

## ADVANCEMENTS IN MECHANICAL SEALING - API 682 FOURTH EDITION

Michael B. Huebner  
Flowsolve Corporation  
Deer Park, TX, USA

Gordon S. Buck  
John Crane Inc.  
Baton Rouge, LA, USA

Henri V. Azibert  
A.W. Chesterton Co.  
Groveland, MA 01834

### ABSTRACT

API 682 is the leading document for mechanical seals in petrochemical, chemical, and pipeline services worldwide. It has combined the aspects of seal design, testing, standardization, and applications to provide the users and OEMs alike with a common source of information for mechanical seals. As seal technology has advanced, the standard has expanded to incorporate new seal designs, materials, seal selection guidance, and piping plans. Although the standard is not yet published, the final draft has been prepared and gives us notice of the upcoming requirements. This tutorial will cover the major changes introduced in the Fourth Edition.

### HISTORY OF API 682

Mechanical seals have been accepted as the standard method for sealing rotating pumps for many years. While some mechanical seal standard existed, they were generally buried in other standards such as DIN 24960, ANSI B73 and API 610. All of these standards were primarily pump standards and any seal references were directed at how mechanical seals would interact with the referenced pumps.

In the late 1980's a group of refinery equipment engineers and managers began to compare sealing solutions in refinery applications. This group, led by V. R. Dodd of Chevron, came up with a general plan and the American Petroleum Institute (API; Washington, D.C.) agreed to establish a standard for mechanical seals: API 682. A Task Force was formed in 1990 and the first meeting was held in January 1991. This Task Force was comprised of fourteen members from various refineries, seal and pump manufacturers. As part of the process in developing the standard, the Task Force created standard definitions for concepts such as seal types, seal arrangements, and seal qualification tests. API 682, First Edition, was published in October 1994.

API 682 First Edition was one of the most successful standards in API's history with sales in over 25 countries. While the First Edition Task

Force had in effect created a standard that was used throughout the world, they had not authored an international standard. In order to gain international acceptance, the American Petroleum Institute opened up the standards development process to global input from the International Organization for Standardization (ISO; Geneva, Switzerland).

In addition to international review, the Second Edition introduced the concept of seal categories and new seal designs such as gas seals and containment seals. Additional options for seal configurations and orientations (such as dual face-to-face and back-to-back) were added. The scope of the standard was also broadened to include seals for chemical duty pumps. In the process new piping plans and test qualification procedures were developed to cover the new scope. The Second Edition of API 682 was confirmed by the international community as ISO-21049 in 2002 with only minor changes from API 682 Second Edition. To completely align API 682 and ISO 21049, API 682 Third Edition was issued in 2004.

Since the publication of the Third Edition, seal technology has continued to advance. End users and OEMs have made recommendations to expand the scope so that the benefits of the standards could be applied to new applications and new seal designs. Improvements in piping plans have made seal installations more reliable. New seal selection concepts have been developed. The API 682 Task Force worked to incorporate the industry needs and new technology into the new standard. The resulting work, API 682 Fourth Edition continues the tradition as the leading standard for mechanical sealing. Recently, the American Petroleum Institute has moved to issue its standards independently of the ISO standards organization. For this reason, the next edition of API 682 will only be issued as API 682 Fourth Edition and not as ISO 21049.

### OVERVIEW OF FIRST EDITION

The mission statement for the First Edition Task Force was captured in the first section of the standard:



---

*This standard is designed to default to the equipment types most commonly supplied that have a high probability of meeting the objective of at least three years of uninterrupted service while complying with emissions regulations.*

---

Although this mission statement no longer appears in the standard, it is important to realize its impact not only on First Edition but on subsequent editions. There were several key assumptions made by the First Edition Task Force in meeting this goal.

- address 90% of the applications in a typical refinery
- address a limited range of shaft sizes and operating conditions
- default to one solution.

The First Edition of API 682 was filled not only with the technical details normally associated with a standard but also with a thorough explanation of how seals should be applied and the background behind many of the requirements of the standard. The document contained notes and comments that gave the reader an insight into the Task Force's reasoning behind many of the requirements. Originally, these notes and comments were intended only for the Task Force; however, the reviewers of the draft standard asked that they be kept in the finished document. Some comments were expanded to become tutorials and were moved to the appendix.

The First Edition also provided a seal selection guide for a number of typical refinery applications. Before this could be done, it was necessary to categorize refinery applications into a number of services: Non-hydrocarbon, Non-flashing hydrocarbon, and Flashing hydrocarbon.

In order to formulate the selection guide, it was also necessary to categorize the many different types of seals that were used in refinery services. Three seal types, A, B, and C, were designated to cover pusher seals, bellows seals, and high temperature seals respectively.

Prior to First Edition, multiple seals were designated as being either "tandem" or "double" seals; however, advances in seal design had rendered these classic terms obsolete. As a result, there was some confusion on how multiple seals

were designated. The Task Force decided to use a more descriptive designation and chose to define dual seal arrangements. A dual seal would be two mechanical seals used in the same seal chamber. The fluid between these two seals could be either pressurized or unpressurized. Three standard arrangements were defined: Arrangement 1 would be a single seal, Arrangement 2 would be a dual unpressurized seal, and Arrangement 3 would be a dual pressurized seal.

End users wanted assurances that the seals offered by the OEMs were capable of meeting the API 682 goals when run under actual conditions. The only way to do this was to require seal performance testing, termed Qualification Testing, on process fluids under representative pressures and temperatures. The goal of the qualification test was to simulate a long-term steady state run followed by a process upset. The simulated process upset consisted of pressure changes, temperature changes and included loss of flush. Five fluids were selected for the qualification tests: water, propane, 20% NaOH, cold oil and hot oil. These five fluids included a wide range of viscosity, vapor pressure, specific gravity, specific heat and atmospheric boiling point. In addition, there were actually three other "test fluids" -- the buffer/barrier fluids: glycol/water, diesel, and low viscosity oil.

API requires a periodic review of its standards and as sealing technology evolved it became apparent that API 682 First Edition should be updated.

## **OVERVIEW OF SECOND AND THIRD EDITIONS**

After the release of API 682 First Edition, gas seals and dry running containment seals became more common in many industries. New piping plans for gas seal control panels and containment seals were necessarily required and developed. In addition, many users and manufacturers wanted to expand the scope of seal configurations and orientations that had been specified by First Edition.

Another criticism of API 682 First Edition was that it considered only API 610 pumps and only refinery applications. The chemical and petrochemical industries routinely use ASME pumps in addition to API 610 pumps. Broadening the scope of pumps covered by API 682 would



allow standardized seals to be applied in a greater number of industries.

The First Edition was written from the perspective of refinery applications and focused on heavy duty pumps and seal designs. Since the standard was being applied to other industries, users recognized the need to select seals according to the severity of the application. This need was met by defining seal categories. There are three categories: Category 1, 2, and 3. Category 1 seals were largely intended for non-API-610 pumps. Category 2 seals were intended for API 610 pumps. Category 3 seals were also intended for API-610 pumps and were essentially the same as the original API 682 First Edition seals.

The Task Force also recognized that not all seals were contacting wet seals. While this technology was certainly the dominant method of applying mechanical seals, other designs were also commonly used. Three new seal types were introduced in the Second Edition: dry running containment seals, non-contacting seals and dual gas barrier seals. Containment seals are the outer seal in a dual unpressurized seal arrangement. In the case of a dry running containment seal, the containment seal will be exposed primarily to buffer gas or vaporized process fluid. Dry running containment seals may be either contacting or non-contacting. Non-contacting inner seals were also introduced in Second Edition. A non-contacting inner seal is designed to operate on liquid, vapor, or mixed phase fluids. Dual gas barrier seals are used in Arrangement 3 and designed to run primarily on a gas barrier fluid such as nitrogen.

The seal arrangement describes the number of seals per cartridge, the orientations of dual seals, and the relative pressure of the buffer/barrier fluid. A chart of acceptable configurations is shown in Figure 1. Where multiple arrangements are listed in a column, they are shown in order of default selection. The arrangements are described by an arrangement code shown in the figure.

