EVALUATION OF THE CASCADE SOLAR DISTILLER IN THE INACTIVATION OF TOTAL COLIFORMS AND *ESCHERICHIA COLI* IN SURFACE WATER

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ABSTRACT
Drinking water scarcity is a global challenge compounded by population growth, climate change, and pathogen contamination, requiring solutions such as solar distillation. This study evaluates a rippling solar distiller to treat contaminated water, analyzing its physicochemical and bacteriological quality. The results show efficiency in the removal of contaminants, reaching potability standards, with a production of 2833 $mL.m^{-2}$ and thermal efficiency above 60%. The technology is promising for isolated communities with high solar radiation.

Keywords: Solar distillation. Drinking water.

INTRODUCTION

The lack of access to drinking water is a global challenge that affects millions of individuals in different parts of the world. Many areas face significant obstacles to obtaining freshwater, which is essential to meet the fundamental needs of communities (Elfeky *et al*., 2023).

According to Orimoloye *et al*. (2021), the population increase and the growing demand for freshwater in recent decades have caused a significant shortage of this resource, with several regions facing this shortage at least once a month throughout the year. Climate change, coupled with human activities, poses serious threats to more than one billion people worldwide (Zhang *et al*., 2021). Waterborne diseases are mainly caused by pathogenic microorganisms of human or animal origin, which follow the fecal-oral route. These pathogens are excreted in the feces of infected individuals and can be ingested through water or water-contaminated food (Abu Amra; Yassin, 2008).

To ensure the health and well-being of the population, water intended for human

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consumption must be drinkable, complying with physical-chemical, microbiological and radioactive requirements established by current legislation. The legislation defines the quality standards that the water must meet, ensuring the absence of harmful substances and harmful microorganisms (Brasil, 2021).

The direct consumption of water from rivers, lakes, seas, and underground reservoirs is generally not recommended, as these water bodies may have physical, chemical, and microbiological characteristics that pose risks to human health. In this context, Mortadi and Laasri (2024) emphasize that the availability of drinking water is progressively decreasing, which challenges the scientific community to develop innovative solutions. This reality requires the application of appropriate equipment and techniques for water treatment, ensuring its safety for later use, meeting the growing need for treated water.

Solar radiation plays a key role in several environmental processes. Almost all energy sources used by humans derive from the sun, and plants depend on this energy to carry out photosynthesis and promote their growth. In this context, there has been an increase in interest in the direct application of solar energy in different scenarios, such as water distillation. Several studies indicate that increased solar radiation is associated with an improvement in the performance of distillation systems (Abujazar *et al*., 2016).

Solar distillation presents itself as a promising solution, as it can enable the production of treated water from surface water using solar energy. It is also noteworthy that regions affected by water scarcity and stress in supply are generally arid areas, characterized by high incidence of solar radiation, which enables the development of solar distillation systems. Thus, the main challenge is to develop distillation methods that are economically viable and accessible.

OBJECTIVE

This study aims to analyze the physicochemical and bacteriological quality of water before and after the solar distillation process, seeking to adapt it to potability standards. For this, a wave type solar distiller is used, aiming at its application in isolated communities that have a high incidence of solar radiation, being a technique of great importance in the treatment of contaminated water for human consumption.

METHODOLOGY

LOCATION OF RESEARCH

The experimental investigations were conducted at the facilities of the State University of Paraíba (UEPB), in the city of Campina Grande - Paraíba, where the controlled conditions allowed the execution of the analyses in a systematic and rigorous manner.

WAVE TYPE SOLAR DISTILLER

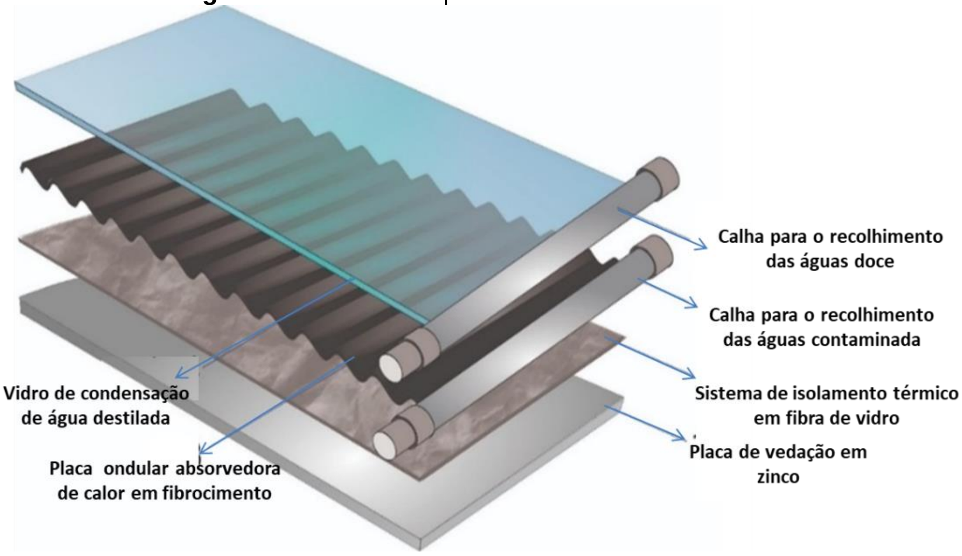
The solar distillation system with a heat-absorbing plate in a wave shape was built as described by Cardoso *et al*. (2022) and is illustrated in Figure 1. The distiller has dimensions of 1.45 meters long, 0.55 meters wide and 0.15 meters thick, resulting in a sun exposure area of 0.78 m². The equipment was operated with a 17° inclination, oriented to the north, a strategy that maximizes heat absorption. This configuration follows the approach of Bouzaid *et al*. (2019), who adjusted the inclination of the absorption plate to match the latitude of the site, adding 10° to compensate for possible errors.

