientation. Nevertheless, given the variability of the results, and the fact that some drum types failed earlier in one orientation, and others in the opposite orientation, it would be wise to require at least one drop test in each orientation for certification, in order to ensure that the worst case is tested.

6.4 Effect of Closure Style

Given the large variety of closure styles used, and the small number of failures that occurred at the closure, it is unrealistic to draw much of a conclusion regarding closure styles. About the only thing that can be said for certain is that, for those drums that used both a buttress thread closure and an NPS thread closure, it did appear that the failures were more likely to occur at the NPS closure. However, any failures that did occur at a closure occurred at drop heights well above the required height, so any of the closure styles used should be adequate.

The biggest problem with closures was found not during drop testing, but during pressure testing. That problem was in not having adequate information as to the closure torque. When such information was readily available, and followed, there were no problems with closure leakage. However, in a few cases, the information on closure torque was not supplied and not easy to obtain. In these cases, some experimentation resulted in a torque that worked, but it is unlikely that the average user of these drums would take the time to perform such experimentation. A torque would be used that has worked in the past, but that may not be at all adequate.

A quick perusal of some web sites for the manufacturers of drums reveals the great number of closure and gasket combinations that these drums can be supplied with, and each combination could require a very different torque to seal it correctly. The problem is much worse with the closures having a hard plastic gasket, such as some of the drums used in this study. It was found that a very small change in the torque could make a great difference in how well the closure system sealed. The softer, elastomer gaskets were much more forgiving, and would work over a relatively wide range of torque values. Whatever closure system is used, it is imperative that the sealing torque be readily available to the user. The torque for the smaller central closure, if one is supplied, must also be included.

7. CONCLUSIONS

All of the drums performed at or above the required level in the drop tests. Each drum set displayed at most two, and often only one, predominant failure mode. A definite preference for one drop orientation over the other was not determined, as different drum types behaved differently in this regard. Therefore, certification testing should include at least one drop in the six o’clock and one in the eight o’clock orientation.

There appeared to be little difference in the performance of the two closure styles, though there were not enough closure failures to say definitively. However, when they leaked, both styles did so at well above the required drop test height.

Most drums readily passed the pressure test at their rated pressure. Of the set that had some failures below the rated value, the results were not consistent with some samples passing easily and others not. As the drums that failed were ones for which no closure torque was given, it is possible that the torque was not the optimum value. This does, however, point out the necessity to make the correct torque values readily available to the user.

8. RECOMMENDATIONS

As all of the drums tested during this study exceeded their required drop test requirements, the system appears to be working well. Since the most vulnerable drop orientation can vary with construction details, it would be worthwhile to require at least one drop test in the two most common orientations to be certain that the most vulnerable orientation has been tested. Given the unexpected finding regarding closure leakage during impact, we would expect there might be additional unexpected results if alternate orientations were used for drops, such as flat on top, bottom, or sides. It is recommended that future studies look at this aspect of impact.

The effect of “venting” of drums following a drop test was often dramatic, with the drum appearing to pass before venting but obviously failing once the pressure was relieved. Any standards relating to drop tests should make note of this fact and require the drum to be vented before determining that it has passed.

Most of the drums tested exceeded their pressure test requirements. In the few cases where the drum leak occurred before the rated pressure, there was doubt as to whether the leak was caused by improper torque. Given the wide variety of closure and gasket styles available, it is essential that the correct torque values be supplied for the particular drum and closure system. In cases where the torque values were printed on the packing slip, there was no problem. It is also essential that personnel using the drums be properly trained and aware of the need to use the correct torque. Further study of the various closure types available on the market is recommended. Also, the gasket types can vary widely, and further work looking at this could be undertaken, possibly with the direct cooperation of the closure manufacturers.

Previous work on containers included plastic and steel pails in the 20 L size range. We suggest that a similar study of these types of containers would also be useful in gauging the effectiveness of dangerous goods packaging programs in a broader sense. The plastic containers are a relatively new container type, and have a different set of manufacturing challenges that need to be addressed.

To our knowledge there have not been any similar studies of other package types, such as combination packs involving bottles and corrugated fibreboard. In particular, plastic inner packages such as the common 4 L jugs can vary greatly from small changes in the manufacturing process. A similar survey of these packages would also prove very interesting.

Also not investigated in this study was the effect of vibration on packaging. It is not currently a requirement for testing, but it is suggested that this factor be considered when looking at package design. It would be relatively straightforward to obtain various package types and subject them to standard vibration tests available to the industry.

9. CERTIFICATION

THIS IS TO CERTIFY THAT THE ABOVE TESTING WAS PERFORMED ACCORDING TO REQUIREMENTS SET FORTH BY THE CLIENT IN A MANNER CONSISTENT WITH GOOD LABORATORY PRACTICES AND ANY SPECIFICATIONS REFERENCED HEREIN.

Lawrence G. Tighe,
Technologist, Environmental Simulation Lab ___________________________

Neil P. Richter, P.Eng
Manager, Environmental Simulation Lab ___________________________

Don LeBlanc, P.Eng
Manager, Climatic Engineering Facility ___________________________

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2. CSTT, Test Plan 2404-1587/TP01 ***Performance Standard for Plastic Drums for Transport Canada,*** 2004

3. Canadian General Standards Board, CAN/CGSB 43.150-97 ***Performance Packagings for Transportation of Dangerous Goods***

4. Transportation Development Centre, Report No. TP 14093E ***Drop Tests of Selected Steel Drums,*** Transport Canada, 2003

5. M.G. Natrella, ***Experimental Statistics***, Chapter 10: *Sensitivity Testing*, Handbook 91, United States Department of Commerce, 1963

APPENDIX A

Photographs

Photo 1 Test setup: Drum holding arrangement for indoor drops

Photo 2 Test setup: Indoor drop underway

Photo 3 Test setup: Drum in final position for outdoor drop
(required for higher drop heights)

Photo 4 Test setup: Internal pressure test

Photo 5 Drum Set A: Typical failure mode - Fracture at cover mold line

Photo 6 Drum Set A: Typical failure mode - Fracture at cover/body seam

Photo 7 Drum Set A: Pressure test in showing test fitting location

Photo 8 Drum Set A: Typical pressure test failure mode - Drip from NPS closure

Photo 9 Drum Set B: Failure mode - Longitudinal fracture of body

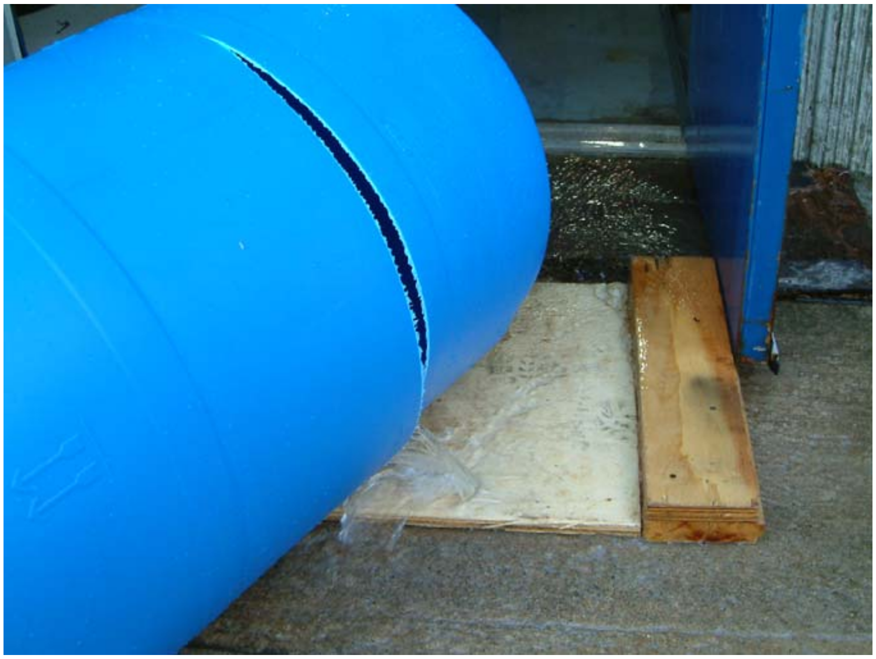


Photo 10 Drum Set B: Failure mode - Circumferential fracture next to rolling rib

Photo 11 Drum Set C: Failure mode - Fracture at cover/sidewall seam (note top ring separated)

