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September 13, 2021 | ioMosaic Webinar Series

Bridging the 3% Inlet Pressure Loss Rule Gap

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This webinar is based on a recent white/video paper which is available for download

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Bridging the 3 % Inlet Pressure Loss Rule Gap

An ioMosaic Corporation White Paper

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Contents

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You might also want to request copies of these additional white/video papers resources

- Analysis of PRV Stability in Relief Systems. Part I - Detailed Dynamics
- Analysis of PRV Stability in Relief Systems. Part II - Screening
- Analysis of PRV Stability in Relief Systems. Part III - How to Avoid the Singing Pressure Relief Valve Problem
- Analysis of PRV Stability in Relief Systems. Part IV - On the Estimation of Speed of Sound and Thermodynamic Properties for Fluid Flow and PRV Stability
- Analysis of PRV Stability in Relief Systems. Part V - Get a Handle on PRV Stability
- PRV Stability Inlet Line Critical Length. A Short Communication

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It is now widely known and recognized that the 3 % rule is not sufficient to guarantee PRV stability

- A hazard is "recognized" where: (a) the employer has identified it; (b) it is known in the industry; or (c) it is blatantly obvious.
- An employer knowledge of the hazard is key. The level of employer knowledge of the hazard can be a significant factor in determining if and to what extent a violation exists.
- If employer knowledge of the hazard is established, the level of that knowledge is considered in determining the classification of the OSHA citation(s).
- Two factors largely determine the gravity of a violation: (1) the severity of the injury that could occur from the violation (i.e., high, medium, or low); and (2) the probability that the injury could result from the violation (i.e., greater probability and lesser probability).

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OSHA violations can result in citations under one or more of the following classifications

Serious A violation is serious if death or serious physical harm (i.e., a substantial impairment to bodily function) could result from the violation. This classification carries a statutory maximum penalty of $ 13,653.

Willful A willful violation is one that is committed with either intentional disregard or plain indifference to the requirements of the PSM Standard. In other words, a hazard exists and the employer had an enhanced knowledge of the hazard or the regulatory requirement prohibiting it, and fails to correct it. Willful violations that cause death to an employee are subject to criminal sanctions, including imprisonment of up to 1 year. [3] This classification carries a statutory maximum penalty of $ 136,532.

Repeat A repeat violation occurs when the employer has been cited previously for violation of the same OSHA standard within a 5 year period. This classification carries a statutory maximum penalty of $ 136,532.

Other than Serious Conversely, a violation is non-serious if death or serious physical harm could not result from the violation. This classification carries a statutory maximum penalty of $ 13,653.

Failure to Abate This violation occurs when an employer fails to abate or correct the hazard within the required time frame after having been cited by OSHA. This classification carries a statutory maximum penalty of $ 13,653 per day beyond the original abatement date.

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ASME Section XIII requires that the inlet pressure drop and backpressure do not adversely affect the operation of the relief device

12.5 INLET PIPING (b) - The pressure drop through the upstream system to the pressure relief valve shall not reduce the relieving capacity below that required to prevent the pressure from exceeding its maximum allowed relief pressure or adversely affect the proper operation, including stability, of the pressure relief valve.

12.8 DISCHARGE PIPING (a) - The size of the discharge lines shall be such that any pressure that may exist or develop will not reduce the relieving capacity of the pressure relief devices below that required to properly protect the pressurized equipment, or adversely affect the proper operation of the pressure relief devices.

However, one should note that the current 3 % rule remains referenced in the non mandatory Appendix M-6 of ASME VIII [14]. Appendix M-6 clearly delineates recoverable and irrecoverable pressure losses but also fails to recognize that the recoverable losses must be considered as well. If a company elects to use this non mandatory Appendix for compliance, then the current 3 % still applies.

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We can trace the origin of the 3 % rule to API sponsored research work at the University of Michigan in 1948

and possible failures of piping connections. Rupture discs and pilot-operated valves are not susceptible to intermittent operation. The rate of flow may be decreased by large pressure drops through the inlet connections.

For a relief valve having approximately 4 per cent blow-down (that is, the valve will snap shut when the pressure has decreased to 4 per cent below the opening or set pressure), these recommendations are made:

1. The pressure drop due to friction should not exceed 1 per cent of the allowable pressure for capacity relief.

2. The pressure drop due to the conversion of pressure to kinetic energy, commonly referred to as velocity head loss, should not exceed 2 per cent of the allowable pressure for capacity relief.

Where the pressure drop across inlet piping for any relief device is appreciable, the pressure value used in Equations 8 and 9, or modifications

Friction, **irrecoverable**

Dynamic, **recoverable**

Source: N.E. Sylvander and D.L. Katz. “The Design and Construction of Pressure Relieving Systems”. University of Michigan Press Engineering Research Bulletin 31, Pages 72-73. (1948).

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Dynamic pressure was identified as a dominant component of pressure loss that can negatively impact PRV stability

A balance of velocity head loss and friction loss could be reached with greater length of inlet pipe so that

$$w_f + \frac{\Delta v^2}{2g} = 2.86 + 5.72 = 8.58 \text{ lb./sq. in.}$$

but the energy loss due to friction would then exceed the 1 per cent recommended. The actual pressure at the relief valve inlet should be used, therefore, in calculating the relief valve area required for maximum flow.

Large size nozzle-type relief valves will tend to have velocity head loss in excess of the 2 per cent allowance for instances where the friction loss is satisfactory. This condition may result in chattering and it is advisable to consider the use of a larger diameter inlet pipe.

Source: N.E. Sylvander and D.L. Katz. "The Design and Construction of Pressure Relieving Systems". University of Michigan Press Engineering Research Bulletin 31, Pages 72-73. (1948).

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Much later (1998), the CCPS “Guidelines for Pressure Relief and Effluent Handling Systems” section 2.4.2.2.1 states:

- “Note that the non-recoverable pressure loss from the vessel to the valve is less than the pressure drop, since the drop includes the change in velocity head from vessel to valve. This velocity head is recoverable (part of the lifting force on the disk), and thus is not included in the determination of inlet loss.”
- When did the requirement change from “total” pressure loss to “irrecoverable” pressure loss?

Source: Used for educational purposes only. Do not copy, share or distribute.

The total pressure drop requirement was probably changed to irrecoverable pressure loss because someone (?) argued that dynamic pressure loss is recoverable

BUT…

- The dynamic pressure loss component can only be recovered at the disk surface (to keep the PRV open) by the returning pressure wave if the PRV has not already fully closed
- This places a strict limitation on the applicability of the 3 % rule to inlet lines where the acoustic length is less than the critical length, i.e. the returning pressure wave has to be recovered at the PRV disk surface before the PRV closes

The underpinnings of the original 3 % rule are essentially the same as the API force balance

- Our understanding of PRV stability has not significantly changed since 1948
- The original 3 % inlet pressure loss rule was intended to include the dynamic component of pressure loss in the inlet line in addition to frictional loss
- The dynamic component of pressure loss is more significant than frictional pressure loss, especially for liquid flow
- The original 3 % rule provided for a 1 % margin between total pressure drop and blowdown

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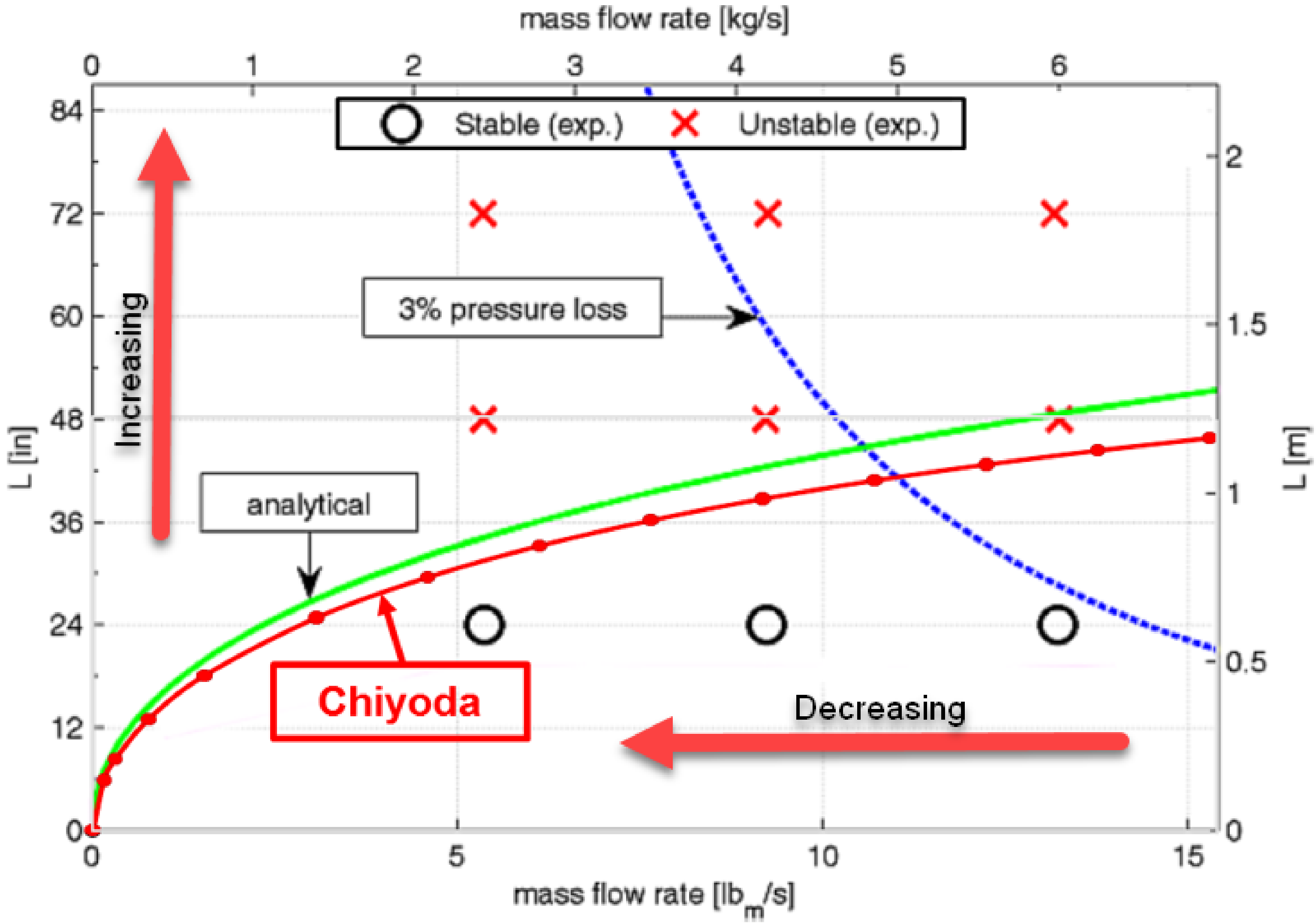
Recent measurements and 1D dynamic modeling by several researchers confirm that the current 3 % rule is not sufficient



