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EFFECT OF SURFACE ROUGHNESS OF CASK FLANGE AND GASKET DIAMETER TO SEALABILITY

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ABSTRACT

In regard to spent fuel storage and transportation casks, metal gasket is selected as sealing material from the standpoint of long-term storage. When cask flange is made of stainless steel, aluminum is chosen as gasket material because it is more flexible than stainless steel. Sealability is obtained by gasket deformation and contact with rough surface of flange. Therefore, it is known that gasket sealability is not kept when flange roughness is larger. In the case of flange with serrations, sealability can be obtained when the flange roughness is larger than another type of flange. It is thought that leakage directly crossing the gasket is relatively small, because serrations were grooved in circumferential direction, however it has not been clearly resolved yet. In this study to clarify the effect of metal gasket stress to leakage seal test was conducted as the first step to measure gasket stress and leak rate using flange with serrations and the interspaces between gasket and flange was estimated. As second step, seal test was conducted with flanges that had different serrations dimensions, and correlation between flange surface profile and leak rate was found. Additionally static/ dynamic impact test results according to JNES and NUPEC test were presented as basic characteristics of the gasket. As a result of the test, it was found that fluid leaked through the interspaces was smaller when gasket diameter was larger. Therefore it was estimated that the larger gasket diameter obtained the longer total length of the interspaces and the larger gasket pressure loss. We found that leakage of fluid could be predicted by measuring gasket stress, its diameter and flange profile.

INTRODUCTION

Important functions of the cask are 1) heat removal, 2) sealing radioactive materials, 3) blocking and 4) preventing an occurrence of criticality. To seal radioactive materials, the cask has metal gaskets as sealing material. The gasket consists of inner jacket of hard metal sheet and outer jacket of soft metal sheet and inside of the jackets there is a metal coil spring made by hard metal. Outer jacket is softer than contact surface of the flange and attached firmly to irregularity of the surface during compression. Sealability of the gasket is provided due to small clearance between surface of the flange and outer jacket of the gasket caused by plasticity of the outer jacket and elasticity of the coil spring.

Plasticity of the gasket caused by softness of outer jacket is important factor for sealability. Contact surface of the flange is cut by tool bit and serrations are formed as spiral configuration (see Figure 1). Nitta et al. reported that sealability of metal gasket was defined by surface roughness of the gasket and flange, and a radial direction gas flow overcoming through the top of serration was mixed with a circumferential direction flow passing through the channel of serrations when contact pressure of metal gasket and flange was relatively low. Also they showed that gas flowed only in a circumferential direction when contact pressure was relatively high [1].

Kato et al. focused a radial direction gas flow and reported that leakage rate could be estimated from measuring surface roughness (0.7-11 micrometer) of the flange [2]. Sakai et al. reported that leakage should be occurred in a circumferential direction and was negligible when flange surface roughness was 5-50 micrometer due to pressure loss in the channel of serrations [3].

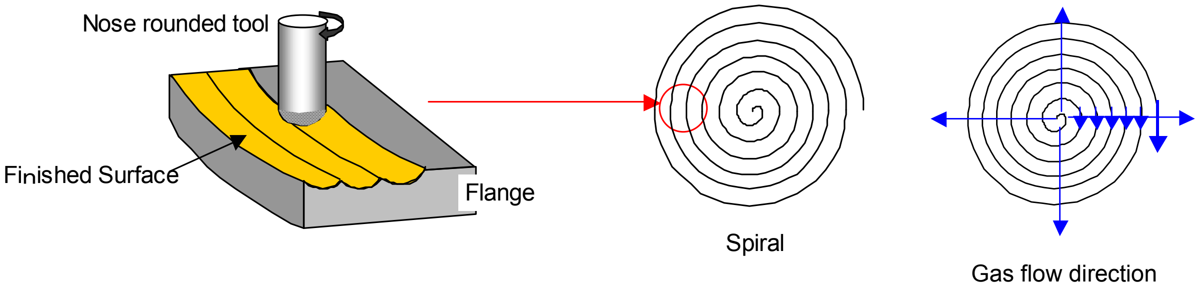
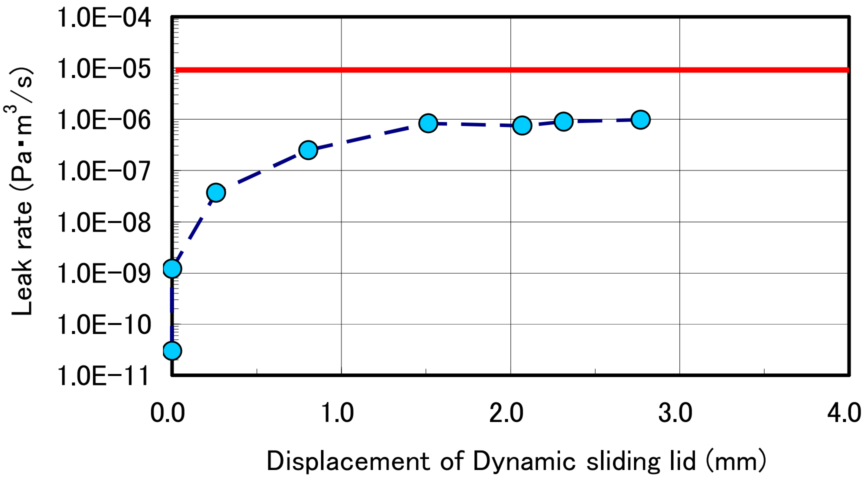


