AEROSPACE STANDARD	AS6235™	REV. A
	Issued 2014-09 Revised 2015-12 Superseding AS6235	

(R) Face Seal Gland Design, Static, O-ring and Other Seals for Aerospace Hydraulic and Pneumatic Applications

RATIONALE

At Revision A, the following changes have been made:

Minor technical and editorial comments, minor dimensional changes

An analytical tool has been provided that details the calculations used to determine gland dimensions

Annex E has been added which provides supporting information

FOREWORD

The methodology for calculating gland dimensions in this document differs from other face seal specifications by using a more scientific approach. The glands in this document are for static face seals and have been specifically designed for aerospace fluid power applications using actual data obtained from testing for the specific elastomer materials and fluids included.

The groove depths have been sized using standard O-rings to AS568 with associated Class 2 tolerances, to provide sufficient squeeze for effective sealing in line with AS5857, i.e., 10% minimum, but not exceed maximum squeeze of 25% prior to any swell and at ambient temperature. Further differences from other face seal gland specifications concern groove diameters as follows:

a. For internal pressure applications the groove major diameters (O.D.) have been determined by limiting cramping (diametric compression) to 1% of the O.D. based on O-ring nominal dimensions while under nominal squeeze.

b For external pressure applications the groove minor diameters (I.D.) have been determined by limiting diametric stretch to 5% of the O-ring I.D. based on O-ring nominal dimensions while under nominal squeeze.

Both these limitations are in line with common industry practice.

The gland volume occupancy has been calculated using volume swell and thermal expansion and is generally limited to 95% maximum. The O-ring volume swell while under compression (squeeze) uses calculations determined from a study presented to AMS-CE Committee.

The calculations use the combined characteristics of fluid volume swell and thermal expansion to result in the greatest increase in O-ring volume by each dash size.

TO PLACE A DOCUMENT ORDER: **Tel: 877-606-7323 (inside USA and Canada)**
Tel: +1 724-776-4970 (outside USA)
Fax: 724-776-0790
Email: CustomerService@sae.org
SAE WEB ADDRESS: http://www.sae.org

SAE values your input. To provide feedback on this Technical Report, please visit http://www.sae.org/technical/standards/AS6235A

Closed glands are required, with exceptions.

Appendix A offers the calculation methodology used to generate the groove dimensions.

Appendix B describes the differences between this Standard and other available documents (i.e., ARP1234 and AS4873).

Appendix C shows the comparison of AS6235 groove depth tolerances with AS4716 and AS5857 groove depth deltas.

Digital Annex D is a Workbook that:

- Records the calculations used to determine the gland dimensions in this Standard.
- Allows users to insert properties of alternate materials and/or higher maximum temperature and/or alternate O-ring sizes and tolerances and determine the required gland dimensions.

Also included in Appendix D is instructions for use of the Workbook.

Annex E provides:

- A record of presentations to AMS-CE Committee and other information used in this Standard.
- Summarizes the data collected and the philosophy implemented.
- Calculations to determine the most critical elastomer material that was used to calculate the gland dimensions in Digital Annex D.

NOTE: The groove dimensions specified in this standard do not support the mounting interface patterns described in ARP490. The requirements of this standard shall not be applied to the seal grooves designed to ARP490 pattern recommendations.

1. SCOPE

This SAE Aerospace Standard (AS) specifies standardized gland design criteria and dimensions for static face seals for internal pressure and external pressure applications for aerospace hydraulic and pneumatic applications using the same size range as AS4716 and AS5857 where applicable. Some small diameter sizes are excluded because they are not practical.

The glands have been specifically designed for applications using AS568 size elastomeric O-rings with related Class 2 tolerances at nominal system operating pressures up to 3,000 psi (20,680 kPa) utilizing no anti-extrusion (backup) rings.

While the gland dimensions herein have been designed for pressures up to 3,000 psi (20,680 kPa) these glands may be used for higher pressures, but extra precautions need to be taken and testing should be performed to ensure integrity of performance.

This specification covers the basic design criteria and recommendations for use with standard size elastomeric O-rings, however, these glands are also suitable for use with other elastomeric and polytetrafluoroethylene (PTFE) based seal geometries.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

ARP490 Electrohydraulic Servovalves

AS568 Aerospace Size Standard for O-rings

ARP1234 Gland Design, Elastomeric O-Ring Seals, Static Axial, Without Back-Up Rings

AS1241 Fire Resistant Phosphate Ester Hydraulic Fluid for Aircraft

AS4716 Gland Design, O-ring and Other Elastomeric Seals

AS4873 Gland Design, Elastomeric O-Ring Seals, Static Radial and Face 800 psi Maximum Service

AS5857 Gland Design, O-ring and Other Elastomeric Seals, Static Applications

AMS-P-83461 Packing, Preformed, Petroleum Hydraulic Fluid Resistant, Improved Performance at 275°F (135°C)

AMS-R-83485 Rubber, Fluorocarbon Elastomer, Improved Performance at Low Temperatures

2.1.2 U.S. Government Publications

Copies of these documents are available online at http://quicksearch.dla.mil/.

MIL-PRF-5606 Performance Specification: Hydraulic Fluid, Petroleum Base; Aircraft, Missile, and Ordnance

MIL-P-25732 Packing, Preformed, Petroleum Hydraulic Fluid Resistant, Limited Service At 275 °F (135 °C) (Inactive)

MIL-PRF-83282 Hydraulic Fluid, Fire Resistant; Low Temperature, Synthetic Hydrocarbon Base NATO Code Number H537

MIL-PRF-87257 Hydraulic Fluid, Fire Resistant; Low Temperature, Synthetic Hydrocarbon Base, Aircraft and Missile

2.1.3 ASME Publications

Available from ASME, P.O. Box 2900, 22 Law Drive, Fairfield, NJ 07007-2900, Tel: 800-843-2763 (U.S./Canada), 001-800-843-2763 (Mexico), 973-882-1170 (outside North America), www.asme.org.

ASME B46.1 Surface Texture (Surface Roughness, Waviness & Lay)

2.1.4 NAS Publications

Available from Aerospace Industries Association, 1000 Wilson Boulevard, Suite 1700, Arlington, VA 22209-3928, Tel: 703-358-1000, www.aia-aerospace.org.

NAS1613 Packing, Preformed, Ethylene Propylene Rubber

2.1.5 ISO Publications

Available from American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, Tel: 212-642-4900, www.ansi.org.

ISO 3601-2 Fluid Power Systems - O-rings. Part 2: Housing Dimensions for General Applications

ISO 4287-1 Geometrical Product Specifications (GPS) - Surface Texture: Profile Method - Terms, Definitions and Surface Texture Parameters

2.2 Related Publications

The following publications are provided for information purposes.

The following publications are provided in Annex E:

Presentation to AMS-CE, “Compression Stress-Relaxation - Added Value or Added Cost?” by Dr. W. R. Keller, May 2102.

Presentation to AMS-CE, “Swell of O-rings in Glands Compared to Conventional Volume Change Measurements,” by Dr. W. R. Keller, August 2005.

Report “Swell of O-rings in Glands Compared to Conventional Volume Change Measurements; Updated Test Results on NBRs in Red Hydraulic Oils,” by Dr. W. R. Keller, 14 June 2013.

Report “Finite Element Analyses of Face Seal Glands, Internal Pressure, SAE AS6235 Design Standard Support” dated April 21 2015.

2.3 Definitions

2.3.1 GLAND AND GROOVE

The terms gland and groove are not interchangeable in this document. The following explains their usage:

- Groove: The recess machined in one component that contains the sealing element.

- Gland: The assembly of the component with a recess to contain the sealing element and the adjoining flat pressure retaining plate in close contact with it.

2.3.2 Clarification of Internal and External Pressure Types

The configuration of the seal and placement of the seal within the gland depends on the direction of pressure. The axial seals may be pressurized from a source located within the seals inner diameter (internal pressure application) or from a pressure source located outside the outer diameter of the seal (external pressure application). See Figures 1 and 2 respectively.

2.3.3 Metric Equivalents

Dimensions and properties in inch/pound/Fahrenheit units are primary; dimensions and properties in SI units are shown as the approximate equivalents of the primary units and are presented only for information. When using the Excel files in the Digital Annex, although the metric spreadsheets can be observed, due to slight discrepancies in conversions it is recommended that the imperial data be regarded as primary for use in applications.

3. TECHNICAL REQUIREMENTS

3.1 Gland Configuration

3.1.1 General

This document depicts groove depths similar to AS5857 in order to achieve a minimum squeeze level of 10% and radial widths similar to those for no backup rings to AS4716 in order to achieve acceptable gland occupancies. Some of the smaller dash sizes have a gland occupancy more than 95%, but in no case is a gland occupancy of 100% exceeded. The glands are sized by diameter and referenced using AS568 O-ring dash sizes. The glands are intended to be closed in order to protect seals from any possible flow erosion, however, there are certain exceptions - see the Important Note in 3.7 (following Figure 3).

At operating pressures exceeding 3,000 psi (20,680 kPa) there is a greater risk of deflection of the flat mating surfaces and/or extension of the retaining bolts resulting in an extrusion gap.

Every precaution should be taken to ensure integrity of the hardware under pressurized conditions including overpressure during impulse testing. Flatness of the mating faces comprising the gland(s) is of high importance and designs should ensure that the extrusion gap presented by any variation of the surfaces from flat is maintained at a minimum to ensure integrity of seal performance. Testing should be performed to ensure satisfactory performance.

The glands have been designed to also permit the use of alternate seal configurations where an extrusion gap may be realized, in which case, each application should be tested to ensure satisfactory performance.

3.1.2 Dimensions

For the dash sizes listed, the dimensions and surface finish requirements in Tables 3 through 8 are similar to those in AS4716 and/or AS5857 for no backup width glands and are calculated to achieve a design goal of 95% maximum gland occupancy including volume swell plus thermal expansion to 275 °F (135 °C). Some of the smaller dash sizes have a gland occupancy in excess of 95% in order to maintain consistency of gland depths and gland widths throughout a series range; however, none of the glands has an occupancy of more than 100% under these conditions.

3.2 Volume Swell and Thermal Expansion Considerations

The volume swell while under compression has been the subject of testing, see report (see E.1.1 and E.1.2) which provides the following equation:

$$\text{Volume Swell \%} = 1.958 + (0.648 \times V) - (0.0156 \times V \times S) \quad \text{(Eq. 1)}$$

where:

V = free-volume change in fluid (from material data sheets)

S = % squeeze in the gland

Note that the Volume Swell resulting from Equation 1 is a whole number.

The minimum O-ring axial squeeze at ambient temperature of 75 °F (23.9 °C) to this standard is 10% per AS5857. Since O-ring volume swell decreases as squeeze is increased, 10% squeeze will render the greatest volume swell. Where O-ring cross-section tolerances are at the maximum and groove depths are at the minimum, these circumstances will generate maximum squeeze and hence will generate the lowest volume swell. The set of circumstances found to generate the largest O-ring volume is with the O-ring dimensions on maximum and the groove depth on maximum (see Section E.2).

The swell and CTE (Coefficient of Thermal Expansion) combinations are based on using the following elastomers and fluids:

- NAS1613 elastomer in High and Low Density Phosphate Ester fluids to AS1241.
- MIL-P-25732, AMS-P-83461, AMS-R-83485 all in MIL-PRF-5606, MIL-PRF-83282. and MIL-PRF-87257 fluids.

See details of elastomer swell and physical properties in Section E.2

It should be noted that for calculation purposes it is essential to use the elastomer that has a combination of the greatest O-ring volume swell and volume thermal expansion. To use the greatest volume swell from all the fluid/elastomer tests and then use a different elastomer that has the greatest thermal expansion is a false set of circumstances.

The elastomer to produce the greatest increase in volume from the total of its discrete fluid volume swell and thermal expansion is AMS-P-83461 NBR Elastomer tested in MIL-PRF-5606 Red Oil 70 hours at 275 °F (135 °C) with a free swell of 16.3% and a CTE of 1.13 $\times 10^{-4}$ in/in/°F (2.03 $\times 10^{-4}$ mm/mm/°C).

A specific exclusion from this specification is all fluorosilicone elastomers. Due to a typical high CTE, this material is not suitable for use in grooves to this specification if used at the maximum operating temperature in the region of 350 °F (177 °C).

NOTE 1: Where the squeeze is increased and/or the known swell and linear coefficient of thermal expansion for an alternate material exceed the limits stated above, the calculations shown in Appendix A should be followed to calculate the minimum radial gland width required to achieve the maximum volume occupancy of 95%.

Appendix D and Digital Annex D (Excel spreadsheet file) may also be used to perform this calculation.

NOTE 2: No accommodation has been made for thermal expansion or contraction of hardware.

The hardware dimensions that affect seal performance through temperature variation are principally the groove depths. At low temperature the seal material will shrink producing a loss in squeeze. However, as the hardware will also shrink, the effect will not be quite so severe. Similarly, as temperature increases the seal will expand, thereby increasing squeeze. However, as the hardware will also expand, the effect similarly will not be quite so severe. Since various materials are used for hardware, it is not possible to account for every material used for hardware, therefore to take the worst possible case, no account is made for thermal effects of hardware dimensions in this standard.

3.3 Groove Diameters

3.3.1 Internal Pressure Applications

The groove outer diameter A is calculated as the O-ring nominal O.D. However, when squeezed axially the O-ring cross-section adopts a “race-track” shape. Assuming the mean diameter of a squeezed O-ring remains the same as that of the O-ring in a free condition, there will be an increase in the O.D. and, therefore, an interference fit of the O-ring O.D. within the groove major diameter (O.D.) A. In line with industry general practice, this specification limits the interference fit (cramming) to a maximum of 1%.

In order to maintain gland occupancy below 100%, the groove outer diameters for -008 and -009 have been increased as follows:

- -008 Size OD increased by 0.003 inch (0.076 mm).
- -009 Size OD increased by 0.001 inch (0.025 mm).

The following tolerances are then applied:

For diameters up to and including 3.010 inches (76.454 mm): +0.000/-0.006 inch (+0.000/-0.152 mm).

For diameters above 3.010 inches (76.454 mm): +0.000/-0.010 inch (+0.000/-0.254 mm).

It can be seen from Table 8 that several of the small sizes exceed 95% maximum gland occupancy. However the likelihood of actually achieving this limit in practice is extremely remote.

3.3.2 External Pressure Applications

The groove inner diameter B is calculated as the O-ring nominal I.D. However, when squeezed axially the O-ring cross-section adopts a “race-track” shape. Assuming the mean diameter of a squeezed O-ring remains the same as that of the O-ring in a free condition, there will be a decrease in the I.D. and, therefore, an interference fit of the O-ring I.D. within the groove minor diameter (I.D.) B. In line with industry general practice, this specification limits the interference fit (stretch) to a maximum of 5%.

The following tolerances are then applied:

For diameters up to and including 3.000 inches (76.200 mm): +0.006/-0.000 inch (+0.152/-0.000 mm).

For diameters above 3.000 inches (76.200 mm): +0.010/-0.000 inch (+0.254/-0.000 mm).

The groove diameters for internal pressure and external pressure applications are listed in Table 8.

3.4 Groove Depths

It is desirable to maintain ambient squeeze no higher than 25% in order to avoid excessive compression set. A squeeze level of 25% at room temperature becomes over 30% squeeze at temperatures of 300 °F (150 °C) or higher. When this is coupled with the fall-off in critical strain to break of most rubber materials, this 30+% squeeze becomes dangerously close to the failure strain of the rubber at high temperatures (for background information see Section E.3). Therefore, this specification has an upper limit on O-ring squeeze of 25% at ambient temperature as shown in Table 1, yet maintain a minimum squeeze at ambient temperature of 10% per AS5857. Table 1 also shows that the minimum squeeze at -65 °F (-54 °C) is maintained above the minimum recommendation of 5% (per AS4716) and only minimally exceeds 25% squeeze with swell and at 275 °F for 000 series only.

For reference, Table 1 also shows the maximum squeeze % for each O-ring cross section when subjected to volume swell and thermal expansion.

Table 1 - Maximum and minimum squeeze levels at various temperature limits

O-ring Series	Minimum Squeeze % -65 °F (-54 °C) (No Swell)	Minimum Squeeze % Ambient (No Swell)	Maximum Squeeze % Ambient (No Swell)	Maximum Squeeze % With Swell at 275 °F (135 °C)
000	9.01	10.45	23.29	27.97
100	8.55	10.00	18.87	23.83
200	8.93	10.37	18.18	23.18
300	8.80	10.24	17.21	22.27
400	8.59	10.04	16.73	21.82

The groove depth L for each O-ring cross-section has been calculated to ensure a minimum of O-ring squeeze of 10% at ambient temperature using the equation below:

O-ring squeezed axial dimension = O-ring minimum cross-section x 0.9

= Calculated Maximum Groove Depth "L" (Eq. 2)

The groove depths "L" are then rounded down to the nearest 0.001 inch (0.025 mm) to ensure a minimum of 10% squeeze.

The following tolerances are then applied:

Series 000, 100, 200: +0.000/-0.004 inch (+0.000/-0.102 mm)

Series 300: +0.000/-0.006 inch (+0.000/-0.152 mm)

Series 400: +0.000/-0.008 inch (+0.000/-0.203 mm)

It should be noted that as swell occurs while in a gland, the squeeze levels listed in Table 1 are valid provided the swell does not result in the O-ring coming into contact with both outer and inner diameters of the gland. Once this contact occurs the O-ring O.D. and I.D surfaces are both subject to compression, therefore, the effective squeeze on the O-ring increases dramatically. As a result, further swell is thereby significantly restricted (Equation 1) and for the O-rings listed in Table 8 as exceeding 95% gland occupancy, the likelihood of actually achieving such high levels is remote.

Also, the likelihood of tolerances on both hardware and O-ring coinciding to produce maximum occupancy, although possible, is remote. The spread of possible % occupancy for the most critical 000 series is very wide. As an example, Table 2 shows the range of gland occupancies for a sample of -008, -013, -020, and -028 sizes for Internal Pressure applications with the gland and O-ring dimensions to provide minimum, nominal and maximum occupancy. Although the goal was to achieve a maximum of 95% occupancy, the slightly excessive maximum possible occupancy for -008 through -013, by virtue of the above explanation, is not a concern.