- Pentair Experimental Data
  (Circle and X symbols)
- 2J3, May 9th 2015, DIERS Meeting and Analytical Model (green line)
- Data Comparison and Analysis by Hisao Izuchi, Chiyoda (red line)

Source: Melhem, G. A. “Analysis of PRV Stability in Relief Systems - Part II”. ioMosaic Corporation White Paper. (2014).

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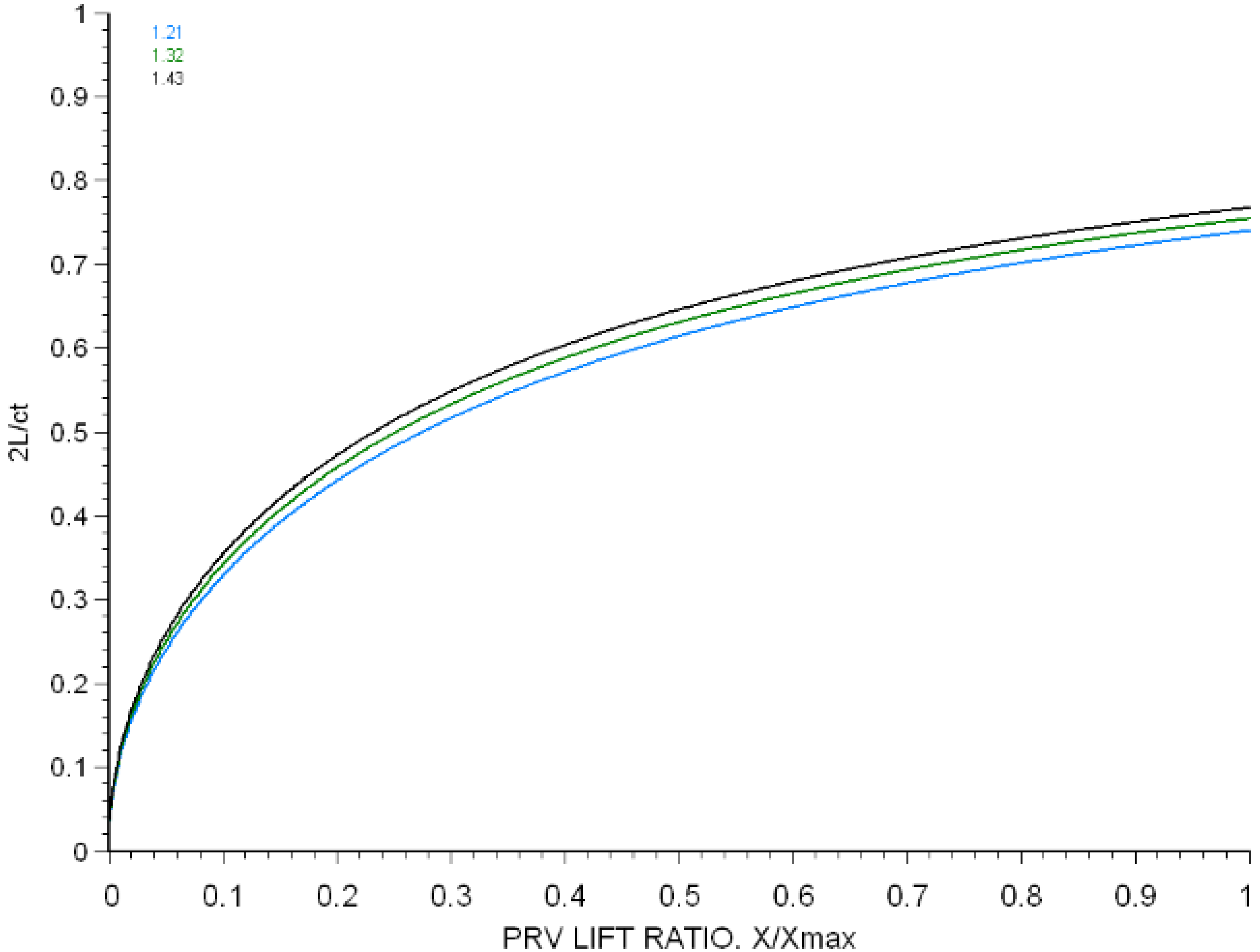
The critical stable inlet line length depends on PRV lift (mass flow) as shown by Izuchi in 2010 AIChE publication



$$L \le \frac{c}{4f_n}\sqrt{\frac{x}{x+x_o}}$$

$$x_o = \frac{P_{set}A_N - m_D g}{K_s}$$

$$t_{valve} \simeq \frac{1}{2f_n}$$

$$\frac{2L}{c} \le \underbrace{\left(\sqrt{\frac{1.43\frac{x}{x_{max}}}{1.43\frac{x}{x_{max}}+1}}\right)}_{\alpha} t_{valve}$$

$$L \le \frac{\alpha}{2} c t_{valve}$$

Source: Melhem, G. A. “Analysis of PRV Stability in Relief Systems - Part II”. Screening, DIERS. (2014, updated May 2015).
Source: Izuchi, H. “Stability Analysis of Safety Valve”. AIChE Spring Meeting. (2010).

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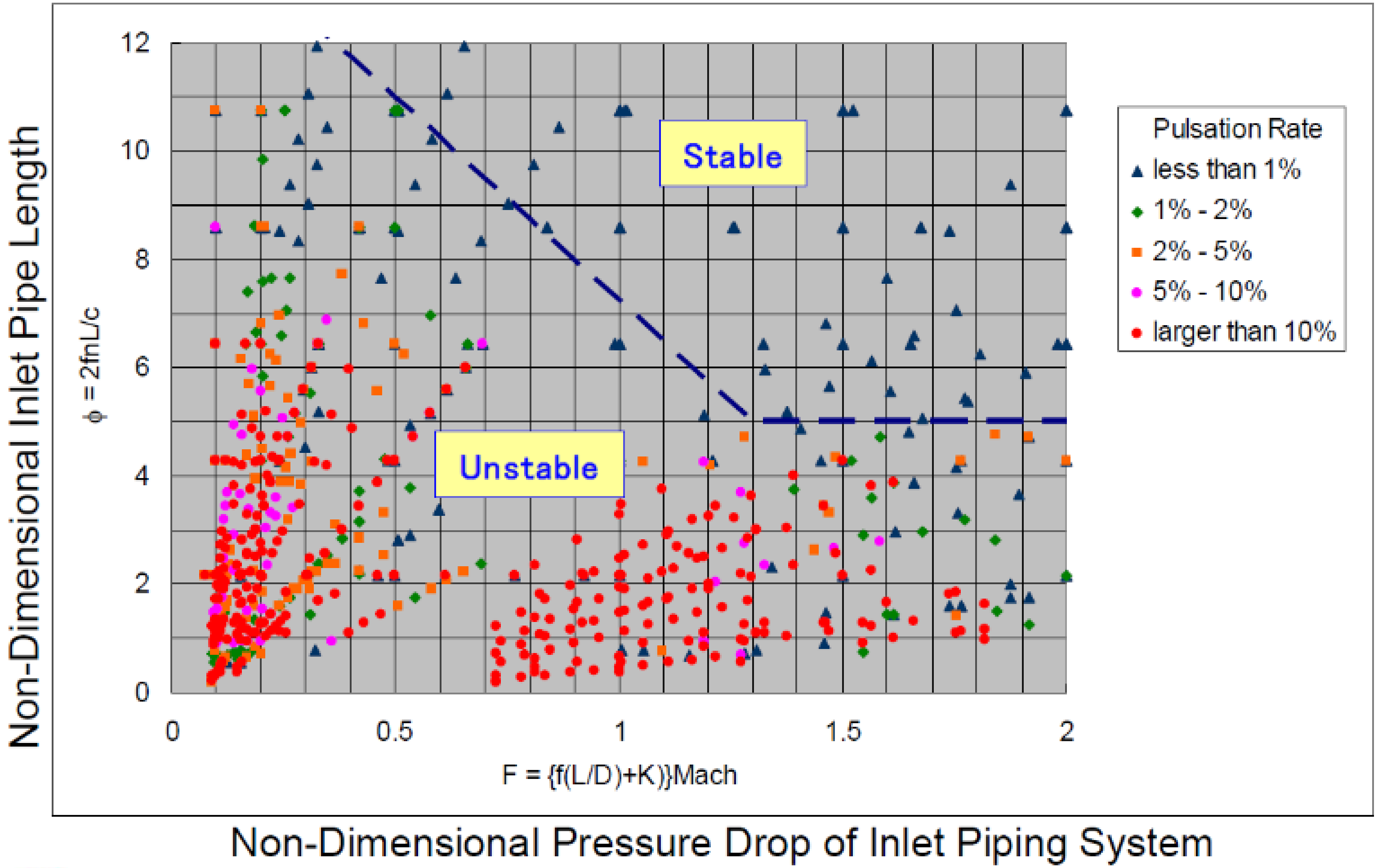
If L >>> L_{crit}, acoustic coupling may not occur leading to low frequency cycling; 1D dynamic modeling is strongly recommended



Source: Izuchi, H. "Chatter of safety valve." In Presentation to API 520 Committee. API. (2008).