Piping plans are a critical component in the successful design of a sealing system. These plans describe methods of controlling the environment around the seal, conditioning the sealed fluid, collecting and controlling seal leakage, and monitoring seal performance. Several new piping plans were introduced in the Second and Third Editions. These included additional options for dual pressurized liquid seals as well as new piping

plans to support containment seals and dual pressurized gas seals. The new piping plans were:

- Plan 14 – combination of Plan 11 and Plan 13 is primarily used in vertical
- Plan 53A – same as Plan 53 in the First Edition
- Plan 53B – closed loop with bladder accumulator providing pressurization
- Plan 53C – closed loop with piston accumulator providing differential pressurization
- Plan 65 – monitoring atmospheric seal leakage
- Plan 71 - dry running containment seals.
- Plan 72 - supplies buffer gas for dry running containment
- Plan 74 – supplies barrier gas for dual pressurized gas seals
- Plan 75 – collects and monitors liquid leakage from dry running containment seals
- Plan 76 – collects and monitors vapor leakage from dry running containment seals

Qualification testing was one of the most significant contributions of the First Edition. This required that seals, offered as compliant to API 682, must have successfully been tested to a strict qualification procedure. The Second Edition expanded on this by defining acceptance criteria for all qualification tests. The maximum allowable leakage during testing was 1000 ppm (vol) vapors (as measured by EPA Method 21) or 5.6 g/h liquid leakage per pair of sealing faces. The maximum allowable face wear at the completion of the testing was less than 1% of the available seal face wear. Second Edition also added new tests for containment seals and dual pressurized gas seals .

Although the exact cost is unknown, it is estimated that the seal manufacturers have invested between 5 and 10 million U.S. dollars in capital equipment in order to conduct the qualification tests specified by API 682. As the tests have been ongoing since 1994 there is perhaps an additional 5 to 10 million dollars of operating costs associated with the tests. It is likely that all manufacturers have not yet completed a full slate of tests and that API 682 qualification testing will continue for years.



## OVERVIEW OF THE FOURTH EDITION

Although the Third Edition of API 682 and ISO 21049 were published in 2004, the contents were essentially the same as the Second Edition of API 682 published in 2002. A Task Force was formed in 2006 to begin working on the Fourth Edition. The first assignment for the Fourth Edition Task Force was to answer questions and comments regarding previous editions. The Task Force members soon realized that major changes, including reorganization and editing, were necessary in order to clarify the specifications of API 682.

## NEW DEFINITIONS

API 682 has created definitions for many of the common features and attributes of mechanical seals and systems. When new concepts are introduced or options are added to the standard, they must be captured in the definitions. The number of definitions has increased and the wording made more concise and descriptive. The longer, more involved definitions have been moved from Section 3 into the general body of the standard. For example, the definitions of Arrangements, Categories and Types have been moved into Section 4.

Mechanical seal terminology can be found in other standards outside of API 682. Previously there had been no attempt create consistent definitions and terminology across these different standards. The definitions in the Fourth Edition have been revised to be more consistent with terms that are used in the sealing industry in general. To help accomplish this, the Task Force worked with members of the Fluid Sealing Association (FSA; Wayne, PA) to insure that all definitions are consistent across various standards and industry in general. Below are the new definitions added to the Fourth Edition.

- Atmospheric Leakage Collector
- Auxiliary Sleeve
- Barrier/Buffer Fluid Chamber
- Containment Device
- Containment Seal Chamber Leakage Collector
- Dynamic Secondary Seal
- Engineered Seal
- External Circulating Device
- Fixed Bushing
- Fixed Throttle Bushing
- Pumped Fluid/Process Fluid

- Seal Sleeve
- Segmented Floating Bushing
- Strainer

## SEAL TYPES

Seal Types describe the basic design features of the seal. These definitions are carried over the previous editions. Type A is a balanced, cartridge mounted seal which utilized elastomeric secondary seals. Type B is a cartridge mounted seal which utilizes the flexible metal bellows and elastomeric secondary seals. The Type C Seal is a cartridge mounted high temperature bellows seals which utilizes flexible graphite secondary seals. Other requirements such as face materials and elastomers are tied to these definitions.

The Fourth Edition expands on these definitions slightly. Type A and B seals have historically been defined as having flexible rotating elements. This means that the springs or bellows assembly will rotate with the shaft. This was selected as the default design in the First Edition due to the high population of these designs in the refinery industry. Type C seals have historically defaulted to stationary flexible elements. There are many cases, however, when it is necessary and beneficial to change from the default designs. For this reason, Type A and B seals are no longer defined as having rotating flexible elements and Type C is not defined as having a stationary flexible element. Instead, both rotating and flexible elements are allowed on all seal types and are considered to be technically equivalent.

Any seal which is outside of the scope of the standard (by design or operating window) is defined as Engineered Seal. An Engineered Seal is not a seal Type but rather identification that special design features may be required to meet the application conditions. The seal OEM is free to deviate from any or all of the requirements of the standard in order to design an appropriate seal. There are no special qualification testing requirements for an Engineered Seal.

In industry, there is sometimes a need to provide a seal which challenges the operating window for any one seal type. In these cases, seal OEMs can provide a mix of Seal Types within the same seal cartridge. For example, an Arrangement 3 (dual pressurized seal) could be configured with a Type B inner seal for improved solids handling and a Type A outer seal for high pressure

capability. This design flexibility is specifically allowed in the Fourth Edition.

### SEAL CONFIGURATIONS

Seal Configuration refers to the orientation of the seal components in an assembly. In previous editions, these were defined as face-to-back, back-to-back, and face-to-face and these terms are carried over into the Fourth Edition. In theory, any orientation (face to back, back to back, face to face) can be used in a dual seal. However, note that acceptance of any orientation is not necessarily the same as endorsement because each orientation has advantages and disadvantages with respect to certain applications, performance and survival of upsets.

good design practices. This has been a challenging and moving target since the scope of the standard has continually changed. In the earlier editions, many design features were stated as default or required features. The Task Force recognized that many of the requirements were over restrictive and minimized the use of many equally successful design features. For these reasons, the Fourth Edition has moved from defining “standard” designs (which imply a requirement) to “default” designs (which imply that other options are available).

In the First Edition, the scope was limited to heavy duty seals in large seal chambers. This allowed for large design features and clearances. As other pump designs (smaller chemical duty pumps) and other seal designs (e.g. gas seals) were

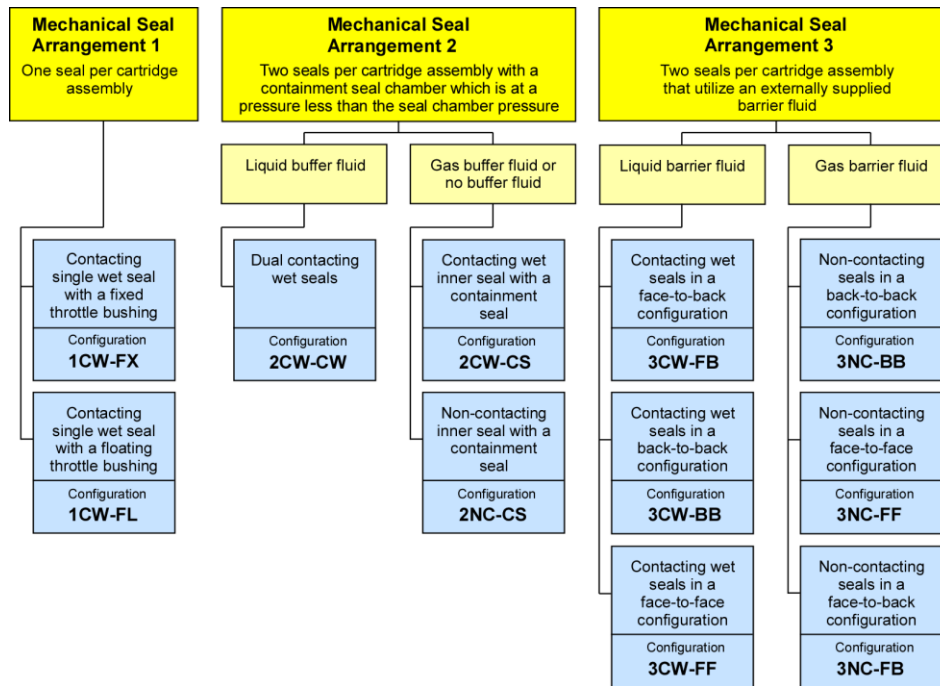


Figure 1. Seal Arrangements and Configurations

### DESIGN FEATURES

API 682 has had a great impact on the design of mechanical seals. The background of this though has been interesting. The standard was never intended to be a specific guideline for how to design a seal. With the wide variety of seal types, application conditions, and operating windows, the implications of design features on the performance of the seal is outside the scope of any one design standard. The standard does however list requirements which have been considered to be

allowed into the standard, the same set of design features were not required and often would not physically fit with the required seal design features. For this reason, the standard has modified the features required for specific designs.