Table 2 - 000 series range of gland occupancies by varying component tolerances

Internal Pressure Applications				
		Gland Occupancy % with Swell & Thermal Expansion		
O-ring & Gland Dash Size	Gland Maximum O.D.	Maximum Gland Volume Minimum O-ring Volume	Nominal Gland Volume Nominal O-ring Volume	Minimum Gland Volume Maximum O-ring Volume
-008	0.331	76.59%	85.34%	98.90%
-013	0.572	72.61%	82.93%	95.10%
-020	1.006	70.64%	81.27%	92.71%
-028	1.504	69.92%	80.49%	91.59%

Refer to Appendix C for comparison of groove depths and tolerances between this standard and AS4716.

3.5 Groove Radial Width

The groove radial widths "G" are based on calculations per Appendix A and generally use a maximum gland volume occupancy of 95%. The groove edge break volume is not included in the calculations. In some cases the groove widths are rounded down for practical and consistency reasons, but in no case does volume occupancy exceed 100%. Tables 3 and 4 list groove widths that are either per calculations, per rounded calculations or the same as AS4716. For -108 size for Internal Pressure, the maximum groove width of 0.146 inch (3.708 mm) is used in order to maintain the minimum inner gland wall thickness.

Table 3 - Groove cross section details for internal pressure applications

Gland and AS568 O-ring Dash No.	Internal Pressure Applications			
	Inches		Millimeters	
	Groove Width G Min Max	Groove Depth L Min Max	Groove Width G Min Max	Groove Depth L Min Max
008 thru 028	0.098 0.103	0.056 0.060	2.489 2.616	1.422 1.524
108	0.141 0.146	0.086 0.090	3.581 3.708	2.184 2.286
109 thru 149	0.141 0.151		3.581 3.835	
210 thru 247	0.188 0.198	0.117 0.121	4.775 5.029	2.972 3.073
325 thru 349	0.281 0.291	0.178 0.184	7.137 7.391	4.521 4.674
425 thru 460	0.375 0.385	0.234 0.242	9.525 9.779	5.944 6.147

Table 4 - Groove cross section details for external pressure applications

Gland and AS568 O-ring Dash No.	External Pressure Applications			
	Inches		Millimeters	
	Groove Width G Min Max	Groove Depth L Min Max	Groove Width G Min Max	Groove Depth L Min Max
006 thru 028	0.098 0.103	0.056 0.060	2.489 2.616	1.422 1.524
106 thru 149	0.141 0.151	0.086 0.090	3.581 3.835	2.184 2.286
210 thru 247	0.188 0.198	0.117 0.121	4.775 5.029	2.972 3.073
325 thru 349	0.281 0.291	0.178 0.184	7.137 7.391	4.521 4.674
425 thru 460	0.375 0.385	0.234 0.242	9.525 9.779	5.944 6.147

For gland dash sizes up to and including -109, the widths for zero backup grooves per AS5857 are larger than those per AS4716. For gland dash sizes -110 and above, the reverse is the case. Since space is always at a premium, but more critical for smaller sizes, the groove widths per AS4716 were adopted.

A further reason is that historically, groove dimensions for specialist designs of face seals have been based on AS4716, which is a derivative of previous Military specifications. AS5857 is a more recent specification and while it is specifically for static seals, designs based on AS4716 dimensions and tolerances were already established with no reason to introduce designs based on AS5857.

For both internal pressure and external pressure applications, the limiting minimum O-ring I.D. was taken into account and was applied as 0.102 inch (2.591 mm) for series 000 O-rings and 0.153 inch (3.886 mm) for all series 100 and larger O-rings.

These limits were determined by assuming a minimum flow passage diameter of 0.062 inch (1.575 mm) and a supporting maximum groove wall thickness of 0.020 inch (0.508 mm) for series 000 O-rings and 0.030 inch (0.762 mm) for series 100 cross-section O-rings.

It is not necessary to apply such limitations to series 200, 300, and 400 O-rings as their inside diameters are much larger. Groove widths and depths by Dash Number are listed in Tables 3 and 4. Size -108 for internal pressure has a different groove width to the remainder of the 100 series sizes in order to maintain a groove I.D. with a minimum of 0.153 inch (3.886 mm)

3.6 Limitations

The design criteria and standard glands set forth in this document are intended for use in static applications with AS568 O-ring dash sizes and the range of dash sizes was selected to be essentially the same as those listed in AS4716 but with the exception of some small sizes that are not practical and are, therefore, omitted.

3.7 Gland Detail

Details for the standard gland design including break edge requirements are depicted in Figures 1 and 2.

NOTE: Dimensions used in Figure 1 through 3 are listed below:

- Groove O.D. for Internal Pressure Applications
- Groove I.D. for External Pressure Applications
- Groove Radial Width
- Groove Depth
- Groove Radius

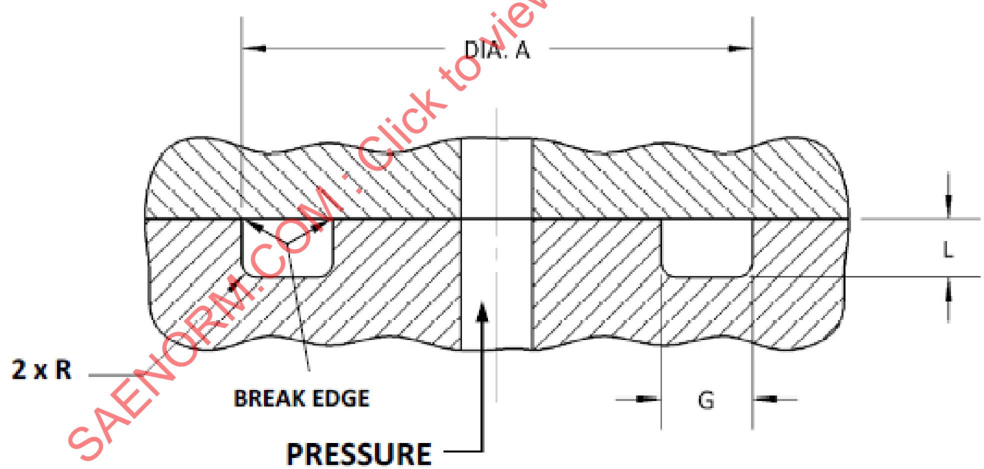


Figure 1 - Gland details - internal pressure applications

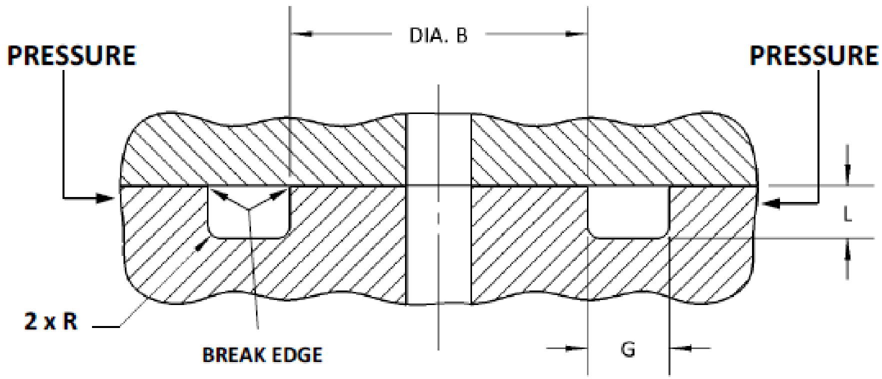


Figure 2 - Gland details - external pressure applications

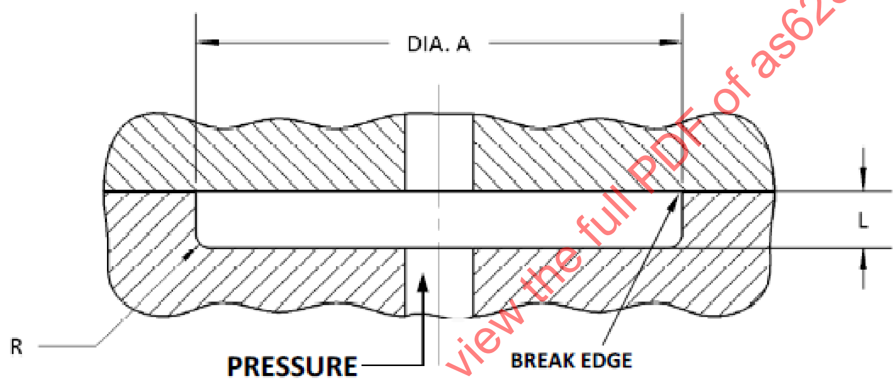


Figure 3 - Gland details - internal pressure applications
(only allowed in special circumstances - see important note below)

IMPORTANT NOTE: Glands for internal pressure applications to Figure 3 are generally not allowed; gland designs to Figure 1 protect the seal against any flow erosion and are required unless the seal is designed with a metal or suitable high modulus plastic internal protecting component. Some internal pressure seal designs incorporate a metal or high modulus plastic component on the I.D. to prevent flow erosion, in which case grooves to Figure 3 may be used. External pressure applications should also use closed glands in order to protect seals from the environment, unless there is a separate component to protect the seal O.D. Seals using these configurations should be tested to prove suitability.

3.7.1 Groove Corner Break Edge

The corner break edge requirements (see Figures 1 through 3) are per AS4716 and AS5857 and are listed in Table 5.

Table 5 - Groove break edge details

System Pressure		Groove Break Edge Requirements	
Pressure (psig)	Pressure (kPa)	inches	mm
≤ 3,000	≤ 20,680	0.005 + 0.005 / -0.000	0.127 + 0.127 / -.000
> 3,000	> 20,680	0.002 + 0.008 / -0.000	0.051 + 0.203 / -.000

3.7.2 Groove Corner Radii

The groove corner radii (see Figures 1 through 3) dimension "R" are per AS4716 and AS5857 and are listed in Table 6.

Table 6 - Groove standard corner radius dimensions

Gland and AS568 Dash No.	Inches		Millimeters	
	Corner Radius Maximum	Corner Radius Minimum	Corner Radius Maximum	Corner Radius Minimum
006 to 028	0.015	0.005	0.381	0.127
106 to 149	0.015	0.005	0.381	0.127
210 to 247	0.025	0.010	0.635	0.254
325 to 349	0.035	0.020	0.889	0.508
425 thru 460	0.035	0.020	0.889	0.508

3.8 Surface Finishes of Glands

The following surface finishes in Table 7 (indicated as surface roughness as defined in ASME B46.1 (ISO 4287-1) shall be used in units containing O-ring and other elastomeric seals.

Table 7 - Surface roughness requirements

Part on Unit	Surface Roughness Ra (µin) per ASME B46.1	Surface Roughness Ra (µm) per ISO 4287-1
Sealing Faces	16 (max) See Note	0.4 (max) See Note
O-ring Contact Diameter (Outer Diameter for Internal Pressure Type) (Inner Diameter for External Pressure Type)	32 (max)	0.8 (max)
O-ring Non-contact Diameter (Inner Diameter for Internal Pressure Type) (Outer Diameter for External Pressure Type)	63 (max)	1.6 (max)

NOTE: The optimum recommended roughness for dynamic application is 4 to 12 µin (0.1 to 0.3 µm) Ra. The use of HVOF (High Velocity Oxygenated Fuel) coatings will require a 4 µin (0.1 µm) Ra (max) roughness with consideration to post process super-finishing/polishing.

The sealing faces are the surface of the closing plate and the bottom of the groove, which are essentially parallel to each other and perpendicular to the flow port.

The gland surfaces must be free from all machining irregularities exceeding the above values. Gland edges shall be smooth and true and free of nicks, scratches, and burrs, etc.

3.9 Groove Dimensions and O-ring Volume Occupancy

The groove I.D. and O.D. dimensions (see Figures 1 through 3) as applicable and maximum volume occupancies are listed in Table 8.

Table 8 - Standard groove diameters for internal and external pressure applications

	Inches		Millimeters		Maximum Gland Occupancy	
Gland and AS568 Dash No.	Groove O.D. A Internal Pressure Max Min	Groove I.D. B External Pressure Min Max	Groove O.D. A Internal Pressure Max Min	Groove I.D. B External Pressure Min Max	Internal Pressure Gland	External Pressure Gland
006	-	0.107 0.112	-	2.718 2.845	-	84.05%
007	-	0.140 0.145	-	3.556 3.683	-	82.91%
008	0.328 0.323	0.173 0.178	8.331 8.204	4.394 4.521	98.58%	82.94%
009	0.357 0.353	0.206 0.211	9.068 8.966	5.232 5.359	99.25%	83.25%
010	0.387 0.382	0.239 0.244	9.830 9.703	6.071 6.198	98.77%	83.24%
011	0.448 0.443	0.301 0.306	11.379 11.252	7.645 7.772	97.21%	84.06%
012	0.511 0.506	0.364 0.369	12.979 12.852	9.246 9.373	95.87%	84.66%
013	0.572 0.567	0.426 0.431	14.529 14.402	10.820 10.947	95.10%	85.11%
014	0.634 0.629	0.489 0.494	16.104 15.977	12.421 12.548	94.49%	85.48%
015	0.696 0.691	0.551 0.556	17.678 17.551	13.995 14.122	94.16%	86.04%
016	0.758 0.753	0.614 0.619	19.253 19.126	15.596 15.723	94.03%	86.50%
017	0.820 0.815	0.676 0.681	20.828 20.701	17.170 17.297	93.55%	86.66%
018	0.882 0.877	0.739 0.744	22.403 22.276	18.771 18.898	93.26%	86.80%
019	0.943 0.938	0.801 0.806	23.952 23.825	20.345 20.472	93.02%	86.92%
020	1.006 1.001	0.864 0.869	25.552 25.425	21.946 22.073	92.71%	87.02%
021	1.067 1.062	0.926 0.931	27.102 26.975	23.520 23.647	92.53%	87.11%
022	1.129 1.124	0.989 0.994	28.677 28.550	25.121 25.248	92.46%	87.27%
023	1.191 1.186	1.051 1.056	30.251 30.124	26.695 26.822	92.23%	87.34%
024	1.254 1.249	1.114 1.119	31.852 31.725	28.296 28.423	92.03%	87.40%
025	1.316 1.311	1.176 1.181	33.426 33.299	29.870 29.997	91.92%	87.52%
026	1.379 1.374	1.239 1.244	35.027 34.900	31.471 31.598	91.75%	87.56%
027	1.441 1.436	1.301 1.306	36.601 36.474	33.045 33.172	91.60%	87.61%
028	1.504 1.499	1.364 1.369	38.202 38.075	34.646 34.773	91.59%	87.77%

Table 8 - Standard groove diameters for internal and external pressure applications (continued)

Gland and AS568 Dash No.	Inches		Millimeters		Maximum Gland Occupancy	
	Groove O.D. A Internal Pressure Max Min	Groove I.D. B External Pressure Min Max	Groove O.D. A Internal Pressure Max Min	Groove I.D. B External Pressure Min Max	Internal Pressure Gland	External Pressure Gland
106	-	0.169 0.174	-	4.293 4.420	-	77.69%
107	-	0.202 0.207	-	5.131 5.258	-	78.10%
108	0.452 0.447	0.235 0.240	11.481 11.354	5.969 6.096	96.10%	78.21%
109	0.513 0.508	0.299 0.304	13.030 12.903	7.595 7.722	94.41%	78.74%
110	0.576 0.571	0.362 0.367	14.630 14.503	9.195 9.322	92.96%	79.46%
111	0.637 0.632	0.424 0.429	16.180 16.053	10.770 10.897	92.08%	80.02%
112	0.700 0.695	0.487 0.492	17.780 17.653	12.370 12.497	91.22%	80.47%
113	0.761 0.756	0.549 0.554	19.329 19.202	13.945 14.072	90.96%	81.08%
114	0.823 0.818	0.612 0.617	20.904 20.777	15.545 15.672	90.75%	81.59%
115	0.885 0.880	0.674 0.679	22.479 22.352	17.120 17.247	90.22%	81.81%
116	0.947 0.942	0.737 0.742	24.054 23.927	18.720 18.847	89.89%	82.00%
117	1.008 1.003	0.799 0.804	25.603 25.476	20.295 20.422	89.70%	82.26%
118	1.071 1.066	0.862 0.867	27.203 27.076	21.895 22.022	89.35%	82.40%
119	1.132 1.127	0.924 0.929	28.753 28.626	23.470 23.597	89.13%	82.52%
120	1.195 1.190	0.987 0.992	30.353 30.226	25.070 25.197	88.85%	82.63%
121	1.256 1.251	1.049 1.054	31.902 31.775	26.645 26.772	88.69%	82.73%
122	1.318 1.313	1.112 1.117	33.477 33.350	28.245 28.372	88.54%	82.82%
123	1.380 1.375	1.174 1.179	35.052 34.925	29.820 29.947	88.48%	83.03%
124	1.443 1.438	1.237 1.242	36.652 36.525	31.420 31.547	88.28%	83.09%
125	1.505 1.500	1.299 1.304	38.227 38.100	32.995 33.122	88.11%	83.16%
126	1.568 1.563	1.362 1.367	39.827 39.700	34.595 34.722	87.95%	83.21%
127	1.630 1.625	1.424 1.429	41.402 41.275	36.170 36.297	87.81%	83.26%

Table 8 - Standard groove diameters for internal and external pressure applications (continued)