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The total pressure drop can be estimated and pro-rated by the wave travel time relative to the PRV opening/closing time

Fluid hammer pressure drop

Fluid inertia term. Becomes important for high-speed flow where inlet pressure drop is highly excessive and severe.

$$t_{wave} = 2\frac{L_p}{c_0}$$

$$\tau = \min\left[\frac{t_{wave}}{t_{valve}}, 1\right] \text{ where } t_{valve} \text{ is the opening or closing time}$$

$$\Delta P_{wave} = \tau \frac{c_0 \dot{M}}{A_p} + \tau^2 \frac{\dot{M}^2}{2\rho_0 A_P^2} \text{ where } 0 \le \tau \le 1$$

$$\Delta P_{f,wave} = \tau^2 \Delta P_f \text{ where } 0 \le \tau \le 1$$

Source: Melhem, G. A. "Analysis of PRV Stability in Relief Systems - Part II". ioMosaic Corporation White Paper. (2014).

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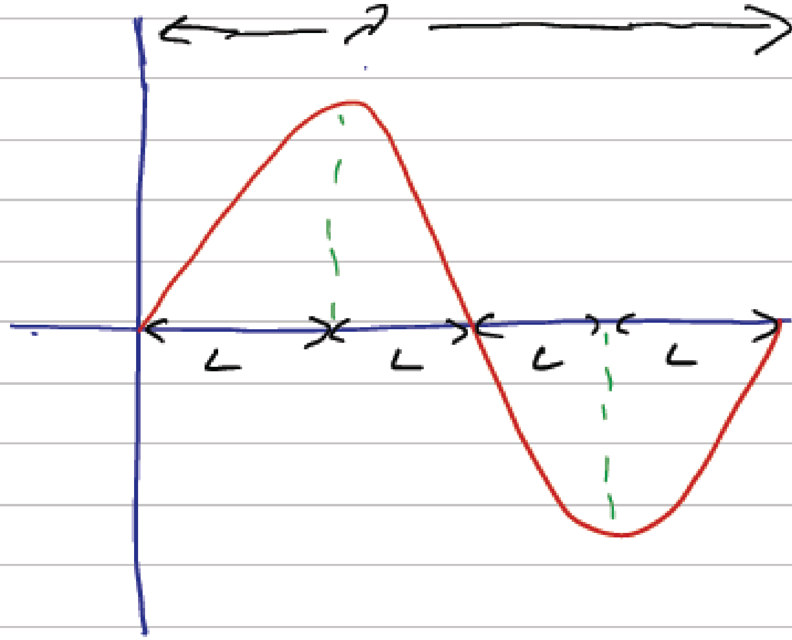
The instability is confirmed to be a quarter wave instability



$$\lambda = \frac{4L}{n}$$

= wave length

$n = 1, 3, 5,$ etc.

$$f = \frac{c}{\lambda} \quad \text{or} \quad c = \lambda f$$

$n = 1$, fundamental mode

Source: ioMosaic Corporation

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The current 3 % IPL should not be used unless the inlet line is shorter than the critical length, say 80 % of critical length

- When using 3 % irrecoverable pressure loss as a criterion, the inlet line length must be less than the critical line length and the backpressure must be within tolerable limits
- If the critical line length is not used, then the total pressure drop (frictional and dynamic) must be less than blowdown minus 1 or 2 percent
- The 3 % rule should be replaced with the API force balance coupled with critical line length, where the inlet line length is less than the critical line length
- 1D dynamics should be used for complex piping, especially where the inlet line length is greater or equal to the critical line length

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Excessive IPL may be tolerable if the PRV has sufficient flow capacity at reduced stable lift

- Confirm installation geometry, mechanical data and properties
- Confirm the steady state hydraulics using more detailed methods
- Establish the steady state IPL at 10 % overpressure
- Establish the critical inlet line length and use the full implementation of the force balance
- Establish how long it takes to repressure the system by performing a dynamic analysis
- If all the above checks fail, and/or the actual inlet line length is longer than the critical line, perform 1D PRV dynamics

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Numerous 1D dynamics simulations have confirmed that

- Chatter and flutter reduce flow rates by 50 % or more and subjects piping to large dynamic reaction forces
- High viscosity flow can cause instability where a low viscosity flow does not
- Presence of gas in inlet stream can alter the speed of sound and change the stability outcome
- Presence of enlargements and other side branches can enhance stability by decoupling frequencies of pressure waves and disk motion
- Discharge line takes time to fill and will continue to flow during chatter

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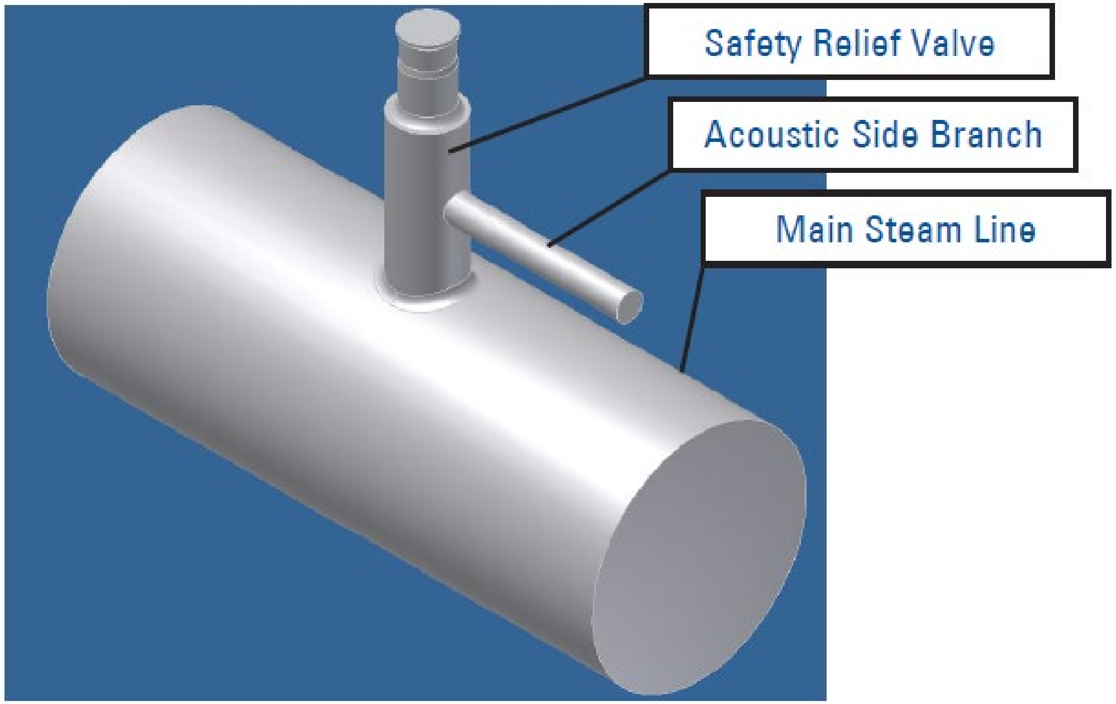
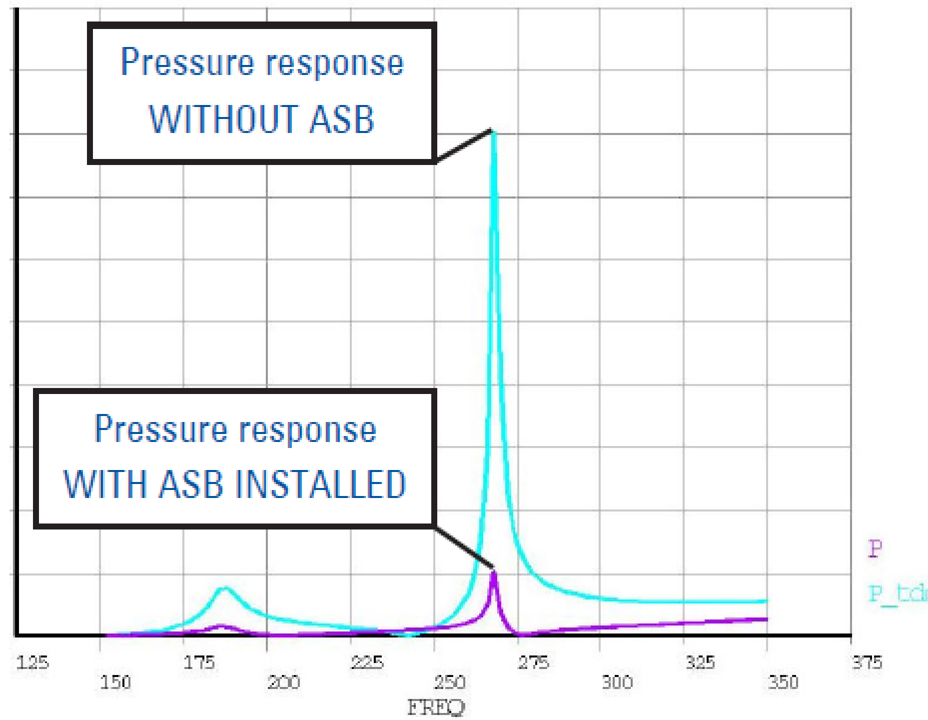
Westinghouse patented a vibration suppression system to change the acoustic natural frequency of a system