Photo 12 Drum Set C: Failure mode - Fracture at cover/sidewall seam, under the recess where top ring locates

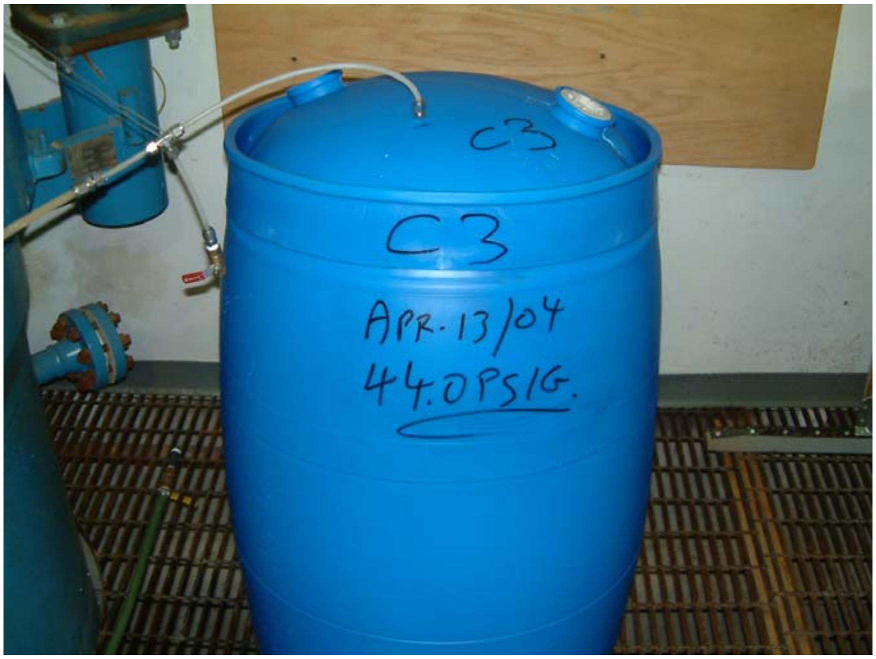


Photo 13 Drum Set C: Pressure test underway

Photo 14 Drum Set C: Pressure test - Maximum pressure reached, no leaks

Photo 15 Drum Set D: Failure mode - Dripping from opposite closure from the one impacted

Photo 16 Drum Set D: Failure mode - Small split on closure neck (opposite from impact side)

Photo 17 Drum Set D: Example of severely distorted closure neck – Still no leaks

Photo 18 Drum Set D: Failure mode - Small split on edge of top/sidewall seam

Photo 19 Drum Set D: Pressure test at maximum pressure

Photo 20 Drum Set E: Failure mode - Fracture between closure neck and top/sidewall seam

Photo 21 Drum Set E: Failure mode - Small hole near closure neck

Photo 22 Drum Set E: Failure mode - Separation at edge of closure well

Photo 23 Drum Set F: Failure mode - Longitudinal split along sidewall

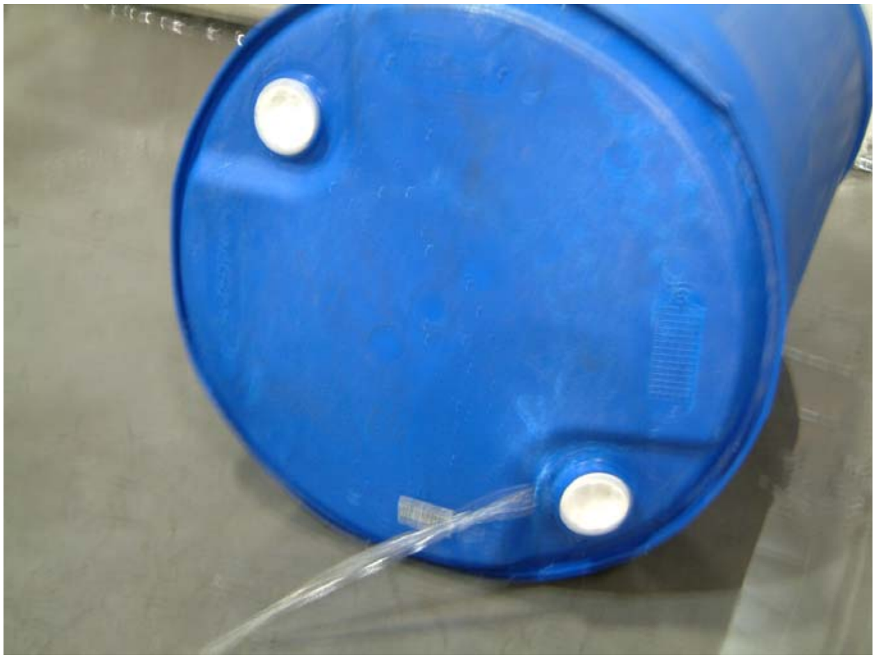


Photo 24 Drum Set F: Second failure mode - Rupture around closure

Photo 25 Drum Set F: Close-up of drum top showing delamination of material

Photo 26 Drum Set F: Pressure test under way

Photo 27 Drum Set G: Failed drum showing
extent of distortion of top handle area

Photo 28 Drum Set G: Typical failure mode - Rupture at top/sidewall line

Photo 29 Drum Set G: Second failure mode - Leaking from closure

Photo 30 Drum Set G: Pressure test under way

Photo 31 Comparison of two gasket types: Rectangular section, soft rubber on the left, round section, hard plastic on the right (both closures with buttress threads)

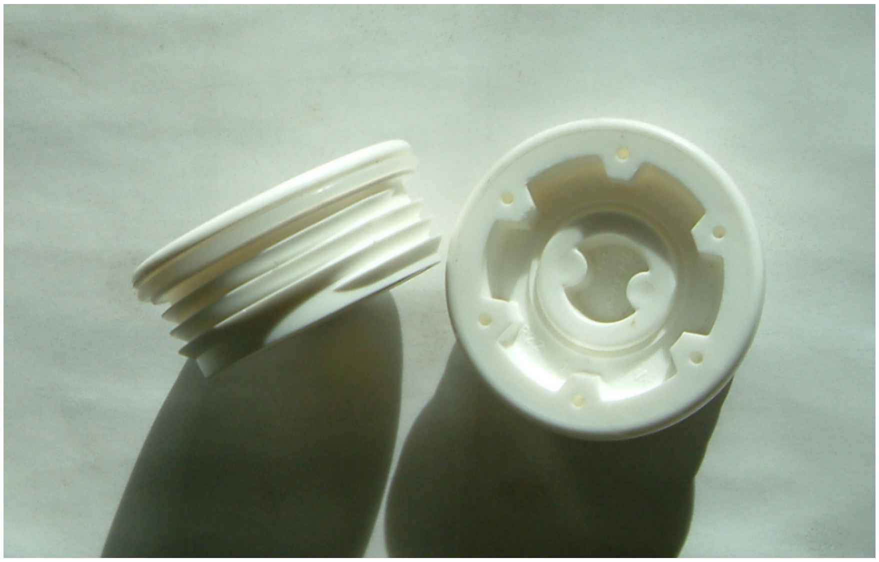


Photo 32 Detail of one closure type: Buttress thread, round, hard plastic gasket, and small secondary bung in the centre