Gland and AS568 Dash No.	Inches		Millimeters		Maximum Gland Occupancy	
	Groove O.D. A Internal Pressure Max Min	Groove I.D. B External Pressure Min Max	Groove O.D. A Internal Pressure Max Min	Groove I.D. B External Pressure Min Max	Internal Pressure Gland	External Pressure Gland
128	1.693 1.688	1.487 1.492	43.002 42.875	37.770 37.897	87.67%	83.31%
129	1.755 1.750	1.549 1.554	44.577 44.450	39.345 39.472	87.71%	83.50%
130	1.818 1.813	1.612 1.617	46.177 46.050	40.945 41.072	87.59%	83.54%
131	1.880 1.875	1.674 1.679	47.752 47.625	42.520 42.647	87.48%	83.57%
132	1.943 1.938	1.737 1.742	49.352 49.225	44.120 44.247	87.37%	83.60%
133	2.005 2.000	1.799 1.804	50.927 50.800	45.695 45.822	87.28%	83.63%
134	2.068 2.063	1.862 1.867	52.527 52.400	47.295 47.422	87.19%	83.66%
135	2.131 2.126	1.925 1.930	54.127 54.000	48.895 49.022	87.19%	83.77%
136	2.193 2.188	1.987 1.992	55.702 55.575	50.470 50.597	87.11%	83.79%
137	2.256 2.251	2.050 2.055	57.302 57.175	52.070 52.197	87.03%	83.81%
138	2.318 2.313	2.112 2.117	58.877 58.750	53.645 53.772	86.96%	83.83%
139	2.381 2.376	2.175 2.180	60.477 60.350	55.245 55.372	86.89%	83.85%
140	2.443 2.438	2.237 2.242	62.052 61.925	56.820 56.947	86.82%	83.87%
141	2.506 2.501	2.300 2.305	63.652 63.525	58.420 58.547	86.87%	83.99%
142	2.568 2.563	2.362 2.367	65.227 65.100	59.995 60.122	86.81%	84.00%
143	2.631 2.626	2.425 2.430	66.827 66.700	61.595 61.722	86.75%	84.01%
144	2.693 2.688	2.487 2.492	68.402 68.275	63.170 63.297	86.69%	84.02%
145	2.756 2.751	2.550 2.555	70.002 69.875	64.770 64.897	86.64%	84.03%
146	2.818 2.813	2.612 2.617	71.577 71.450	66.345 66.472	86.59%	84.04%
147	2.881 2.876	2.675 2.680	73.177 73.050	67.945 68.072	86.61%	84.11%
148	2.943 2.938	2.737 2.742	74.752 74.625	69.520 69.647	86.56%	84.12%
149	3.006 3.001	2.800 2.805	76.352 76.225	71.120 71.247	86.51%	84.13%

Table 8 - Standard groove diameters for internal and external pressure applications (continued)

Gland and AS568 Dash No.	Inches		Millimeters		Maximum Gland Occupancy	
	Groove O.D. A Internal Pressure Max Min	Groove I.D. B External Pressure Min Max	Groove O.D. A Internal Pressure Max Min	Groove I.D. B External Pressure Min Max	Internal Pressure Gland	External Pressure Gland
210	1.019 1.014	0.734 0.739	25.883 25.756	18.644 18.771	91.58%	82.05%
211	1.080 1.075	0.796 0.926	27.432 27.305	20.218 23.520	91.25%	82.25%
212	1.143 1.138	0.859 0.864	29.032 28.905	21.819 21.946	90.85%	82.43%
213	1.204 1.199	0.921 0.926	30.582 30.455	23.393 23.520	90.60%	82.59%
214	1.266 1.261	0.984 0.989	32.156 32.029	24.994 25.121	90.37%	82.74%
215	1.328 1.323	1.046 1.051	33.731 33.604	26.568 26.695	90.09%	82.87%
216	1.390 1.385	1.109 1.114	35.306 35.179	28.169 28.296	90.06%	83.12%
217	1.451 1.446	1.171 1.176	36.855 36.728	29.743 29.870	89.90%	83.21%
218	1.514 1.509	1.234 1.239	38.456 38.329	31.344 31.471	89.68%	83.31%
219	1.575 1.570	1.296 1.301	40.005 39.878	32.918 33.045	89.54%	83.39%
220	1.638 1.633	1.359 1.364	41.605 41.478	34.519 34.646	89.36%	83.47%
221	1.699 1.694	1.421 1.426	43.155 43.028	36.093 36.220	89.25%	83.54%
222	1.762 1.757	1.484 1.489	44.755 44.628	37.694 37.821	89.25%	83.76%
223	1.887 1.882	1.609 1.614	47.930 47.803	40.869 40.996	88.96%	83.86%
224	2.012 2.007	1.734 1.739	51.105 50.978	44.044 44.171	88.71%	83.95%
225	2.137 2.132	1.859 1.864	54.280 54.153	47.219 47.346	88.62%	84.16%
226	2.262 2.257	1.984 1.989	57.455 57.328	50.394 50.521	88.42%	84.23%
227	2.387 2.382	2.109 2.114	60.630 60.503	53.569 53.696	88.24%	84.28%
228	2.512 2.507	2.234 2.239	63.805 63.678	56.744 56.871	88.15%	84.41%
229	2.637 2.632	2.359 2.364	66.980 66.853	59.919 60.046	88.01%	84.45%
230	2.762 2.757	2.484 2.489	70.155 70.028	63.094 63.221	87.87%	84.49%
231	2.887 2.882	2.609 2.614	73.330 73.203	66.269 66.396	87.75%	84.52%
232	3.012 3.002	2.734 2.739	76.505 76.251	69.444 69.571	87.92%	84.67%

Table 8 - standard groove diameters for internal and external pressure applications (continued)

	Inches		Millimeters		Maximum Gland Occupancy	
Gland and AS568 Dash No.	Groove O.D. A Internal Pressure Max Min	Groove I.D. B External Pressure Min Max	Groove O.D. A Internal Pressure Max Min	Groove I.D. B External Pressure Min Max	Internal Pressure Gland	Internal Pressure Gland
233	3.137 3.127	2.859 2.864	79.680 79.426	72.619 72.746	87.81%	84.70%
234	3.262 3.252	2.984 2.989	82.855 82.601	75.794 75.921	87.71%	84.72%
235	3.387 3.377	3.109 3.119	86.030 85.776	78.969 79.223	87.61%	84.74%
236	3.512 3.502	3.234 3.244	89.205 88.951	82.144 82.398	87.52%	84.76%
237	3.637 3.627	3.359 3.369	92.380 92.126	85.319 85.573	87.44%	84.78%
238	3.762 3.752	3.484 3.494	95.555 95.301	88.494 88.748	87.37%	84.80%
239	3.887 3.877	3.609 3.619	98.730 98.476	91.669 91.923	87.39%	84.90%
240	4.012 4.002	3.734 3.744	101.905 101.651	94.844 95.098	87.32%	84.92%
241	4.137 4.127	3.859 3.869	105.080 104.826	98.019 98.273	87.26%	84.93%
242	4.262 4.252	3.984 3.994	108.255 108.001	101.194 101.448	87.20%	84.94%
243	4.387 4.377	4.109 4.119	111.430 111.176	104.369 104.623	87.14%	84.95%
244	4.512 4.502	4.234 4.244	114.605 114.351	107.544 107.798	87.12%	85.00%
245	4.637 4.627	4.359 4.369	117.780 117.526	110.719 110.973	87.07%	85.00%
246	4.762 4.752	4.484 4.494	120.955 120.701	113.894 114.148	87.02%	85.01%
247	4.887 4.877	4.609 4.619	124.130 123.876	117.069 117.323	86.98%	85.02%
325	1.899 1.894	1.475 1.480	48.235 48.108	37.465 37.592	89.67%	82.37%
326	2.023 2.018	1.600 1.605	51.384 51.257	40.640 40.767	89.37%	82.53%
327	2.147 2.142	1.725 1.730	54.534 54.407	43.815 43.942	89.12%	82.67%
328	2.270 2.265	1.850 1.855	57.658 57.531	46.990 47.117	88.94%	82.80%
329	2.395 2.390	1.975 1.980	60.833 60.706	50.165 50.292	88.81%	83.03%
330	2.520 2.515	2.100 2.105	64.008 63.881	53.340 53.467	88.59%	83.12%
331	2.645 2.640	2.225 2.230	67.183 67.056	56.515 56.642	88.39%	83.21%
332	2.770 2.765	2.350 2.355	70.358 70.231	59.690 59.817	88.21%	83.28%

Table 8 - Standard groove diameters for internal and external pressure applications (continued)

Gland and AS568 Dash No.	Inches: Groove O.D. A Internal Pressure Max Min	Inches: Groove I.D. B External Pressure Min Max	Millimeters: Groove O.D. A Internal Pressure Max Min	Millimeters: Groove I.D. B External Pressure Min Max	Maximum Gland Occupancy: Internal Pressure Gland	Maximum Gland Occupancy: External Pressure Gland
333	2.895 2.890	2.475 2.480	73.533 73.406	62.865 62.992	88.11%	83.41%
334	3.020 3.010	2.600 2.605	76.708 76.454	66.040 66.167	88.13%	83.48%
335	3.145 3.135	2.725 2.730	79.883 79.629	69.215 69.342	87.98%	83.53%
336	3.270 3.260	2.850 2.855	83.058 82.804	72.390 72.517	87.85%	83.58%
337	3.395 3.385	2.975 2.980	86.233 85.979	75.565 75.692	87.84%	83.74%
338	3.520 3.510	3.100 3.110	89.408 89.154	78.740 78.994	87.72%	83.78%
339	3.645 3.635	3.225 3.235	92.583 92.329	81.915 82.169	87.61%	83.81%
340	3.770 3.760	3.350 3.360	95.758 95.504	85.090 85.344	87.51%	83.85%
341	3.895 3.885	3.475 3.485	98.933 98.679	88.265 88.519	87.42%	83.88%
342	4.020 4.010	3.600 3.610	102.108 101.854	91.440 91.694	87.42%	84.00%
343	4.145 4.135	3.725 3.735	105.283 105.029	94.615 94.869	87.34%	84.03%
344	4.270 4.260	3.850 3.860	108.458 108.204	97.790 98.044	87.26%	84.05%
345	4.395 4.385	3.975 3.985	111.633 111.379	100.965 101.219	87.19%	84.07%
346	4.520 4.510	4.100 4.110	114.808 114.554	104.140 104.394	87.12%	84.09%
347	4.645 4.635	4.225 4.235	117.983 117.729	107.315 107.569	87.09%	84.15%
348	4.770 4.760	4.350 4.360	121.158 120.904	110.490 110.744	87.03%	84.17%
349	4.895 4.885	4.475 4.485	124.333 124.079	113.665 113.919	86.97%	84.19%
425	5.025 5.015	4.475 4.485	127.635 127.381	113.665 113.919	84.96%	81.28%
426	5.150 5.140	4.600 4.610	130.810 130.556	116.840 117.094	84.89%	81.31%
427	5.275 5.265	4.725 4.735	133.985 133.731	120.015 120.269	84.82%	81.33%
428	5.400 5.390	4.850 4.860	137.160 136.906	123.190 123.444	84.76%	81.35%
429	5.525 5.515	4.975 4.985	140.335 140.081	126.365 126.619	84.77%	81.44%
430	5.650 5.640	5.100 5.110	143.510 143.256	129.540 129.794	84.71%	81.46%

Table 8 - standard groove diameters for internal and external pressure applications (continued)

Gland and AS568 Dash No.	Inches		Millimeters		Maximum Gland Occupancy	
	Groove O.D. A Internal Pressure Max Min	Groove I.D. B External Pressure Min Max	Groove O.D. A Internal Pressure Max Min	Groove I.D. B External Pressure Min Max	Internal Pressure Gland	External Pressure Gland
431	5.775 5.765	5.225 5.235	146.685 146.431	132.715 132.969	84.65%	81.48%
432	5.900 5.890	5.350 5.360	149.860 149.606	135.890 136.144	84.60%	81.50%
433	6.025 6.015	5.475 5.485	153.035 152.781	139.065 139.319	84.55%	81.51%
434	6.150 6.140	5.600 5.610	156.210 155.956	142.240 142.494	84.50%	81.53%
435	6.275 6.265	5.725 5.735	159.385 159.131	145.415 145.669	84.45%	81.55%
436	6.400 6.390	5.850 5.860	162.560 162.306	148.590 148.844	84.41%	81.56%
437	6.525 6.515	5.975 5.985	165.735 165.481	151.765 152.019	84.37%	81.58%
438	6.775 6.765	6.225 6.235	172.085 171.831	158.115 158.369	84.32%	81.64%
439	7.025 7.015	6.475 6.485	178.435 178.181	164.465 164.719	84.25%	81.67%
440	7.275 7.265	6.725 6.735	184.785 184.531	170.815 171.069	84.18%	81.69%
441	7.525 7.515	6.975 6.985	191.135 190.881	177.165 177.419	84.11%	81.71%
442	7.775 7.765	7.225 7.235	197.485 197.231	183.515 183.769	84.11%	81.78%
443	8.025 8.015	7.475 7.485	203.835 203.581	189.865 190.119	84.05%	81.80%
444	8.275 8.265	7.725 7.735	210.185 209.931	196.215 196.469	83.99%	81.82%
445	8.525 8.515	7.975 7.985	216.535 216.281	202.565 202.819	83.94%	81.83%
446	9.025 9.015	8.475 8.485	229.235 228.981	215.265 215.519	83.94%	81.95%
447	9.525 9.515	8.975 8.985	241.935 241.681	227.965 228.219	83.86%	81.97%
448	10.025 10.015	9.475 9.485	254.635 254.381	240.665 240.919	83.78%	81.99%
449	10.525 10.515	9.975 9.985	267.335 267.081	253.365 253.619	83.70%	82.01%
450	11.025 11.015	10.475 10.485	280.035 279.781	266.065 266.319	83.68%	82.06%
451	11.525 11.515	10.975 10.985	292.735 292.481	278.765 279.019	83.62%	82.07%
452	12.025 12.015	11.475 11.485	305.435 305.181	291.465 291.719	83.56%	82.08%
453	12.525 12.515	11.975 11.985	318.135 317.881	304.165 304.419	83.51%	82.09%

Table 8 - Standard groove diameters for internal and external pressure applications (continued)

Gland and AS568 Dash No.	Inches		Millimeters		Maximum Gland Occupancy	
	Groove O.D. A Internal Pressure Max Min	Groove I.D. B External Pressure Min Max	Groove O.D. A Internal Pressure Max Min	Groove I.D. B External Pressure Min Max	Internal Pressure Gland	Internal Pressure Gland
454	13.025 13.015	12.475 12.485	330.835 330.581	316.865 317.119	83.46%	82.10%
455	13.525 13.515	12.975 12.985	343.535 343.281	329.565 329.819	83.42%	82.11%
456	14.025 14.015	13.475 13.485	356.235 355.981	342.265 342.519	83.44%	82.17%
457	14.525 14.515	13.975 13.985	368.935 368.681	354.965 355.219	83.40%	82.18%
458	15.025 15.015	14.475 14.485	381.635 381.381	367.665 367.919	83.36%	82.18%
459	15.525 15.515	14.975 14.985	394.335 394.081	380.365 380.619	83.33%	82.19%
460	16.025 16.015	15.475 15.485	407.035 406.781	393.065 393.319	83.29%	82.19%

4. NOTES

4.1 Revision Indicator

A change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications nor in documents that contain editorial changes only.

PREPARED BY SAE SUBCOMMITTEE A-6C2, SEALS OF
COMMITTEE A-6, AEROSPACE ACTUATION, CONTROL AND FLUID POWER SYSTEMS

APPENDIX A - CALCULATIONS TO DETERMINE GLAND DIMENSIONS

A.1 NOMENCLATURE

A	Groove O.D. for Internal Pressure Applications
B	Groove I.D. for External Pressure Applications
G	Groove Radial Width
L	Groove Depth
R	Groove Radius
a	Groove O.D. for External Pressure Applications
b	Groove I.D. for Internal Pressure Applications
Vro	Volume of Square encompassing Outer Radius
Vri	Volume of Square encompassing Inner Radius
x	Centroid radial offset for a Quadrant
Rao	Area of outer Radius Quadrant
Rai	Area of inner Radius Quadrant
XA	Centroid diameter for Outer Radius
XB	Centroid diameter for Inner Radius
Vro	Volume of outer Radius Quadrant
Vri	Volume of inner Radius Quadrant
Vg	Volume of Gland
D	O-ring I.D.
d	O-ring Cross-Section Diameter
Do	Squeezed O-ring O.D.
Di	Squeezed O-ring I.D.
Ro	O-ring Radius to center of Cross-Section, free condition
ro	O-ring Cross-Section Radius, free condition
m	Length of Flat in Cross-Section of squeezed O-ring
M	Overall Length of Cross-Section of squeezed O-ring
Vo	Volume of new O-ring (No Swell)
Vf	Volume Swell % of O-ring when free (not under squeeze load)

Vc	Volume Swell % of O-ring when under squeeze load
Vs	Volume of O-ring after Swell
Vst	Volume of O-ring after Swell and Thermal expansion
Ti	Temperature Increase above Ambient
CTE	Coefficient of Thermal Expansion (Linear)

A.2 CALCULATIONS

A.2.1 Groove Diameter

A.2.1.1 For internal pressure applications, the groove maximum O.D. “A” is equal to the O-ring nominal O.D.

i.e., O-ring nominal I.D. plus twice nominal cross section

$$A_{Max} = D_{Nom} + 2(d_{Nom}) \quad \text{(Eq. A1)}$$

Refer to Figure A1.

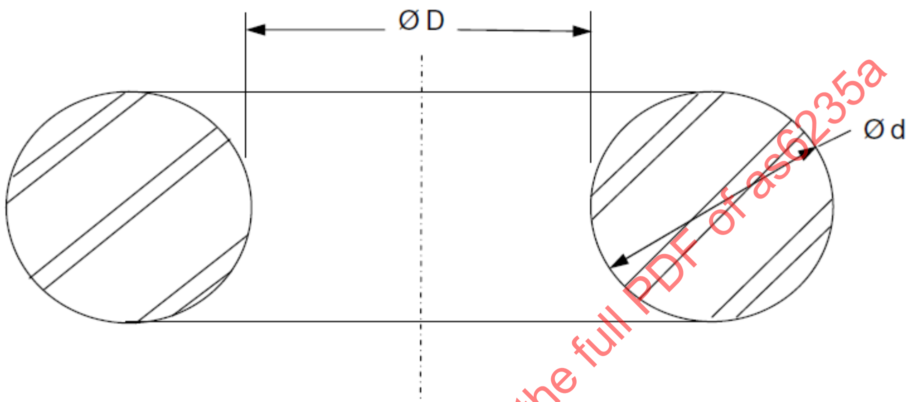


Figure A1 - Free O-ring dimensions

A.2.1.1.1 Adjustment in Groove Diameter for Internal Pressure applications

An industry recognized limitation on cramping of the O.D. for O-rings is 1% maximum of diameter. For the purposes of this specification the 1% cramping limitation is applied to the squeezed O-ring O.D. with the groove O.D. at nominal and with the O-ring I.D. and cross-section dimensions at nominal.

$$\text{Cross-Section Area of un-squeezed O-ring} = \frac{\pi d^2}{4} \quad \text{(Eq. A2)}$$

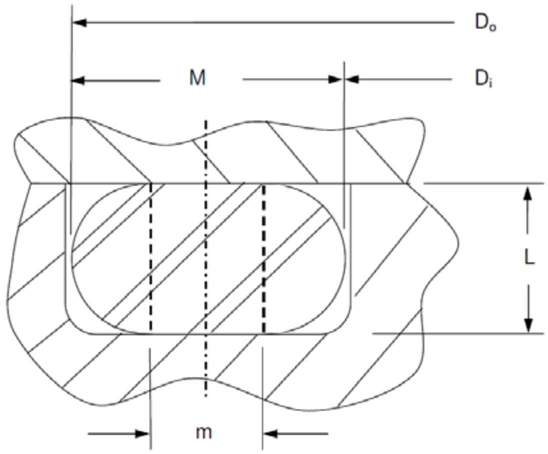


Figure A2 - Squeezed O-ring dimensions

NOTE: Clearance is shown between O-ring and groove O.D. and I.D for clarity.

