VDMA
Fluid Power Association

23rd ISC

# International Sealing Conference

**Stuttgart, Germany**
**Sept.30 - Oct.1, 2026**

Sealing the future –
Facing the challenges of tomorrow

UNI STUTTGART

Fachverband Fluidtechnik im VDMA e. V. Lyoner Str. 18
50628 Frankfurt am Main
Germany

Phone +49 69 6603-1513
E-Mail maximilian.baxmann@vdma.eu

Internet www.vdma.eu/fluid

# Extension of the pressure and temperature operating range of spring energized metallic seals by surface texturization

**ALLEGRE Loïck, CAO Chen, KWEDER Jonathan, LEDRAPPIER Florent, JULIAA Jean-François**

As industrial systems advance toward higher efficiency, sustainability, and digital integration, sealing technologies must meet increasingly demanding functional and environmental requirements. Future energy and process applications operate under extreme thermomechanical loads and chemically aggressive conditions, making sealing integrity essential. This drives the need for innovation in materials selection, interface mechanics, and long-term reliability engineering.

Spring-energized metallic seals are designed for exceptional performance, achieving helium leak rates below $1x10^{-10}$ Pa·m³/s in harsh environments. With proper selection of internal components, metallic groove design, and suitable material choices, these seals endure high temperatures, high pressures, irradiation, long-term stress relaxation, and corrosive media such as acids, solvents, molten salts, and liquid metals. Their robustness enables use across numerous advanced industrial and energy systems.

A key performance factor is the outer layer of the seal—either a metallic coating or liner—responsible for plastically deforming to fill microscopic leak paths caused by flange surface roughness. Soft, low-alloy materials like aluminium or silver are typically used, but their applicability can be limited by media compatibility, temperature capability, lifetime expectation, and available tightening forces designed in the physical joint.

To address these limitations, a texturized spring-energized metallic seal was developed. Its engineered surface pattern increases local contact pressure and reduces required system loads, promoting effective plastic deformation of the liner into flange surface imperfections. Compared to sharp-edge solutions such as Delta seals or metal seals assemblies, the texturized seal provides a wider seal track, maintaining performance even on degraded or previously used flange surfaces.

Optimization of texturization geometry enables replacing soft liner materials with more robust options such as Nickel 201, without changing cross-section geometry or increasing required compression forces in the joint assembly. This material substitution greatly reduces long-term aging effects—especially creep of the sealing layer—under high-temperature and chemically aggressive service conditions. As a result, these kinds of texturized metallic seals offer enhanced durability, stability, and reliability for next-generation industrial and energy infrastructures.

## 1 Introduction: Background related to metallic seals behaviour

The high sealing performance for nuclear application is generally obtained by using spring energized seals [1]. Based on their physical architecture, a proper design of components allows these seals to address large temperature and pressure ranges, exposure to different medias (water, gas, lead, etc), performs in irradiated conditions, and resists corrosion. An example of this metallic seal, shown in Figure 1 and some of its characteristics are as follows:

- The design of the internal spring provides the best balance between elastic recovery, generally needed to withstand accidental unloading, the flexibility required to address large amounts of flange waviness, and the mechanical stiffness required to ensure a proper plastic deformation of the seal lining into the flange surface defects (roughness, scratches, indents, etc.).
- The seal lining itself is made of a soft metal, like pure silver, low alloyed aluminium or nickel. By nature, the permeability of this lining is much lower than any available polymeric solution, and can even be neglected in analysis in most of cases. The seal lining relies on plastic deformation to allow material to flow into the flange roughness and close all remaining leak-path at the seal-flange interface.
- An intermediate lining is sometimes placed in between the spring and the sealing lining to prevent the soft sealing lining from any damage related to the penetration of spring coils through the soft outer material.

*Figure 1: Spring energized metallic seals architecture*

These seals are typically installed in a manufactured groove designed to ensure a proper compression of each seal and help to withstand the internal system pressure. The metal-to-metal contact between flanges prevents the seals from collapsing in application and limits over-compression. The mechanical behavior of these seals is characterized by Figure 2 which presents the evolution of the linear reaction force of the seal as a function of its compression.

Several key-parameters are defined to describe the seals. Usual symbols, reported in Figure 2, correspond to the following behavior:

- Y2 (N/mm): Linear load of a seal after tightening at nominal compression (e2 mm) at room temperature,
- Y1 (N/mm): Linear load below which the leak rate exceeds a target value during an unloading in standard conditions (room-temperature and pressure differential of 1 bar)
- Rt (mm): Total elastic recovery after compression
- Ru (mm): Useful elastic recovery corresponding to the minimal point where the seal continues to achieve an acceptable leak-tightness, during unloading.