Figure 1. Flange surface

Previous studies indicated that there was a leakage in a circumferential direction and were estimated that larger gasket had advantage to leakage due to its long channel length. However gas flows in radial and circumferential directions were not verified individually because measurement was conducted at same time.

Recently, we conducted testing to assess the aging effect of the seal boundary made by the Japan Nuclear Energy Safety Organization (JNES)[4]. Based on the test results, we confirmed that seal performance equivalent to the gaskets tested by JNES was achieved (ex. Figure 2), and we developed a gasket that could be used similarly to the gaskets specified by AESJ (Atomic Energy Society of Japan)-SC-F002:2010[5].



Test assembly

Figure 2. Test (Dynamic sliding lid)

In this study we compared two types of flange surface configuration, spiral serrations and concentric circle serrations, to prove the radial direction flow by substantiative experiment (see Figure 3). If flange had concentric circle serrations, there would be no leakage in a circumferential direction. Also we conducted seal test for flanges which had different serration pitches to find impact not only of flange surface configuration but also of surface roughness on sealability, and confirmed the configuration which has sealability at low contact pressure.

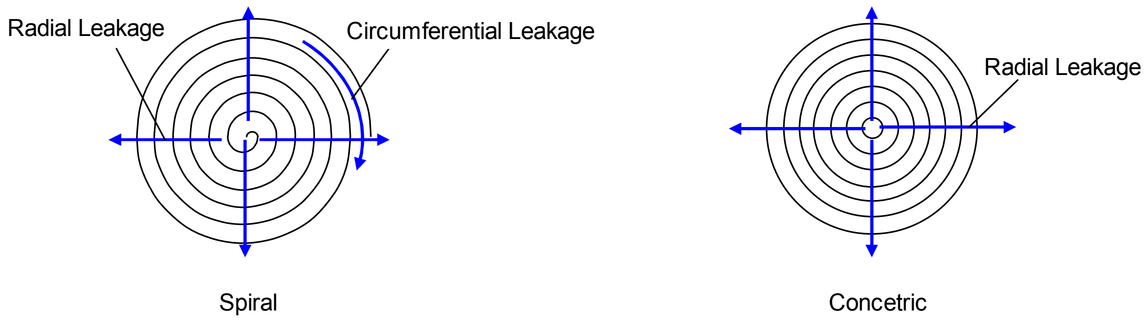


Figure 3. Test flange serrations and leakage directions

EXPERIMENT

<u>Test conditions</u>

To simplify the test condition, flat metal sheet was selected instead of outer jacket and serrations were formed on metal platen instead of contact flange. Test equipment is shown in Figure 4 and Photograph 1. Test conditions are the followings.