Photo 33 Example of a type c closure:
Note the small, threaded knockout bung in the centre

APPENDIX B

Data Sheets
Calculations
Charts

LEGEND

Statistical Analysis

N: Total number of drops per set
R: Total number of failures per set
j: Any integer (e.g., 0, 1, 2, 3 …)
y_j: Instance of a drop from a specific height
n: Total number of drops at a particular height, per set
r_j: Number of failures at a specific drop height, per set
A: Sum of the products of r_j and j, per set
B: Sum of the products of r_j and j^2, per set
d: Height increment/decrement per drop (0.2 m in this case)
m: Estimate for the mean of the distribution of drops
s: Estimate of the standard deviation of the distribution of drops

Formulas

For R $\leq$ N/2:

$$A = \sum (j * r_j), \text{ where j ranges from 0 to } k\text{, and } k > 0$$

$$B = \sum (j^2 * r_j) , \text{ where j ranges from 0 to } k\text{, and } k > 0$$

$$m = y_o + d * [(A / R) - ½]$$

$$s = 1.620 * d [(((R * B) – (A^2)) / R^2) + .029]$$

For R > N/2:

$$A = \sum [j * (n - r_j)]$$

$$B = \sum [j^2 * (n - r_j)]$$

$$m = y_o + d * [(A / (N - R)) + ½]$$

$$s = 1.620 * d [((((N – R) * B) – (A^2)) / (N - R)^2) + .029]$$

Data Sheet 2403-1587-DS1

Drum Type:_1H1/Y1.9/150
Manufacturer Code:___A
Closure Type:__2 in. NPS_and 2 in. Buttress with rubber gasket__
Tare weight: 9.6 kg (21.2 lb)
Target fill weight: 216.3 kg (477 lb)

Orientation: ☐ 6 o’clock

Test Start Date:_Mar 5, 2004

Drum #

Drop height	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
7.6																				
7.4																				
7.2																				
7.0																				
6.8																				
6.6																				
6.4																				
6.2																				
6.0																				
5.8																				
5.6																				
5.4	X				X															
5.2		X		O		X		X												
5.0			O				O		X		X		X		X					
4.8										O		O		O		X				
4.6																	X			
4.4																		X		O
4.2																			O	
4.0																				
3.8																				
3.6																				
3.4																				
3.2																				
3.0																				
2.8																				
2.6																				
2.4																				
2.2																				
2.0																				
1.8																				

Key
Pass test at a height: O
Fail test at a height: X

Set A Detailed Drop Test Results

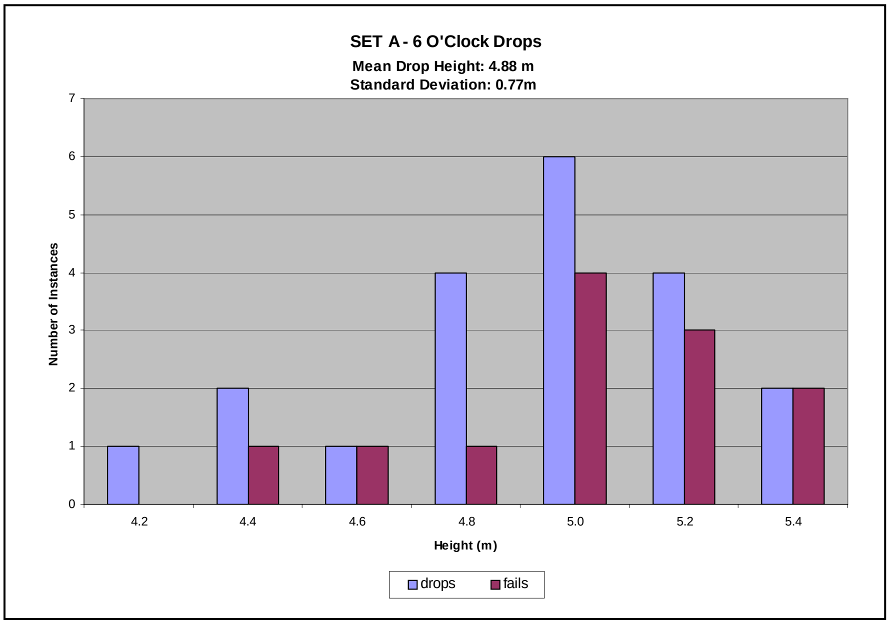
Drum # (SET A)	Height (m)	Position	Result	Comments
Preliminary Drops				
1	1.0	6 o'clock	PASS	Buttress Bung Down, unless stated otherwise
2	3.0	6 o'clock	PASS	
3	4.4	6 o'clock	FAIL	Leak at NPS bung
4	4.2	6 o'clock	FAIL	Top Cover Split and NPS bung popped out
5	4.0	6 o'clock	PASS	NPS bung facing down
6	4.2	6 o'clock	PASS	NPS bung facing down
7	4.4	6 o'clock	PASS	NPS bung facing down
8	4.0	6 o'clock	PASS	Revert to Buttress bung down
9	4.2	6 o'clock	PASS	
10	4.4	6 o'clock	FAIL	NPS bung popped out
11	5.0	8 o'clock	PASS	
12	5.2	8 o'clock	PASS	
13	5.4	8 o'clock	PASS	
14	5.6	8 o'clock	PASS	
15	5.8	8 o'clock	PASS	**Use 6 o'clock, Buttress down for official drops**
Official Staircase Drop Series				
1	5.4	6 o'clock	FAIL	Top cover seam split
2	5.2	6 o'clock	FAIL	Split where top / body meet
3	5.0	6 o'clock	PASS	
4	5.2	6 o'clock	PASS	
5	5.4	6 o'clock	FAIL	Top cover seam split
6	5.2	6 o'clock	FAIL	Top cover seam split
7	5.0	6 o'clock	PASS	
8	5.2	6 o'clock	FAIL	Splits along top cover seam and at top / body junction
9	5.0	6 o'clock	FAIL	Pin-hole leak at corner of impact fold
10	4.8	6 o'clock	PASS	
11	5.0	6 o'clock	FAIL	Split at top cover seam
12	4.8	6 o'clock	PASS	
13	5.0	6 o'clock	FAIL	Split at top cover seam
14	4.8	6 o'clock	PASS	
15	5.0	6 o'clock	FAIL	Split at top cover seam
16	4.8	6 o'clock	FAIL	Split at top / body junction
17	4.6	6 o'clock	FAIL	Split at top cover seam
18	4.4	6 o'clock	FAIL	Split at top cover seam
19	4.2	6 o'clock	PASS	
20	4.4	6 o'clock	PASS	