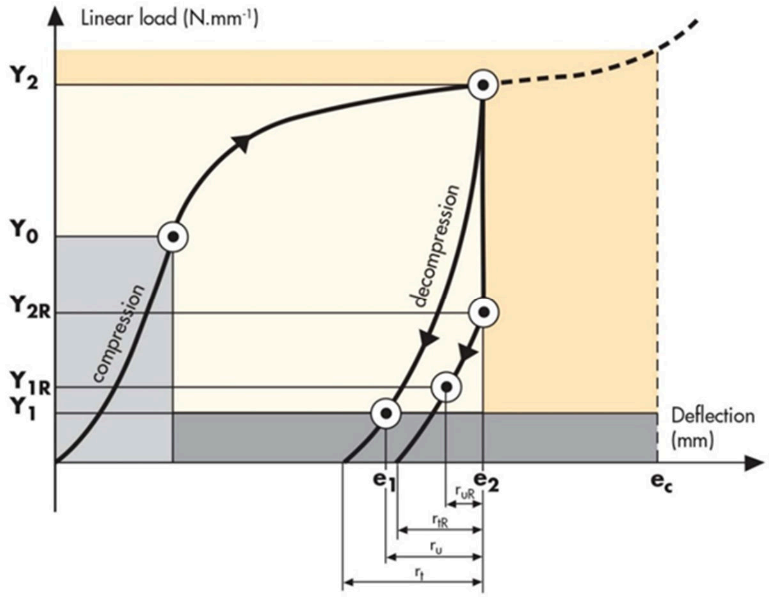


*Figure 2: Spring energized metallic seals characteristic curve*

Figure 2 also highlights the evolution of the seal behavior in service conditions, related to the softening of materials due to service or accidental temperature and finally, creep mechanisms for long-term use.

Different ageing mechanisms can contribute to reduce the seal reaction force:

- As the seal lining is compressed between the spring and the flange surface and the application temperature increases, the creep mechanism of the seal lining leads to a progressive decrease of it's the lining thickness. This effect is balanced by the elastic recovery of the spring but leads to the progressive decrease of reaction force of the seal and the overall elastic recovery illustrated in Figure 2.
- In the case of high-pressure applications, the internal pressure tends to stretch the seal and can act to increase the measured system reaction force. This increase also contributes to compress the seal lining more, leading to additional material thinning. This effect leads to a significant decrease of measured reaction force once internal pressure is removed and can be critical in case of cyclic pressure system usage.
- When seals are installed in heterogenous connections (i.e. flanges made of materials with different thermal expansion characteristics), or connections subjected to high temperature gradients due to fast thermal transients, the seals can be subjected to radial shear. This effect leads to a progressive and repeated spread of the seal lining across the seal track width, with an accumulation of plastic deformation that makes it thinner and thinner until performance failure of the sealing function.

## 2 Design of texturized metallic seals

### *2.1 Presentation of the texturized metallic seal concept*

The design of the spring energized metallic seals is driven by the choice of the sealing material, generally driven by the intended service and potential extreme exposure conditions. Based on this input, the stiffness of the spring has to be designed to be high enough to ensure the targeted sealing performance while the cross-section geometry remains fixed to maximize the elastic recovery of the seal in a way that complies with the available system compression force. As an example, for a 6 mm cross-section, the setting force needed to achieve a 1 x $10^{-8}$ Pa.$m^3$/s Standard Helium Leak Rate (SHeLR) is as follows:

- ~250 N/mm with sealing lining made of Aluminum 1050A,
- ~400 N/mm with a sealing lining made of pure silver,
- ~900 N/mm with a sealing lining made of Nickel 201.

Increasing the setting force with a given cross-section requires a stiffer spring design and leads to more plastic deformation in the spring during the initial seal compression. Ultimately, a seal with this kind of design can expect to have a smaller initial spring-back available. As a result, the softest available material is generally preferred as the seal lining, but such materials also are known to have greater creep rates and are more sensitive to the ageing mechanisms detailed above.