A. Test equipment: Test press

B. Test piece (flat metal sheet):

1) Material: Aluminum
2) Thickness 0.5 mm
3) Diameter 60 mm

C. Test piece (metal platen):

1) Material: Stainless steel
2) Surface type: Spiral serrations, concentric circle serrations and random surface configuration without serrations
3) Surface roughness (design): Ra 1.2, 2.1and 21.3 micrometer for serrations
   Ra 0.1, 0.4 and 1.6 micrometer for random surface configuration without serrations

D. Ring spacer: Diameter 40 mm, width 2 mm

E. Detect gas: Helium

F. Vacuum pressure: Max 0.1 Pa

G. Detector: Helium leak detector INFICON UL-5000

H. Leakage criteria: Max 1.0×10^{-10} Pa m^3/s

I. Sealable contact pressure: Calculated from the result of stress under leakage criteria. Calculation formula was the following.

$$\sigma = W/(\pi \cdot w(D_0 - w))$$

σ : Sealable contact pressure (N/mm^2)
W: Load (N)
w: Ring spacer width (2mm)
D_0: Outer diameter of ring spacer (40mm)

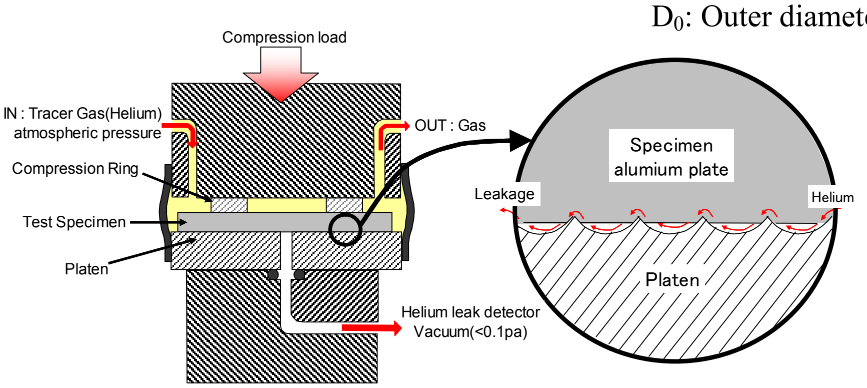


Figure 4. Outline of test equipment

Photograph 1. Test press

Actual roughness of the plate is shown in Table 1. Measurement was conducted according to JIS B 0601-1982 “Geometrical product specification- Surface texture, profile method- terms and definitions and surface texture parameters”.

Table 1. Test condition of test pieces

Surface finish condition		Processing condition: Feed pitch mm	Processing condition: Nose R mm	Roughness Ra: Predict μm	Roughness Ra: Actual μm
Serrated finish	Spiral	0.2	2.7	0.3	1.2
		0.2	1.5	0.5	1.4
		0.2	0.2	5.3	5.8
	Concetric	0.2	2.7	0.3	1.0
		0.2	1.5	0.5	1.8
		0.2	0.2	5.3	5.2
Random finish				0.4	0.3
				1.6	1.1
				6.3	2.5

Leak test was conducted according to the following method to identify “Sealable contact pressure”.

1) Metal sheet was put on the lower metal platen.
2) Ring spacer was put on the metal sheet.
3) Ring spacer was compressed with the upper metal platen until contact pressure was 20 N/mm^2.
4) Helium gas was injected outside of test pieces (metal sheet and platen) and Helium leak detector detected the gas passed through the gap of the test pieces.
5) Leak rate was measured every 10N/mm2 until the leak rate was under leakage criteria. Sealable contact pressure means calculated contact pressure when leak rate is leakage criteria.

Test result

Relations of contact pressure and leak rate are indicated in Figure 5 and 6.

Leak rate was smaller for every test pieces when contact pressure was higher.