Drop Height Calculations, Set A

SET A - 6 o'clock drops: N = 20, R = 12 therefore R > N/2

	y (m)	n - r	j	j^2	(n - r) * j	(n - r) * j^2
y_0	4.2	1	0	0	0	0
y_1	4.4	1	1	1	1	1
y_2	4.6	0	2	4	0	0
y_3	4.8	3	3	9	9	27
y_4	5	2	4	16	8	32
y_5	5.2	1	5	25	5	25

A (sum of all (n - r) * j)	**23**
B (sum of all (n - r) * j^2)	**85**
m (estimate of the mean, in metres)	**4.88**
s (estimate of standard deviation, metres)	**0.77**



Pressure Test Results, Drum Set A

Drum No.	Pressure achieved, kPa	Comments
A37	186	Leak at NPS closure
A38	154	Leak at NPS closure, and buttress closure
A39	224	Leak at NPS closure
A40	229	Leak at NPS closure, and buttress closure
A41	214	Leak at NPS closure
Average	201 kPa	Rated press. = 150 kPa

Data Sheet 2403-1587-DS1

Drum Type: 1H1/Y1.9/150
Manufacturer Code: B
Closure Type: 2 in. NPS and 2 in. Buttress with rubber gasket
Tare weight: 10.4 kg (22.9 lb)
Target fill weight: 216.9 kg (478.3 lb)

Orientation: ☐ 6 o'clock

Test Start Date: Mar 10, 2004

Drum #

Drop height	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
7.6																				
7.4																				
7.2																				
7.0																				
6.8																				
6.6																				
6.4																X		X		O
6.2													X		O		O		O	
6.0								X				O		O						
5.8					X		O		X		O									
5.6		X		O		O				O										
5.4	O		O																	
5.2																				
5.0																				
4.8																				
4.6																				
4.4																				
4.2																				
4.0																				
3.8																				
3.6																				
3.4																				
3.2																				
3.0																				
2.8																				
2.6																				
2.4																				
2.2																				
2.0																				
1.8																				

Key
Pass test at a height: O
Fail test at a height: X

Set B Detailed Drop Test Results

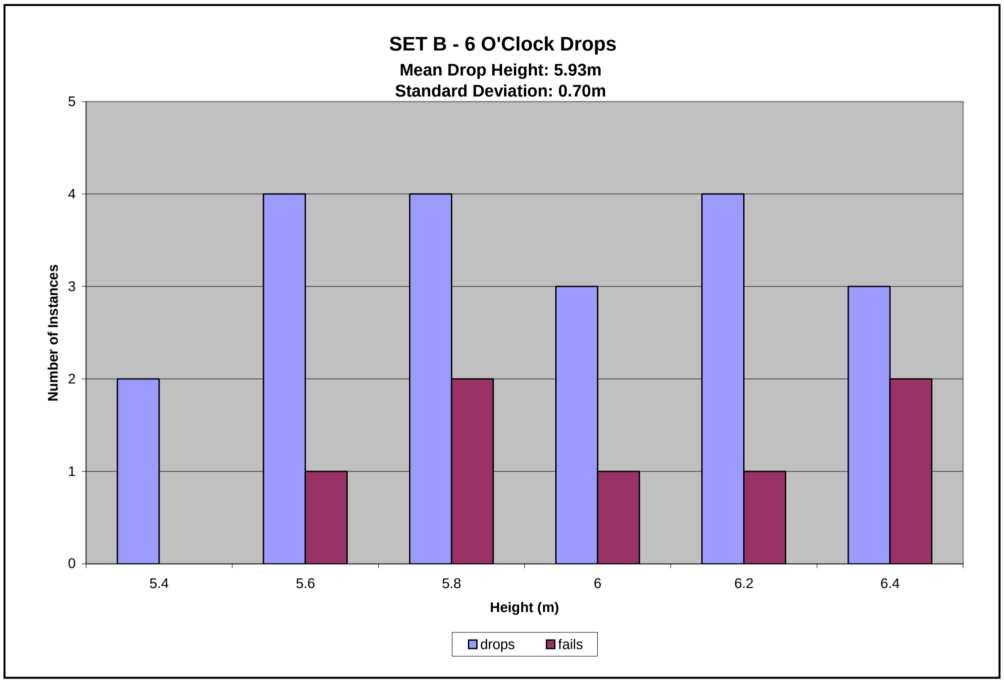
Drum # (SET B)	Height (m)	Position	Result	Comments
Preliminary Drops				
1	4.0	6 o'clock	PASS	Buttress Bung Down, unless stated otherwise
2	4.4	6 o'clock	FAIL	NPS bung popped out
3	4.4	6 o'clock	PASS	Impact on NPS bung
4	5.0	6 o'clock	PASS	Impact on NPS bung
5	5.4	6 o'clock	PASS	Impact on NPS bung
6	5.8	8 o'clock	PASS	
7	6.0	8 o'clock	PASS	
8	6.2	8 o'clock	PASS	
9	6.2	8 o'clock	FAIL	Drum turned - impact closer to 6 o'clock
10	6.2	8 o'clock	PASS	**Use 6 o'clock, Buttress down for official drops**
Official Staircase Drop Series				
11	5.4	6 o'clock	PASS	
12	5.6	6 o'clock	FAIL	Drip at NPS Closure after Venting
13	5.4	6 o'clock	PASS	
14	5.6	6 o'clock	PASS	
15	5.8	6 o'clock	FAIL	Split at rolling rib
16	5.6	6 o'clock	PASS	
17	5.8	6 o'clock	PASS	
18	6.0	6 o'clock	FAIL	NPS Closure popped off
19	5.8	6 o'clock	FAIL	NPS Closure popped off
20	5.6	6 o'clock	PASS	
21	5.8	6 o'clock	PASS	
22	6.0	6 o'clock	PASS	
23	6.2		N/A	Void - drum landed on bottom
24	6.2	6 o'clock	FAIL	NPS Closure Popped off and Drum Split along Side
25	6.0	6 o'clock	PASS	
26	6.2	6 o'clock	PASS	
27	6.4	6 o'clock	FAIL	Pin-hole at Impact Fold
28	6.2	6 o'clock	PASS	
29	6.4	6 o'clock	FAIL	Drip at NPS Closure after Venting
30	6.2	6 o'clock	PASS	
31	6.4	6 o'clock	PASS	

Drop Height Calculations, Set B

SET B - 6 o'clock drops: N = 20, R = 7 therefore R <= N/2

	y (m)	r	j	j^2	r * j	r * j^2
y_0	5.6	1	0	0	0	0
y_1	5.8	2	1	1	2	2
y_2	6	1	2	4	2	4
y_3	6.2	1	3	9	3	9
y_4	6.4	2	4	16	8	32

A (sum of all r * j)	**15**
B (sum of all r * j^2)	**47**
m (estimate of the mean, in metres)	**5.93**
s (estimate of standard deviation, in metres)	**0.70**



Pressure Test Results, Drum Set B

Drum No.	Pressure achieved, kPa	Comments
B31	256	Leak at NPS closure
B32	202	Leak at NPS closure
B33	234	Leak at NPS closure
B34	229	Leak at NPS closure, and buttress closure
B35	193	Leak at NPS closure
Average	223 kPa	Rated press. = 150 kPa

Data Sheet 2403-1587-DS1

Drum Type:_1H1/Y1.9/150
Manufacturer Code:___C
Closure Type:__2 in. NPS_and 2 in. Buttress with rubber gasket__
Tare weight: 10.3 kg (22.7 lb)
Target fill weight: 216.9 kg (474.6 lb)