(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
23 August 2012 (23.08.2012)

WIPO | PCT

(10) International Publication Number
WO 2012/112169 A1

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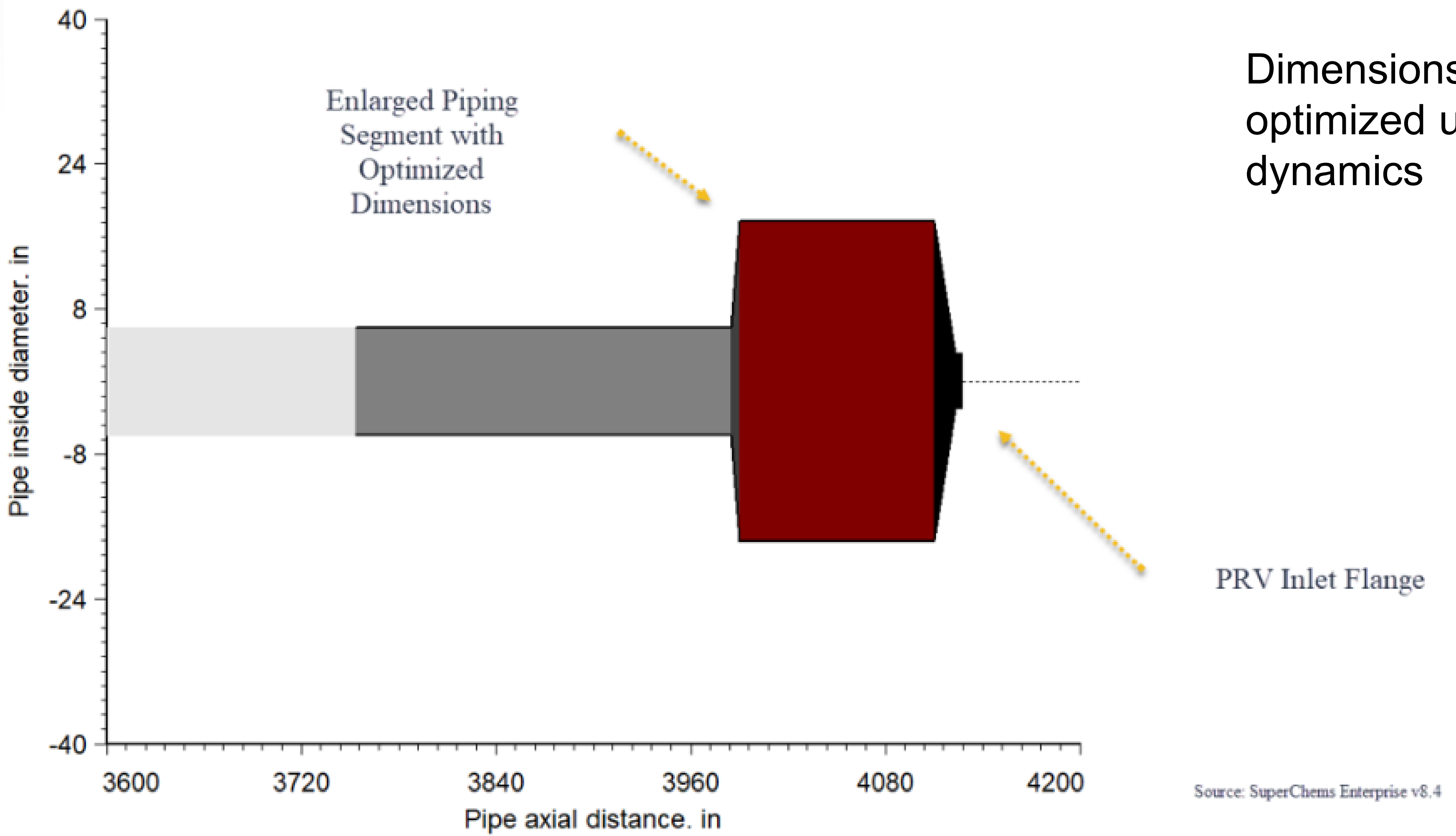
The use of an enlarged piping segment in front of a PRV can eliminate instability



Dimensions to be optimized using 1D dynamics

Source: SuperChems Enterprise v8.4

Source: Process Safety Office® - ioMosaic Corporation

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The enlarged piping segment is similar to a low pass filter that can attenuate sound power at high frequencies

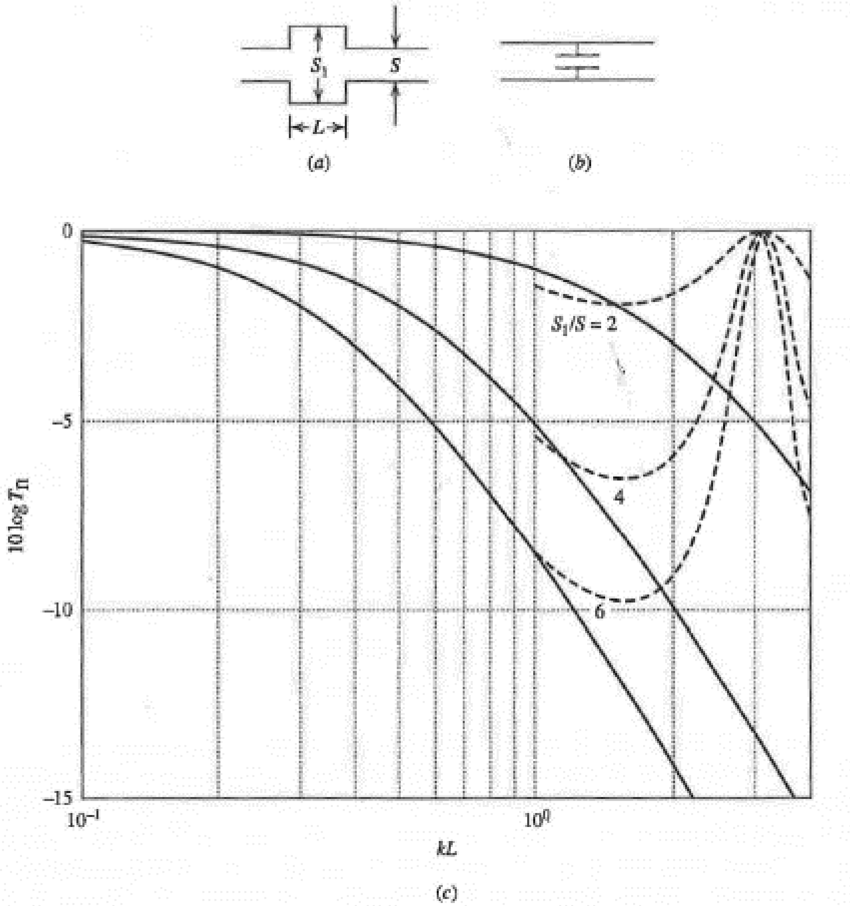


Figure 10.11.1 A simple low-pass acoustic filter consists of an enlarged section of cross-sectional area S_1 and length L in a pipe of cross-sectional area S. (*a*) Schematic. (*b*) Analogous electrical filter. (*c*) Attenuation for several values of S_1/S. Solid lines are from (10.11.2) for $kL \ll 1$. Dashed lines are from Problem 10.11.6 for $kL \gg 1$.

and, according to (10.10.13), is in parallel with the impedance $\rho_0 c/S$ of the continuation of the pipe. Substituting (10.11.1) into (10.10.16) yields a power transmission coefficient of

$$T_\Pi \approx \frac{1}{1 + \left(\frac{S_1 - S}{2S} kL\right)^2} \qquad (10.11.2)$$

This equation shows that at low frequencies the power transmission is total and gradually decreases with increasing frequency. T_Π is 0.50 when $kL = 2S/(S_1 - S)$. This type of acoustic filter is analogous to the low-pass electrical filter produced by shunting a capacitor across a transmission line, as shown in Fig. 10.11.1*b*, but only when $kL < 1$. The equation fails when $kL > 1$. Figure 10.11.1*c* shows the approximate power transmission coefficient in decibels as a function of kL for several values of S_1/S. Note that T_Π does not drop to 0.5 at $kL = 1$ until $S_1/S > 3$.

The cut-off frequency is given by:

$$f_c = \left(\frac{cS}{\pi L(S_1 - S)}\right)$$

Source: Kinsler, L., Frey, A., Coppens, A., and J. Sanders. "Fundamentals of Acoustics." John Wiley & Sons, 4th Edition. (2000).