Figure 1. Solar Distiller with Wave Shape Heat Absorber Plate

Source: The authors, 2025.

The internal components of the solar distiller are presented and described in Figure 2, consisting of six main parts. During the manufacture of the prototype, priority was given to the use of low-cost materials, easily accessible in local commerce, with good strength and durability, ensuring the adequacy to the construction and objectives of this study.

Figure 2. Internal components of the solar distiller.



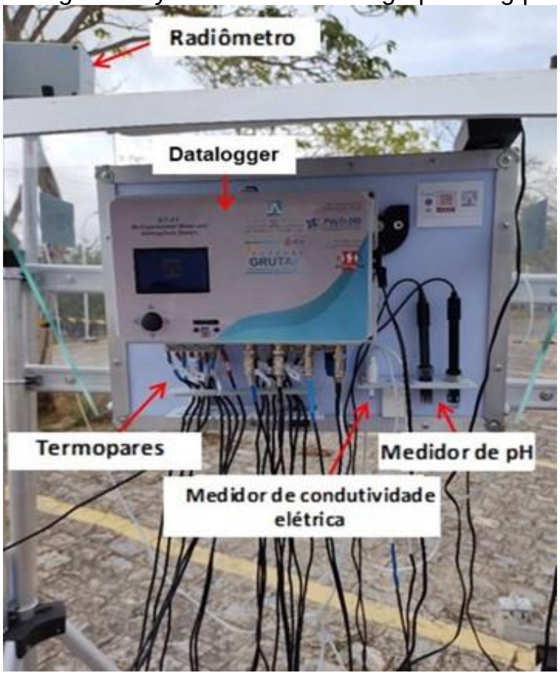
Source: Adapted from Cardoso *et al*., 2022.

DISTILLATION SYSTEM OPERATING MODE

The distiller was fed with water collected from the Bodocongó dam in the city of Campina Grande - Paraíba. The system was operated in continuous recirculation in a black tank, where the water in the feed traveled through the absorber plate that was heated by solar energy. By absorbing the heat, the water evaporated and condensed on the inner side of the glass, due to the temperature of the glass being lower than the temperature of the water vapor. Then, the condensed water was collected by a trough and measured in a graduated cylinder.

The system was monitored from 7 a.m. to 5 p.m. whenever it was in operation, positioned in a strategic area without shading. For the measurement of meteorological data (solar radiation, ambient temperature), physicochemical data (electrical conductivity and pH) and temperature at different points of the distillation system, the Integrated Multianalysis System with Connectivity and Datalogger Function was used for Monitoring Solar Desalination Plants and Other Water and Effluent Treatment Systems (Figure 3), which was developed by the Research Group in Advanced Water Treatment (GRUTAA) in partnership with the Startup ALCALITECH - Manufacture of Devices and Equipment of Measurement and Control Ltda (RAMOS *et al*., 2021).

Figure 3. Integrated system for measuring operating parameters.



Source: Adapted from Silva *et al*., 2024.

Solar radiation was measured in the range between (1.0 to 1300.0 W.m-2) with an accuracy of ± 1.0 W.m-2. Temperatures at different points in the system were measured using K-type thermocouples with a range (-50 to 300 °C) and an accuracy of ± 1.0 °C. Produced water was measured using a graduated laboratory vessel (0 to 1000 mL) with an accuracy of ± 10.0 mL.