The seal requires lead-in chamfers if a secondary seal will be installed over a sharp edge or corner. This was intended to prevent O-ring damage and the standard has called out minimum requirements for large cross section O-rings with a large radial squeeze. Seal designers often use

different O-ring sizes and radial squeezes internal to the seal if it is required for the seal design. These have different chamfer requirements. The Fourth Edition states that gasketing internal to the seal cartridge is up to the seal OEM and may vary from the published recommendations.

Seal faces which can be exposed to reverse pressure in operation or a vacuum under static conditions must have the faces retained so they will not dislodge under these conditions. In previous editions, the figure illustrating this requirement showed a snap ring retaining the face. While mechanical devices such as snap rings are commonly used, it is not the only option. Many seals are designed which provide hydraulic loading of the seal face into the gland by virtue of the face gasketing. These designs can operated with either OD or ID pressurization and still maintain proper operation. These options are described and illustrated in the Fourth Edition.

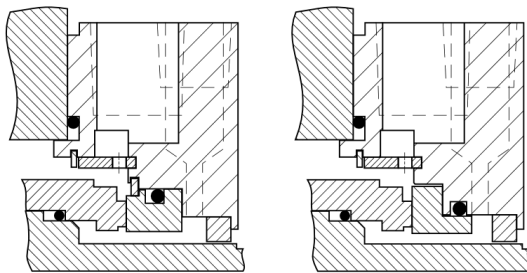


Figure 2. Examples of face retentions methods

One of the most difficult aspects of the standard focuses on clearances between rotating and stationary components. There is an inherent tendency to make clearances very large. This has the benefit of providing addition space around the seals for fluid circulation and radial motion. Unfortunately, it also has the effect of limiting design features and, in some cases, degrading the performance of the seal. In the First Edition, the requirement for 3 mm [1/8"] radial clearance was based on fluid circulation in the seal chamber and this was carried on through the following editions regardless of size, seal type, or equipment. Clearance around other components such as bushings and pump rings were also defined in the previous editions of the standard. Some design features, such as clearance between the ID of a stationary component and OD of a rotating component, were not defined.

In the Fourth Edition, the Task Force reevaluated the requirements of the radial clearances considering all of the seal Types,

Categories, Arrangements, and design features. These were combined into a single table to clearly illustrate the clearances and their impact on the seal design. This has resulted in a more complex but more logical set of clearances for the scope of the standard.

Table 1. Clearances Between Rotating and Stationary Components

Inside Diameter	Outside Diameter		Minimal Diametral Clearance	
ID seal chamber and gland plate	OD rotating seal part	CW seal type NC seal type	6 mm (0.250 in) 3 mm (0.125 in)	Fig. 3
ID stationary seal part	OD rotating seal part	shaft < 60 mm shaft > 60 mm	1 mm (0.139 in) 2 mm (0.079 in)	Fig. 3
ID stationary gland part	OD internal circulation device	shaft < 60 mm shaft > 60 mm	1 mm (0.139 in) 2 mm (0.079 in)	Fig. 4
ID containment fixed bushing	OD rotating seal part	shaft < 60 mm shaft > 60 mm	1 mm (0.139 in) 2 mm (0.079 in)	Fig. 5

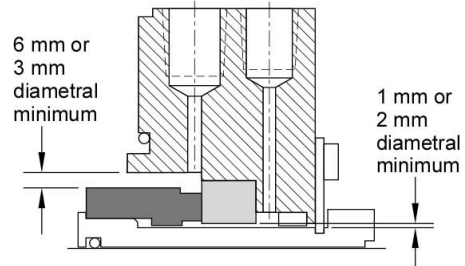


Figure 3. Minimum Clearances

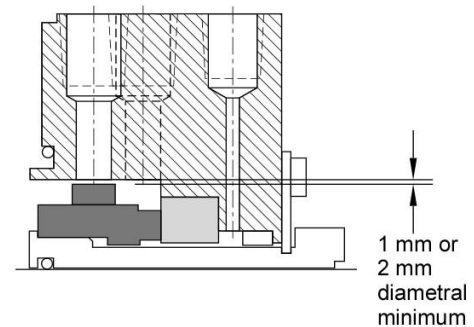


Figure 4. Minimum Clearances

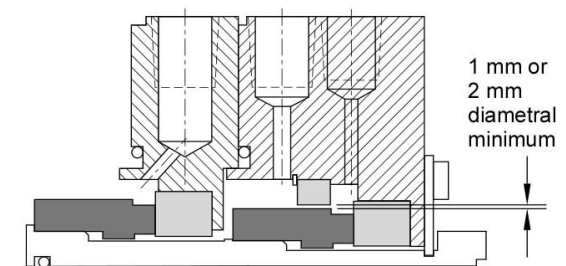


Figure 5. Minimum Clearances

These specifications come with specific caveats which are listed in the standard. The seal components are not intended to restrict shaft movement. Clearances used on a specific design must be adequate to ensure reliability and safety. Listed clearances are minimums and are intended for use in API 610 and ASME B73 pumps. Finally, the clearances are intended to prevent contact and not based on cooling or circulation. These clearances are intended to be applied to the scope of equipment defined in API 682 Fourth Edition. Non-cartridge seals, older/obsolete pump designs, or other types of rotating equipment may require different values.

Some reviewers have been critical of these changes and believe these are too lenient. The Task Force end users and seal OEMs considered these comments seriously by carefully reviewing their current design standards and history of seal failures. The resulting clearances specified by the standard have proven to be acceptable in service and provide the seal OEM with the best flexibility in seal designs. It is understood however that these are minimal values and not necessarily used in every design or application. It is the responsibility of the seal OEM to ensure that the seal design clearances are correct for the seal application and component. Clearances on other features such as fixed and floating throttle bushings are unchanged from previous editions.

Vapor pressure margin is the difference between the seal chamber pressure and the vapor pressure of the fluid. This is an important consideration since contacting wet (CW) mechanical seals require liquid for cooling, lubrication, and fluid film support. In the First Edition, this was simply stated that the seal must have a minimum 3,5 bar [50 PSI] or 10% vapor pressure margin. In the Second Edition, the standard introduced the concept of a temperature margin. This would evaluate the application to determine if the fluid could absorb the heat generation of the seal faces and not flash. This specific evaluation was particularly useful for pumps with very low vapor pressure, stable fluids operating at low pressures. While these various evaluations are all reasonable, some have proven to be difficult to apply or to obtain the data to properly evaluate. For these reason, the Fourth Edition has reverted to a simple requirement for 3,5 bar [50 PSI] margins. The requirement for a minimum seal chamber pressure of 0.35 bar [5 psi] above atmospheric pressure has been retained from the previous editions.

Mechanical seals have ports in the seal gland which are required for connection to the piping plans. In previous edition, these ports were required to be plugged with solid metal plugs and sealed with appropriate lubricant or sealant. The purpose of this requirement was to ensure that the ports would not be inadvertently left unplugged after the seal was installed into the pump. While this was a sound requirement, it led to many unforeseen complications. Many times, installing and removing plugs during shipping, pump testing, and final installations resulted in damaged threads. There were also many instances of seal failures being caused by excessive thread sealant contaminating the seal faces. Even when installed correctly, there was always a concern for selecting the correct sealant/lubricant based on chemical compatibility with the process fluid and operating temperature. In some chemical or finished products services, the sealant could result in unacceptable process contamination.

For these reasons, the Fourth Edition has eliminated the requirement to install metal plugs in all of the ports. The concern for leaving ports open has been addressed by installing red plastic plugs with a center tab to allow it to be easily distinguished from a solid metal plug. In addition, the plug shall have a bright yellow warning tag informing the user in several languages to connect or plug all ports as required by the service. The seal will be shipped with a plastic bag containing the correct metal plugs, in the correct material and with a seal assembly drawing illustrating the piping connection requirements.

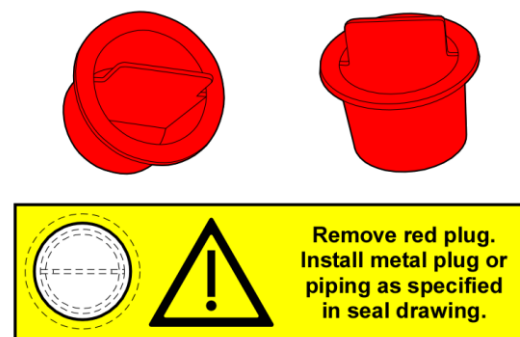


Figure 6. Illustration of plug and label

Many common seal designs have components which must be assembled onto the seal sleeve. It is critical that these be located correctly to provide the proper seal loading and axial motion capability. In the earlier editions of the standard, this concern was addressed by requiring that the seal sleeve

have a shoulder for positively locating the components in the correct location. The Fourth Edition recognizes that there are other means of achieving this such as dog point set screws (with locating holes) and pins.