The TEXEAL® concept aims to change that paradigm by replacing soft material outer seal lining by texturized harder/stronger materials. As previously discussed, the analysis of the performance mechanisms of metallic seals relies on the plastic deformation of the soft seal lining onto the flange surface roughness. Designing and manufacturing small cavities into the seals' surface helps promote the plastic deformation of this material with cumulated benefits [2], [3], [4]:

- Cavities reduce the bearing ratio, resulting in greater local contact pressure, which helps the plastic deformation of the seal lining into the imperfections of the flange surfaces.
- The discontinuity in the surface of the material also provides space where the material can flow during compression, which makes it easier for the material to flow and close these leak paths due to the flange surface roughness with a given contact pressure.

The development of surface texturization techniques allows for the deployment of this concept. In this case, the use of femto-second laser technology in the industrial process enables the ablation of metal without significantly melted or thermally affected zones to be created around the laser impact. Such a process can create cavities on seals, without any modification of material behavior related to strain hardening or quenching effects. The texturization can be performed selectively only along the sealing track, as shown in the following figure reducing processing time on texturization of surfaces that will not be used to create a seal interface.


*Figure 3: Spring energized metallic seal with texturized surface*

## *2.2 Expected benefits*

Besides the possibility to reduce the compression force required for with a given seal design, the texturized metallic seal concept, with a proper design of the texturized pattern, allows the design of a seal with an outer lining made of Nickel 201 that is leak-tight with the same cross-section and the same compression force as a seal with a silver outer lining. Such a material change can have several benefits:

- The yield stress of nickel decreases more slowly than silver when the system temperature increases, which makes nickel more suitable for high temperature applications,
- The creep resistance of nickel is also drastically improved over silver, thanks in part to a higher melting point. The creep rate at a given stress level, or even normalized by the yield strength has been proved by several decades of in laboratory testing, which makes the option relevant of long-term use, with a limited relaxation [5], [6], [7].
- The yield strength of annealed Nickel 201 is not significantly different from that of silver, but the work-hardening effect of nickel is much more significant, and explains the usual difficulties to achieve a given sealing performance with the nickel lining without texturization as stated above. Once texturized, the surface behavior of the nickel is improved for a better compressive interaction with the flange roughness and reduces the contact stress of the seal to flange interface. As the untexturized material is unchanged, the thickness decrease related to internal pressure is significantly reduced even after texturization and the ability of these seals to withstand cyclic pressure and thermal transients is generally improved.

These different topics have been addressed by dedicated tests detailed hereafter.

# 3 Experimental validation

## *3.1 Pressurized water conditions*

The following table compares the sealing performance of different seals with 13 mm cross-section and the same seating linear load, used in different test conditions that combine service temperature up to 350 °C with internal pressure up to 160 bars. The only parameter that varies between different seal designs (i.e. different columns) is the seal lining material and surface finish (texturized or un-texturized).

The data detailed in this table corresponds to Standard Helium Leakage Rate (SHeLR) measured with a mass-spectrometer in global vacuum test condition.

*Table 1: Leak test with temperature & internal pressure*

| **Experimental leakage rate (Pa.m³/s SHeLR)** | **Reference Silver Lining** | **Non-Texturized Nickel 201 Lining** | **Texturized Nickel 201 Lining** |
|---|---|---|---|
| 1 bar @ 25 °C | $< 1 \times 10^{-9}$ | $1 \times 10^{-6}$ | $< 1 \times 10^{-9}$ |
| 1 bar @ 350 °C | $3 \times 10^{-8}$ | $1 \times 10^{-3}$ | $7 \times 10^{-9}$ |
| 161 bar @ 350 °C | $1 \times 10^{-5}$ | N/M* | $2 \times 10^{-8}$ |

*: Not measured due to previous failed test at atmospheric pressure

This first experiment reveals that the replacement of the silver of the reference seal by nickel leads to a worse measured leakage rate, which follows logically the greater hardness of the material ($Hv_{0.2}$ = 120 for the Nickel to be compared to $Hv_{0.2}$ = 45 for the pure silver).

Considering the textured nickel, the sealing performance at room temperature and with a pressure difference of 1 bar is under the detection limit of the mass spectrometer used for these tests.

The surface texturing improves the sealing performance of this lining material and even improves the seal leak performance at temperature, and with pressure applied compared to the reference seal with a silver lining. These observations confirm the expected benefits of texturizing the seal lining.

## *3.2 Ageing behaviour*

The long-term ageing behaviour of seals has been addressed within the context of nuclear spent-fuel storage and transport casks. The concept of dual-purpose casks relies on the ability to transport the casks after an interim storage period of several decades, to a final repository site [5], [6], [7].