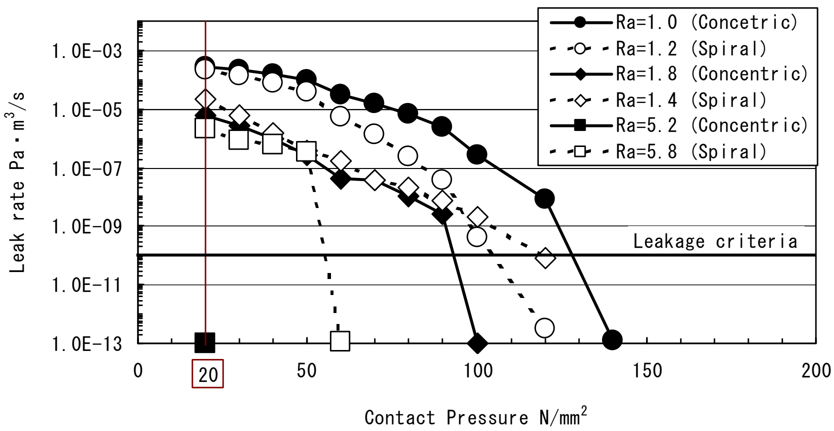


Figure 5. Contact pressure and Leak rate of serrated finish platen

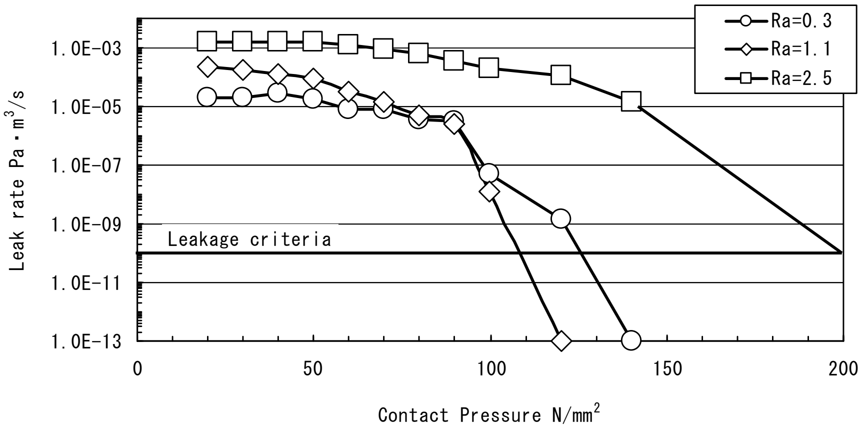


Figure 6. Contact pressure and Leak rate of random finish platen

Figure 7 shows surface roughness and sealable contact pressure.

Sealable contact pressure of metal sheet on serrated finish platen (both spiral and concentric) was lower when surface roughness was higher. On the other hand, sealable contact pressure of metal on random finish platen was higher when surface roughness was higher. Sealable contact pressure of metal sheet on spiral serration platen was higher than concentric circle serrations when surface roughness was high. It was estimated that the differences was caused by no circumferential direction gas leakage in concentric circle serrations. Therefore it would be possible to separate the leak rate of radial and circumferential direction from the differences of metal platen finish.

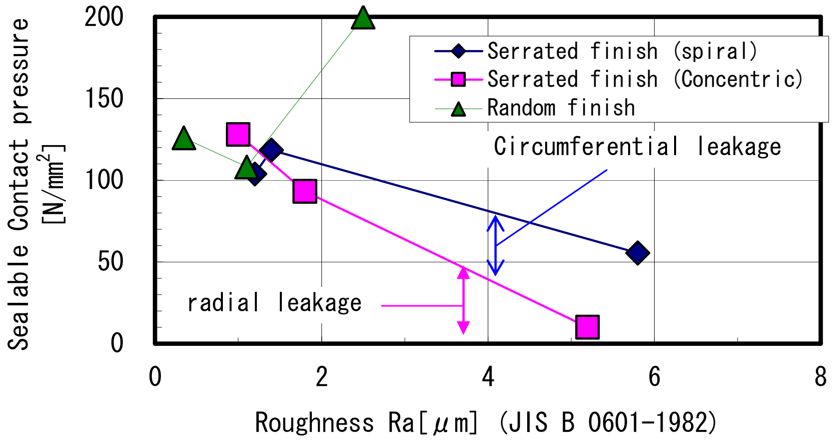


Figure 7. Surface roughness and Sealable contact pressure

Discussion

In this study we found that there were 2 types of gas flow, radial and circumferential direction, and there was a possibility to separate each flow individually. Flange that had concentric circle serrations had advantage for seal. However serrations have been configured as spiral and selecting concentric circle serrations forming on the flange seems distant.

Kato et al. predicted that larger gasket had higher leak rate. They considered only radial direction gas leakage and did not consider circumferential direction gas leakage. If we adopt their opinion, larger diameter flange shall have high leak rate.