It is critical that seal sleeves have an adequate thickness to maintain the required cylindricity for assembly, installation, and removal. In the previous editions, this was listed as a minimum of 2,5 mm [0.100'] at the thinnest section. The definition of the thinnest section included the groove for the setting plate slot. In the Fourth Edition it was recognized that the setting plate slot is a local feature (much like the holes for the drive collar) and did not reduce the rigidity of the sleeve. The thickness requires remain the same with the exemption of the setting plate slot.

Set screws are the most common method for attaching a seal drive collar to the pump shaft. The assembly method, while fairly simple, is based quite a number of assumptions. The set screw, when installed, must penetrate into the shaft plastically deforming the shaft around the point of the set screw. This requires that the set screw material is harder than the shaft and that it is installed with adequate force to properly seat into the shaft. The resulting load in the set screws prevents the screw from backing out in most applications. When designing a drive collar or locking device with set screws the designer must consider the ultimate holding capacity of the assembly. Adding additional set screws will increase the load rating but not in an additive manner. The standard also limits the number of set screws to less than nine without customer approval.

To help the designer correctly design the set screws capacity of the drive collar, the Fourth Edition provides guidance on estimating the set screws load capacity. The standard also introduces the requirement that the load rating must be at least 150% of the load generated by the seal design at maximum pressure for the seal category. Examples for these calculations are shown in the Annex F.

Seal face materials are one of the most critical design factors of any seal and they have received special attention in all of the editions of the standard. For Category 1 seals, the basic requirement has previously been for premium grade, blister resistant carbon versus self-sintered silicon carbide (SSSiC). The selection of SSSiC was driven by the superior chemical compatibility characteristics of this material in chemical duty

applications. For Category 2 and 3 seals, the requirement previously was for premium grade, blister resistant carbon versus reaction bonded silicon carbide (RBSiC). This SiC was selected due its long record of excellent performance in refinery services.

In practice however, the selection of face materials is more complex and, for a variety of reasons, seal OEMs may select materials differently than these default selections. For example, it is critical that SSSiC is used in caustic services regardless of the seal Category. In most cases, resin impregnated carbons are used although in light hydrocarbons, metallized carbons provide superior performance. Metallized carbons may also provide better performance under high pressure conditions due to a higher stiffness and better heat transfer characteristics.

In the Fourth Edition, all seals, regardless of the seal Category will be have default face materials of premium grade, blister resistant carbon vs either SSSiC or RBSiC. The seal OEM and user will determine the specific grade which is best suited for the specific application. In addition, other materials such as graphite loaded SSSiC, graphite loaded RBSiC, and tungsten carbide can be used with purchaser's approval. All materials are considered to be homogeneous and all must have been qualified through the seal qualification procedures.

Elastomer gasket materials are used as secondary seal throughout most seal assemblies. These often take the form of O-rings although other shapes are also used. The selection of elastomeric materials depends primarily upon the required chemical compatibility and durometer (hardness) required by the design. Fortunately there are a wide variety of compounds to choose from in standard O-ring sizes. API 682 has historically had very few requirements for elastomers. The basic elastomer was a fluoroelastomer (FKM) with options for perfluoroelastomers (FFKM) for more aggressive services. The Fourth Edition adds additional requirements. The standard will now require that materials have a proven track record (two installations with a least one year operation). Elastomer requirements have also been tied to the seal qualification testing.

Type B seals are designed for general duty application in heavy duty pumps (API 610). The standard material of construction requires Alloy C276 bellows for improved physical properties and





chemical resistance. This applies only to the bellows core (diaphragms). In the Fourth Edition, there is an additional allowance for the use of Alloy 718 for the bellows. This can have improved corrosion resistance in some applications. This seal would still have elastomer secondary seals so it would not be substitute for a Type C seal.

Internal circulating devices (often called “pumping rings”) are devices which provide circulation from a seal cavity to an external accessory device and back. These are most commonly used on Plan 23, Plan 52, and Plan 53 systems. The actual design of the device is not covered in the specification but there are some design features which are noted. The porting in the seal gland will have the fluid outlet at the top (to allow venting) and the inlet at the bottom of the gland as space allows. This helps promote thermosyphoning. Designs for the circulation device include considerations such as tangential ports, cutwaters, dams, and the selection either an axial flow or radial flow device designs. The pumping ring performance must meet performance criteria determined by temperature rise in the piping plan.

## REQUIREMENTS FOR SEAL CATEGORIES

A Seal Category defines a set of requirements covering the features, materials, operating window, and intended equipment. In general terms, a

Category 1 seal is intended for chemical duty pumps. A Category 2 seal is a seal with limited features and is intended for heavy duty pumps. A Category 3 seal is a seal with full features and is also intended for heavy duty pumps. Some of the implications of the Seal Category include injection design and throttle bushing requirements. There are also documentation and testing requirements tied into these definitions.

Seal Categories were originally introduced to address the concerns of supplying a full featured (and often more expensive) seal into an application where a high level of sophistication and features was not required. The Category 1 and 2 seals have been used most extensively with Category 3 used more sparingly in demanding or critical applications.

In the Fourth Edition, the higher level design features of a Category 3 seal have been placed onto the Category 2 seals. All Category 2 seals must now have distributed flush arrangements. All Category 2 seals must have floating carbon throttle bushing. There is also an option to specify a segmented carbon bushing in Category 1 and 2 seals if additional leakage restriction is required.

The only effective differences between Category 2 and 3 are now the testing, seal qualification, and documentation requirements.

Table 2. Comparison of Requirements of Seal Categories

Feature	Category 1	Category 2	Category 3
Seal chamber size	ASME B73.1 and ASME B73.2	API 610	API 610
Temperature range	-40°C to 260°C (-40°F to 500°F)	-40°C to 400°C (-40°F to 750°F)	-40°C to 400°C (-40°F to 750°F)
Maximum pressure, absolute	20 bar (315 PSI)	40 bar (615 PSI)	40 bar (615 PSI)
Face materials	Premium blister resistant carbon versus silicon carbide	Premium blister resistant carbon versus silicon carbide	Premium blister resistant carbon versus silicon carbide
Distributed flush required for single seals with rotating flexible elements	When specified by purchaser or required in low vapor pressure margin applications	Required	Required
Throttle bushing requirements for single seals	Fixed carbon bushing required. Purchaser may specify floating carbon bushing	Floating carbon bushing required	Floating carbon bushing required
Scope of vendor qualification test	Tested as Category 1 seal unless core components have been qualified as Category 2 or 3	Tested as Category 2 seal unless core components have been qualified as Category 3	Testing required as complete cartridge assembly
Proposal data requirements	Minimal	Minimal	Rigorous
Contract data requirements	Minimal	Minimal	Rigorous

## ACCESSORIES

Seal accessories can be defined as any piece of hardware which is required to support the mechanical seal or the seal piping plan. These include such items as an orifice, seal cooler, or seal barrier fluid reservoir. API 682 has historically defined design characteristics of accessories and, over time, these have increased in scope to cover more accessories. In addition, the level or detail and specificity of the requirements have increased. The Fourth Edition carries over most of the requirements from previous editions but has added these new accessories.

### *Air Coolers*

Air cooling is a useful alternative for piping plans when external utilities (such as cooling water) are not available. Air coolers are also often the only solution when high temperatures fluid must be cooled due to the potential of fouling in water cooled seal coolers. The standard places many of the same requirements on water cooled and air cooled seal coolers such as tags (venting of Plan 23 systems), tubing (minimum 0.500", 0.065 wall 316 stainless steel), and over pressurization protection. In addition, seal cooler sizing is now based on application conditions and not the pump shaft size as was done in previous editions. Fins may be aluminum or stainless steel.

### *Strainer*

While strainers have been used sparingly in most seal applications, they are supported in the defined piping plans. Strainers are limited to minimum mesh size 125um.

### *Reservoirs*

Reservoirs have specific requirements which have been carried over from previous editions. These include materials of construction, port locations, instrumentations, and dimensions. The standard specified that the working volume of the barrier or buffer fluid must be either 3 gallons (for shaft sizes smaller than 2.500") or 5 gallons (for shaft sizes greater than 2.500"). In the Fourth Edition, the size requirement is expanded to require that working volume is sufficient for a minimum of 28 days of operation without the need to add additional barrier or buffer fluid.

### *Bladder Accumulators*

Bladder accumulators are used to provide pressurization of the barrier fluid in Plan 53B systems. The expansion of the bladder allows the system to make-up lost barrier fluid leakage while providing feedback on seal performance through a pressure drop in the system. One of the challenges in selecting a bladder accumulator is selecting a size which allows for longer periods of time without operator intervention while not experiencing a large fluctuation in pressure. Annex F in the Fourth Edition is an excellent tutorial on how to size, pre-charge, and operate a Plan 53B system in operation.