The ageing tests performed consist in the installation of metal seals in blind bolted flanges and placed in a furnace for different period of times and different temperatures. Then, a partial opening of the test hardware, assisted with an instrumented hydraulic press device, was used to measure the evolution the residual reaction force and elastic recovery of each seal.

Within this context of ageing tests [8], the following figure compares the evolution of texturized metallic seal reaction force (red filled circles) and spring back (red unfilled circles) during ageing 450 days at 150 °C with the behaviour of reference silver seal (black filled circles and unfilled circles, respectively), with the same cross-section and the same initial installation force. In this figure, the reaction forces are normalized by average of the initial behaviour of silver seals.

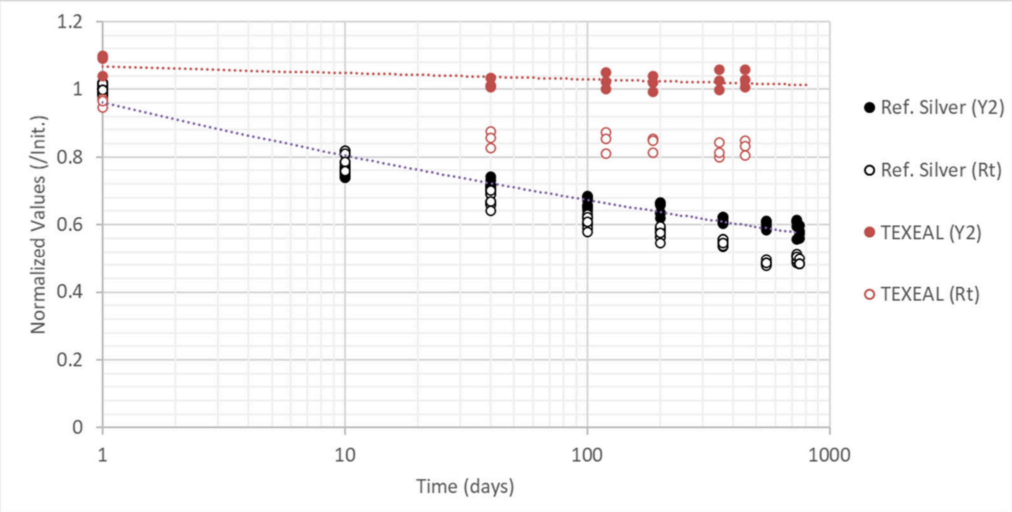


*Figure 4: Comparison of texturized metallic seal behaviour with reference silver seals during ageing test at 150 °C*

These ageing tests reveal that no significant evolution of reaction force and spring-back is noticed for textured nickel seals, while the silver seals lost 40 to 50 % of their initial loading behaviour. The decrease of seal reaction forces and elastic recovery make them more sensitive to unloading after ageing.  This can be related to accidental load cases (like a drop event for the spent fuel casks), but also related to normal service conditions, like the influence of external loads on pipes network, internal system pressure, or thermal transients. The slight decrease of TEXEAL® spring-back between the first compression (left-hand side) and the first intermediate measurement is related to the collapse of cavities which were created with the surface texturization in its initial compressive interaction with the experimental hardware.

In this situation, the use of non-texturized nickel, if technically possible with a sufficient available system compression force typically is designed with a stiffer internal spring with a value of elastic-recovery that is drastically smaller. The figure above emphasizes the advantages of the textured Nickel 201 lining in terms of ageing behaviour and the trend can be assumed to be amplified with a temperature increase due to the speed-up of creep with temperature according to Arrhenius's law.

### *3.3 High temperature behaviour*

The validation of benefits of textured Nickel 201 lining at higher temperatures is considered for a specific application holding at 100 bar and 500 °C for a duration of 16 months.

In this situation, the silver lining is inappropriate due to an excessive plastic deformation and creep of the material due to high temperature exposure that is predicted to lead to the failure of sealing performance. This point is typically balanced in design by the use of silver plating, whereby the small thickness (< 50 μm) of a plated surface and adhesion on the substrate by electroplating reduces the risks of use related to its plastic deformation. Even if the thinning of the plated material is still noticed under loaded conditions, the influence of the thickness reduction on the seal performance is mechanically limited by the smaller initial thickness of the plating [9].

The first common consequence of using silver plating in an application like this could be a decrease of the contact width of the seal and a decrease of the ability of the material to close efficiently flow into the surface defects of the flanges (roughness and scratches) that lead to leak paths.