Refer to Figure A2.

Assuming the squeezed cross-section area remains the same as the cross-section area in the free condition, then

$$\text{Squeezed O-ring cross-section area} = \frac{\pi d^2}{4} = \frac{\pi L^2}{4} + (L \times m) \qquad \text{(Eq. A3)}$$

$$\therefore m \times L = \frac{\pi d^2}{4} - \frac{\pi L^2}{4} \;\therefore m = \frac{\pi d^2}{4L} - \frac{\pi L^2}{4L} \quad \text{and} \;\therefore m = \frac{\pi}{4L}\left(d^2 - L^2\right)$$

The overall length of squeezed O-ring cross section $M = m + L$

Substituting,

$$M = \frac{\pi}{4L}\left(d^2 - L^2\right) + L \qquad \text{(Eq. A4)}$$

Assuming the mean diameter of the O-ring cross-section remains in the same position when squeezed as it is in the free condition,

Then the Squeezed O-ring O.D. $D_o = \text{O-ring Mean Diameter} + \text{Squeezed Cross Section}$

$$\therefore D_o = D + d + M$$

$$\therefore D_o = D + d + \frac{\pi}{4L}\left(d^2 - L^2\right) + L \qquad \text{(Eq. A5)}$$

Now, we allow 1% cramming of the O-ring O.D.,

Therefore, maximum groove O.D. $A_{Max} = (D_o x0.99) - 1/2 \text{ Tolerance for Dia A}$

Round this result up to the next whole 0.001 inch (0.025 mm) (Eq. A6)

For actual groove O.D. “A” choose the largest dimension from Equations A1 and A6 (Eq. A7)

Note that tolerances applied to Dia. A are:

Up to Dia. 3.010 inches (76.454 mm): +0.000/-0.005 inch (+0.000/-0.127 mm)

Above 3.010 inches (76.454 mm): +0.000/-0.010 inch (+0.000/-0.254 mm)

In order to maintain gland occupancy below 100%, the groove outer diameters for -008 and -009 have been increased as follows:

- -008 Size OD increased by 0.003 inch (0.076 mm)
- -009 Size OD increased by 0.001 inch (0.025 mm)

A.2.1.2 For external pressure applications, the groove minimum I.D. is equal to the O-ring nominal I.D.

$$B = D_{Nom} \quad \text{(Eq. A8)}$$

A.2.1.2.1 Adjustment in Groove Diameter for Internal Pressure Applications

For the purposes of this specification the industry recognized maximum 5% stretch limitation is applied to the squeezed O-ring I.D. with the groove I.D. at nominal and with the O-ring I.D. and cross-section dimensions at nominal. Assuming the mean diameter of the O-ring cross-section remains in the same position when squeezed as it is in the free condition, then the Squeezed O-ring I.D. D_i = O-ring mean diameter - Squeezed cross-section

$$\therefore D_i = D - M$$

$$\therefore D_i = D - \frac{\pi}{4L}\left(d^2 - L^2\right) + L \quad \text{(Eq. A9)}$$

Now, we allow 5% stretch of the O-ring I.D.,

therefore, maximum Groove I.D. $\therefore B_{Min} = (D_i \ x \ 1.05) - 1/2 \text{Tolerance for Dia B}$ (Eq. A10)

Round this result down to the next whole 0.001 inch (0.025 mm)

For actual groove I.D. “B” choose the smallest dimension from Equations A8 and A10 (Eq. A11)

Note that tolerances applied to Dia. B are:

Up to Dia. 3.000 inches (76.200 mm): +0.000/-0.005 inch (+0.000/-0.127 mm)

Above 3.000 inches (76.200 mm): +0.000/-0.010 inch (+0.000/-0.254 mm)

A.2.2 Groove Radial Width

The groove widths listed in Tables 3 and 4 are derived from calculations that accommodate a maximum of 95% gland occupancy after volume swell effect from fluid and thermal expansion have been included.

NOTE: The groove diameters and widths on some of the smaller sizes have been changed to be able to accommodate them in this Standard and the O-ring volume occupancy may exceed 95%, however, none exceed 100% occupancy.

A.2.3 Groove Depth

Groove depths are established to achieve a minimum O-ring squeeze of 10% per AS5857, with a target maximum squeeze of 25% prior to volume swell and at ambient temperature, as recommended in a presentation to by Dr. R. W. Keller (see Annex E).

$$\text{Minimum Groove Depth L} = \text{Minimum O} - \text{ring axial dimension after minimum 10\% squeeze} \qquad \text{(Eq. A12)}$$

A.2.3.1 Squeeze

The percentage squeeze is determined by the following formula:

$$\text{Squeeze \%} = \frac{\text{O - ring Free Cross Section} - \text{Groove Depth}}{\text{O} - \text{ring Free Cross Section}} \text{x100\%} \qquad \text{(Eq. A13)}$$

$$\text{Min Squeeze \%} = \frac{d_{Min} - L_{Max}}{d_{Min}} \text{ x 100\%} \qquad \text{(Eq. A14)}$$

$$\text{Max Squeeze \%} = \frac{d_{Max} - L_{Min}}{d_{Max}} \text{ x 100\%} \qquad \text{(Eq. A15)}$$

Min O-ring axial dimension after squeeze = Min groove depth

$$L = d_{Min} \text{ x 90\%} \qquad \text{(Eq. A16)}$$

The groove depth L is then rounded down to the nearest 0.001 inch (0.025 mm)

Tolerances to “L” dimensions are then applied as follows:

000, 100, 200 O-ring series - +0.004/-0.000 inch (+0.102/-0.000 mm)

300 O-ring series - +0.006/-0.000 inch (+0.152/-0.000 mm)

400 O-ring series - +0.008/-0.000 inch (+0.203/-0.000 mm)

A.2.3.2 Gland Occupancy

The Gland Occupancy percentage is determined by the following formula:

$$\text{Gland Occupancy \%} = \frac{\text{Volume of O} - \text{ring}}{\text{Volume of Gland}} \text{ x 100\%} \qquad \text{(Eq. A17)}$$

For maximum gland occupancy:

- The volume of the O-ring is calculated using maximum I.D. and maximum cross-section.
- The volume of the Gland is calculated using groove minimum Diameter (A or B as applicable), minimum Depth and maximum Corner Radius.

A.2.3.3 Volume of New O-ring at Ambient (i.e., not subject to any fluid swell)

The volume of O-ring (volume of Torus) $= 2\pi^2 Ro \times ro^2$

For ease of use for our purposes, i.e., using dimensions specified in AS568 of O-ring I.D. and O-ring cross section, this can be re-written as Volume of O-ring (max).

$$V_o = \pi^2 \left[\frac{(D + d) \times d^2}{4} \right] \quad \text{(Eq. A18)}$$

NOTE: It is assumed that when squeezed, an O-ring does not suffer any decrease in volume.

A.2.3.4 Volume of O-ring due to Swell from Fluid Effects and Thermal Expansion

The elastomer material was chosen that produced a combination of volume swell in a particular fluid and thermal expansion for the same material resulting in the greatest increase in volume.

The O-ring Volume swell due to fluid is determined by applying a formula determined by testing and submitted in a presentation to SAE AMS-CE Committee:

$$\text{Volume Change under Squeeze } V_c = 1.958 + (0.648 \text{ x } V_f) - (0.0156 \text{ x } V_f \text{ x } S) \quad \text{(Eq. 1)}$$

where:

V_f % = Free Volume Change in Fluid (from material data sheets)

S = % Squeeze in the Gland

NOTE: Enter "V_f "and "S" as whole numbers, the resulting Volume Swell in fluid and Under squeeze "V_C "will be a whole number. After calculating squeeze, swell is calculated for each individual O-ring using Equation 1 above.

Since swell varies with squeeze, the maximum volume has to be calculated taking into account:

a. Maximum, nominal and minimum groove depths

b. Maximum, nominal and minimum O-ring dimensions

The volume swell for AMS-P-83461 NBR Elastomer tested in MIL-PRF-5606 Red Oil 70 hours at 275 °F (135 °C) with a free swell of 16.3% and a CTE of 1.13 x10^{-4} in/in/°F (2.03 x 10^{-4} mm/mm/°C).

Using the result from Equation 1 above, the swelled volume of the O-ring = Original Volume x (1+Swell)

$$Vs = Vo \times (1 + Vc) \quad \text{(Eq. A19)}$$

O-ring Volume after Swell with Thermal Expansion V_{st} = Volume after Swell x [1+(Temp Increase x CTE)]^3

$$V_{st} = V_s \text{ x } [1+(Ti \text{ x } 1.13E\text{-}04)]^3 \quad \text{(Eq. A20)}$$

A.2.4 Gland Volume

A.2.4.1 Gland Volume Ignoring Groove Corner Radii And Corner Edge Breaks

Refer to Figures A3 and A4.

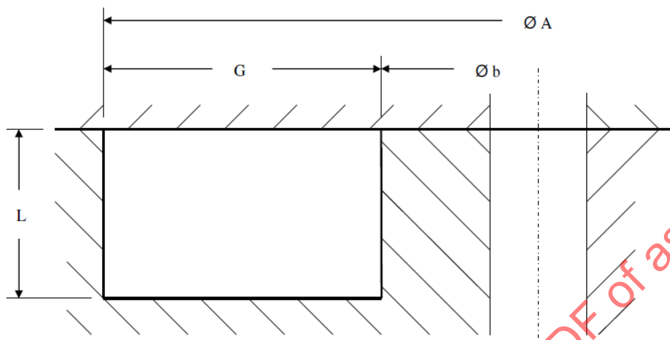


Figure A3 - Gland detail for internal pressure applications without groove corner radii

Gland Minimum Volume not including Radii (Internal Pressure Applications) $= \frac{\pi}{4}\left[A_{Min}{}^2 - b^2\right] x\, L_{Min}$ (Eq. A21)

where:

$$b = A_{Min} - (2G_{Min}) \quad \text{(Eq. A22)}$$

Gland Minimum Volume not including Radii (External Pressure Applications) $= \frac{\pi}{4}\left[a^2 - B_{Min}{}^2\right] x\, L_{Min}$ (Eq. A23)

where:

$$a = B_{Min} + (2G_{Min}) \quad \text{(Eq. A24)}$$

NOTE: Groove corner break edge chamfers are not included in calculations.

A.2.4.2 Gland Volume including Gland Corner Radii

Refer to Figure A4.

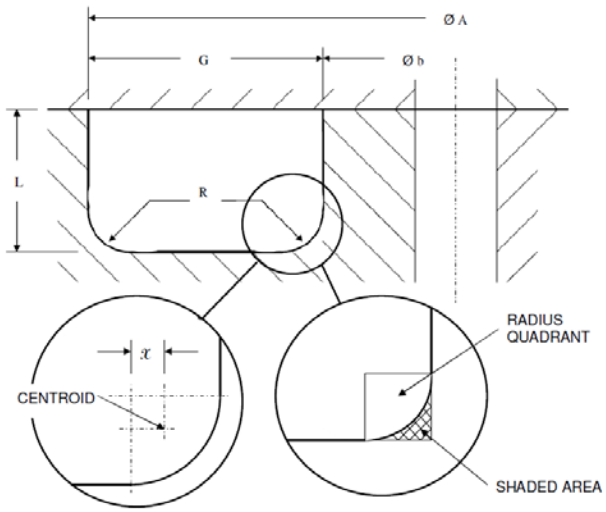


Figure A4 - Gland for internal pressure applications with groove corner radii details

Volume of shaded areas applied to O.D. and I.D. corner radii need to be deducted from Equations A21 and 23 to determine true gland volume (excluding corner edge breaks).

For Internal Pressure Gland

Max Volume of outer quadrant square $Vro_{Max} = \frac{\pi}{4}\left[A_{Min}{}^2 - (A_{Min} - 2R_{Max})^2\right]R_{Max}$ (Eq. A25)

Max Volume of inner quadrant square $Vri_{Max} = \frac{\pi}{4}\left[(b_{Max} + 2R_{Max})^2 - b_{Max}{}^2\right]R_{Max}$ (Eq. A26)

For External Pressure Gland

Max Volume of outer quadrant square $Vro_{Max} = \frac{\pi}{4}\left[a_{Min}{}^2 - (a_{Min} - 2R_{Max})^2\right]R_{Max}$ (Eq. A27)

Max Volume of inner quadrant square $Vri_{Max} = \frac{\pi}{4}\left[(B_{Min} + 2R_{Max})^2 - B_{Min}{}^2\right]R_{Max}$ (Eq. A28)

Area of Radius Quadrant $= \frac{\pi}{4}R_{Max}{}^2$ (Eq. A29)

Distance of quadrant centroid from Radius axial origin = x

For Internal Pressure application, outer Radius, centroid diameter $X_A = A_{Min} - 2(R_{Max} - x)$ (Eq. A30)

For Internal Pressure application, inner Radius, centroid diameter $X_b = b_{Max} + 2(R_{Max} - x)$ (Eq. A31)

For External Pressure application, outer Radius, centroid diameter $X_a = a_{Min} - 2(R_{Max} - x)$ (Eq. A32)

For External Pressure application, inner Radius, centroid diameter $X_B = B_{Min} + 2(R_{Max} - x)$ (Eq. A33)

For Internal Pressure:

Volume of Outer Radius Quadrant = Radius Quadrant Area x circumference of centroid diameter

$$= \frac{\pi}{4} R_{Max}^{2} \times X_A \times \pi \qquad \text{(Eq. A34)}$$

Volume of Inner Radius Quadrant = Quadrant Area x circumference of centroid diameter

$$= \frac{\pi}{4} R_{Max}^{2} \times X_b \times \pi \qquad \text{(Eq. A35)}$$

For External Pressure:

Volume of Outer Radius Quadrant = Quadrant Area x circumference of centroid diameter

$$= \frac{\pi}{4} R_{Max}^{2} \times X_a \times \pi \qquad \text{(Eq. A36)}$$

Volume of Inner Radius Quadrant = Quadrant Area x circumference of centroid diameter

$$= \frac{\pi}{4} R_{Max}^{2} \times X_B \times \pi \qquad \text{(Eq. A37)}$$

Refer to Figures A1 and A2.

For Internal Pressure:

Volume of outer shaded area = Equation A25 - Equation A34 (Eq. A38)

Volume of inner shaded area = Equation A26 - Equation A35 (Eq. A39)

For External Pressure:

Volume of outer shaded area = Equation A27 - Equation A36 (Eq. A40)

Volume of inner shaded area = Equation A28 - Equation A37 (Eq. A41)

Minimum Gland Volume

For Internal Pressure

= Min Gland Vol. excluding radii – Vol. of outer shaded area – Vol. of inner shaded area

= Equation A21 - Equation A38 - Equation A39 (Eq. A42)

For External Pressure

= Min Gland Vol. excluding radii – Vol. of outer shaded area – Vol. of inner shaded area

= Equation A23 - Equation A40 - Equation A41 (Eq. A43)

A.2.5 Gland Volume Occupancy

Investigation has demonstrated that the set of circumstances to achieve maximum gland occupancy results from:

a. Maximum O-ring Cross-section

b. Maximum O-ring I.D.

c. Minimum Groove Depth

d. Minimum Groove Diameter

e. Minimum Groove Width

$$\text{Gland Occupancy Internal Pressure application } \% = \frac{\text{Max Vol of O} - \text{ring}}{\text{Min Vol of Internal Pressure Gland}} \text{ x } 100\% \quad \text{(Eq. A43)}$$

$$= \frac{\text{Eq. A20}}{\text{Eq. A42}} \times 100\% \quad \text{(Eq.A44)}$$

$$\text{Gland Occupancy External Pressure application } \% = \frac{\text{Max Volume of O - ring}}{\text{Min Volume of External Pressure Gland}} \text{ x100\%} \quad \text{(Eq. A45)}$$

$$= \frac{\text{Eq. A20}}{\text{Eq. A43}} \times 100\% \quad \text{(Eq. A46)}$$

By adjusting groove radial width “G”, the target occupancy of 95% can be achieved.

Where the calculated groove width is greater than that of AS4716, then the calculated groove width is used, otherwise groove widths per AS4716 are used.

For some of the smaller sizes the groove width varies from the above statement, also the maximum volume occupancy is above the 95% target. This is in order to be able to include them in the standard gland sizes per this document. It should also be noted that although the maximum volume occupancy for some sizes may exceed 95%, in no case does it exceed 100%.

Some of the smaller dash sizes have been eliminated due to being impractical.

Tolerances are then applied to the groove width, generally per AS4716, as follows:

All 000 series: +0.005/-0.000 inch (+0.127/-0.000 mm)

All 100, 200, 300, 400 series: +0.010/-0.000 inch (+0.254/-0.000 mm)

APPENDIX B - COMPARISON TO OTHER FACE SEAL STANDARDS

B.1 INTRODUCTION

This appendix describes the differences between AS6235 and some other available documents, and thereby explains in detail why AS6235 was compiled for Aerospace Fluid Power Applications. Other available specifications are ARP1234 and AS4873. The major differences are explained in the following paragraphs.

B.2 DASH SIZE RANGE

The dash size range used by A6 for Fluid Power applications is listed in AS4716 and AS5857 both of which are gland standards for radial sealing applications. AS6235 uses the same size range, which is not as extensive as for ARP1234 and AS4873.