Orientation: ☐ 6 o'clock

Test Start Date:_Mar 10, 2004

Drum #

Drop height	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
7.6																				
7.4																				
7.2																				
7.0																				
6.8																				
6.6																				
6.4																				
6.2																				
6.0																				
5.8																				
5.6	**X**																			
5.4		**X**										**X**				**X**				**O**
5.2			**X**		**X**		**X**		**X**		**O**		**X**		**O**		**X**		**O**	
5.0				**O**		**O**		**O**		**O**				**O**				**O**		
4.8																				
4.6																				
4.4																				
4.2																				
4.0																				
3.8																				
3.6																				
3.4																				
3.2																				
3.0																				
2.8																				
2.6																				
2.4																				
2.2																				
2.0																				
1.8																				

Key
Pass test at a height: O
Fail test at a height: X

Set C Detailed Drop Test Results

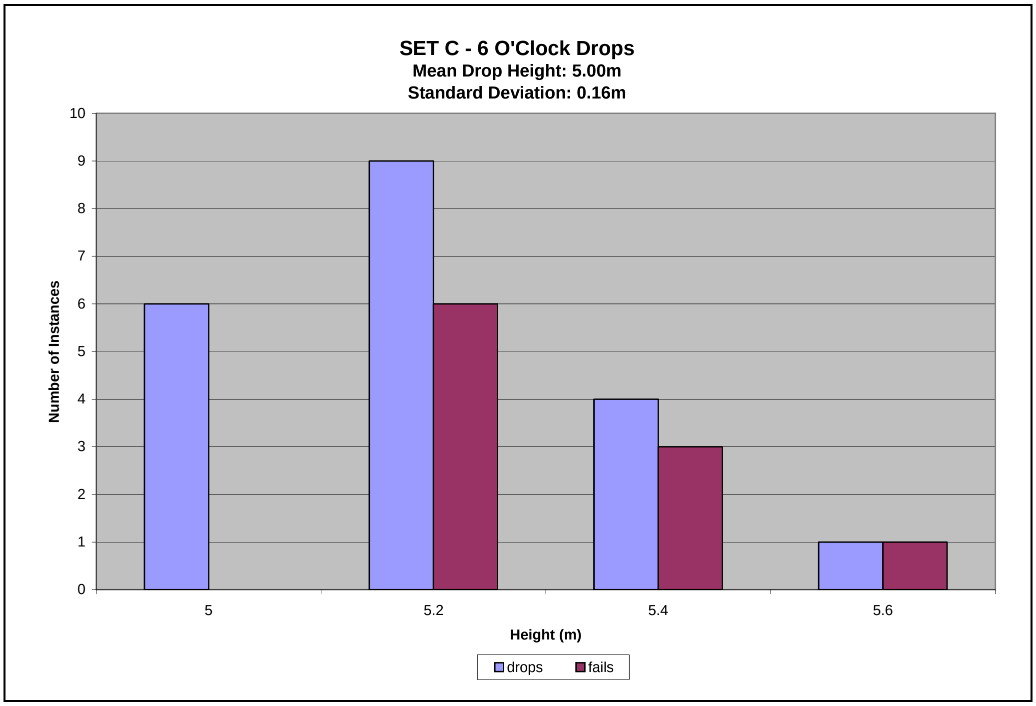
Drum # (SETC)	Height (m)	Position	Result	Comments
Preliminary Drops				
1	4.4	6 o'clock	FAIL	Top Split Open
2	4.2	6 o'clock	PASS	
3	4.6	6 o'clock	PASS	
4	5.0	6 o'clock	PASS	
5	5.2	6 o'clock	PASS	
6	5.4	6 o'clock	FAIL	Top Split Open
7	5.4	8 o'clock	FAIL	Small leak at fold
8	5.2	8 o'clock	PASS	
9	5.4	8 o'clock	PASS	
10	5.6	8 o'clock	PASS	**Use 6 o'clock, Buttress bung down for official drops**
Official Staircase Drop Series				
11	5.6	6 o'clock	FAIL	Top split open across 1/2 diameter
12	5.4	6 o'clock	FAIL	Top split open across 1/2 diameter
13	5.2	6 o'clock	FAIL	Top split open across 1/2 diameter
14	5.0	6 o'clock	PASS	Top ring came off, and signs of stress (e.g. white streaks) around groove where the ring attaches, but no leaks
15	5.2	6 o'clock	FAIL	Top split open at the impact folds
16	5.0	6 o'clock	PASS	
17	5.2	6 o'clock	FAIL	Top split open at the impact folds
18	5.0	6 o'clock	PASS	
19	5.2	6 o'clock	FAIL	Top split open at the impact folds
20	5.0	6 o'clock	PASS	
21	5.2	6 o'clock	PASS	
22	5.4	6 o'clock	FAIL	Top split open at the impact folds
23	5.2	6 o'clock	FAIL	Pin-hole leak at intersection of top seam and impact fold
24	5.0	6 o'clock	PASS	
25	5.2	6 o'clock	PASS	
26	5.4	6 o'clock	FAIL	Top split at folds
27	5.2	6 o'clock	N/A	Void - hit on side
28	5.2	6 o'clock	FAIL	Top split across 1/2 diameter
29	5.0	6 o'clock	PASS	
30	5.2	6 o'clock	PASS	
31	5.4	6 o'clock	PASS	

Drop Height Calculations, Set C

SET C - 6 o'clock drops: N = 20, R = 10 therefore R <= N/2

	y (m)	r	j	j^2	r * j	r * j^2
y_0	5.2	6	0	0	0	0
y_1	5.4	3	1	1	3	3
y_2	5.6	1	2	4	2	4

A (sum of all r * j)	**5**
B (sum of all r * j^2)	**7**
m (estimate of the mean, in metres)	**5.20**
s (estimate of standard deviation, in metres)	**0.16**



Pressure Test Results, Drum Set C

Drum No.	Pressure achieved, kPa	Comments
C3	303	No leaks: test stopped at approx. 200% rated
C4	276	No leaks: 150% rated
C5	276	No leaks: 150% rated
C6	276	No leaks: 150% rated
C7	276	No leaks: 150% rated
Average	> 276 kPa	Rated press. = 150 kPa

Data Sheet 2403-1587-DS1

Drum Type:_1H1/Y1.9/250______________________
Manufacturer Code:___D__________
Closure Type:__2 in. NPS_and 2 in. Buttress with rubber gasket__
Tare weight: ______13.1 kg (28.9 lb)____________________
Target fill weight: __217.4 kg (479.3 lb)______________

Orientation: ☐ 6 o'clock

Test Start Date:_Apr 14, 2004___

Drum #

Drop height	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
7.6																				
7.4																				
7.2														**X**						
7.0													**O**		**X**		**X**			
6.8								**X**				**O**				**O**		**X**		**X**
6.6	**X**						**O**		**X**		**O**								**O**	
6.4		**X**				**O**				**O**										
6.2			**X**		**O**															
6.0				**O**																
5.8																				
5.6																				
5.4																				
5.2																				
5.0																				
4.8																				
4.6																				
4.4																				
4.2																				
4.0																				
3.8																				
3.6																				
3.4																				
3.2																				
3.0																				
2.8																				
2.6																				
2.4																				
2.2																				
2.0																				
1.8																				