Then, the adhesion of the silver lining on its substrate, combined with thermal transients and thermal expansion of different materials involved can lead to an undesirable shear stress at the interface between the plating and its substrate.

Figure 5 presents a distribution of total deformation according to non-linear numerical simulation with Finite Element Analysis (FEA), that involves plastic and visco-plastic behaviour of these materials at temperature. With just a few simulated thermal cycles, the analysis reveals a mesh distortion which can correspond to a very high deformation (logarithmic strain close to 1,5, which corresponds to a conventional strain greater than 300%) and is not acceptable for performance of metallic materials.

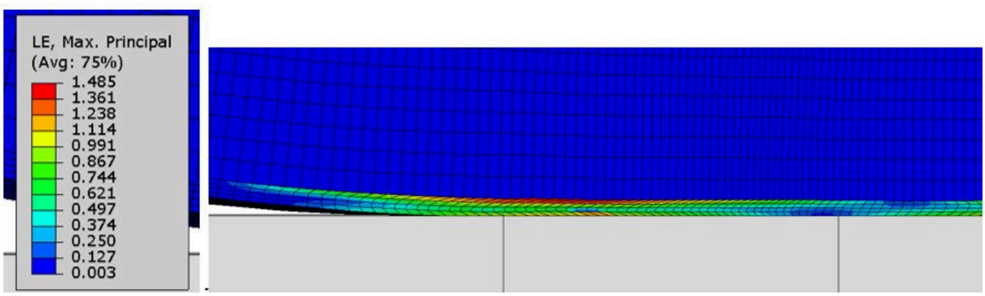


*Fig. 5: Simulation of silver coated seal – Distribution of deformation after thermal cycles*

This excessive shear of the interface is predicted to lead to a failure and delamination of the seal-plating interface that can be reproduced experimentally, as shown in Figure 6, highlighting the blistering effect and delamination of the plating after thermo-mechanical testing.

*Fig. 6: Delamination of silver plating after thermal cycles*

This damage mechanism is significantly improved by the replacement of silver plating by a textured nickel lining, thanks to the following characteristics:

- The coefficient of thermal expansion of Nickel 201 is similar to the behaviour of other refractory nickel-based alloys generally considered for high temperature applications (like Alloy 625),
- The non-adhesion of the sealing lining on the under-lining allows some micro-sliding at the interface and reduces the related shear-stresses,
- The work-hardening behaviour of the Nickel 201 alloy enables a consolidation of the lining in the case of significant mechanical loads.

These benefits have been confirmed by a numerical simulation of the thermal loads on nickel seals, as illustrated in the following figure. The maximum plastic strain in the seal lining is limited to 0.1, which is acceptable without risk of damage. The corresponding tests are still in progress at the time of writing, to confirm this point experimentally and confirm sealing performances.

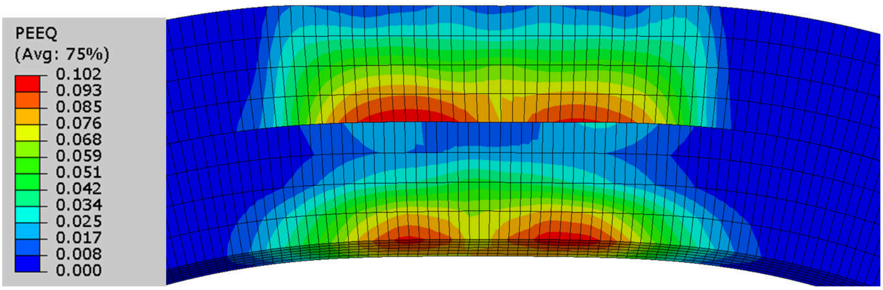


*Fig. 7: Aspect of texturized Nickel seal after thermal cycles*

# 4 Summary and Conclusion

The development of the texturized metallic seal concept, which relies on texturization of metallic seal surfaces and allows the replacement of soft material, like silver or aluminium by other stronger materials that are initially excluded from design consideration due to their hardness that is not ideal to ensure leak-tightness. This concept is a paradigm shift as it helps to consider new materials to improve temperature resistance or creep resistance, as well as the irradiation behaviour or corrosion resistance in harsh environments, like molten salts, and sodium cooled applications.

Current investigations focus mainly on the replacement of silver, which is a convenient sealing material for its softness and ductility, by texturized low-alloyed Nickel 201, which is characterized by significant work-hardening behavior but maintains a significantly better temperature resistance. The surface texturing, performed by femto-laser technologies, allows a modification of surface behavior without changing the physical properties of the base material, even in the neighborhood of the cavities that form the texturization pattern.