B.3 INTERNAL AND EXTERNAL PRESSURE APPLICATION

For face seal applications, AS4873 includes for internal pressure types only whereas AS6235 includes for both internal and external pressure applications.

B.4 PRESSURE LIMITATIONS

AS4873 limits pressure to 800 psi (5,516 kPa) whereas AS6235 accommodates pressure up to 3,000 psi (20,684 kPa) and offers recommendations for higher pressures.

B.5 CLOSED GLAND REQUIREMENT

ARP1234 and ISO 3601-2 both allow an open internal gland (no gland wall) for internal pressure applications. This specification requires an internal gland wall in order to protect the seal from flow erosion, which may otherwise be particularly severe when flow passages are machined on an angle rather than being perpendicular to the hardware face. A closed gland outer wall is also required for external pressure applications in order to protect seals from the environment. Exceptions to this requirement are mentioned in the note following Figure 3.

B.6 FLUID SERVICE

By O-ring cross-section, AS4873 lists two different groove widths depending on service. One is for fuel and engine oil, the other is for vacuum and gases. Fluids for aerospace fluid power applications are not mentioned

AS6235 lists the fluids and elastomer materials that are used in aerospace fluid power applications, and groove widths are determined by calculating for maximum O-ring occupancy under the worst conditions of dimensional tolerances, swell while under squeeze and thermal expansion of the aforesaid elastomer/fluid combinations.

B.7 GROOVE DIAMETERS

Some groove diameters to AS6235 differ compared to ARP1234 and AS4873. This is because allowance has been made to limit cramming of the O-ring O.D. on internal pressure types to 1%, and to limit stretch to 5% on external pressure types. In both cases the limitations are calculated with O-rings at nominal dimensions and groove diameters at nominal dimensions.

Tables B1A and B1B show groove diameters for AS6235 that differ from those of ARP1234 and AS4873.

Table B1A - Comparison of groove diameters, AS6235, ARP1234, AS4873 (inches)

Specification and AS568 O-ring Dash Size	AS6235 Groove Diameter		ARP1234 Groove Diameter		AS4873 Groove Diameter
	Internal Pressure +0.000 -0.005	External Pressure +0.005 -0.000	Internal Pressure +0.000 -0.005	External Pressure +0.005 -0.000	Internal Pressure +0.000 -0.005
006	-	0.107	-	0.114	-
007	-	0.140	-	0.145	-
008	0.328	0.172	0.316	0.176	0.316
009	0.357	0.206	0.348	0.208	0.348
010	0.387		0.379		0.379
011	0.448		0.441		0.441
012	0.511		0.504		0.504
013	0.572		0.566		0.566
014	0.634		0.629		0.629
015	0.696		0.691		0.691
016	0.758		0.754		0.754
017	0.820		0.816		0.816
018	0.882		0.879		0.879
019	0.943		0.941		0.941
020	1.006		1.004		1.004
021	1.067		1.066		1.066
022	1.129		1.129		1.129
106	-	0.169	-	0.174	-
107	-	0.202	-	0.206	-
108	0.452	0.235	0.443	0.237	0.443
109	0.513		0.505		0.505
110	0.576		0.568		0.568
111	0.637		0.630		0.630
112	0.700		0.693		0.693
113	0.761		0.755		0.755
114	0.823		0.818		0.818
115	0.885		0.880		0.880
116	0.947		0.943		0.943
117	1.008		1.005		1.005
118	1.071		1.068		1.068
119	1.132		1.130		1.130
120	1.195		1.193		1.193
121	1.256		1.255		1.255

Table B1A - Comparison of groove diameters, AS6235, ARP1234, AS4873 (inches) (continued)

Specification and AS568 O-ring Dash Size	AS6235 Groove Diameter		ARP1234 Groove Diameter		AS4873 Groove Diameter
	Internal Pressure +0.000 -0.005	External Pressure +0.005 -0.000	Internal Pressure +0.000 -0.005	External Pressure +0.005 -0.000	Internal Pressure +0.000 -0.005
210	1.019		1.012		1.012
211	1.081		1.074		1.074
212	1.143		1.137		1.137
213	1.204		1.199		1.199
214	1.267		1.262		1.262
215	1.328		1.324		1.324
216	1.391		1.387		1.387
217	1.452		1.449		1.449
218	1.514		1.512		1.512
219	1.576		1.574		1.574
220	1.638		1.637		1.637
325	1.899		1.895		1.895
326	2.023		2.020		2.020
327	2.147		2.145		2.145

Table B1B - Comparison of groove diameters, AS6235, ARP1234, AS4873 (millimeters)

Specification and AS568 O-ring Dash Size	AS6235 Groove Diameter		ARP1234 Groove Diameter		AS4873 Groove Diameter
	Internal Pressure +0.000 -0.127	External Pressure +0.127 -0.000	Internal Pressure +0.000 -0.127	External Pressure +0.127 -0.000	Internal Pressure +0.000 -0.127
006	-	2.718	-	2.896	-
007	-	3.556	-	3.683	-
008	8.331	4.369	8.026	4.470	8.026
009	9.068	5.232	8.839	5.283	8.839
010	9.830		9.627		9.627
011	11.379		11.201		11.201
012	12.979		12.802		12.802
013	14.529		14.376		14.376
014	16.104		15.977		15.977
015	17.678		17.551		17.551
016	19.253		19.152		19.152
017	20.828		20.726		20.726
018	22.403		22.327		22.327
019	23.952		23.901		23.901
020	25.552		25.502		25.502
021	27.102		27.076		27.076
022	28.677		28.677		28.677
106	-	4.293	-	4.420	-
107	-	5.131	-	5.232	-
108	11.481	5.969	11.252	6.020	11.252
109	13.030		12.827		12.827
110	14.630		14.427		14.427
111	16.180		16.002		16.002
112	17.780		17.602		17.602
113	19.329		19.127		19.127
114	20.904		20.7778		20.777
115	22.479		22.352		22.352
116	24.054		23.952		23.952
117	25.603		25.527		25.527
118	27.203		27.127		27.127
119	28.753		28.702		28.702
120	30.353		30.302		30.302
121	31.902		31.877		31.877

Table B1B - Comparison of groove diameters, AS6235, ARP1234, AS4873 (millimeters) (continued)

Specification and AS568 O-ring Dash Size	AS6235 Groove Diameter		ARP1234 Groove Diameter		AS4873 Groove Diameter
	Internal Pressure +0.000 -0.127	External Pressure +0.127 -0.000	Internal Pressure +0.000 -0.127	External Pressure +0.127 -0.000	Internal Pressure +0.000 -0.127
210	25.883		25.705		25.705
211	27.457		27.280		27.280
212	29.032		28.880		28.880
213	30.582		30.455		30.455
214	32.182		32.055		32.055
215	33.731		33.630		33.630
216	35.331		35.230		35.230
217	36.881		36.805		36.805
218	38.456		38.405		38.405
219	40.030		39.980		39.980
220	41.605		41.580		41.580
325	48.235		48.133		48.133
326	51.384		51.308		51.308
327	54.534		54.483		54.483

B.8 GROOVE DEPTH TOLERANCES AND O-RING SQUEEZE

The groove depths for ARP1234 have a tolerance of ±0.003 inch (0.076 mm) throughout. For 000 and 100 series O-rings this limitation is too large to enable the target of 10% minimum squeeze and 25% maximum squeeze to be achieved, therefore, in AS6235, the groove depth tolerance is set at ±0.002 inch (0.051 mm).

AS4873 uses a sliding groove depth tolerance. While the groove depth tolerance for 000 and 100 series is in line with the requirements of AS6235, for the 200, 300, and 400 series AS6235 uses tighter tolerances on groove depth than AS4873 in order to maintain squeeze between the acceptable limits of 10 to 25%.

The groove depths in AS4873 (which is a supplemental document to AIR1234) are less than those to AIR1234, consequently the squeeze range at ambient temperature is 19 to 32%.

This standard addresses the squeeze requirement at ambient temperature for a maximum of 25% per AMS-CE recommendations for low fill elastomers and a minimum of 10% squeeze per AS5857. Note that the groove depths and their appropriate tolerances in AS6235 permit a squeeze level at ambient temperature not exceeding 25% while a minimum of 10% squeeze is maintained.

B.9 O-RING VOLUME INCREASE DUE TO SWELL AND THERMAL EXPANSION

ARP1234, originally released in 1979 and primarily for use in engine lubrication systems, allows for a maximum of 30% O-ring volume swell but with no allowance is made for thermal expansion. This has proved adequate for engine lubrication but is considered unsuitable for fluid power applications because the high volume swell of 30% used in ARP1234 has been proven by research within AMS-CE Committee to be incorrect for the elastomer materials in use by aerospace fluid power applications when under squeeze.

AS6235 uses a more scientific approach by using actual data from testing to accommodate for volume swell from fluid while under compression (squeeze), and known thermal expansion of specified elastomer materials (see 3.2), to calculate maximum O-ring volume and thereby permit maximum gland volume occupancy to be calculated.

B.10 GLAND OCCUPANCY LIMITS

In checking the groove dimensions of ARP1234 using the formulae in ARP1234, it was found that for some of the small sizes for 000 and 100 series O-rings have gland occupancies in excess of the 100% that ARP1234 specifies at the required 30% volume swell.

AS4873 is a supplemental document to ARP1234 and generally accommodates 30% O-ring volume swell, but states that the range of swell accommodated is 25 to 35%.

In AS6235, gland occupancy using maximum O-ring volume calculated from volume swell while under compression and subject to thermal expansion, is generally limited to 95% maximum under the most adverse dimensional tolerance conditions. However, there are some exceptions in 000 and 100 series in order to maintain consistency in groove widths and it should be noted that for these exceptions O-ring volume occupancy does not exceed 100%. For reference, AS6235 includes a table listing maximum gland occupancy % by individual dash size for all sizes.

APPENDIX C - COMPARISON OF AS6235 GROOVE DEPTH WITH AS4716 GROOVE DEPTH

C.1 The groove depth dimensions for AS6235 are listed in Tables 3 and 4 which are repeated below for ease of use.

Table 3 - Gland cross section details for internal pressure applications

Gland and AS568 O-ring Dash No.	Internal Pressure Applications			
	Inches		Millimeters	
	Groove Width G Min Max	Groove Depth L Min Max	Groove Width G Min Max	Groove Depth L Min Max
008 thru 028	0.098 0.103	0.056 0.060	2.489 2.616	1.422 1.524
108	0.141 0.146	0.086 0.090	3.581 3.708	2.184 2.286
109 thru 149	0.141 0.151		3.581 3.835	
210 thru 247	0.188 0.198	0.117 0.121	4.775 5.029	2.972 3.073
325 thru 349	0.281 0.291	0.178 0.184	7.137 7.391	4.521 4.674
425 thru 460	0.375 0.385	0.234 0.242	9.525 9.779	5.934 6.147

Table 4 - Gland cross section details for external pressure applications

Gland and AS568 O-ring Dash No.	External Pressure Applications			
	Inches		Millimeters	
	Groove Width G Min Max	Groove Depth L Min Max	Groove Width G Min Max	Groove Depth L Min Max
006 thru 028	0.098 0.103	0.056 0.060	2.489 2.616	1.422 1.524
106 thru 149	0.141 0.151	0.086 0.090	3.581 3.835	2.184 2.286
210 thru 247	0.188 0.198	0.117 0.121	4.775 5.029	2.972 3.073
325 thru 349	0.281 0.291	0.178 0.184	7.137 7.391	4.521 4.674
425 thru 460	0.375 0.385	0.234 0.242	9.525 9.779	5.934 6.147

The groove depth dimensions for both piston seals and rod seals to AS4716 and AS5857 were reviewed.

Historically, groove dimensions for specialist designs of face seals have been based on AS4716, which is a derivative of previous Military specifications. AS5857 is a more recent specification and while it is specifically for static seals, designs based on AS4716 dimensions and tolerances were already established with no reason to introduce designs based on AS5857.

Both these standards are for radial applications and for example for piston seals, when calculating the maximum and minimum groove depths, the following need to be taken into account:

a. Tolerances on cylinder bore.

b. Tolerances on Piston O.D.

c. Tolerances on groove diameter.

d. Clearances between piston and cylinder at full laydown (piston O.D. in contact with cylinder bore).

Tables C1A and C1B use maximum bore diameter, minimum piston O.D. and minimum groove diameter to calculate:

a. Minimum groove depth at full laydown.

b. Maximum effective gland depth (from cylinder bore to bottom of the seal groove) opposite to laydown position.

c. Range of gland depth.

Table C1A - Maximum and minimum groove depths for AS4716 and AS5857 piston seal hardware (inches)

<table>
<tr><th>Gland and AS568 O-ring Dash No.</th><th>Minimum Groove Depth</th><th>Maximum Groove Depth</th><th>Groove Depth Delta</th></tr>
<tr><td>004</td><td>0.0555</td><td>0.0605</td><td rowspan="5">0.0050</td></tr>
<tr><td>005, 006</td><td>0.0515</td><td>0.0565</td></tr>
<tr><td>008</td><td>0.052</td><td>0.057</td></tr>
<tr><td>007, 009,</td><td>0.0525</td><td>0.0575</td></tr>
<tr><td>000 – 012</td><td>0.053</td><td>0.058</td></tr>
<tr><td>013 – 017</td><td>0.0525</td><td>0.0590</td><td rowspan="2">0.0065</td></tr>
<tr><td>018 - 028</td><td>0.0530</td><td>0.0595</td></tr>
<tr><td>104</td><td>0.083</td><td>0.0875</td><td rowspan="8">0.0045</td></tr>
<tr><td>105</td><td>0.084</td><td>0.0885</td></tr>
<tr><td>107, 108</td><td>0.0865</td><td>0.0910</td></tr>
<tr><td>109</td><td>0.087</td><td>0.0915</td></tr>
<tr><td>106, 112 – 114,</td><td>0.085</td><td>0.095</td></tr>
<tr><td>111</td><td>0.0845</td><td>0.0890</td></tr>
<tr><td>115 – 119</td><td>0.0850</td><td>0.0900</td></tr>
<tr><td>120 – 129</td><td>0.0860</td><td>0.0905</td></tr>
<tr><td>130 – 140</td><td>0.0850</td><td>0.0905</td><td>0.0055</td></tr>
<tr><td>110</td><td>0.084</td><td>0.090</td><td>0.0060</td></tr>
<tr><td>141, 149</td><td>0.0845</td><td>0.0910</td><td>0.0065</td></tr>
<tr><td>210, 211</td><td>0.1190</td><td>0.1250</td><td rowspan="2">0.0060</td></tr>
<tr><td>212 – 222</td><td>0.1195</td><td>0.1260</td></tr>
<tr><td>223 – 227</td><td>0.1190</td><td>0.1260</td><td>0.0070</td></tr>
<tr><td>228 – 243</td><td>0.1185</td><td>0.1265</td><td>0.0080</td></tr>
<tr><td>244 – 247</td><td>0.1180</td><td>0.1270</td><td>0.0090</td></tr>
<tr><td>325 – 329</td><td>0.1840</td><td>0.1910</td><td>0.0070</td></tr>
<tr><td>330 – 345</td><td>0.1835</td><td>0.1915</td><td>0.0080</td></tr>
<tr><td>346 – 349</td><td>0.1830</td><td>0.1920</td><td>0.0090</td></tr>
<tr><td>425 – 445</td><td>0.2355</td><td>0.2460</td><td>0.0105</td></tr>
<tr><td>446, 447</td><td>0.2350</td><td>0.2465</td><td>0.0115</td></tr>
<tr><td>448 – 460</td><td>0.2350</td><td>0.2480</td><td>0.0130</td></tr>
</table>

Table C1B - Maximum and minimum groove depths for AS4716 and AS5857 piston seal hardware (millimeters)

Gland and AS568 O-ring Dash No.	Minimum Groove Depth	Maximum Groove Depth	Groove Depth Delta
004	1.410	1.537	0.127
005, 006	1.308	1.435	
008	1.321	1.448	
007, 009,	1.334	1.461	
000 – 012	1.346	1.473	
013 – 017	1.334	1.499	0.165
018 - 028	1.346	1.511	
104	2.108	2.223	0.114
105	2.134	2.248	
107, 108	2.197	2.311	
109	2.210	2.324	
106, 112 – 114,	2.159	2.413	
111	2.146	2.261	
115 – 119	2.159	2.286	
120 – 129	2.184	2.299	
130 – 140	2.159	2.299	0.140
110	2.134	2.286	0.152
141, 149	2.146	2.311	0.165
210, 211	3.023	3.175	0.152
212 – 222	3.035	3.200	
223 – 227	3.023	3.200	0.178
228 – 243	3.010	3.213	0.203
244 – 247	2.997	3.226	0.229
325 – 329	4.674	4.851	0.178
330 – 345	4.661	4.864	0.203
346 – 349	4.648	4.877	0.229
425 – 445	5.982	6.248	0.267
446, 447	5.969	6.261	0.292
448 – 460	5.969	6.299	0.330

While the above calculations and tables apply to piston seals to AS4716 and AS5857, a similar situation applies to rod seals to those standards

It can be seen that for AS6235 the groove depth dimensions I per each cross-section is less than the groove depth range for piston seals to AS4716 and AS5857 and, therefore, should be adequate to maintain effective sealing throughout all tolerance variations of parts and hardware.

APPENDIX D - DESCRIPTION OF DIGITAL ANNEX D

D.1 INTRODUCTION

The attached Digital Annex is an Excel file consisting of 5 worksheets with labels as follows:

a. Calculator

b. Internal Pressure Imperial

c. Internal Pressure Metric

d. External Pressure Imperial

e. External Pressure Metric

All worksheets are protected, however worksheets b, c, d, and e do not have the cells' contents hidden, i.e., the user can see the construction of each cell for further reference.

D.1.1 Calculator

This worksheet is interactive with the other four worksheets. The layout consists of 3 separate "blocks" to permit results to be obtained for gland dimensions and tolerances in either inches or millimeters, minimum and maximum squeeze and gland occupancy:

per the AS6235 Standard.

for alternate elastomer materials

for non-standard O-rings

A more detailed explanation is presented in Section D.2.