To support these efforts, the standard will define some basic characteristics of an accumulator. Standard sizes are 20 L [5 gal] and 35 L [9 gal] depending upon shaft size. These sizes were selected to provide a minimum of 28 days of operation without operator intervention. The shell of the accumulator shall be carbon steel and the bladder material will be recommended by the manufacturer based on available options and operating conditions. Because Plan 53B pressures can vary with ambient temperatures, a pressure alarm with a temperature bias is recommended. Tags and labeling requirements are also included.

### *Piston Accumulator*

A piston accumulator is used to provide barrier fluid pressurization in Plan 53C systems. This consists of a piston with different hydraulically loaded areas which provides pressurized barrier fluid based on a reference pressure in the pump. The accumulator is defined in two sizes: maximum 2,8 L [0.7 gal] for shaft sizes 60mm or less and maximum 5,1 L [1.28 gal] for shaft sizes larger than 60mm. The metallic material should be the same as the seal gland and the gasketing elements (O-rings, lip seals) shall be suitable for exposure to both the process and barrier fluid.

### *Collection Reservoir for Liquid Leakage*

Liquid leakage which leaves the seal gland can be collected with a Plan 65 and Plan 75. The Condensate Collection Reservoir, used with a Plan 75, had been defined in previous editions. Even though the Plan 65 has been defined and used extensively in some industries, there has been no attempt to create a definition for a standard Plan 65 detection vessel. The Fourth Edition defines that

the Plan 65 system is considered part of the pressure boundary and is subject to pressure requirements of the rest of the seal support system. The reservoir shall have a capacity of at least 3 L [0.75 gal] and be equipped with a locally indicating level transmitter. The collection reservoir should be constructed from schedule 40 pipe.

### SEAL TESTING – AIR TEST

The First Edition introduced the concept of air testing of seal assemblies prior to shipping. This was intended to perform a quality check on the assembly and identify face distortion, gross damage or missing gaskets. This testing has been very successful and may be one of the most significant contributions from the standard. There have been some discussions on the allowable size of the testing vessel and the allowable leakage rates.

As the scope of the standard has increased, it has made it difficult to apply the same test criteria to all seals. For example, some seal designs (gas seals or containment seals) may be designed to operate on a slight leakage. Other designs such as dual pressurized seal assemblies have such a small volume between the seals that the tests are very sensitive. The standard notes these testing challenges but does not change the test pressure or acceptance criteria from previous editions. When testing at 1,7 bar [25 PSI] the pressure drop cannot exceed 0,14 bar [2 PSI] in five minutes.

### SEAL TESTING - QUALIFICATION TESTING

Seal qualification testing is an attempt to demonstrate that the mechanical seals offered in compliance with API 682 have a reasonable assurance that they can meet the performance and life expectations in the standard. While this seems to a trivial matter, the reality is that it requires a thoughtful approach to address the many different options, designs features, materials, arrangements, and seal types available in the standard. This process began with liquid seal qualification testing in the First Edition and expanded to include gas seal and containment seal testing in the Second Edition. While most of the qualification testing remains the same as previous editions, the Fourth Edition introduces a few new requirements and test procedures.

One of the challenges for seal OEMs is to perform the required testing for the correct options. There are literally thousands of combinations of variables which could be tested. Seal OEMs have invested millions of dollars in testing to comply with the standard and it is problematic to introduce new test requirements especially if it voids previously valid testing. For this reason, API 682 has created a common sense balance between testing and benefits. One of the methods used to achieve this is to allow for evaluating “core seal components” and then reusing them in different designs without additional qualification testing.

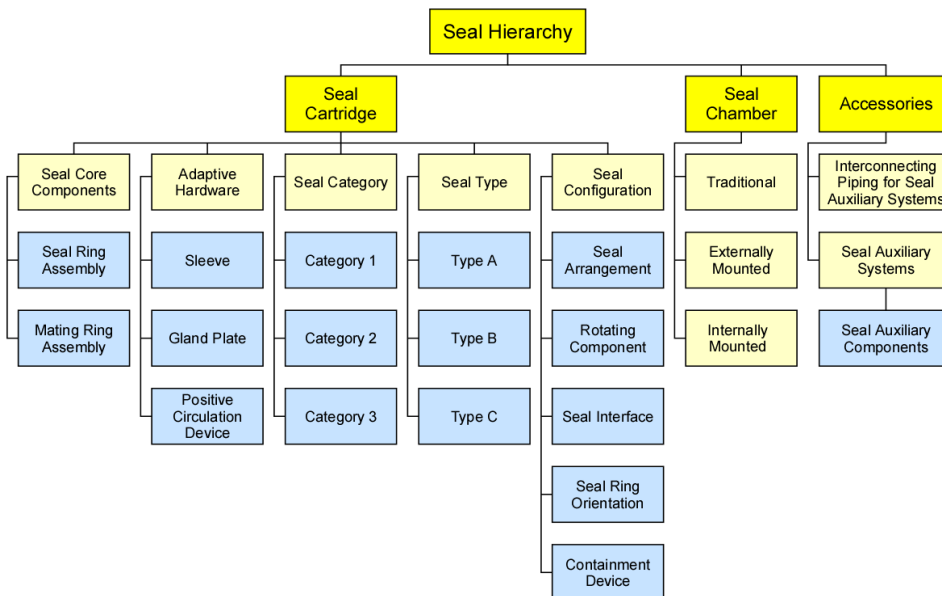


Figure 7. Hierarchy of Mechanical Seals

This is one of the key differences between Category 2 and Category 3. The problem within the standard was that it did not specifically define what is considered “core seal components.”

The Fourth Edition addresses this by setting up a hierarchy of seal parts (Figure 7.) The core components consist of the seal ring and mating rings. Adaptive hardware consists of sleeves glands and circulating devices. Seal Categories, Types, Configurations complete the description of the seal cartridge. These definitions are used to describe how core seal components can be shared among different seal models and categories.

In the First Edition, testing dual seals required that the inner seal be tested as an individual test followed by an evaluation of the complete dual seal assembly. These requirements continued in the Second and Third Editions even as the standard added additional options for face-to-face and back-to-back orientations. There were some serious technical difficulties with applying the test requirements to these new orientation options since the seal would be exposed to operation with high ID pressurization. This limitation was so severe that no seal OEMs offered these as an option.

To address this concern, a new procedure was developed to demonstrate the performance of dual liquid seals in face-to-face and back-to-back orientations. The complete seal assembly must be tested and be accepted according to the existing dual liquid seal test criteria. In addition to this test, the seal must demonstrate its ability to survive reverse pressurization and upset conditions which might be experienced in service. After operating at steady state conditions, the inboard side of the seal will be flooded with liquid and brought up to base point conditions. The barrier fluid will then be decreased to 0 bar [0 PSI] for one minute to demonstrate the seals ability to handle high reverse pressure. The barrier fluid will be re-pressurized and reach equilibrium. The seal then be shut down and sit statically for one hour with full base point conditions on the inner seal and no pressure in the barrier fluid system. This will demonstrate the seal ability to seal process fluids with a loss of barrier pressure.

Another consideration in qualification testing is the requirement for evaluating seal face materials. A seal qualification test is not only defined by the seal model, size, and test fluid but also the face material combination. To minimize

testing requirements and encourage the introduction of new face materials, the standard allows face material combinations to be qualified as a mating pair and used across multiple seals with a single test. When a seal is qualified on with a specific mating pair on a specific fluid, any other qualified seal may use the same mating pair in the same fluid without additional testing.

Due to the complexity of the qualification testing procedures, the detailed protocol for qualification testing of seals was moved to the annex of the standard. This re-organization simplified the standard for the majority of users while providing the necessary details required by seal manufacturers to accurately and consistently conduct tests. Annex I also provides a historical perspective on the qualification testing and the intent of the testing.

Annex I of the standard illustrates how qualification testing for different seal configurations has generally been organized by seal manufacturers (Table 3). While the design details may vary, the basic seal configuration largely dictates the qualification test scope, procedure and fluid. Due to the large number of possible combinations of these parameters (approximately 4000) it is unlikely that seal manufacturers have tested or will test all possible combinations in all possible qualification test fluids. Instead, seal manufacturers often first focus their testing efforts on the defaults of API 682, their own most popular products and the most representative test conditions for specific service applications. Users should verify that the required seal qualification tests have been performed for their intended application.