These design opportunities are now documented by experimental results involving thermal ageing, thermal cycling and are compared with measurements of helium sealing performances, which provides evidences of the technical benefits of this technology.

This seal concept therefore opens the way to applications such as:

- Long term ageing
- Ability to sustain high pressure and high temperature combined
- Possibility to consider metals like Nickel for its chemical resistance
- Possibility for very large seal with Nickel sealing lining

# 5 Nomenclature

| ***Variable*** | ***Description*** | ***Unit*** |
|---|---|---|
| $Y_2$ | Linear reaction force at nominal compression | N/mm |
| $Y_{2R}$ | Linear reaction force at nominal compression after ageing | N/mm |
| $Y_1$ | Minimum linear reaction force required to keep the targeted sealing performance during unloading | N/mm |
| $R_t$ | Total elastic recovery of seals | mm |
| $R_u$ | Useful elastic recovery of seals that corresponds to the linear load $Y_1$ | mm |
| $T$ | Temperature | [°C] |

## 6 References


[1] Technetics Group, 2024, “Static Metallic Seals Catalog,” accessed Sept. 15, 2025, https://technetics.com/technetics-products/metal-seals/

[2] Y. Marthouret, T. Zaouter, F. Ledrappier, G. Kermouche – “Wedge indentation of elastoplastic solids - from single indentation to interaction between indenters”. 2023. ⟨hal-03517125v5⟩

[3] R. Plessinger, E. Volpe, F. Ledrappier, J.F. Juliaa, E. Motyka, S. Roeseler, T. Noyes, B. Jones – “Evaluation of Performance Characteristics of a Surface Texturized Metallic Seal Using Helium Mass Spectrometry and Numerical Simulation” – Journal of Engineering for Gas Turbines and Power – ASME Feb. 2026, Vol. 148

[4] F. Ledrappier, T. Zaouter, M. Tessier, J.F. Juliaa, P. Favre – «  Numercial approach to predict the sealing performance of TEXEAL® texturized metallic seals” – International Symposium – Contribution of Materials Investigatinos and Operating Experience to LWRs’ Safety, Performance and Reliability – Fontevraud 10 – Sept. 2022 – Avignon – France

[5] H. Sassoulas, L. Morice, P. Caplain, C. Rouaud, L. Mirabel und F. Beal, “Ageing of metallic gaskets for spent fuel casks: Century-long life forecast from 25,000-h-long experiments,“ Nuclear Engineering and Design, 236 (22), pp. 2411-2417, 2006.

[6] L. Qiao, S. Nagelschmidt, U. Herbrich – “Application of a modified Arrhenius equation to describe the time-temperature equivalence in relaxation analysis of metal sels” – Journal of Civil Engineering and Architecture n°11 – 2017.

[7] G. Jezdan, R. Schneider-Eickhoff, F. Ledrappier, J. Becker, S. Carstens – “Prediction models for the long-term performance of metal seals in dual-purpose casks” – Proceedings of the 21st International Symposium on the Packaging and Transportation of Radioactive Materials – PATRAM 25 – July 2025 – San Antonio, TX – USA

[8] F. Ledrappier, M. Tessier, J.F. Juliaa, A. Bommenel – « Characterization of the ageing behavior of HELICOFLEX® TEXEAL® Texturized metallic seals” – Proceedings of the 21st International Symposium on the Packaging and Transportation of Radioactive Materials – PATRAM 25 – July 2025 – San Antonio, TX – USA

[9] F. Ledrappier, A. Bommenel, J.F. Juliaa – “Major sealing challenges in SMR & AMR development” – International Congress on Advances in Nuclear Power Plants - ICAPP 2025 – Juan-les-Pins – Sept. 2025.

## 7 Authors

**TECHNETICS Group France – MAESTRAL Laboratory**

**2, rue James Watt, 26700 Pierrelatte, France :**

Allegre Loick, loick.allegre@technetics.com,

Dr. Ledrappier Florent, florent.ledrappier@technetics.com,

Juliaa Jean-François, jean-francois.juliaa@technetics.com

**TECHNETICS Group**

**Falkenweb 1, 41468 Neuss, Germany :**

Dr. Cao Chen, chen.cao@technetics.com

**TECHNETICS Group US**

**2791 The Boulevard, Columbia, SC 29209, USA:**

Kweder Jonathan, jonathan.kweder@technetics.com

https://doi.org/10.61319/NFM5WLSH