This is similar in concept to a high pass filter which was the subject of a Westinghouse patent recently for the singing relief valve instability mitigation

This is equivalent to a short side branch (see figure to right) with a radius and length much smaller than the wavelength (lumped element assumption). This side branch acts like an acoustic mass and applies a different acoustic impedance to the system than the low-pass filter. Again using continuity of acoustic impedance at the junction yields a power transmission coefficient of the form [1]:

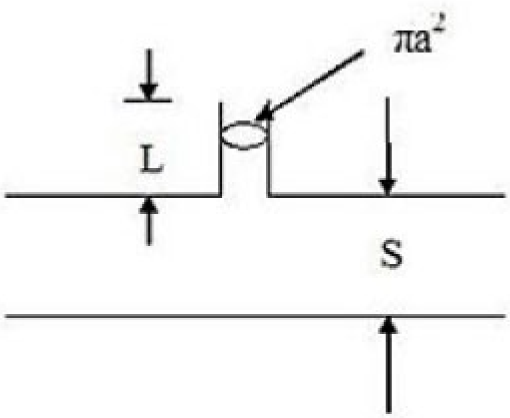
$$T_\pi = \left(\frac{1}{1 + \left(\frac{\pi a^2}{2SLk} \right)^2} \right)$$

where a and L are the area and effective length of the small tube, and S is the area of the pipe.

The cut-off frequency is given by:

$$f_c = \left(\frac{ca^2}{2SL} \right)$$

High-Pass Filter Schematic



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To get a handle on PRV stability we need to understand how the instability occurs

- It's all about the pressure waves
- What happens when flow starts?
- What happens when flow is stopped?
- PRV stability vs. inlet line length for a liquid system
- PRV stability vs. inlet line length for a vapor system
- PRV stability methods and some useful learnings

3% inlet pressure loss does not guarantee PRV stability. Additional PRV stability analysis is required.

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External video content links are provided below

Chapter 1 “3% Inlet Pressure Loss Does Not Guarantee PRV Stability”:
https://cdn.jwplayer.com/previews/zYsnK32m-1NR9vqM6

Chapter 2 “Additional PRV Stability Analysis is Required”:
https://cdn.jwplayer.com/previews/wMoRfsFe-1NR9vqM6

Chapter 3 “It’s All About the Pressure Waves”:
https://cdn.jwplayer.com/previews/6hx2dlPH-1NR9vqM6

Chapter 4 “What Happens When Flow Starts?”:
https://cdn.jwplayer.com/previews/0FvuroQu-1NR9vqM6

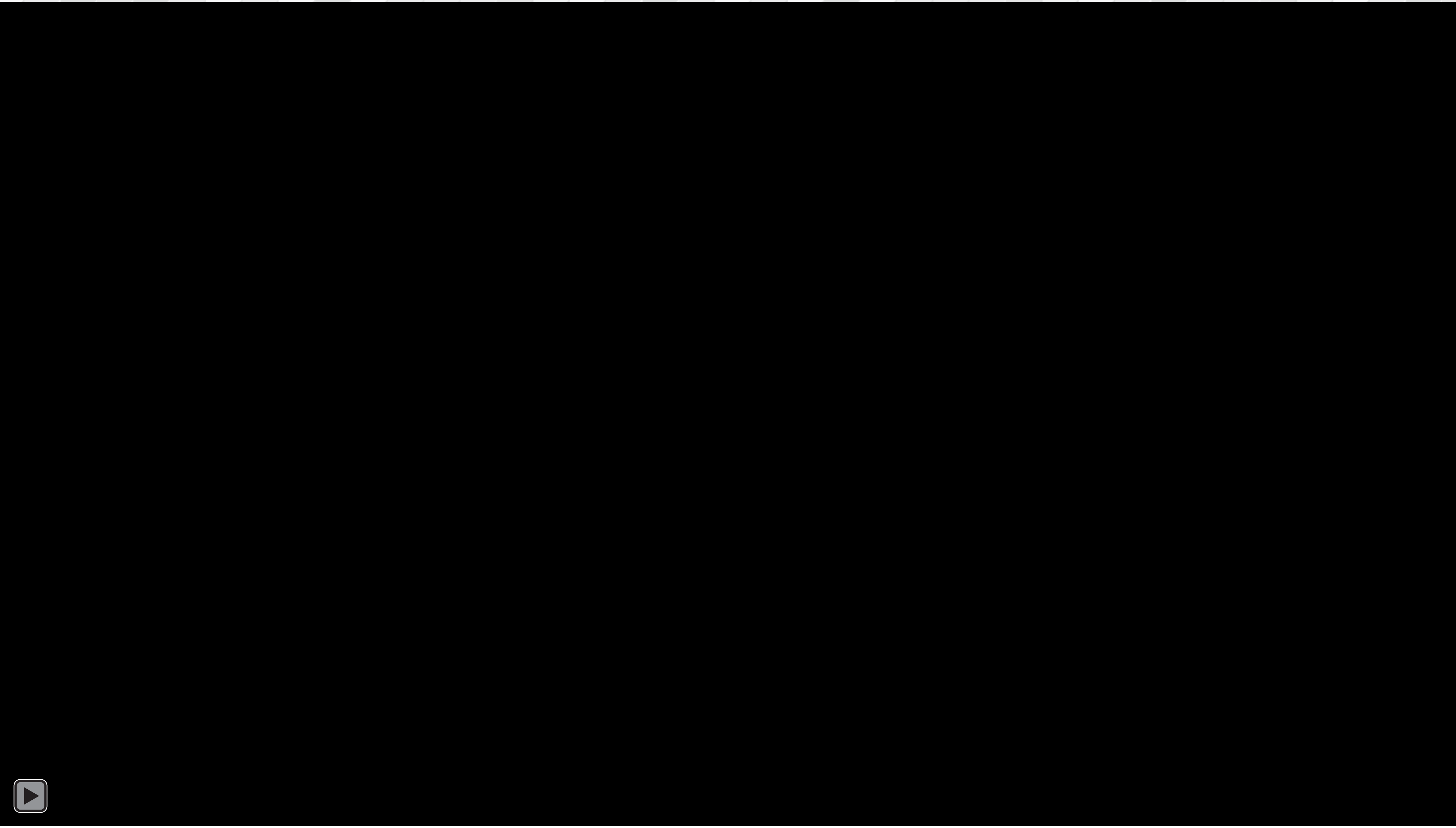
Chapter 5 “What Happens When Flow is Stopped?”:
https://cdn.jwplayer.com/previews/JaSwEYNi-1NR9vqM6

Chapter 6 “PRV Stability vs Inlet Line Length for a Liquid System”:
https://cdn.jwplayer.com/previews/AepDtEOP-1NR9vqM6

Chapter 7 “PRV Stability vs Inlet Line Length for a Vapor System”:
https://cdn.jwplayer.com/previews/q33k03lE-1NR9vqM6

Chapter 8 “PRV Stability Methods”:
https://cdn.jwplayer.com/previews/YSnUROBv-1NR9vqM6

Chapter 9 “Conclusions”:
https://cdn.jwplayer.com/previews/cu0oYdQ2-1NR9vqM6



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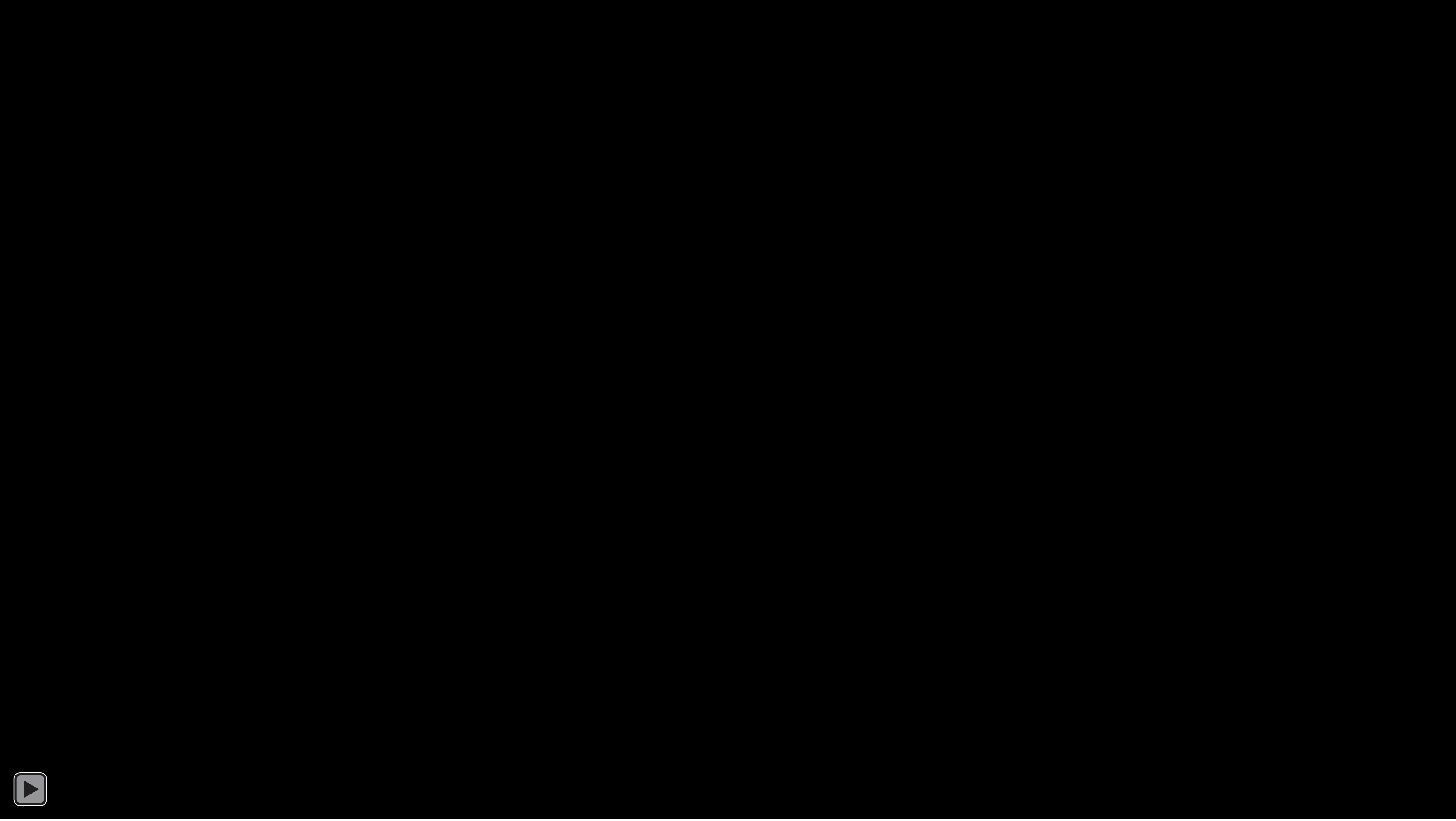