On the other hands we found that circumferential direction gas leakage was larger than radial direction gas leakage. Circumferential direction gas leakage would be lower when flange diameter was larger due to pressure loss of leak gas in the gap between serrations and gasket. If it would be true, leak rate of larger diameter flange will be not high. According to the hypothesis, there is possibility that total leak rate of larger diameter gasket is smaller than small diameter gasket because radial direction gas leakage goes up and circumferential direction gas leakage goes down at same time when gasket diameter goes up.

Next step of this study was leak rate calculation of 2000 mm diameter spiral serration flange.

LEAK RATE CALCULATION OF 2000MM DIAMETER METAL SHEET

Leak rate of 2000 mm diameter metal sheet was estimated according to the following method.

1) Measure height and pitch of serrations on the metal platen by confocal laser scanning microscopy (see Table 2).
2) Calculate the serrations angle (θ) according to the following formula (see Figure 8).

$$Rz = R(1-\cos\delta)$$
$$\delta = \arccos(1-Rz/R)$$
$$\theta = 2(90^\circ - \delta)$$
$$= 2(90^\circ - \arccos(1-Rz/R))$$

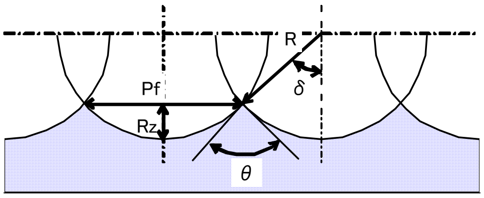


Figure 8. Serrations angle (θ)

3) Estimate leak rate at Ra 5.8 based on the serrations angle (θ) (see Table 2 and Figure 9).

Table 2 Calculate the serrations angle

Suraface serration finish condition	Measured			Predict	Measured
	Roughness Ra µm	Serration pitch pf µm	Serration hight Rz µm	Serration Angle θ°	Leak rate at 20 N/mm^2 Pa·m^3/s
Spiral	1.2	143	4.7	165.04	2.2×10^{-4}
	1.4	169	5.5	165.15	2.2×10^{-5}
	5.8	163	19.1	125.68	2.1×10^{-6}
Concentric	1.0	155	5.0	165.20	2.8×10^{-4}
	1.8	159	6.4	161.53	6.4×10^{-6}
	5.2	143	23.5	103.25	$\leqq 1.0\times10^{-13}$

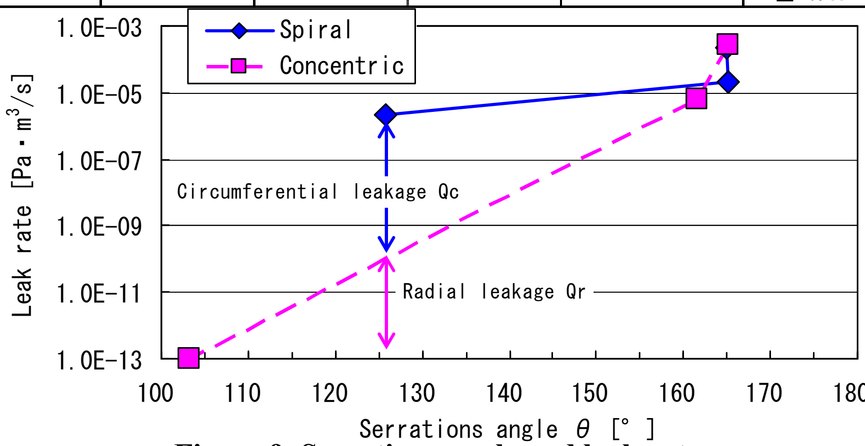


Figure 9. Serrations angle and leak rate

4) Radial direction leak rate of 40 mm diameter (Qr40) was assumed 9.0×10^{-11} Pa m^3/s (see Figure 9).
5) Total leak rate of 40 mm diameter metal sheet (Qt40=2.1×10^{-6} Pa m^3/s) was assumed to consist of Qr40 and circumferential direction leak rate of 40 mm diameter (Qc40) (see Figure 9).
6) Qc40 was assumed 2.1×10^{-6} Pa m^3/s.
7) Gap height between flat plates (ε) was calculated based on the following formula "contact leakage formula of parallel flat plates" of Kato et al [2] (see Figure 10).