## SEAL SELECTION PROCEDURE

API 682 provides guidance on selecting mechanical seals for specific applications. This is an informative annex which means that it only provides guidance and is not a requirement of the standard. Although chemical and petrochemical industries are now covered by API 682, this selection procedure does not attempt to cover every application due to the myriad of process fluids involved in these industries. The procedure is a series of steps that directs the user to collect information on the application, regulations, and local requirements. This information is used

Table 3. Organization of Seal Qualification Testing

Seal design parameters <sup>a</sup>						Test parameters <sup>b</sup>		
Category	Seal balance diameter mm	Face material pair	Type	Flexible element	Configuration	Scope	Procedure	Fluid
1	38 to 75	Carbon/SSiC	A	Rotating	1CW-FX	Inner Seal	Dynamic, static and cyclic phase according to I.4.1 approx. 100 h	Water Propane NaOH Oil hot Oil cold
					1CW-FL <sup>c</sup>			
					2CW-CW <sup>c</sup>	Inner Seal and Arrangement		
					2NC-CS			
	>75 to < 127				3CW-FB <sup>c</sup>	Arrangement		
					3CW-BB			
					3CW-FF			
					3NC-BB <sup>c,e</sup>			
	3NC-FB <sup>e</sup>							
2	50 to 75	Carbon/RBSiC	B	Stationary	2CW-CS <sup>d</sup>	Only Containment Seal	Dynamic and static phase according to I.4.5 approx. 200 h	Nitrogen, Oil or Diesel, and Nitrogen, Steam, or Propane according to Table I.3
		SSiC/SSiC	C		2NC-CS <sup>d</sup>			
3	>100 to < 127	RBSiC/RBSiC			3NC-BB <sup>c,e</sup>	Arrangement	Variable barrier gas pressure according to I.4.6 approx. 1 h	Nitrogen
				3NC-FB <sup>e</sup>				
				3NC-FF <sup>e</sup>				

<sup>a</sup> A test seal cartridge is specified by the parameters in this column and the representative materials and geometry of its core seal components. In dual seals combinations of face material pairs, types and flexible element positions are possible.

<sup>b</sup> For a specific service, a seal vendor's commercial product only needs to be tested in the representative test fluid.

<sup>c</sup> Default

<sup>d</sup> 2CW-CS and 2NC-CS shall be tested as inner seal, arrangement and containment seal in accordance with I.4.1 and I.4.5.

<sup>e</sup> 3NC-BB, 3NC-FB and 3NC-FF shall be tested as arrangement in accordance with I.4.1 and I.4.6.

<sup>f</sup> Commercially available petroleum based diesel fuel

to select the seal category, type, arrangement, and piping plan. While there are some limitations to this approach, it has provided users with solid advice on considerations which must be made while selecting a seal. The Fourth Edition keeps the current selection procedure but also adds an alternative selection process.

One of the primary reasons why a user selects a specific seal arrangement is to mitigate process fluid leakage to atmosphere. Seals which pump relatively benign process fluid can easily be sealed with a single seal because leakage to the atmosphere is not critical or can be easily controlled. Arrangement 2 seals can provide addition leakage control by capture leakage across the single seal and collecting it for proper disposal. Some small amounts of process fluid may leak to the atmosphere. If no leakage is allowed, a user will often select an Arrangement 3 seal which prevents leakage by virtue of the high pressure barrier fluid. The larger question is however, when

should I use each of these options? How does a user know when leakage is considered hazardous?

In Fourth Edition, an alternative method was presented based on methodology proposed by Michael Goodrich. This alternative method is primarily directed towards selection of the sealing arrangement using Material Data Sheet information. The alternative method takes into account the toxicity of a process fluid and not just its physical properties. The selection is based on the fluid hazard code according to the United Nations Globally Harmonized System of Classification and Labeling of Chemicals (GHS) and the European Union Regulation on the classification, and packaging of substances and mixtures. The substances are categorized in "H" statements and "R" codes. Tables are provided placing the H statement or R code into a one of four groups. A Seal Selection Logic is then provided based on these groups to select the seal arrangement including the additional need for a floating carbon bushing for Arrangement 1 seals.

This seal selection takes into account exposure limits for hazardous or toxic chemicals and mixtures of these chemicals, and is thus a benefit to a broader audience, not just petroleum refining based processes.

It is important to note that a hazard assessment is only one criterion which must be considered. Other consideration such as the fluid properties, dry running of the equipment, seal leakage detection strategies, leakage disposal options and process contamination must also be considered before making a final selection.

### DATA SHEETS AND DATA TRANSFER

API 682 has contained data sheets in every edition and these have continually evolved in response to user feedback and the needs of the standards. These serve not only as a means to communicate operating conditions and purchasing specification but also to specify between the many options used in the standard. The Fourth Edition will contain a two page data sheet and, unlike previous editions, it will cover all of the seal categories. Data sheets are available in either SI or U.S. Customary Units. The data sheet as developed by the Task Force has intelligence built into the

selections by activating or deactivating cells based on the selections. It is not clear how these will be distributed during the release of the standard.

The transfer of required data and documents is the joint responsibility of purchaser and vendor. Annexes C, E and H of the standard include representative forms and checklists. It is not necessary to use the exact forms from Annexes C, E and H but those forms contain all the information to be transferred.

### SEAL CODE

A seal code is a clear method of communicating the basic specification for the mechanical seal. While API 682 has introduced new seal codes with each edition, there has been reluctance from industry to abandon the old five digit API 610 seal code (e.g. BSTFN). The primary problem with the old seal code is that it does not apply to the requirements and definitions in API 682. In the Fourth Edition, the Task Force attempted to address this by introducing a new seal which contains elements of the old API 610 code (Table 4).

Table 4. Seal Code Description

Seal			Design Options			Size	Plans
Category	Arrangement	Type	Containment Device	Gasket Material	Face Material	Shaft size mm	Piping Plan
1	2	A	-	P	F	O	- 050 - 11/52

**Category** designated as 1, 2, or 3

**Arrangement** designated as 1, 2, or 3

**Type** designated as A, B, or C

**Containment Devices**  
L – plain bushing  
F – fixed bushing  
C – containment device  
S – segmented bushing

X – unspecified

**Gasket Material**  
F – fluoroelastomer (FKM)  
G – PTFE spring energized  
H – nitrile  
I – perfluoroelastomer (FFKM)  
R – flexible graphite  
X – unspecified

**Face Materials**  
M – C vs Ni-WC  
N – C vs RBSiC  
O – RBSiC vs Ni-WC  
P – RBSiC vs RBSiC  
Q – SSiC vs SSiC  
R – C vs SSiC  
S – Graphite loaded RBSiC vs graphite loaded RBSiC  
T – Graphite loaded SSiC vs graphite loaded SSiC  
X – Unspecified

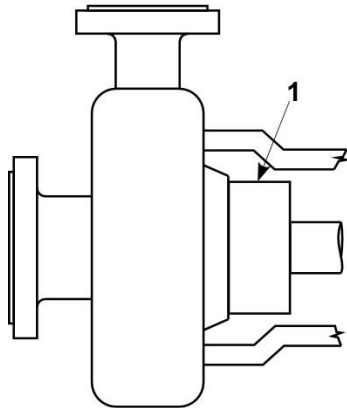
**Shaft Size** designated as nearest largest size in three digits  
Example: 20mm designated 020

**Piping Plan** designated by plan number separated by “/” if required  
Example: 11/52

## PIPING PLANS

A seal piping plan is designed to improve the environment around the mechanical seal and therefore increase the performance and reliability of the seal. Piping plans range from very simple systems such as fluid recirculation into the seal chamber to complex systems which provide pressurization, cooling and circulation for support fluids and gases. The standard not only defines the basic operation of the piping plan but also the requirements for instrumentation and the design of seal support equipment.

In the latest revision to API 682, the majority of the piping plans are carried over from the previous edition without any modifications. There are however several overall changes to existing piping plans as well as the addition of several new piping plans.



### *Modifications to Existing Piping Plans*

One of the most significant changes in API 682 Fourth Edition is the move from switches and indicators to transmitters. Historically, piping plans used switches to detect if a pressure or level has exceeded a certain value. Operators monitored parameters such as pressure, temperature, or level by visually watching indicators or gauges. In the Fourth Edition, piping plans have moved to a design requirements where transmitters, with local indicators, are the default selection for monitoring piping plan parameters. This still allows the operator to visually monitor the parameters at the equipment but also monitor them in the control room through the continuous output from the transmitter.