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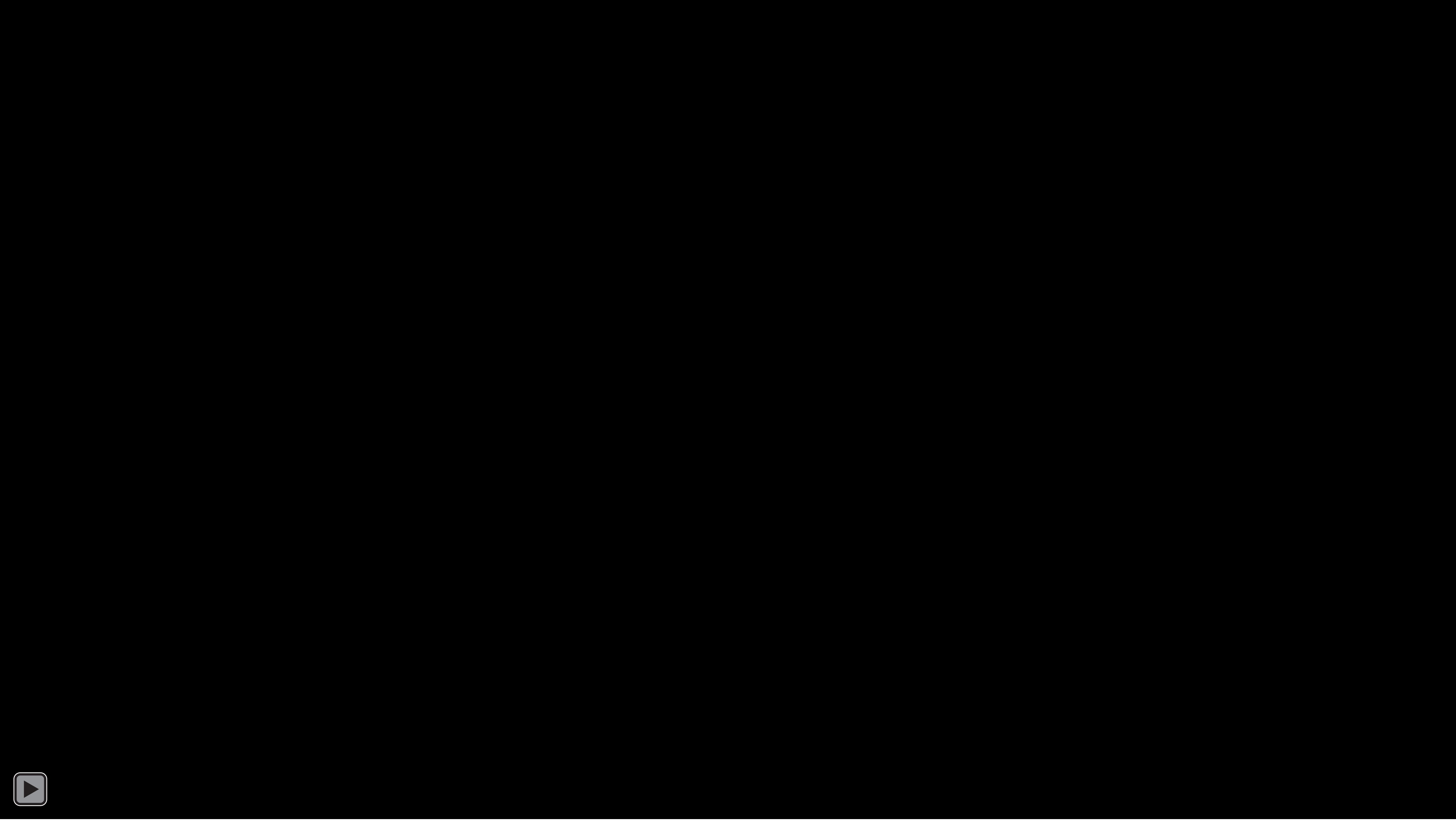

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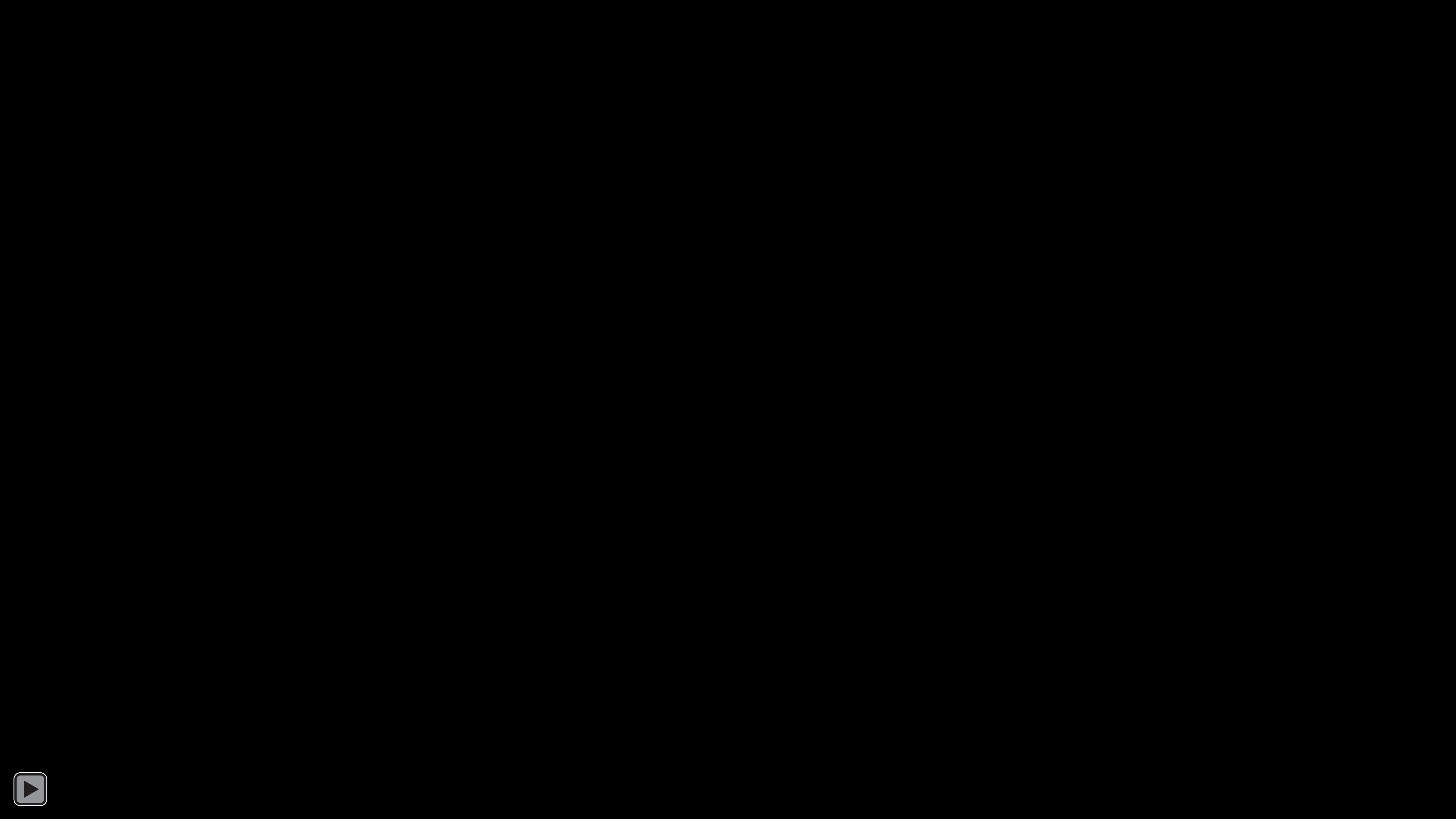