<u>Key</u>
Pass test at a height: O
Fail test at a height: X

Set D Detailed Drop Test Results

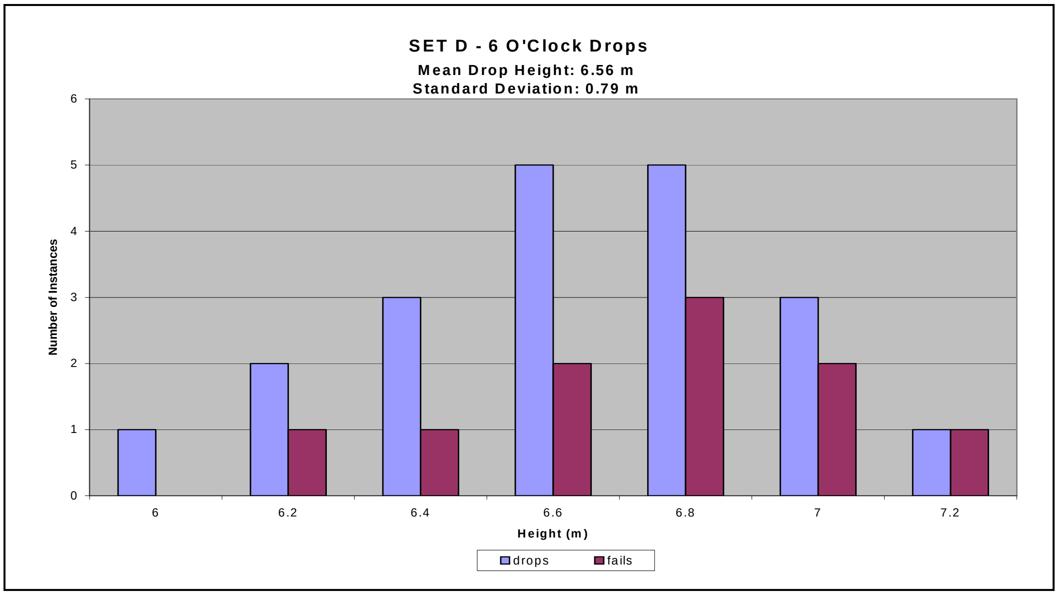
Drum # (SETD)	Height (m)	Position	Result	Comments
Preliminary Drops				
1	5.4	6 o'clock	PASS	
2	5.6	6 o'clock	PASS	
3	5.8	6 o'clock	PASS	
4	6.0	6 o'clock	PASS	
5	6.2	6 o'clock	FAIL	Small hole by closure
6	6.2	8 o'clock	PASS	
7	6.4	8 o'clock	PASS	
8	6.6	8 o'clock	FAIL	Small leak by closure - Drum turned in air - Landed closer to 6 o'clock
9	6.6	8 o'clock	PASS	**Use 6 o'clock, Buttress bung down, for official drops**
Official Staircase Drop Series				
10	6.6	6 o'clock	FAIL	Small leak by closure
11	6.4	6 o'clock	FAIL	Leak at closure opposite the one impacted on
12	6.2	6 o'clock	FAIL	Leak at fold, under top ring
13	6.0	6 o'clock	PASS	
14	6.2	6 o'clock	PASS	
15	6.4	6 o'clock	PASS	
16	6.6	6 o'clock	PASS	
17	6.8	6 o'clock	FAIL	Small leak near opposite closure
18	6.6	6 o'clock	FAIL	Leak above impact closure
19	6.4	6 o'clock	PASS	
20	6.6	6 o'clock	PASS	
21	6.8	6 o'clock	PASS	
22	7.0	6 o'clock	PASS	
23	7.2	6 o'clock	FAIL	Sm. leak near opposite closure (after venting)
24	7.0	6 o'clock	FAIL	Leak at opposite closure from impact
25	6.8	6 o'clock	PASS	
26	7.0	6 o'clock	FAIL	Hole near opposite closure
27	6.8	6 o'clock	FAIL	Leak at opposite closure (cap cracked)
28	6.6	6 o'clock	PASS	
29	6.8	6 o'clock	FAIL	Tear near opposite closure and 2nd at fold

Drop Height Calculations, Set D

SET C - 6 o'clock drops: N = 20, R = 10 therefore R <= N/2

	y (m)	**r**	**j**	**j^2**	**r * j**	**r * j^2**
y_0	6.2	1	0	0	0	0
y_1	6.4	1	1	1	1	1
y_2	6.6	2	2	4	4	8
y_3	6.8	3	3	9	9	27
y_4	7	2	4	16	8	32
y_5	7.2	1	5	25	5	25

A (sum of all r * j)	**27**
B (sum of all r * j^2)	**93**
m (estimate of the mean, in metres)	**6.64**
s (estimate of standard deviation, in metres)	**0.66**



Pressure Test Results, Drum Set D

Drum No.	Pressure achieved, kPa	Comments
D1	375	No leaks after 5 min at 150% rated
D2	375	No leaks: 150% rated
D3	375	No leaks: 150% rated
D4	375	No leaks: 150% rated
D5	375	No leaks: 150% rated
Average	> 375 kPa	Rated press. = 250 kPa

Data Sheet 2403-1587-DS1

Drum Type: 1H1/Y1.9/200
Manufacturer Code: E
Closure Type: (2) 2 in. Buttress thread, rubber gaskets
Tare weight: 8.605 kg (19 lb)
Target fill weight: 225.5 kg (495 lb)

Orientation: ☐ 6 o'clock

Test Start Date: Nov 24, 2004

Drum #

Drop height	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
5.0																				
4.8																				
4.6																				
4.4																		X		
4.2																	O		X	
4.0				X										X		O				O
3.8			O		X						X		O		O					
3.6		O				X		X		O		O								
3.4	O						O		O											
3.2																				
3.0																				
2.8																				
2.6																				
2.4																				
2.2																				
2.0																				
1.8																				
1.6																				
1.4																				
1.2																				
1.0																				
0.8																				
0.6																				
0.4																				
0.2																				
0.0																				