$$Qr = \pi \varepsilon^3 (P_1^2 - P_0^2)/(12 \eta \cdot \mathrm{Ln}(ro/ri)) \quad (1)$$

$$\varepsilon = (9.0 \times 10^{-11} \times 12 \times 0.0196 \times 10^{-3} \times \mathrm{Ln}((20 \times 10^{-3})/(18 \times 10^{-3}))/(\pi \times ((1.01 \times 10^5)^2 - 0.1^2)))^{1/3}$$
$$= 4.1 \times 10^{-9} \mathrm{m} = 0.0041 \mu\mathrm{m}$$

ε : Gap height (m)
η : Elastic coefficient (Pa-s)
0.0196×10^{-3} Pa-s at He
P_0: Inner pressure (Pa)
P_1: Outer pressure (Pa)
ro: Outer radius (m)
ri: Inner radius (m)

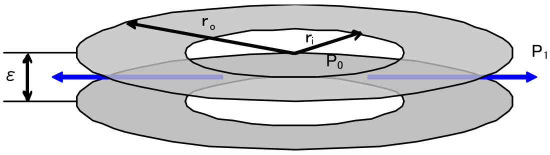


Figure 10 Conceptual diagram of the formula

8) Radial leak rate of 2000 mm diameter metal sheet (Qr2000) was assumed according to the formula (1).

$$Qr2000 = \pi \times (4.1 \times 10^{-9})^3 \times ((1.01 \times 10^5)^2 - 0.1^2) / (12 \times 0.0196 \times 10^{-3} \times \mathrm{Ln}(1.0/0.998))$$
$$= 4.7 \times 10^{-9} \text{ Pa m}^3/\text{s}$$

9) Gap height in channel (ε) was calculated based on the following formula"leakage formula in the case of rectangular channel" of Nitta et al [1] (see Figure. 11).

$$Qc = w \varepsilon^3 (P_1^2 - P_0^2) / (24 \eta L) \quad (2)$$

$$\varepsilon = ((2.1 \times 10^{-6} \times 24 \times 0.0196 \times 10^{-3} \times 1.47) / (163 \times 10^{-6} \times ((1.01 \times 10^5)^2 - 0.1^2))^{1/3}$$
$$= 9.6 \times 10^{-6} \mathrm{m} = 9.6 \mu\mathrm{m}$$

ε : Gap height (m)
w: Width of channel (m)
L: Length of channel (m)

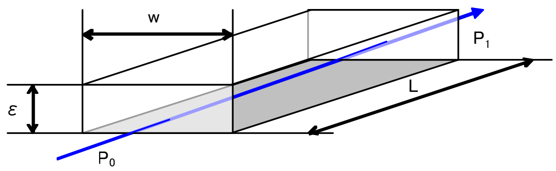


Figure 11. Conceptual diagram of the formula

10) Circumferential direction leak rate of 2000 mm diameter metal sheet (Qc2000) was assumed according to the formula (2).

$$Qc2000 = 163 \times 10^{-6} \times (9.6 \times 10^{-6})^3 \times ((1.01 \times 10^5)^2 - 0.1^2) / (24 \times 0.0196 \times 10^{-3} \times 77.2)$$
$$= 4.1 \times 10^{-8} \text{ Pa m}^3/\text{s}$$

11) Total leak rate of 2000 mm diameter metal sheet (Qt2000) was estimated as the following.

$$Qt2000 = Qr2000 + Qc2000$$
$$= 4.7 \times 10^{-9} + 4.1 \times 10^{-8}$$
$$= \underline{4.6 \times 10^{-8} \text{ Pa m}^3/\text{s}}$$

In the case of serrated forming flange, total leak rate of 2000 mm diameter metal sheet ($2.1x10^{-6}$ Pa m^3/s) was estimated almost 1/100 compared with 40 mm diameter metal sheet ($4.6x10^{-8}$ Pa m^3/s). We predict that leakage of larger diameter metal sheet is negligible low level. Also we predict the gasket has similar trend as the metal sheet.

CONCLUSIONS

In this study we found that there were 2 leakage types and they could be measured separately. Also we calculated that sealability of serrated forming flange had advantage when surface roughness of the flange was high and flange diameter was large.

Metal sheet sealability differed according to conditions not only in roughness of the contact surface but also in forming method of contact surface etc. It is indicated that adequate serration forming condition leads high performance of gasket and Figure 9 shows that high angle of serration has low leak rate.

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