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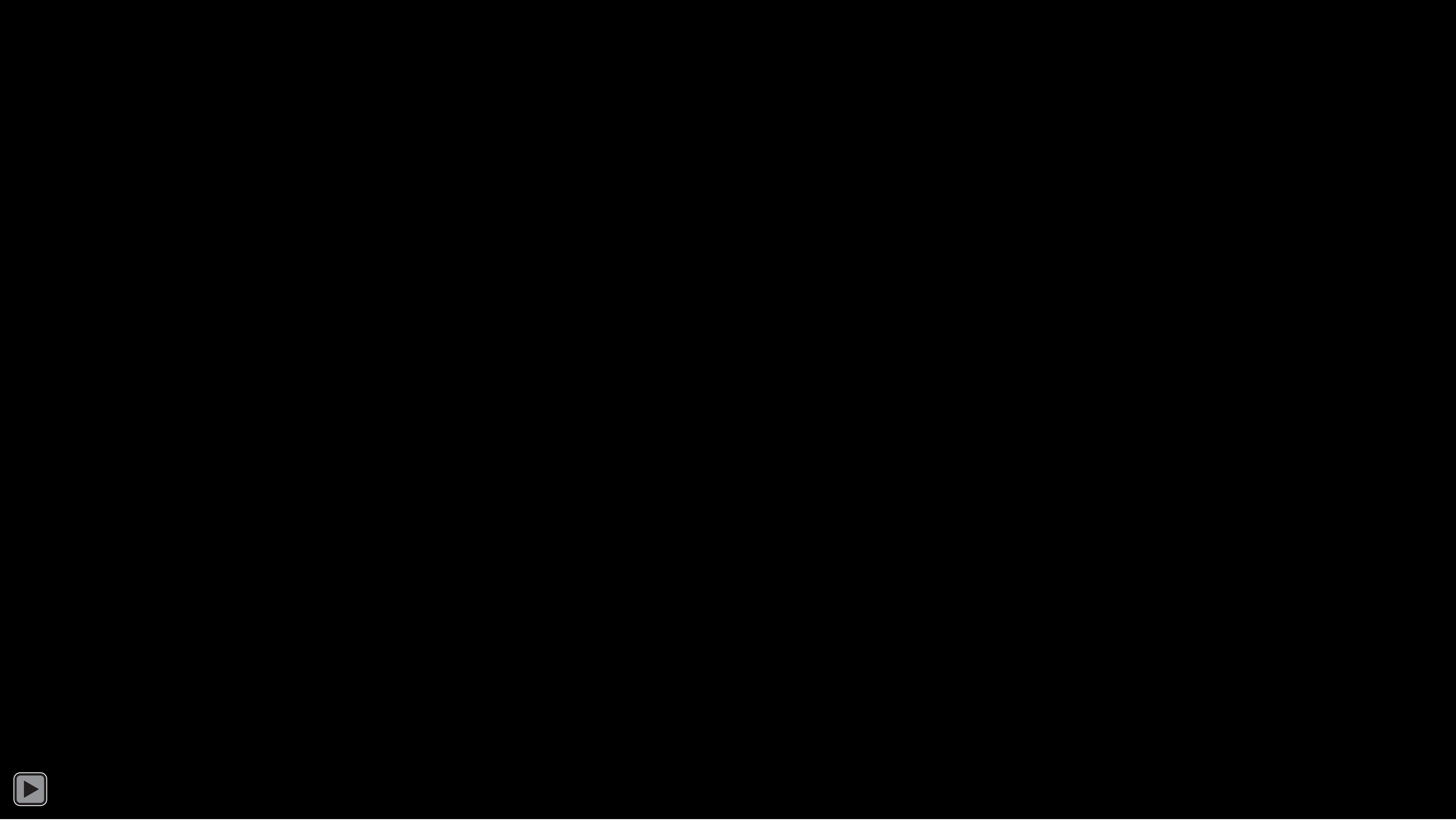

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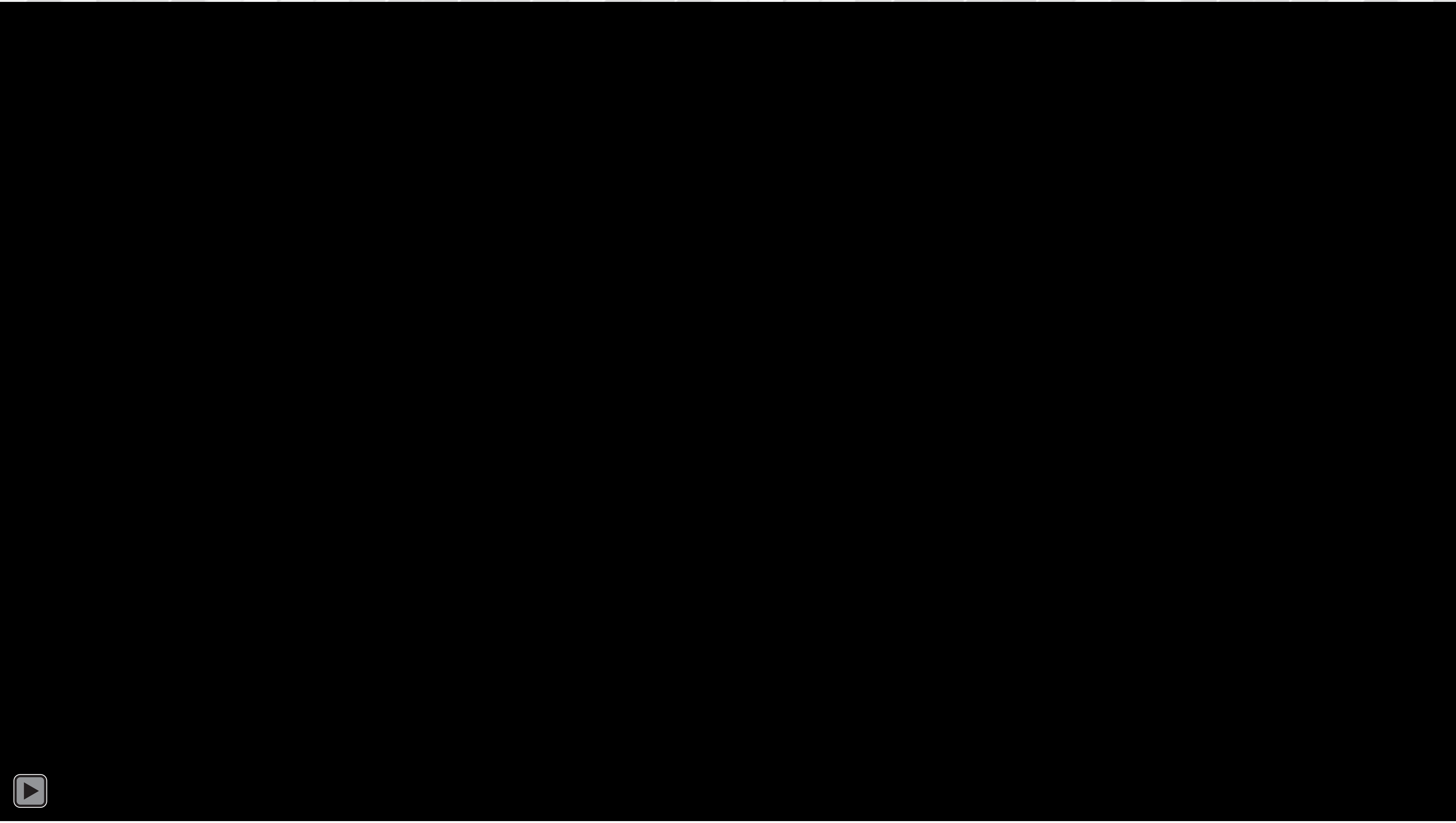

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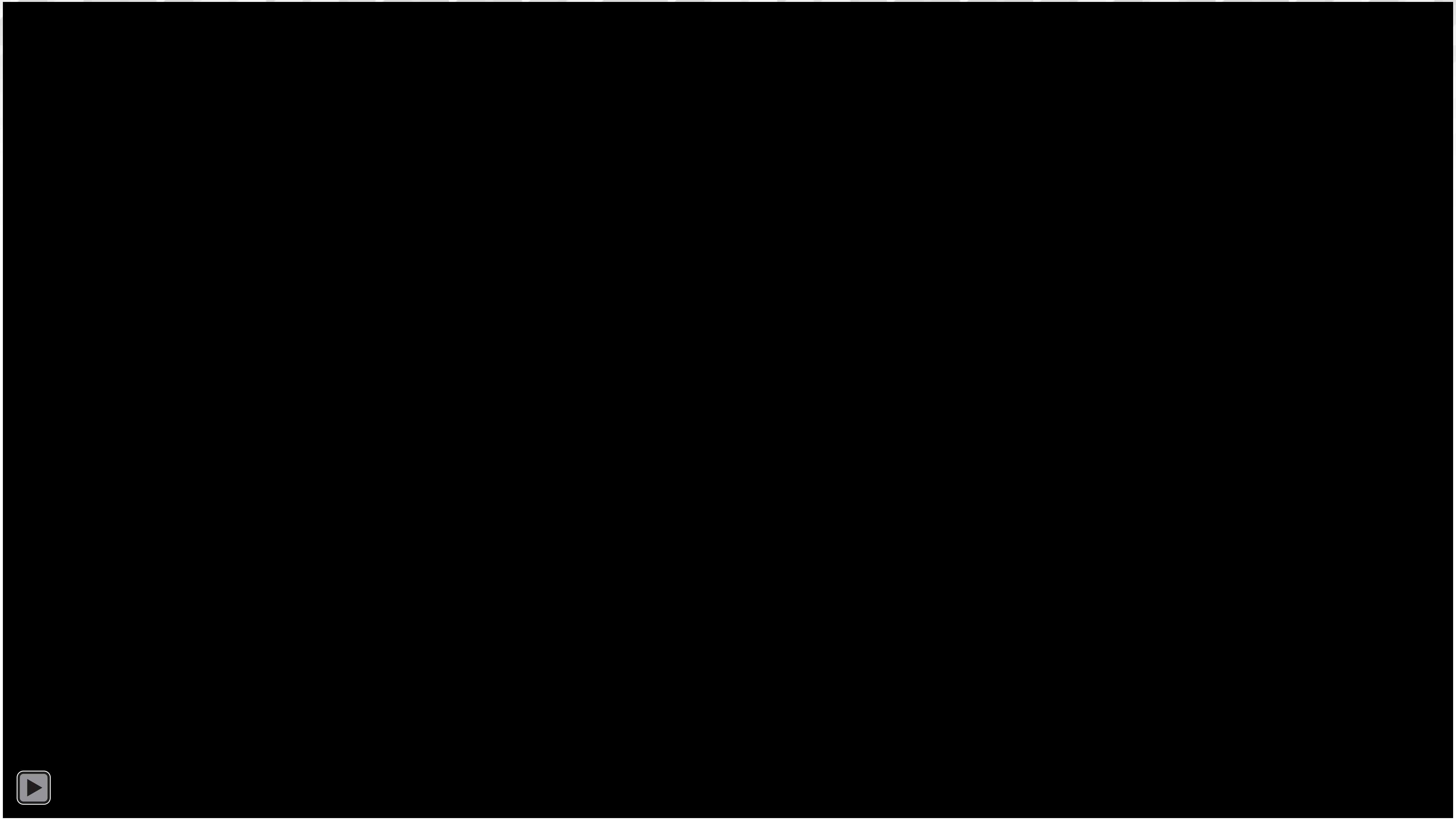