## NEW PIPING PLANS

### *Plan 03*

Historically, a mechanical seal installed into a closed seal chamber with no circulation was defined as a Plan 02. This was used primarily in low duty applications, high temperature services, or process fluids with a high solids content. In more recent years, pump OEMs have engineered pump designs which create a circulation of process fluids in and out of the seal chamber to provide seal cooling. This is primarily done by using a tapered seal chamber with flow modifiers to create the circulation. This eliminates the need for common piping plans such as a Plan 11. These designs are most commonly used on smaller, lower duty pumps such as ASME B73 in chemical duty services. The Plan 03 was introduced to define this method of providing circulation for the mechanical seal (Figure 8).

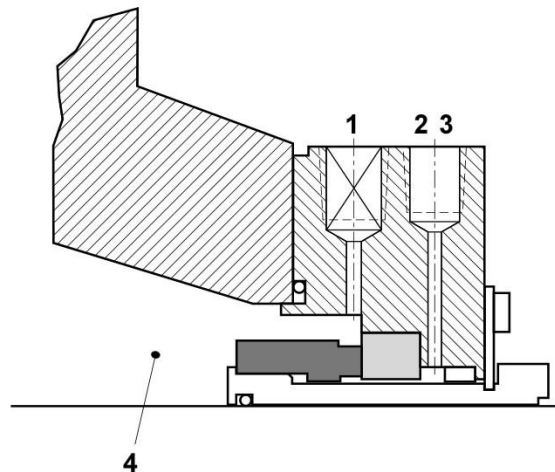


Figure 8. Plan 03

### *Plan 55*

Dual mechanical seals are divided into two basic modes of operation. They can be operated as an Arrangement 3 seal with a barrier fluid maintained at a pressure greater than seal chamber pressure. They can also be operated as an Arrangement 2 with a buffer fluid maintained at a lower pressure than the seal chamber pressure. Arrangement 3 seals have historically had an piping plan option which allowed for circulation of the buffer fluid from an external source. This was defined as a Plan 54. There was no comparable piping plan defined for the circulation of an unpressurized buffer fluid from an external source for Arrangement 2 seals. At the request of end

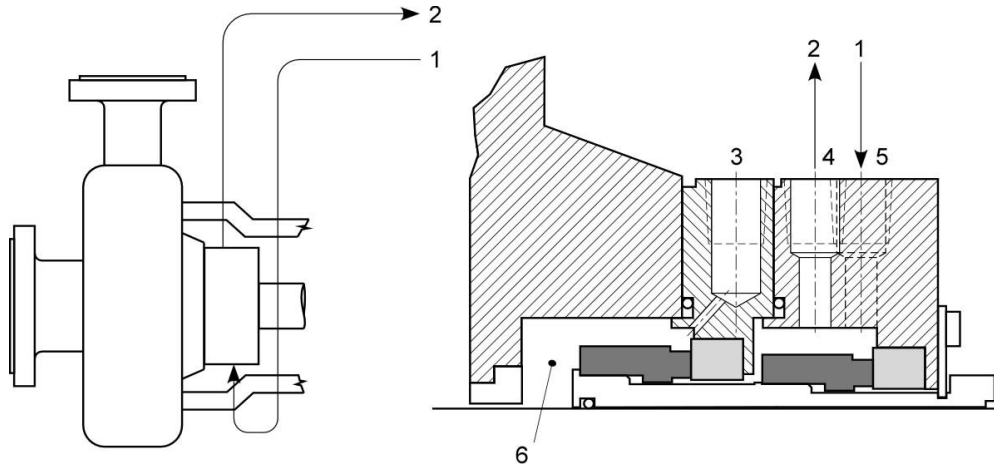


Figure 9. Plan 55

users on the API committees, the Plan 55 was introduced to provide this option (Figure 9). A Plan 55 is defined as the circulation of a low pressure buffer fluid to an Arrangement 2 seal. Just like the Plan 54, the details of the design of a Plan 55 system are outside the scope of API 682 since they are so varied and depend heavily of the requirements of the specific installation and industry.

*Plan 65A and Plan 65B*

Plan 65 has historically defined a method of detecting atmospheric leakage from a seal. This was done by directing the leakage from the seal gland or pump bracket to a ground level detection vessel which contained an orifice in the drain line. If a high rate of leakage was flowing into the

detection vessel, the fluid level in the vessel would increase and would be detected by a level switch indicating a seal failure. The two primary aspects of this plan were that it detected a high flow rate and was only instrumented with a level switch.

In the Fourth Edition, end users recommended allowing for an option to detect leakage by measuring accumulated leakage. In this plan, the liquid would flow from the seal gland or pump bracket into a closed collection vessel. As the leakage collected over time, the level in the collection vessel would rise and provide information of the performance of the seal. This plan will require that the operator periodically drain the collection vessel to allow for continuous operation.

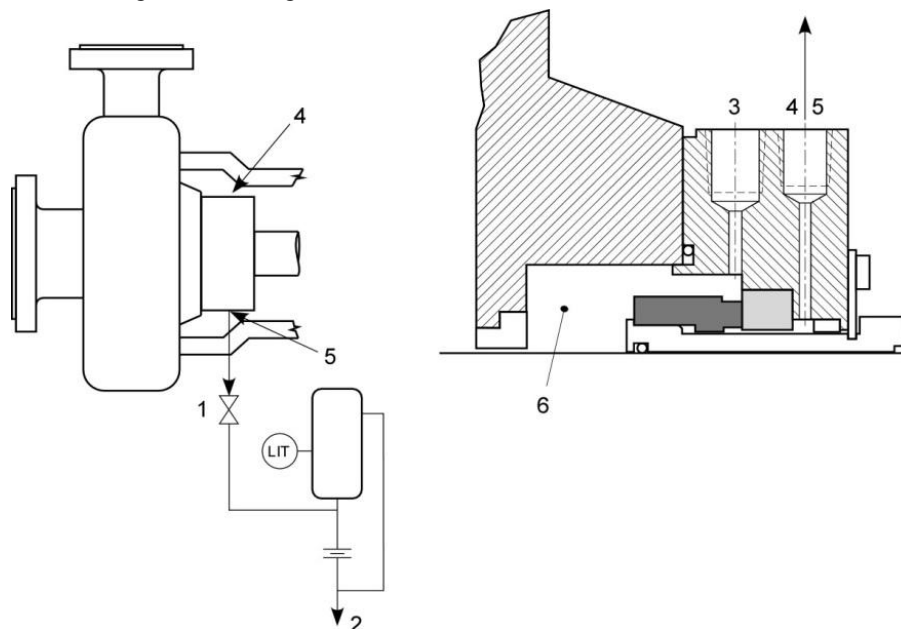


Figure 10. Plan 65A



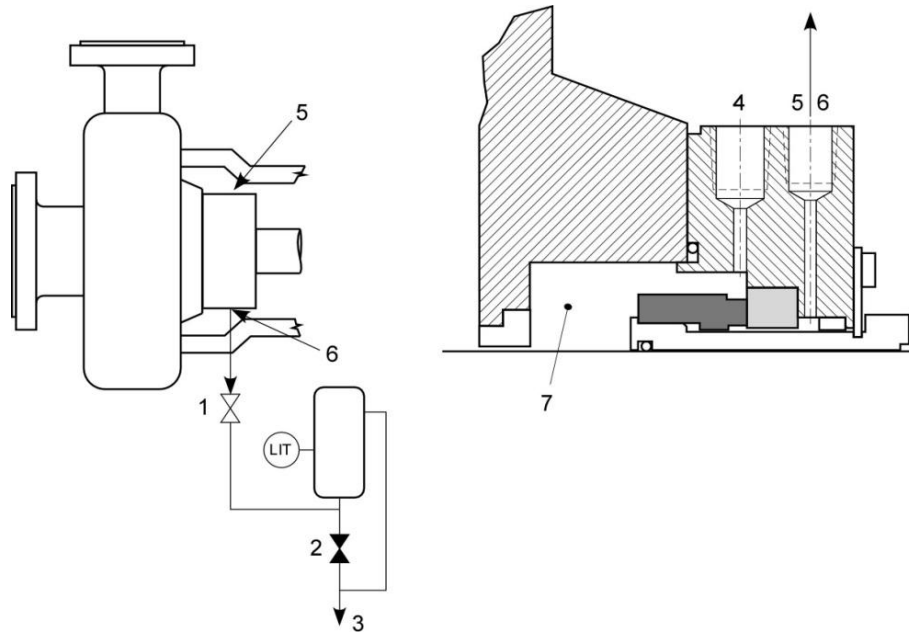


Figure 11. Plan 65B

To distinguish between the two options, the first method, detection of a leakage rate, has been designated as a Plan 65A (Figure 10). The second, new piping plan which detects accumulated leakage has been defined as a Plan 65B (Figure 11). Both of these plans require by default the use of a level transmitter to allow for trending of the level in the collection vessel. Both of these plans are considered as technically equivalent and can be used to satisfy the requirements of a Plan 65.