D.1.2 Worksheets for Internal and External Pressure Applications in Imperial and Metric Units

Worksheets b and d, are the worksheets used to calculate the gland dimensions used in AS6235 and as such are included as a record, Worksheets c and e are metric conversions of worksheets b and c respectively for information purposes. Because worksheets c and e are conversions, the calculations for groove widths may not tally entirely when converted back to inches and gland occupancies may also not tally. However the accuracy of results in worksheets c and e are sufficiently close to be workable.

An additional row has been made to each worksheet to permit calculations for gland dimensions for non-standard O-ring dimensions and tolerances.

All four worksheets are protected, however each cell reveals the calculation although no changes can be made.

D.2 INSTRUCTIONS ON THE USE OF THE CALCULATOR WORKSHEET

NOTE: This worksheet can be printed for record purposes.

NOTE: When using the Excel files in the Digital Annex, although the metric spreadsheets can be observed, because of slight discrepancies due to conversions it is recommended that the imperial data be regarded as primary for use in applications.

D.2.1 Major Choices

Refer to Figure D1A for the explanation below.

Note that only the white cells can be changed. All results are in the yellow cells.

All cells other than the white cells are protected and cannot be changed by the user.

There are two fields to enter personal information; the user's name and project information.

The magenta cells indicating Y/N choices in their adjacent white cells cause other magenta cells to change to the appropriate heading parameter, e.g., changing Y to N in cell F6 will cause cell L6 to change to "Y", i.e., Metric Units and the CTE in cell P13 to change from in/in/°F to mm/mm/°C, cell P16 to change from °F to °C, and cells JK17 and P21 to change from INCHES to MILLIMETERS.

The current settings show the following choices:

We have chosen Imperial units (inches and °F), so cell F6 is set at "Y". To change this to Metric units, click on the "Y" cell and a drop-down list arrow will appear. Click on the arrow and the list of Y and N will appear; to make your choice, click on "Y" or "N".

We have chosen an Internal Pressure application, cell R6 indicating "Y". It will be noticed that yellow cells G23 and L23 are blank since these are results for External Pressure applications and not pertinent to the current choice. If a choice of "N" in cell R6 is made this will enable the External Pressure application to replace the Internal Pressure application, consequently cell X6 will change to "Y" and cells F9 – I9 will change to "EXTERNAL PRESSURE". Also cells G20 and L20 would be become blank and cells G23 and L23 would be populated.

The current choice for elastomer material is the AS6235 standard, indicated by "N" in cell X9 to NOT choose special elastomer characteristics.

We are not considering non-standard O-ring sizes and/or tolerances as indicated by "N" in cell W19.

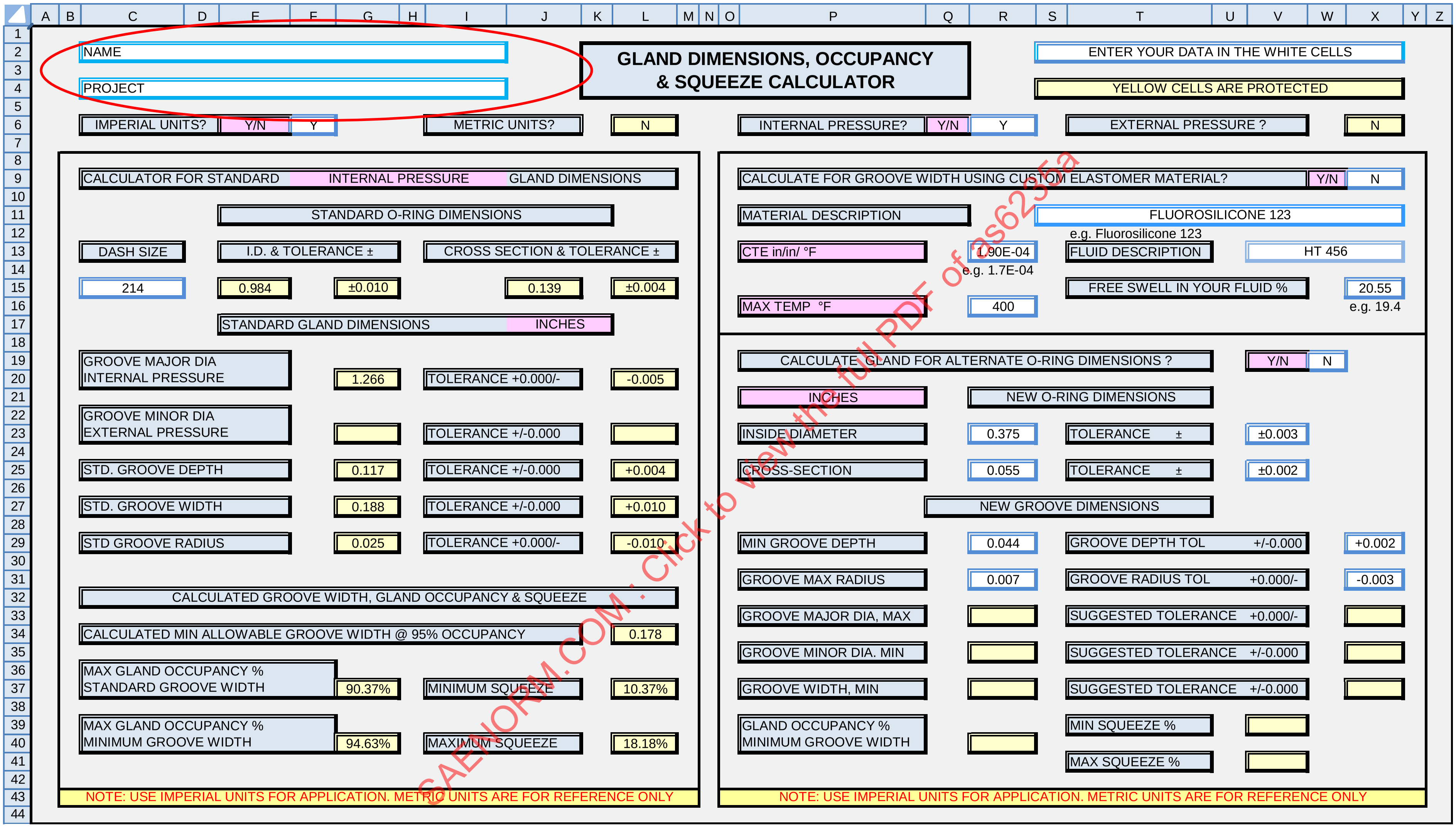


Figure D1A - Gland dimensions calculation sheet

D.2.2 Calculations for Standard O-rings Using Standard Elastomer Material

Standard O-rings are defined as being to AS568 the range used in AS4716 (with the exception of some of the smaller sizes which are not practical).

Standard Elastomer materials are those covered by this specification and are listed in 3.2 The material that is the basis for calculations is AMS-P-83461 NBR Elastomer tested in MIL-PRF-5606 Red Oil 70 hours at 275 °F (135 °C) with a free swell of 16.3% and a CTE of 1.13 x10^{-4} in/in/°F (2.03 x 10^{-4} mm/mm/°C).

Refer to Figure D1B in the following example. This example will use Imperial units, Internal Pressure application, and Standard Elastomer material. By making the appropriate Dash Size entry in the Calculator worksheet cell C15 as -214 per Table D1, the dimensions and tolerances for a standard -214 O-ring are displayed, see the circled cells in Figure D1B. Also the standard gland dimensions and tolerances maximum and minimum squeeze along with the minimum groove width and the corresponding gland occupancy are displayed in the circled cells.

Table D1 - Entries and results for standard O-ring and gland dimensions

CELL	DESCRIPTION	ENTRY	RESULT/DISPLAY
F6	IMPERIAL UNITS?	Y	L6 = N J17, P21 = INCHES
R6	INTERNAL PRESSURE?	Y	X6 = N F9-I9 = INTERNAL PRESSURE
C15	O-RING DASH SIZE	NUMBER FROM DROP-DOWN LIST -214 in this example	E15, G15, J15, L15 - O-RING DIMENSIONS & TOLERANCES POPULATED
			G25, L25, G27, L27, G29, L29 STANDARD GLAND DIMENSIONS & TOLERANCES POPULATED G20, L20 POPULATED G23, L23 NOT POPULATED G37, L37, L40 POPULATED
			L34, G40 POPULATED FOR REFERENCE IF MINIMUM GROOVE WIDTH WITH MAX 95% OCCUPANCY IS REQUIRED

The user will notice that for External Pressure applications the size range begins at -006, while for Internal Pressure applications the size range begins at -008, i.e., for Internal Pressure sizes -006 and -007 are not practical. Similarly, sizes -106 and -107 which are included in the range for External Pressure applications are not included in the range for Internal Pressure applications.

Note that cells G23 and L23 are not populated. Similarly when entering an External Pressure application, cells G20 and L20 are not populated.

If, while working on an Internal Pressure application, “N/A” is selected in the pull-down list for the dash size, all the cells in the block for “CALCULATOR FOR STANDARD INTERNAL PRESSURE GLAND DIMENSIONS” will be blank.

If, for instance, while working on an External pressure application, any of sizes -006, -007, -106, or -107 have been entered and the application is changed to Internal Pressure, since these sizes are not included for Internal Pressure applications in the AS6235 standard, all the cells displaying data for standard dimensions, squeeze and occupancy will change to be blank.

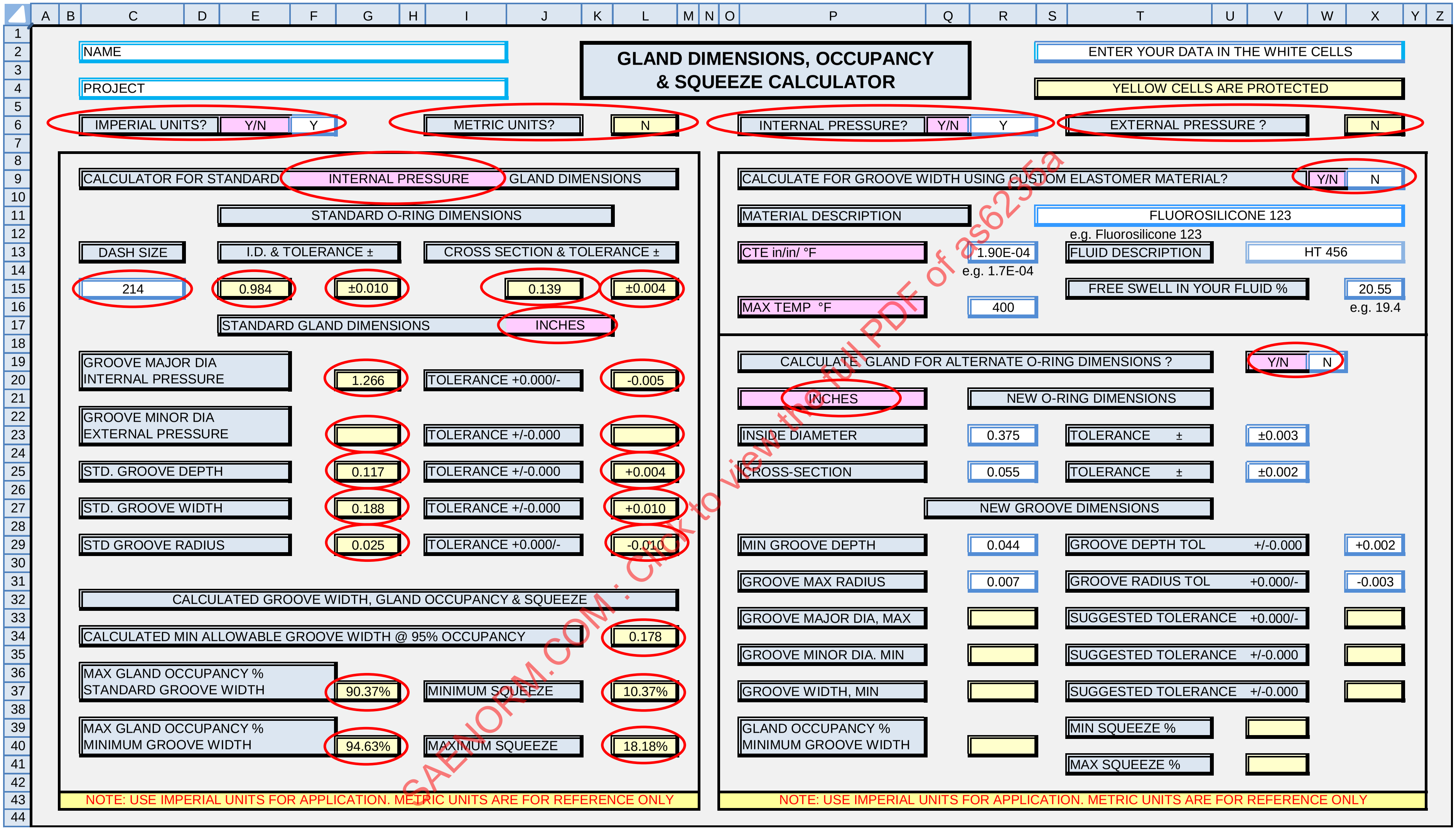


Figure D1B - Gland dimensions calculation sheet for standard O-rings using AS6235 standard elastomers

D.2.3 Calculations for Standard O-rings Using a Custom Elastomer Material

To use a custom elastomer material, the maximum application temperature, Coefficient of Linear Thermal Expansion (CTE) and the free swell in the application fluid must be known.

Refer to Figure D2 in the following example.

We are going to assume that the entries in Table D1 remain the same, with the exception of cell X9 “CALCULATE FOR GROOVE WIDTH USING CUSTOM ELASTOMER MATERIAL” which we will change from “N” to “Y” using the pull-down list.

Table D2 - Entries for standard O-ring dimensions with custom elastomer material properties, and resulting gland dimensions, tolerances, O-ring squeeze and gland occupancies

CELL	DESCRIPTION	ENTRY	RESULT/DISPLAY
X9	CALCULATE FOR NON-STANDARD ELASTOMER MATERIAL	Y	Allows calculations using new elastomer material properties
S11 – X11	MATERIAL NAME/CODE	ENTER	YOUR DESCRIPTION RECORDED
V14 – X14	FLUID FOR THE APPLICATION	ENTER	YOUR DESCRIPTION RECORDED
R13	LINEAR COEFFICIENT OF THERMAL EXPANSION (CTE)	ENTER PER INCH/INCH/° F FORMAT	e.g., 1.9E-04
R16	MAXIMUM TEMPERATURE	ENTER TEMPERATURE	e.g., 400 °F
X15	FREE SWELL	ENTER SWELL %	NUMBER ONLY, e.g., 20.55
			L34 CALCULATED MINIMUM GROOVE WIDTH FOR 95% MAX GLAND 0CCUPANCY G40 GLAND OCCUPANCY AT MINIMUM GROOVE WIDTH NOW POPULATED G37, GLAND OCCUPANCY FOR STANDARD GROOVE NOW POPULATED

Note that when toggling cell X9, cell G37, gland occupancy for the standard groove is now 102.61% which obviously is not acceptable. The calculated minimum groove width for 95% maximum gland occupancy in cell L34 changes from 0.178 to 0.207 inches, which is the new dimension to be used. With a new groove width of 0.207 inches, the gland occupancy in cell G40 is 94.76% which is acceptable. Also the minimum recommended.

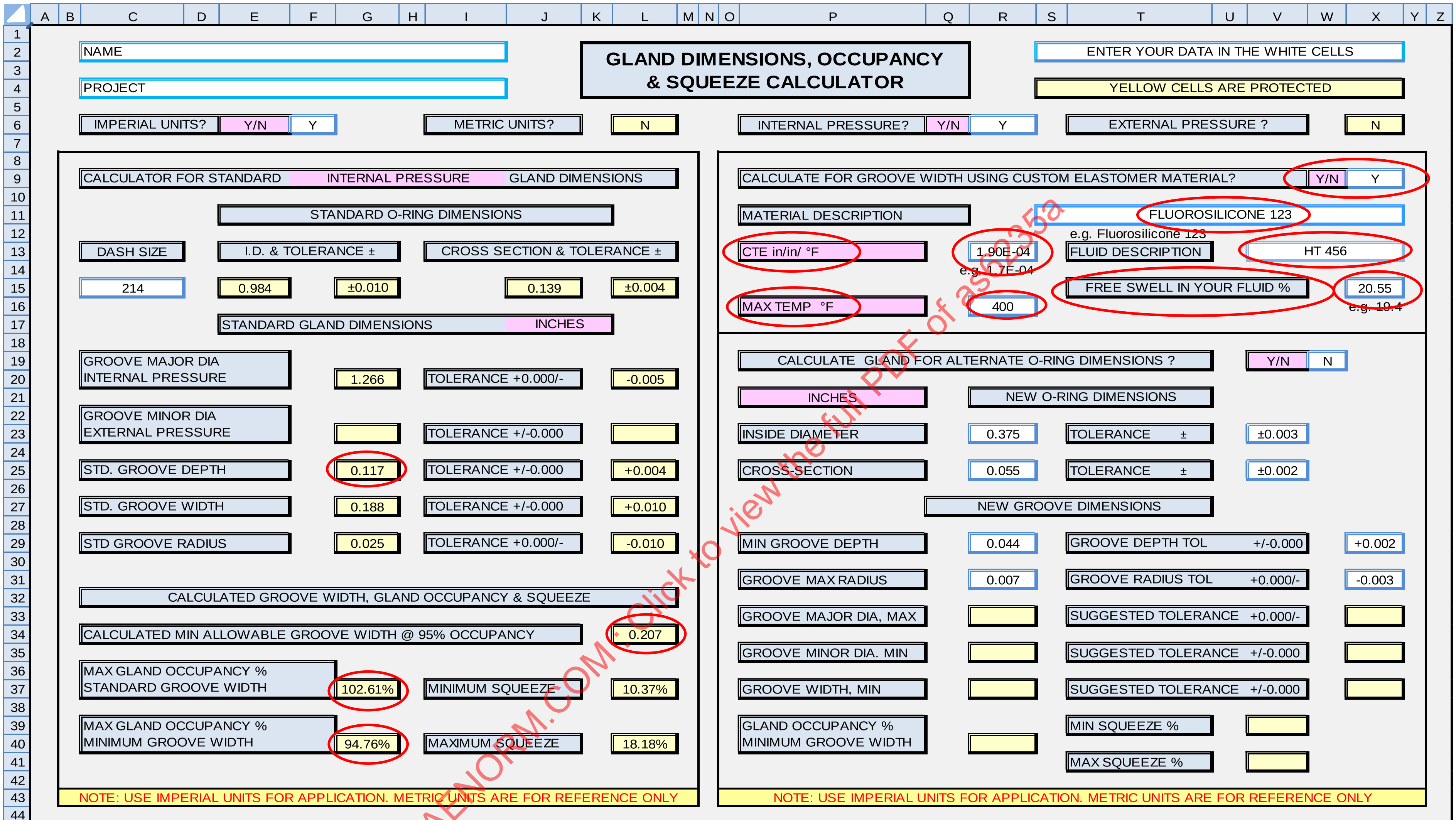


Figure D2 - Gland dimensions calculation sheet for standard O-Ring size using non-standard elastomer material