Key
Pass test at a height: O
Fail test at a height: X

Set E Detailed Drop Test Results

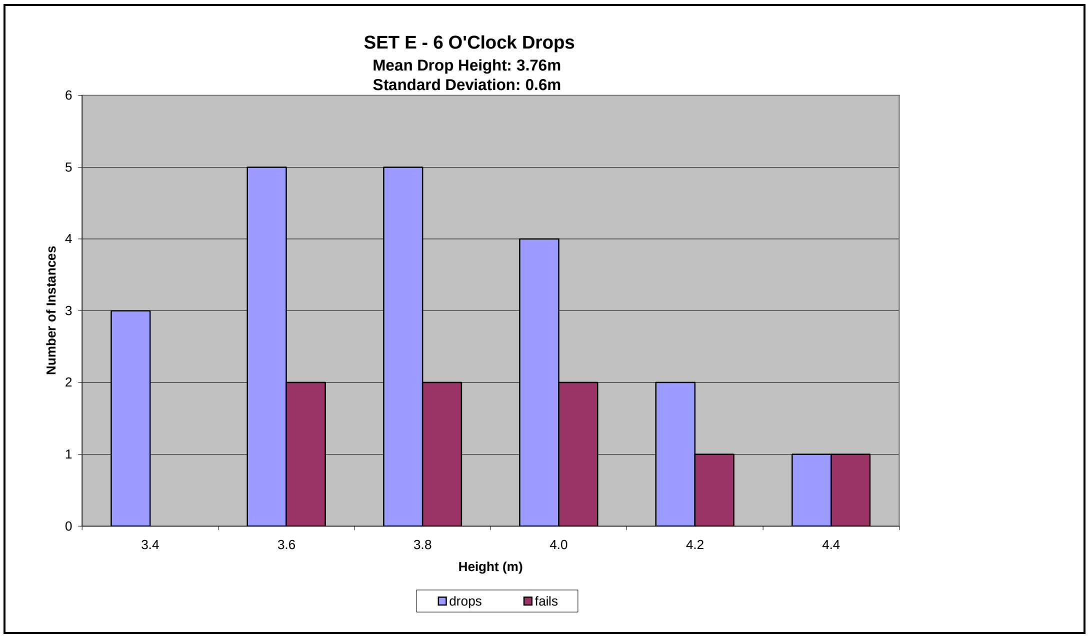
Drum # (SET E)	Height (m)	Position	Result	Comments
Preliminary Drops				
6	4.0	6 o'clock	PASS	
7	5.0	6 o'clock	PASS	
8	5.6	6 o'clock	PASS	
9	6.2	6 o'clock	FAIL	Drum split on side
10	6.0	6 o'clock	FAIL	Drum split on top & impact closure cracked
11	6.0	8 o'clock	FAIL	Drum split on top cover near closure
12	5.6	8 o'clock	PASS	Drum split on top cover near closure
13	5.4	8 o'clock	FAIL	Drum split on top cover near closure
14	5.2	8 o'clock	FAIL	Top cover split near closure & drip @ closure
15	5.0	8 o'clock	FAIL	Top cover split near closure & drip @ closure
16	4.6	8 o'clock	FAIL	Top cover split near closure & drip @ closure
17	4.2	8 o'clock	FAIL	Top cover split near closure & drip @ closure
18	3.8	8 o'clock	FAIL	Top cover split near closure & drip @ closure
				Use 8 o'clock for official drops
Official Staircase Drop Series				
19	3.4	8 o'clock	PASS	
20	3.6	8 o'clock	PASS	
21	3.8	8 o'clock	PASS	
22	4.0	8 o'clock	FAIL	Split on top cover near closure
23	3.8	8 o'clock	FAIL	Split on top cover near closure
24	3.6	8 o'clock	FAIL	Split on top cover near closure
25	3.4	8 o'clock	PASS	
26	3.6	8 o'clock	FAIL	Small split on top cover near closure
27	3.4	8 o'clock	PASS	
28	3.6	8 o'clock	PASS	
29	3.8	8 o'clock	FAIL	Small split on top cover near closure
30	3.6	8 o'clock	PASS	
31	3.8	8 o'clock	PASS	
32	4.0	8 o'clock	FAIL	Small split on top cover near closure
33	3.8	8 o'clock	PASS	
34	4.0	8 o'clock	PASS	
35	4.2	8 o'clock	PASS	
36	4.4	8 o'clock	FAIL	Split on top cover near closure
37	4.2	8 o'clock	FAIL	Small split on top cover near closure
38	4.0	8 o'clock	PASS	

Drop Height Calculations, Set E

SET E - 6 o'clock drops: N = 20, R = 8 therefore R <= N/2

	y (m)	r	j	j^2	r * j	r * j^2
y_0	3.6	2	0	0	0	0
y_1	3.8	2	1	1	2	2
y_2	4.0	2	2	4	4	8
y_3	4.2	1	3	9	3	9
y_4	4.4	1	4	16	4	16

A (sum of all r * j)	**13**
B (sum of all r * j^2)	**35**
m (estimate of the mean, in metres)	**3.83**
s (estimate of standard deviation, in metres)	**0.57**



Pressure Test Results, Drum Set E

Drum No.	Pressure achieved, kPa	Comments
E1	300	No leaks after 5 min at 150% rated
E2	300	No leaks: 150% rated
E3	300	No leaks: 150% rated
E4	300	No leaks: 150% rated
E5	300	No leaks: 150% rated
Average	> 300 kPa	Rated press. = 200 kPa

Data Sheet 2403-1587-DS1

Drum Type: 1H1/Y1.5/100
Manufacturer Code F
Closure Type: (2) 2 in. Buttress thread, Plastic gaskets
Tare weight: 8.2 kg (18.1 lb)
Target fill weight: 223.1 kg (491.9 lb)

Orientation: ☐ 6 o'clock

Test Start Date: Nov 12, 2004

Drum #

Drop height	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
5.0																				
4.8																				
4.6																				
4.4																				
4.2																				
4.0																				
3.8		**X**																		**X**
3.6	**O**		**X**												**X**				**O**	
3.4				**X**		**X**				**X**		**X**		**O**		**X**		**O**		
3.2					**O**		**X**		**O**		**O**		**O**				**O**			
3.0								**O**												
2.8																				
2.6																				
2.4																				
2.2																				
2.0																				
1.8																				
1.6																				
1.4																				
1.2																				
1.0																				
0.8																				
0.6																				
0.4																				
0.2																				
0.0																				

Key
Pass test at a height: O
Fail test at a height: X

Set F Detailed Drop Test Results

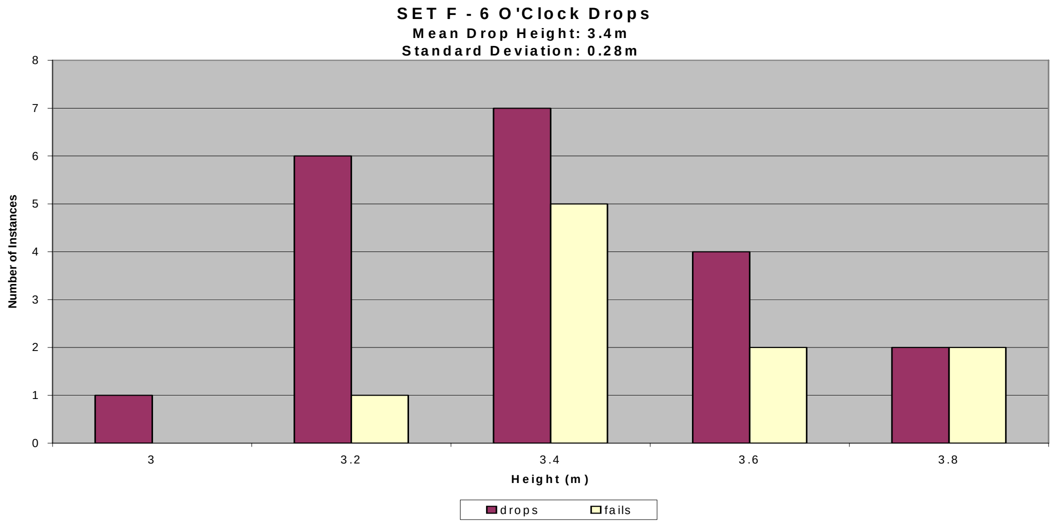
Drum # (SET E)	Height (m)	Position	Result	Comments
Preliminary Drops				
9	3.2	6 o'clock	PASS	
10	3.8	6 o'clock	FAIL	Leak at closure and drum split along side
11	3.6	6 o'clock	FAIL	Split along side of drum
12	3.4	6 o'clock	PASS	
13	3.6	6 o'clock	FAIL	Split along side of drum
14	3.6	8 o'clock	FAIL	Small drip from both closures
15	3.4	8 o'clock	PASS	
16	3.6	8 o'clock	PASS	
				Use 6 o'clock for official drops
Official Staircase Drop Series				
17	3.6	6 o'clock	PASS	
18	3.8	6 o'clock	FAIL	Split along side & cover partly separated
19	3.6	6 o'clock	FAIL	Split along side
20	3.4	6 o'clock	FAIL	Split along side & cover partly separated
21	3.2	6 o'clock	PASS	
22	3.4	6 o'clock	FAIL	Split along side
23	3.2	6 o'clock	FAIL	Split along side
24	3.0	6 o'clock	PASS	
25	3.2	6 o'clock	PASS	
26	3.4	6 o'clock	FAIL	Double split along side
27	3.2	6 o'clock	PASS	
28	3.4	6 o'clock	FAIL	Top split around closure
29	3.2	6 o'clock	PASS	
30	3.4	6 o'clock	PASS	
31	3.6	6 o'clock	FAIL	Split along side
32	3.4	6 o'clock	FAIL	Split along side
33	3.2	6 o'clock	PASS	
34	3.4	6 o'clock	PASS	
35	3.6	6 o'clock	PASS	
36	3.8	6 o'clock	FAIL	Split along side and around closure

