# Understanding Leakage – Engineered Sealing Solutions for Nuclear Power

In the nuclear power generation industry, safety is the fundamental principle around which all practices revolve. From uranium mining and fuel fabrication to electricity generation, reactor heating and the treatment and storage of radioactive waste and spent fuel, nuclear power generation demands the utmost attention to safety standards. As such, the scientific and technical understanding of the risks surrounding nuclear energy production and the technical solutions required to limit or eliminate hazardous factors are paramount to ensuring the safety of all those involved. Nuclear industrial entities, utilities, organizations, authorities and others in the industry are committed to safety principles, technology and culture. However, public perceptions of risks are often driven by many other factors, and, in some countries, by political movements that strongly support negative attitudes and perceptions.

**Leakage, Leak Tightness, Sealing – Is it That Easy?**

When used by the media, the term "leakage," as it pertains to nuclear power generation, is always a cause for alarm. Scientists and technicians in the nuclear energy industry also take the term seriously and view such issues with a results-oriented, systematic approach. The concern expressed by these professionals inherently drives safety, innovation and education, and propels the industry to the highest safety standards. A vital aspect of ensuring safety against leaks and equipment failure is presented through the use of innovative and highly reliable sealing systems.

Sealing devices and associated technologies are applied wherever joints of components or parts require the prevention of fluid or gas flow. Sealing systems are an integral part of mechanical joints for many essential systems in nuclear installations, as well as between specific systems and components. These systems often include, but are not limited to:

- Reactor pressure vessels
- Main coolant pumps
- Steam generators
- Pressurizers
- Pipes and pumps
- Heat exchangers
- Valves
- Radioactive waste and fuel element transportation and storage casks
- Gates between plant sections and buildings

Despite their small footprints relative to an entire nuclear power production installation, sealing systems play a significant role in ensuring overall safety. Reliable and efficient performance in their specific applications is of the utmost importance.

Maintaining the highest level of safety while ensuring the effective performance of a nuclear power plant comes down to one statement: "Keep it tight." However, there are many considerations involved in the implementation of such a task. The following will provide a detailed explanation of leakage, the fundamental aspects of sealing and the high-performance concepts behind engineered sealing solutions.

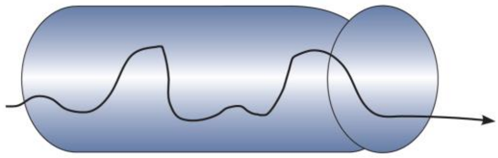
**Developing an Understanding of Leakage**

Leakage is the flow of a fluid and/or a gas through an orifice or permeation in a material, typically occurring as a result of a pressure differential. It is important to understand that all materials and mechanical joints permit some leakage over a period of time. This leakage may range from as much as several liters or cubic feet per minute to as little as a bubble of gas in several years, or even several thousands of years.

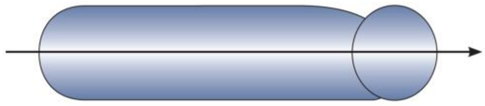
In order to design and manufacture a wide range of seals to satisfy a broad array of sealing requirements, including an acceptable leakage rate, it is necessary to establish leakage rate criteria for the selection or design of a suitable seal. A specification that defines a “no leak” or “zero leakage” requirement is, in a technical sense, unrealistic and may prove quite costly.

Leak tightness must be considered in relation to the medium being sealed, the normal operating conditions, the sealing requirements regarding safety, protection against contamination and reliable function per an applicable situation.
In characterizing leakage and performing leakage testing, the flow of gas is used. Even at very low pressures, gases behave and flow like fluids. Gas flow is categorized into three different types of flow modes: turbulent flow, laminar flow and molecular flow (Fig. 1).

Thus, leakage appears as a result of hardware failure and/or hardware design and is generally measured by pressure per volume over a period of time.



Path of a molecule through a leak path in turbulent flow.



Path of a molecule through a leak path in laminar flow.

Path of a molecule through a leak path in molecular flow.

**Fig. 1: Modes of Gas Flow**

Regarding the sealed medium, the molecular size and its relation to the width of the flow path are vital for leak tightness. The flow of media with larger molecules, like oils, is easier to seal than smaller molecules, such as helium or other light gases.

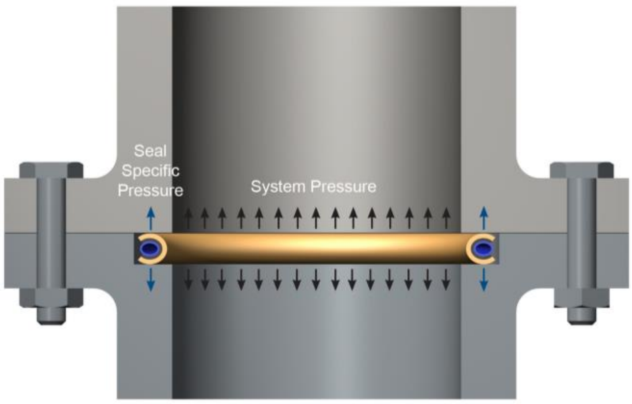



**Fig. 2: Typical Bolted Mechanical Joint**

This image (Fig. 2) features a typical bolted mechanical joint assembly, such as those used in nuclear steam supply systems in various applications. The bolted joint relies on each subcomponent to work properly and its successful performance depends on the quality and design of each of the three major subcomponents of bolted joints:

1. Flanges (including the flange design, groove dimensions and surface finish)
2. Bolts or fasteners
3. Seal and/or gasket

These three main components cannot be designed independently of each other. They must be considered together as a system during the design process. If any single part of the bolted joint assembly does not perform properly, the joint as a whole will not achieve expectations and may leak. As a result, the assembly’s leakage, and therefore its leak tightness, is a function of the clamping loads at the bolts, which defines the specific pressure of the mechanical joint. In simpler terms, the smaller the area, the higher the sealing effect.

However, the geometrical dimensions of the assembly work against the performance principle of sealing. Assemblies with large diameter mechanical joints require that the sealing performance increase by magnitudes as the “relative leakage,” defined as the leakage per millimeter circumference of the sealing in the assembly, determine the tightness performance of the entire assembled system.

System pressure and the temperature of the medium flowing inside the assembly move the structure and influence its designed mechanical and geometrical properties. All subcomponents, including the sealing components, age over time, while the electrochemical properties of metal-to-metal connections, as well as chemical ingredients or impurities of the flowing medium, drive corrosion and change surface geometry and condition.

These major influencers introduce several demands that must be fulfilled by the sealing device:

- It must follow the mechanical modifications of the assembly
- It must adapt to deformations or the changing conditions of flange mating surfaces.

In this context, we understand that sealing is a “controlling system” which, by its material and mechanical properties, regulates deforming influencers while keeping the assembly below determined leakage rates. “Elasticity” and “plasticity,” the main properties of sealing systems, can be exploited to perform controlling functionality.

This controlling system property must be maintained in nuclear steam supply operating systems over a long period of time. Generation III and Generation III+ nuclear reactors are designed for extended fuel reload intervals or extended operating cycles, often between 18 and 24 months. These operating cycles determine the frequency of regular maintenance outages.

**A Short History on Sealing Approaches**

The above principles of leakage led to the following design properties of components:

- For large, heavy flanges with large surfaces and clamping loads/compression loads:
    - Sealing was arranged within the mechanical joints as part of the mechanical structure. Gaskets were traditionally bolted to adjust the amount compression of the seals
    - Mechanical joints required intense maintenance and/or repair, and were leakage prone
    - Costs associated with construction and manufacturing of flanges were high
    - Increasing the clamping load was the principle method to ensure leakage parameters, which imposed high stresses to bolts, surfaces and sealing materials
- Graphite and high-nickel alloys were introduced to sealing technology
- Problems with flanges were tested and settled with improved sealing solutions

**Metal-to-Metal Concept**

The structural stability and elasticity of a mechanical joint is contrary to the mechanical requirements for a sealing material. Thus, the two functions of mechanical connections for structures (ensuring stability/the metal-to-metal principle) and the sealing function (elasticity and plasticity) were separated. An integrated approach to engineering for flange and sealing designs, based on the exploitation of specific material properties, made it possible to create engineered solutions for sealing tasks while achieving defined sealing performance requirements.

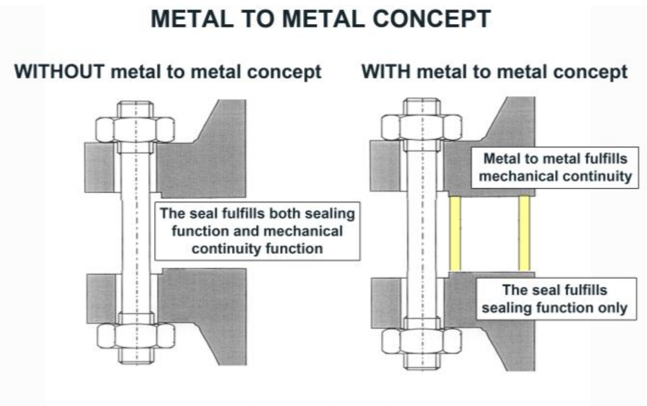


Fig 3: Metal to Metal Concept

The metal-to-metal concept provides nuclear power plant systems with the ability to seal mechanical joint assemblies together regarding the following criteria:

- Optimal seal compression
- Low elastic solicitation
- Rigidity of the assembly
- Thermal and pressure transients of the operating conditions

In our next article, part two of a four-part series, we will examine lessons learned from both installed base nuclear power plants and new nuclear facilities, including referenced examples and technical solutions for each.

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Technetics Group, a part of EnPro Industries (NYSE: NPO), provides innovative solutions for the world's most critical and demanding applications, from nuclear reactor pressure vessels to aero engines. Technetics Group is a globally trusted source for engineered components, seals, assemblies, and sub-systems that are custom-designed for high performance and extreme applications in the semiconductor, aerospace, power generation, oil and gas, medical and other industries.

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