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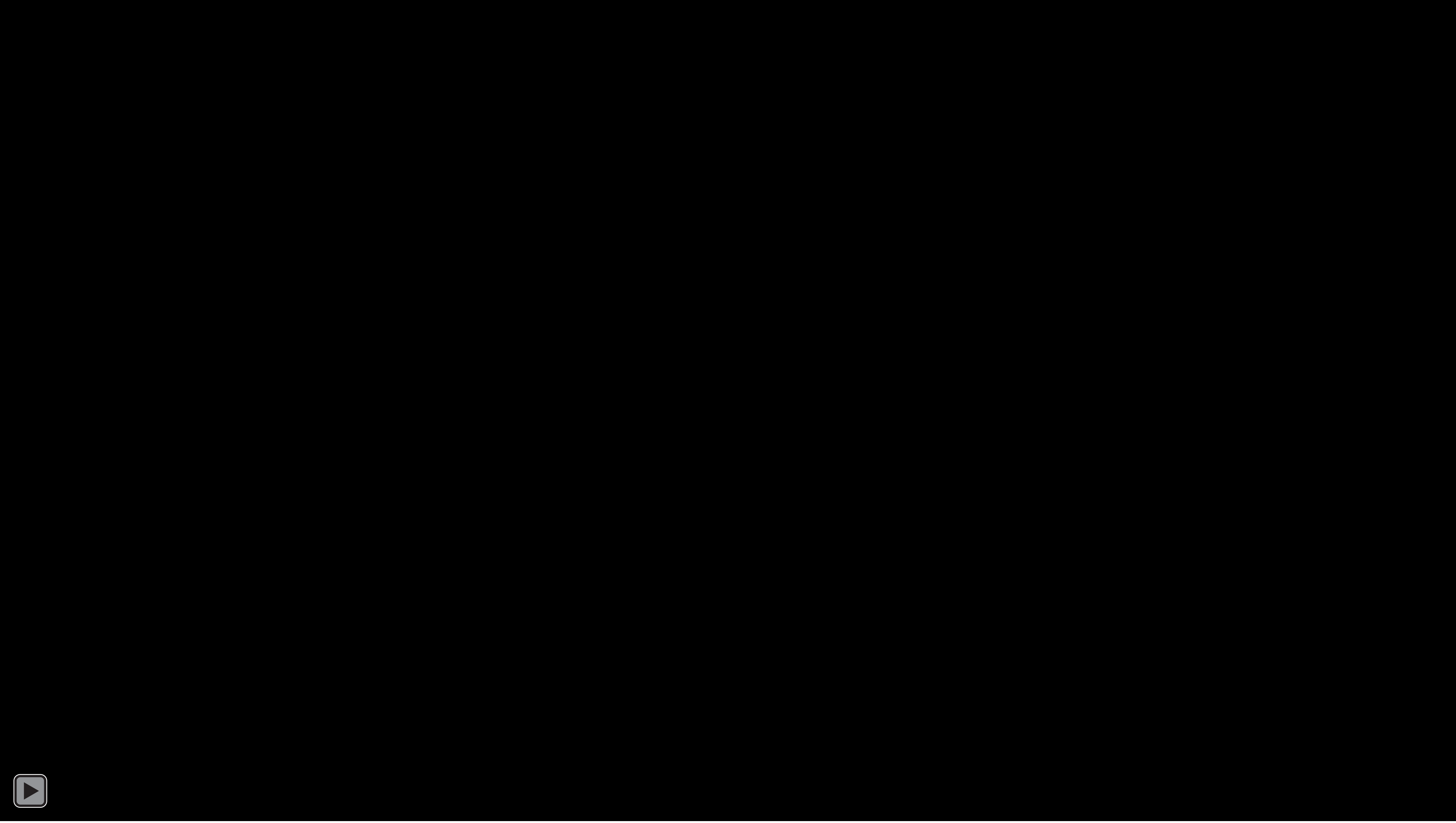

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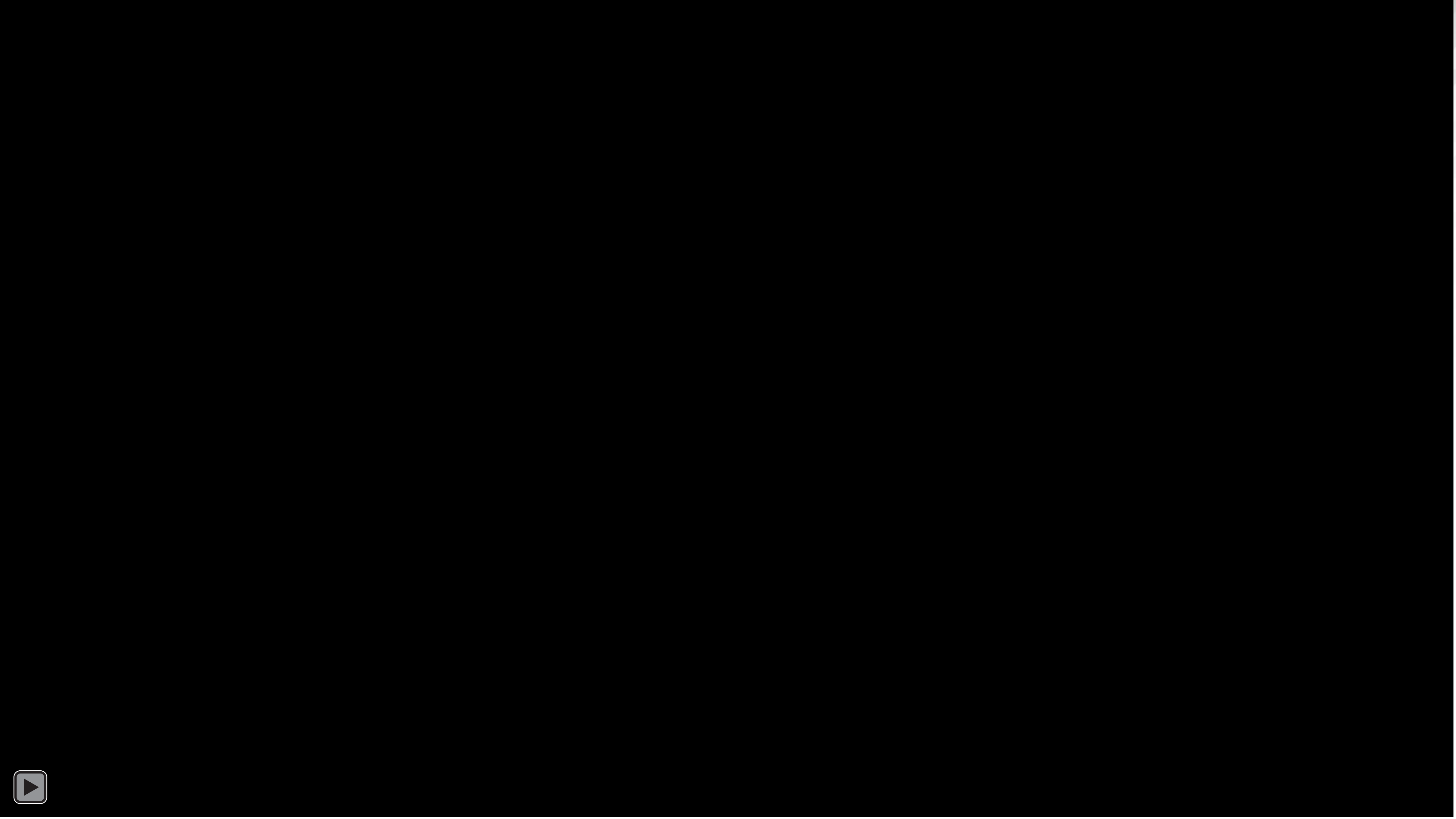

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Through innovation and dedication to continual improvement, ioMosaic has become a leading provider of integrated process safety and risk management solutions. ioMosaic has expertise in a wide variety of areas, including pressure relief systems design, process safety management, expert litigation support, laboratory services, training, and software development.

ioMosaic offers integrated process safety and risk management services to help you manage and reduce episodic risk. Because when safety, efficiency, and compliance are improved, you can sleep better at night. Our extensive expertise allows us the flexibility, resources, and capabilities to determine what you need to reduce and manage episodic risk, maintain compliance, and prevent injuries and catastrophic incidents.

Our mission is to help you protect your people, plant, stakeholder value, and our planet.

For more information on ioMosaic, please visit: **www.ioMosaic.com**

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