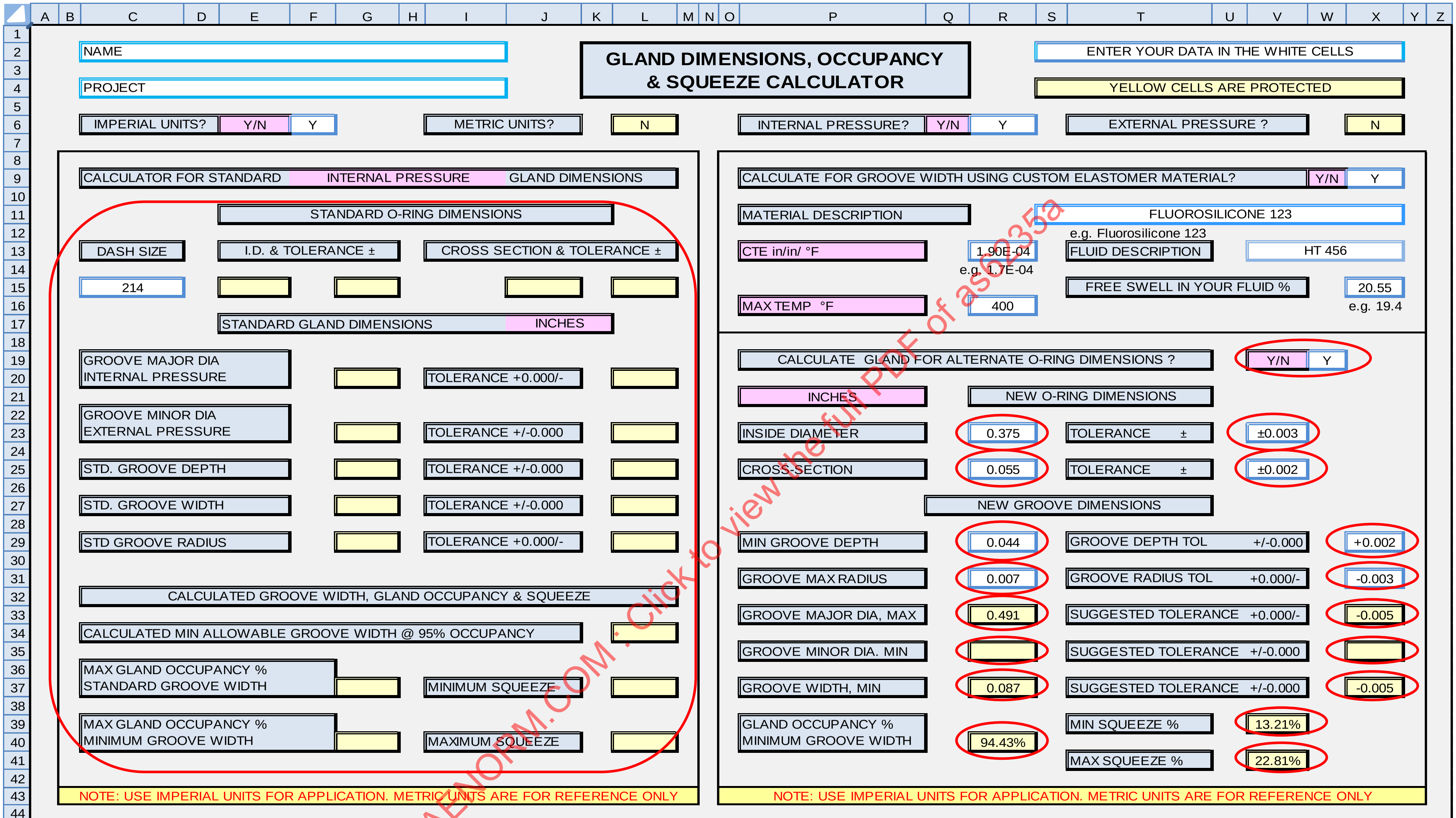


Figure D3 - Gland dimensions calculation sheet for non-standard O-ring and non-standard elastomer material

D.2.4 Calculations for Non-Standard O-rings Using a Custom O-ring

Refer to Figure D3 in the following example.

Assuming we will use the same custom elastomer material as in the previous example, now switch cell W19 from "N" to "Y" to activate the section used for a non-standard O-ring. This will also de-activate the section used for a standard O-ring, i.e., the O-ring and groove dimensions and data in the left block will all be blank.

Enter new O-ring dimensions and tolerances in the white cells indicated. Enter a new groove minimum depth and depth tolerance to achieve the desired O-ring squeeze indicated in cells V39 and V41. Enter the groove radius and its tolerance per your requirements in cells R31 and X31. Table D3 shows the required entries and results.

Table D3 - Entries for non-standard O-ring dimensions with custom elastomer material properties, and resulting gland dimensions and tolerances, O-ring squeeze and gland occupancies

CELL	DESCRIPTION	ENTRY	RESULT
W19	CALCULATE FOR NON-STANDARD O-RING DIMENSIONS	Y	ACTIVATES CELLS FOR NON-STANDARD O-RING & DE-ACTIVATES CELLS FOR STANDARD O-RING AND GLAND
R23, V23 R25, V25	NEW O-RING DIMENSIONS & TOLERANCES	ENTER DIMENSIONS	GROOVE MAJOR DIAMETER (MAX) POPULATED IN CELL R33 SUGGESTED GROOVE DIA. TOLERANCE POPULATED IN CELL X33 GROOVE MINOR DIAMETER IN CELL R35 AND ASSOCIATED TOLERANCE ARE NOT POPULATED
R29, X29	NEW GROOVE DEPTH & TOLERANCE	ENTER DIMENSIONS	MINIMUM & MAXIMUM SQUEEZE POPULATED IN CELLS V39, V41
R31, X31	NEW GROOVE RADIUS & TOLERANCE	ENTER DIMENSIONS	MINIMUM GROOVE WIDTH POPULATED IN CELL R37 SUGGESTED TOLERANCE POPULATED IN CELL X37 GLAND OCCUPANCY AT MINIMUM GROOVE WIDTH POPULATED IN CELL R40

It can be seen that a solution has been found for the O-ring dimensions and groove depth and radius dimensions entered. By the choice of groove depth and tolerance the % squeeze is within the recommended limits of AS6235, i.e., between 10% and 25%. Also notice that the major groove diameter (max) at 0.490 inch is larger than the nominal O-ring O.D. of 0.485 inch in order to cater for an increase in the O-ring O.D. when it is squeezed axially, and maintain a maximum of 1% cramping on the squeezed O-ring O.D. (using nominal O-ring and gland dimensions).

It can be seen that the groove minimum minor diameter in cell R35 and associated tolerance in cell X35 are not populated. Similarly, for an External pressure application, cells R33 and X33 will not be populated.

Note that in all cases, if the groove minor diameter is less than the allowed limit to permit a minimum port diameter and a minimum internal gland wall, "N/A" will appear.

ANNEX E - ELASTOMER BACKGROUND, TEST DATA AND INTERPRETATION

E.1 PUBLICATIONS

E.1.1 “Swell of O-rings in Glands Compared to Conventional Volume Change Measurements,” by Dr. W. R. Keller, August 2005.

INTERNATIONAL SEAL

The O-Ring Business Merger of FNGP and ISC

Freudenberg-NOK General Partnership
O-Ring Division

Test Report
Authors: Robert W. Keller
Date: 31-August 2005

Title: Swell of O-Rings in Glands compared to conventional Volume Change Measurements

Purpose: To determine if there is a relationship between squeeze and volume change of O-Rings confined in their glands compared to conventional free volume change measurements per ASTM D471.

Results:

1. O-Rings under actual application squeeze swell considerably less than free swell conditions used in tests such as ASTM D471.
2. The more the squeeze of the O-Ring, the less the swell which does make sense.
3. A relationship between the swell of an O-Ring in the squeezed gland condition and the squeeze amount and free volume change determined by ASTM D471 was found as:
   a. Squeezed swell = 1.95729 + (0.647765*VC) – (0.0155877*VC*SQ) [1]
   b. Where,
      i. VC – free volume change determined by ASTM D471 immersion
      ii. SQ – % squeeze of the O-Ring cross section, in the range of 5-35% squeeze.
4. The above relationship covers a variety of different polymer types and immersion fluids.
5. The above relationship can be used to predict the swell of actual O-Rings knowing the free volume change and the squeeze in the gland.

Recommendations:

1. Equation [1] above should be used to estimate the actual swell of O-Rings in their gland knowing the free volume change and the squeeze conditions in the gland.
2. While 25% is considered the maximum that materials can swell in the free state and still function properly as O-Rings (based on the assumption that the O-Ring gland has roughly 25% free volume available), a more realistic approach based on this data would suggest an upper swell limit for free volume change of 35%. This will yield an actual volume change in the O-Ring gland of roughly 23% at the condition of 5% squeeze in low squeeze applications. Lower actual volume changes of the O-Rings in glands will occur with higher squeeze levels.

Page 1 of 15

Page 1: Note equation to determine volume change (swell) dependent on squeeze and volume well in fluid in the free condition.

Introduction

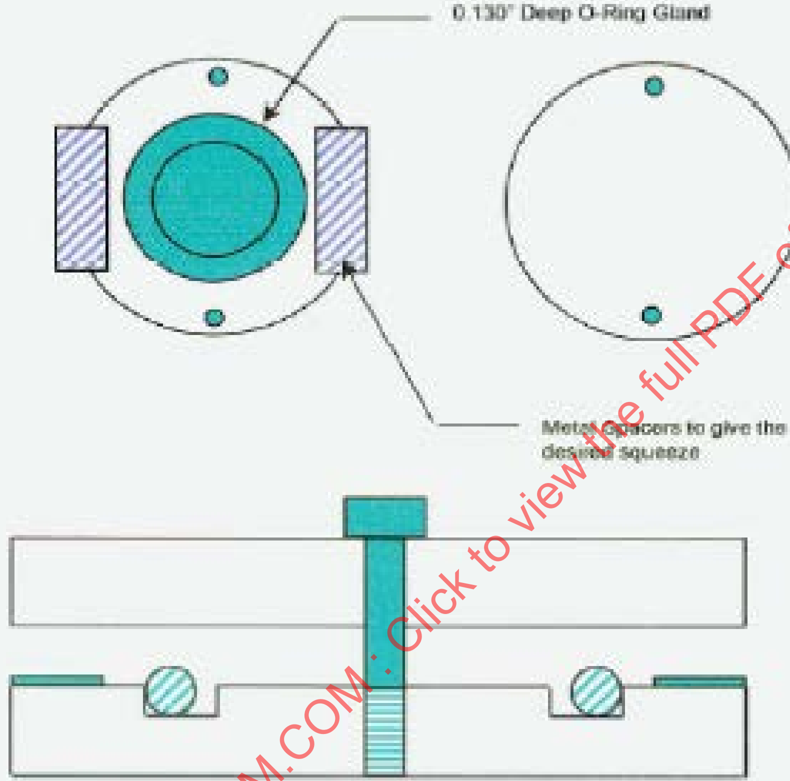
One question that continuously arises is "what swell can I expect of this O-Ring in this fluid in this gland at the operating temperature?" As a first estimate, most people will use the results determined from conventional immersion testing per ASTM D471 to answer that question. However, that would be a very crude approximation since the actual O-Ring in the gland is confined, under squeeze, and there is limited volume available for swelling. This paper summarizes several years of work on this subject using several different rubber materials and various fluids.

To measure the volume change of the free sample compared to an O-Ring in the gland, simple experimental test fixtures were made as shown in Figure 1. The width of the O-Ring groove was standard for the cross section (gland width = 0.285 ± 0.005 inches). An AS568-325 size O-Ring was selected for this study for the following reasons:

- The ring is large enough to give high reliability in volume change measurements per ASTM D471.
- The cross section of the ring is large enough to get accurate shim heights and very tightly controlled squeeze values in the fixture.
- The fixtures are small enough to fit inside convenient vessels for fluid aging at elevated temperatures.

The point of the work was to study the actual volume change of the seal in the gland compared to free volume change values determined through ASTM D471 techniques and to determine if there was a predictive model to more accurately estimate the volume change of actual seals in glands. For comparison, a freely suspended AS568-325 size O-Ring was immersed in the same test fluid to get the free volume change per ASTM D471.

FIGURE 1


0.130" Deep O-Ring Gland
Metal Spacers to give the desired squeeze

Results and Discussion

The results are tabulated in Table 1 for the wide variety of materials and immersion conditions tested. Typical of the results are the relationships shown in Figures 1, 2, and 3. No matter what material or what immersion fluid was used, swell of the actual O-Ring in the gland was reduced by the amount of squeeze compared to free volume change measurements by ASTM D471. Additional squeeze caused less swell of the actual O-Ring. Intuitively, this makes sense since the O-Ring in the groove is under squeeze so it will at like a material with a much higher stiffness and the O-Ring is confined by the groove.

Figure 2

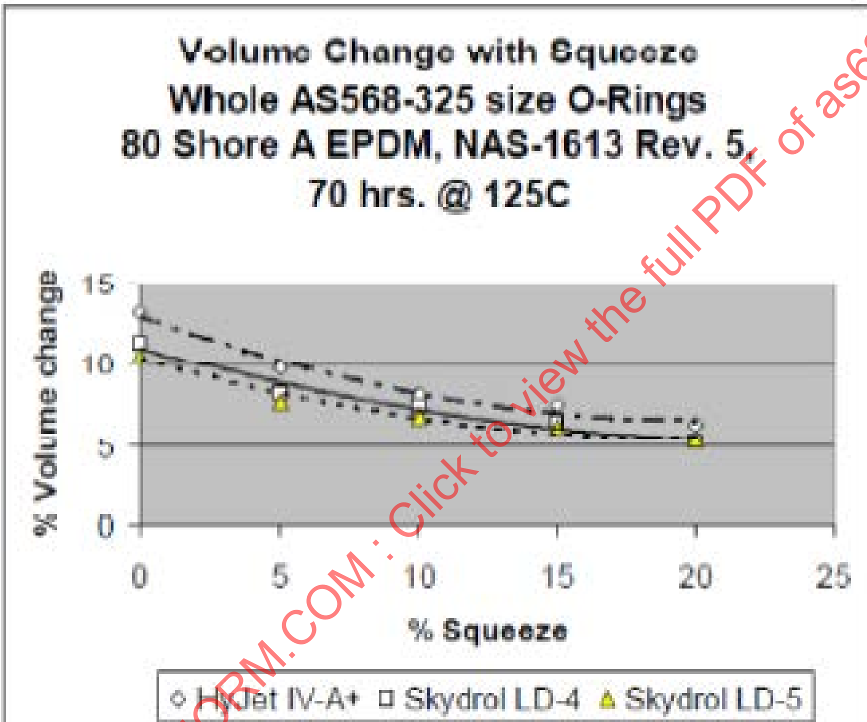


Figure 3

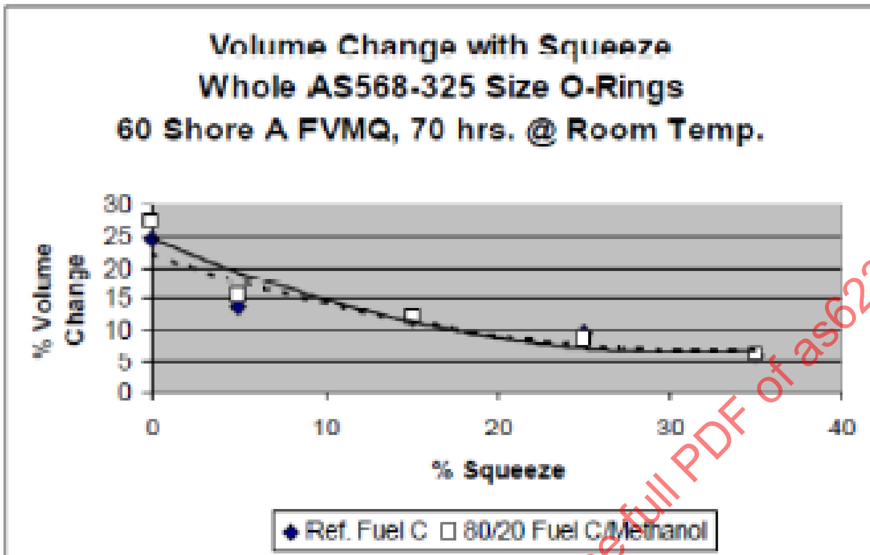
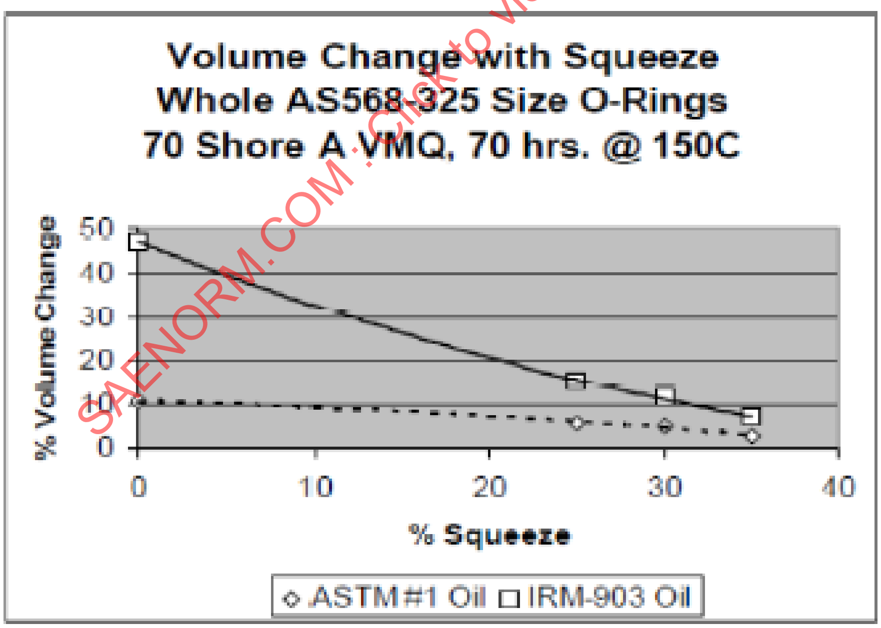