Drop Height Calculations, Set F

SET C - 6 o'clock drops: N = 20, R = 10 therefore R <= N/2

	y (m)	r	j	j^2	r * j	r * j^2
y_0	3.2	1	0	0	0	0
y_1	3.4	5	1	1	5	5
y_2	3.6	2	2	4	4	8
y_3	3.8	2	3	9	6	18

A (sum of all r * j)	**15**
B (sum of all r * j^2)	**31**
m (estimate of the mean, in metres)	**3.40**
s (estimate of standard deviation, in metres)	**0.28**



Pressure Test Results, Drum Set F

Drum No.	Pressure achieved, kPa	Comments
F4	160	No leaks (several void tests attempting to find correct closure torque)
F5	175	No leaks
F6	165	No leaks
F7	125	Leak at closure
F8	165	No leaks
Average	> 150 kPa	Rated press. = 100 kPa

Data Sheet 2403-1587-DS1

Drum Type: 1H1/Y1.9/200
Manufacturer Code G
Closure Type: (2) 2 in. Buttress thread, Plastic gaskets
Tare weight: 8.4 kg (18.5 lb)
Target fill weight: 220.7 kg (486.5 lb)

Orientation: ☐ 6 o'clock

Test Start Date: Nov 24, 2004

Drum #

Drop height	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
5.0																				
4.8																				
4.6																				
4.4																				
4.2								**X**		**X**										
4.0	**X**						**O**		**O**		**X**		**X**				**X**			
3.8		**X**				**O**						**O**		**X**		**O**		**X**		**O**
3.6			**X**		**O**										**O**				**O**	
3.4				**O**																
3.2																				
3.0																				
2.8																				
2.6																				
2.4																				
2.2																				
2.0																				
1.8																				
1.6																				
1.4																				
1.2																				
1.0																				
0.8																				
0.6																				
0.4																				
0.2																				
0.0																				

Key
Pass test at a height: O
Fail test at a height: X

Set G Detailed Drop Test Results

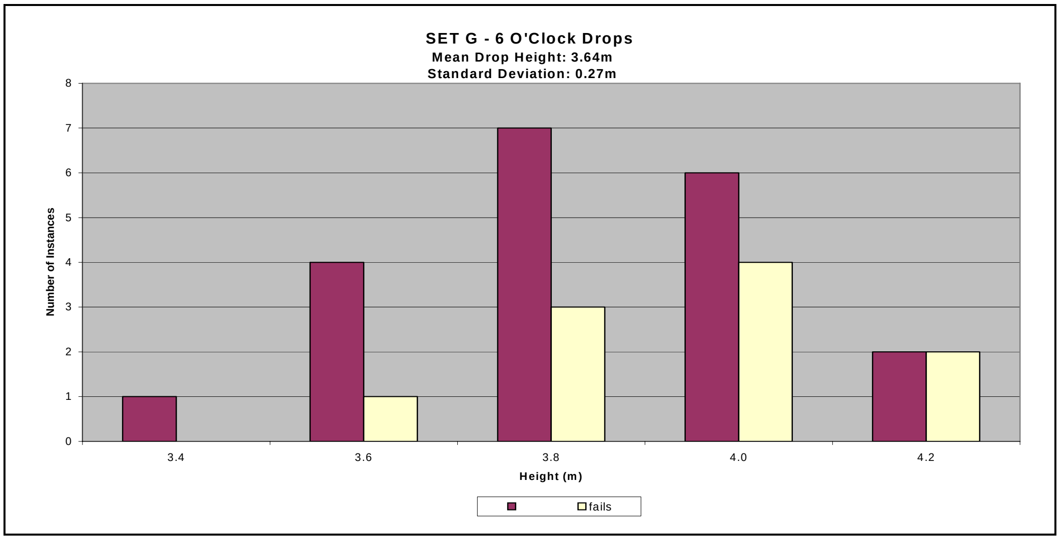
Drum # (SET E)	Height (m)	Position	Result	Comments
Preliminary Drops				
1	4.0	6 o'clock	FAIL	Leak & buttress closure
2	3.6	6 o'clock	PASS	
3	3.8	6 o'clock	PASS	
4	3.8	8 o'clock	PASS	
5	4.2	8 o'clock	PASS	
6	4.6	8 o'clock	PASS	
				Use 6 o'clock for official drops
Official Staircase Drop Series				
7	4.0	6 o'clock	FAIL	Drum split below cover seam
8	3.8	6 o'clock	FAIL	Leak at closure
9	3.6	6 o'clock	FAIL	Leak at closure
10	3.4	6 o'clock	PASS	(few drops from cover - stopped after 30 sec)
11	3.6	6 o'clock	PASS	
12	3.8	6 o'clock	PASS	
13	4.0	6 o'clock	PASS	
14	4.2	6 o'clock	FAIL	Leak at closure
15	4.0	6 o'clock	PASS	
16	4.2	6 o'clock	FAIL	Leak at closure
17	4.0	6 o'clock	FAIL	Drum split on top near closure
18	3.8	6 o'clock	PASS	
19	4.0	6 o'clock	FAIL	Leak at closure
20	3.8	6 o'clock	FAIL	Leak at closure
21	3.6	6 o'clock	PASS	
22	3.8	6 o'clock	PASS	
23	4.0	6 o'clock	FAIL	Drum split below cover seam
24	3.8	6 o'clock	FAIL	Drum split below cover seam
25	3.6	6 o'clock	PASS	(few drops from cover - stopped after 20 sec)
26	3.8	6 o'clock	PASS	

Drop Height Calculations, Set G

SET C - 6 o'clock drops: N = 20, R = 10 therefore R <= N/2

	y (m)	R	j	j^2	r * j	r * j^2
y_0	3.4	1	0	0	0	0
y_1	3.6	3	1	1	3	3
y_2	3.8	4	2	4	8	16
y_3	4	2	3	9	6	18

A (sum of all r * j)	**17**
B (sum of all r * j^2)	**37**
m (estimate of the mean, in metres)	**3.64**
s (estimate of standard deviation, in metres)	**0.27**



Pressure Test Results, Drum Set G

Drum No.	Pressure achieved, kPa	Comments
G28	280	Pass: leak at closure
G29	225	Pass: leak at small plug in centre of 2 in. bung*
G30	105	Fail: leak at small plug*
G31	Void	Bung threads stripped
G32	300	Pass: 150% rated
G33	190	Fail: leak at small plug*
Average	220 kPa	Rated press. = 200 kPa *torque not checked on small bung – see discussion in Section 2.2.1 of report