#### *Plan 66A and Plan 66B*

These two piping plans are new editions to API 682 and ISO 21049. They were introduced to capture methods of detecting seal failures and were primarily used in the pipeline industry. The two primary objectives of these piping plans are to allow for early detection of seal leakage and to minimize seal leakage from leaving the seal gland.

A Plan 66A achieves this by installing two close clearance throttle bushings into the seal gland behind the seal face. Leakage from the seal will be restricted by the inner bushing and increase the pressure behind the seal face. This will be detected by a pressure transmitter in this cavity. As leakage flows past the seal it will flow into the drain cavity at a low pressure and be directed into the drain and Plan 65 system (Figure 12).

The option for a Plan 66B allows the variation of providing only one close clearance bushing in the gland and a plug orifice in the drain line. Leakage past the seal face enters the drain cavity and is partially restricted from flow out of the drain. If the leakage rate is high, the drain cavity will become pressurized and will be detected by a pressure transmitter connected to this cavity. While this variation is not as sensitive as the Plan 66A option, it can be easily adapted into existing seal glands (Figure 13).

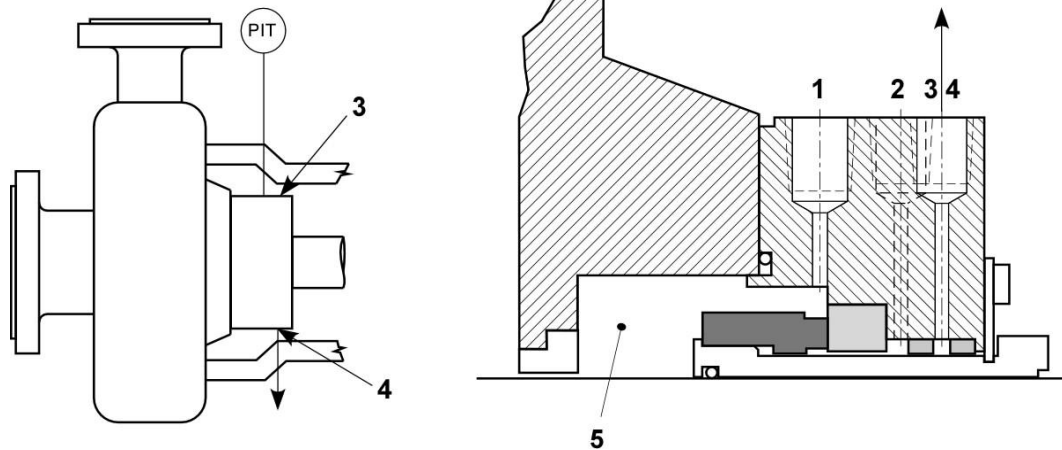


Figure 12. Plan 66A

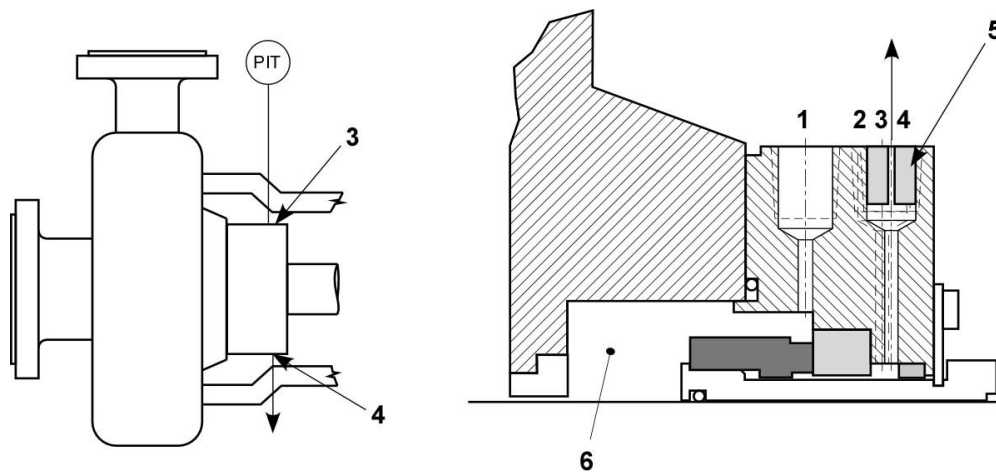


Figure 13. Plan 66B

*Plan 99*

One of the challenges with defining and using seal piping plans is that different users may want to provide slight variations to the defined plans. Very slight changes, such as changing a pressure indicator to a pressure transmitter, has historically been done without changing the designation of the piping plan. There are however cases where the changes are significant and may require different instrumentation or operating procedures for the equipment. Piping Plan 99 was introduced to address this situation.

A Plan 99 is an engineered system which must be fully defined in the project or purchasing specification for the system. There are no defined objectives for the plan or no defined equipment required. The Plan 99 may be a simple addition to an existing piping plan or an entirely new piping

plan. There is an expectation that all applicable requirements of the standard for instrumentation, design guidelines, or auxiliary equipment that is applicable to the Plan 99 will be applied.

**CONCLUSIONS**

API 682 continues to evolve to meet the needs of seal users and manufacturers. The Fourth Edition has been developed to address advances in seal technology and expand the scope of applications beyond that covered in the first, second and Third Editions. Additional piping plans and seal qualification testing have been added to Fourth Edition. While there have been changes, the objectives of the standard have remained the same: to provide longer seal life while meeting emissions requirements. The resultant document will continue to serve as the

most significant standard for mechanical sealing systems in centrifugal pumps.

Mechanical Engineering, Texas A&M University, College Station, Texas.

### ACKNOWLEDGMENTS

The authors would like to thank the American Petroleum Institute for its cooperation and permission to publish this paper. The authors also wish to extend their gratitude to all members of the API 682 Task Force whose tireless work and dedication made this paper possible. Special recognition goes to the API 682 Task Force Chairman, Mr. Rick Eickhoff, for his leadership, patience and sacrifices throughout the development of this standard.

Goodrich, Michael, 2010, "Risk Based Pump-Seal Selection Guideline Complementing ISO 21049/API 682", Proceedings of the 26th International Pump Users Symposium, Turbomachinery Laboratory, Department of Mechanical Engineering, Texas A&M University, College Station, Texas.

### REFERENCES

API Standard 610, Tenth Edition, 2004, "Centrifugal Pumps for Petroleum, Heavy Duty Chemical, and Gas Industry Services", October 2004; ISO 13709: 2003; American Petroleum Institute, Washington, D. C.

Huebner, M. B., Thorp, J. M., Buck, G. S., Fernandez, C. L., 2001, "Advances in Mechanical Sealing – An Introduction to API 682 Second Edition," Proceeding of the Nineteenth International Pump Users Symposium, Turbomachinery Laboratory, Texas A&M University, College Station, Texas, pp. 59 – 65.

API Standard 682, First Edition, 1994, "Shaft Sealing Systems for Centrifugal and Rotary Pumps," American Petroleum Institute, Washington, D.C.

ISO/FDIS 21049:2011(E), 2011, "Pumps – Shaft Sealing Centrifugal and Rotary Pumps," International Standard Organization, Geneva, Switzerland

API Standard 682, Second Edition, 2001, "Pumps – Shaft Sealing Systems for Centrifugal and Rotary Pumps," American Petroleum Institute, Washington, D.C.

Lavelle, Kenneth E., Key, William E., Grace, Ronald L., Young, Lionel A., Wang, George and Holman, Al C., 1993, "Improvement of a High Temperature Bellows Seal", Proceedings of the 10th International Pump Users Symposium, Turbomachinery Laboratory, Department of Mechanical Engineering, Texas A&M University, College Station, Texas.

API Standard 682, Third Edition, 2004, "Pumps – Shaft Sealing Centrifugal and Rotary Pumps," American Petroleum Institute, Washington D.C.

Arnold, T., Fone, C, 2010, "Mechanical Seal Performance and Related Calculations," Proceeding of the Twentysixth International Pump Users Symposium, Turbomachinery Laboratory, Texas A&M University, College Station, Texas, pp. 97 – 111.

Buck, Gordon S., 1993, "Implications of the New Pump Shaft Sealing Standard", Hydrocarbon Processing Magazine, Gulf Publishing Company.

Gabriel, Ralph and Niamathullah, Syed K., 1996, "Design and Testing of Seals to Meet API 682 Requirements", Proceedings of the 13th International Pump Users Symposium, Turbomachinery Laboratory, Department of