Figure 4

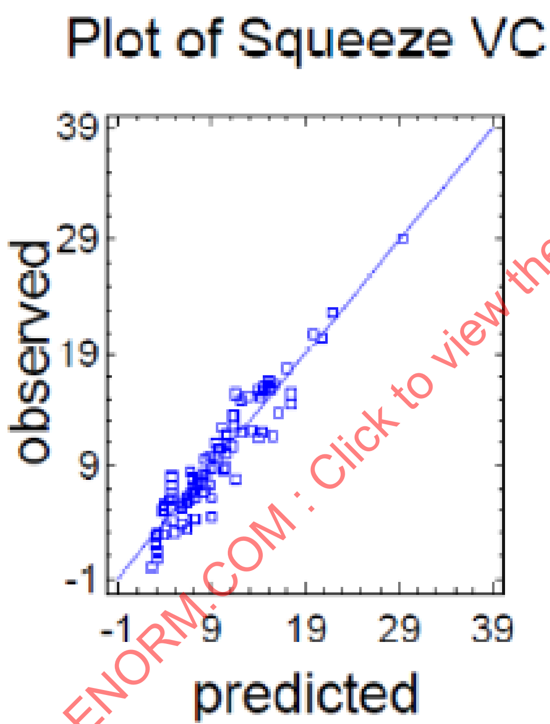


Page 5 of 15

All of the data in Table 1 was analyzed to determine if a relationship consisted between the squeeze, free volume change, and volume change of the actual O-Ring in the groove. The results are given in Figure 5 below with the following statistics for the fit of the data:

R-Squared = 88.48 %
R-Squared adjusted for degrees of freedom = 88.26%
Standard error of estimate = 1.77

Figure 5



The resulting equation predicting the swell of the O-Ring in the gland based on known squeeze and free volume change determined by ASTM D471 is:

$$\textit{Squeezed swell} = 1.95729 + (0.647765 * VC) - (0.0155877 * VC * SQ) \qquad [1]$$

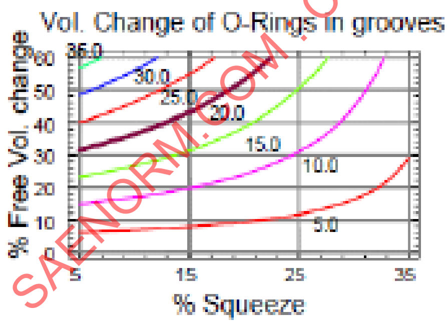
- Where,
  - VC = % volume change determined by ASTM D471 immersion tests
  - SQ = % squeeze of O-Ring cross section
  - Squeezed swell = measured swell of whole O-Ring in gland.

The utility of Equation [1] is:

- It utilizes current data available for many materials in conventional test reports.
  - For example, if the volume change of an NAS-1613 EPDM compound in Skydrol LD-4 is reported as +11.3% after 70 hours @ 125C immersion, and the application maximum squeeze of the O-Ring is 18.0%, then Equation [1] predicts that the swell of the O-Ring in the application will be 6.11% ± 1.77%.
  - If the ring used in the example above is exposed to 22.5% squeeze in the application (considering a design change), Equation [1] predicts that the swell of the O-Ring in the application will be 5.31 ± 1.77%.
- Generally, Squeeze min., max., and nominal can be determined from the tolerance stack of the O-Ring and the gland.
- No "new" data need be generated to use this equation.

This equation is also plotted in Figure 6 as a contour plot for estimations.

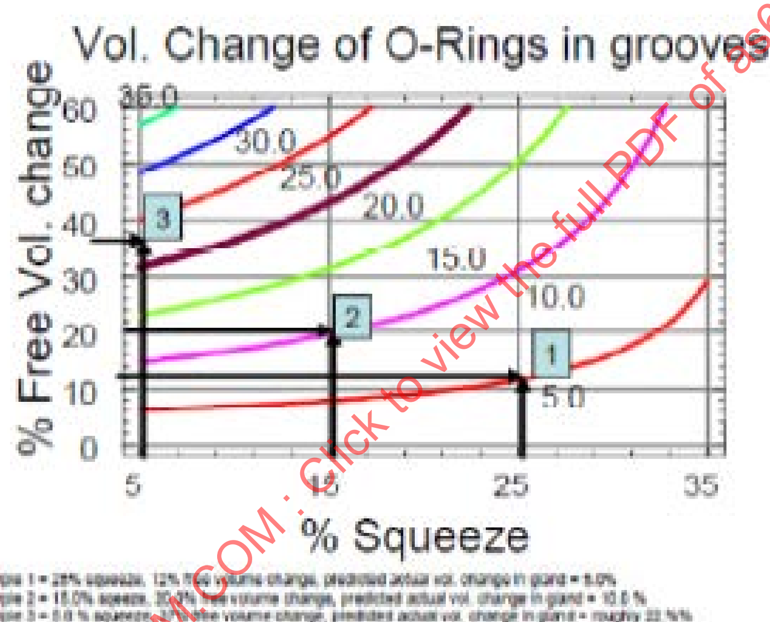
Figure 6



If we used Figure 6 and the data for our first O-Ring example:

- 11.3% free volume change per ASTM D471 in Skydrol LD-4, 70 hours @ 125C
- 18.0 % max. squeeze in the application

Figure 7



Estimate from Contour plot of actual volume change of O-rings in actual groove applications (blue squares as examples).

The function is also plotted in Figure 8 as a Surface plot.

Figure 8

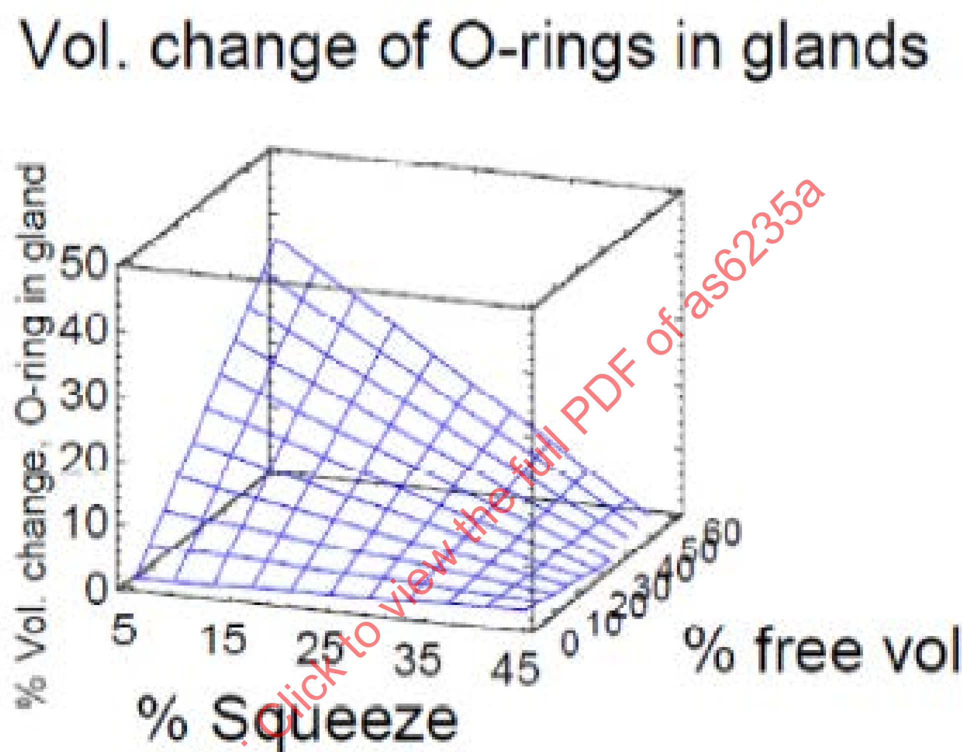

Vol. change of O-rings in glands
% Vol. change, O-ring in gland
50
40
30
20
10
0
5
15
25
35
45
% Squeeze
0
10
20
30
40
50
60
% free vol

Table 1

% Squeeze	% Free Vol. Chg.	% Vol. Chg. In groove	Description
5	18.0	14.9	70 duro FVMQ in Ref. Fuel C, 70 hours @ Room Temp.
15	18.0	11.0	70 duro FVMQ in Ref. Fuel C, 70 hours @ Room Temp.
25	18.0	5.8	70 duro FVMQ in Ref. Fuel C, 70 hours @ Room Temp.
5	16.9	7.7	70 duro FVMQ in Ref. Fuel B, 70 hours @ Room Temp.
15	16.9	4.4	70 duro FVMQ in Ref. Fuel B, 70 hours @ Room Temp.
25	16.9	3.3	70 duro FVMQ in Ref. Fuel B, 70 hours @ Room Temp.
5	33.0	20.6	Fuel Resistant 70 duro NBR in 85/15 Ref. Fuel C/Methanol, 70 hours @ Room Temp.
15	33.0	16.3	Fuel Resistant 70 duro NBR in 85/15 Ref. Fuel C/Methanol, 70 hours @ Room Temp.
25	33.0	10.2	Fuel Resistant 70 duro NBR in 85/15 Ref. Fuel C/Methanol, 70 hours @ Room Temp.
5	23.0	16.7	Fuel Resistant 70 duro NBR in Ref. Fuel C, 70 hours @ Room Temp.
15	23.0	15.5	Fuel Resistant 70 duro NBR in Ref. Fuel C, 70 hours @ Room Temp.
25	23.0	6.5	Fuel Resistant 70 duro NBR in Ref. Fuel C, 70 hours @ Room Temp.
5	12.2	6.1	Fuel Resistant 70 duro NBR in Ref. Fuel B, 70 hours @ Room Temp.
15	12.2	4.3	Fuel Resistant 70 duro NBR in Ref. Fuel B, 70 hours @ Room Temp.
25	12.2	3.1	Fuel Resistant 70 duro NBR in Ref. Fuel B, 70 hours @ Room Temp.
5	48.0	29.1	70 duro NBR in 85/15 Ref. Fuel C/Methanol, 70 hours @ Room Temp.
15	48.0	[illegible]	70 duro NBR in 85/15 Ref. Fuel C/Methanol, 70 hours @ Room Temp.
25	48.0	11.9	70 duro NBR in 85/15 Ref. Fuel C/Methanol, 70 hours @ Room Temp.
5	-0.57	0.16	70 duro NBR in Ref. Fuel A, 70 hours @ Room Temp.
15	[illegible]	0.02	70 duro NBR in Ref. Fuel A, 70 hours @ Room Temp.
25	-0.57	0.04	70 duro NBR in Ref. Fuel A, 70 hours @ Room Temp.

Table 1 (continued)

% Squeeze	% Free Vol. Chg.	% Vol. Chg. In groove	Description
5	-1.7	-0.4	Fuel Resistant 70 duro NBR in Ref. Fuel A, 70 hours @ Room Temp.
15	-1.7	-0.4	Fuel Resistant 70 duro NBR in Ref. Fuel C, 70 hours @ Room Temp.
25	-1.7	-0.5	Fuel Resistant 70 duro NBR in Ref. Fuel C, 70 hours @ Room Temp.
5	31.4	20.8	60 duro FVMQ in 80/20 Ref. Fuel C/Methanol, 70 hours @ Room Temp.
15	31.4	16.2	60 duro FVMQ in 80/20 Ref. Fuel C/Methanol, 70 hours @ Room Temp.
25	31.4	12.3	60 duro FVMQ in 80/20 Ref. Fuel C/Methanol, 70 hours @ Room Temp.
5	26.3	17.7	60 duro FVMQ in 80/20 Ref. Fuel C/Ethanol, 70 hours @ Room Temp.
15	26.3	15.2	60 duro FVMQ in 80/20 Ref. Fuel C/Ethanol, 70 hours @ Room Temp.
25	26.3	9.9	60 duro FVMQ in 80/20 Ref. Fuel C/Ethanol, 70 hours @ Room Temp.
25	10.8	8.2	70 duro VMQ in ASTM #1 Oil, 70 hours @ 150C
30	10.8	4.9	70 duro VMQ in ASTM #1 Oil, 70 hours @ 150C
35	10.8	0.7	70 duro VMQ in ASTM #1 Oil, 70 hours @ 150C
25	52.3	16.0	70 duro VMQ in IRM-903 Oil, 70 hours @ 150C
30	52.3	12.5	70 duro VMQ in IRM-903 Oil, 70 hours @ 150C
35	52.3	4.2	70 duro VMQ in IRM-903 Oil, 70 hours @ 150C
20	24.5	8.6	High performance, 70 duro CR in HCFC-123, 70 hours @ 100C
20	20.5	7.3	High performance, 80 duro CR in HCFC-123, 70 hours @ 100C
25	24.5	6.8	High performance, 70 duro CR in HCFC-123, 70 hours @ 100C
25	20.5	6.7	High performance, 80 duro CR in HCFC-123, 70 hours @ 100C
30	24.3	3.6	High performance, 70 duro CR in HCFC-123, 70 hours @ 100C
30	20.5	5.6	High performance, 80 duro CR in HCFC-123, 70 hours @ 100C

Table 1 (continued)

% Squeeze	% Free Vol. Chg.	% Vol. Chg. In groove	Description
21	6.5	3.6	70 duro CR in 50/50 HFC-134a/PAG Oil, 70 hours @ 100C
21	2.4	-0.08	70 duro CR in mineral oil, 70 hours @ 100C
21	28.8	13.5	70 duro CR in HCFC-123, 70 hours @ 100C
21	24.5	10.4	70 duro CR in 50/50 HCFC-22/mineral oil, 70 hours @ 100C
21	48.6	14.5	70 duro Green HNBR in 50/50 HCFC-22/mineral oil, 70 hours @ 100C
21	42.5	11.5	70 duro Black HNBR in 50/50 HCFC-22/mineral oil, 70 hours @ 100C
5	24.7	13.8	60 duro FVMQ in Ref. Fuel C, 70 hours @ Room Temp.
15	24.7	11.9	60 duro FVMQ in Ref. Fuel C, 70 hours @ Room Temp.
25	24.7	9.5	60 duro FVMQ in Ref. Fuel C, 70 hours @ Room Temp.
35	24.7	5.9	60 duro FVMQ in Ref. Fuel C, 70 hours @ Room Temp.
5	27.2	15.5	60 duro FVMQ in 80/20 Ref. Fuel C/Methanol, 70 hours @ Room Temp.
15	27.2	12.1	60 duro FVMQ in 80/20 Ref. Fuel C/Methanol, 70 hours @ Room Temp.
25	27.2	8.7	60 duro FVMQ in 80/20 Ref. Fuel C/Methanol, 70 hours @ Room Temp.
35	27.2	6.1	60 duro FVMQ in 80/20 Ref. Fuel C/Methanol, 70 hours @ Room Temp.
25	11.1	4.1	70 duro VMQ in ASTM #1 Oil, 48 hours @ 150C
25	10.5	5.7	70 duro VMQ in ASTM #1 Oil, 72 hours @ 150C
25	10.9	6.6	70 duro VMQ in ASTM #1 Oil, 168 hours @ 150C
25	10.8	7.3	70 duro VMQ in ASTM #1 Oil, 336 hours @ 150C
25	10.7	8.0	70 duro VMQ in ASTM #1 Oil, 504 hours @ 150C
25	10.8	8.1	70 duro VMQ in ASTM #1 Oil, 840 hours @ 150C
25	10.8	8.2	70 duro VMQ in ASTM #1 Oil, 1008 hours @ 150C

Table 1 (continued)

% Squeeze	% Free Vol. Chg.	% Vol. Chg. In groove	Description
30	11.1	2.8	70 duro VMQ in ASTM #1 Oil, 48 hours @ 150C
30	10.5	5.0	70 duro VMQ in ASTM #1 Oil, 72 hours @ 150C
30	10.9	5.4	70 duro VMQ in ASTM #1 Oil, 168 hours @ 150C
30	10.8	5.5	70 duro VMQ in ASTM #1 Oil, 336 hours @ 150C
30	10.7	5.3	70 duro VMQ in ASTM #1 Oil, 504 hours @ 150C
30	10.8	5.1	70 duro VMQ in ASTM #1 Oil, 840 hours @ 150C
30	10.8	4.9	70 duro VMQ in ASTM #1 Oil, 1008 hours @ 150C
35	11.1	1.4	70 duro VMQ in ASTM #1 Oil, 48 hours @ 150C
35	10.5	2.7	70 duro VMQ in ASTM #1 Oil, 72 hours @ 150C
35	10.9	2.9	70 duro VMQ in ASTM #1 Oil, 168 hours @ 150C
35	10.8	2.8	70 duro VMQ in ASTM #1 Oil, 336 hours @ 150C
35	10.7	1.9	70 duro VMQ in ASTM #1 Oil, 504 hours @ 150C
35	10.8	1.3	70 duro VMQ in ASTM #1 Oil, 840 hours @ 150C
35	10.8	0.7	70 duro VMQ in ASTM #1 Oil, 1008 hours @ 150C
25	47.2	11.4	70 duro VMQ in IRM 903 Oil, 48 hours @ 150C
25	47.5	15.2	70 duro VMQ in IRM-903 Oil, 72 hours @ 150C
25	48.1	15.7	70 duro VMQ in IRM-903 Oil, 168 hours @ 150C
25	46.9	15.9	70 duro VMQ in IRM-903 Oil, 336 hours @ 150C
25	49.0	16.1	70 duro VMQ in IRM-903 Oil, 504 hours @ 150C
25	51.3	16.3	70 duro VMQ in IRM-903 Oil, 840 hours @ 150C
25	52.3	15.9	70 duro VMQ in IRM-903 Oil, 1008 hours @ 150C