PHYSICOCHEMICAL AND BACTERIOLOGICAL PARAMETERS OF CONTAMINATED WATER

Physicochemical tests of water

The physicochemical parameters of the contaminated and treated waters, such as apparent color, chloride, total hardness, turbidity, sodium, total dissolved solids (TDS), will be evaluated according to what is indicated in Annex 11 of the Table of Organoleptic Drinking Standard contained in Ordinance GM/MS No. 888/2021 of the Ministry of Health. In addition, temperature, pH, electrical conductivity, alkalinity, salinity and potassium will be evaluated. Chart 1 presents methodologies and/or equipment used in the determination of physicochemical parameters, following the specifications described in the Standard Methods for Examination of Walter and Waste Water (Baird; Eaton; Rice, 2017).

Table 1: Physicochemical parameters analyzed and equipment used.

Parameter	Unit	Method/Equipment
Temperature	°C	Thermocouples
ph	---	pH meter
Electrical conductivity	μ $^{S.cm-1}$	Conductivity meter
Apparent color	Uh	Colorimeter
Chloride	mg Cl-L-1	Mohr
Hardness	mg CaCO3L-1	Titrametric - EDTA
Alkalinity	mg CaCO3L-1	Titrametric with indicator
Turbidity	NTU	Turbidimentro
Sodium	mg Na+$^{L-1}$	Flame photometer
Potassium	mg K+$^{L-1}$	Flame photometer
SDT	mgL-1	Multi-parameter probe

Source: The authors, 2025.

Bacteriological tests of water

The contamination parameters of the waters studied before and after the distillation process, which were analyzed to prove the efficiency of the bacteriological treatment, are indicated in Annex 1 of the Table of Bacteriological Standard of Water for Human Consumption inherent in the Table of Sporogenic Bacteria of Thermotolerant Coliforms (Escherichia coli and total coliforms) of water for human consumption, contained in Ordinance GM/MS No. 888/2021 of the Ministry of Health. The decontamination processes aim to destroy or inactivate pathogenic microorganisms capable of causing diseases or other undesirable organisms.

Presence Test - Absence (P/A)

The Presence-Absence (P/A) test allows qualitative assessment of the presence or absence of indicator bacteria in a 100 mL sample volume. For this assay, a sterile vial containing specific culture medium was used, using the Colilert kit, which uses enzymatic substrate technology. The sample was incubated at 35 ± 0.5 °C for 24 hours, after which the color change and the presence of fluorescence were verified, as described by Ceballos and Diniz (2017).

During the test, the presence of total coliforms is indicated by metabolization of the ONPG indicator, resulting in a cloudy yellow coloration of the sample. The presence of *Escherichia coli* is identified by metabolizing the MUG indicator, which makes the sample fluorescent (Idexx, 2024).

DEVELOPMENT

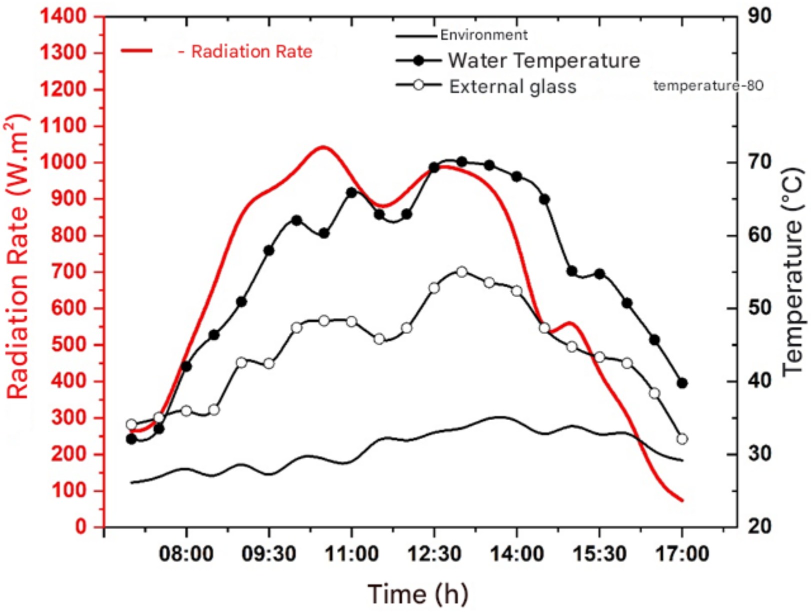
Data corresponding to a specific day of the experiment were performed and highlighted in Figures 4, 5, and 6, chosen based on the best results found during monitoring. For the purpose of the study, the thermal profiles, values of accumulated distilled water production and the hourly thermal efficiency as a function of solar radiation are presented, respectively. To which predetermined parameters were measured every 30 minutes, starting at 07:00 AM and ending at 17:00 PM.

THERMAL PROFILES OF THE DISTILLER

In Figure 4, it is observed that the wind speed varied between 0.5 and 3.9 m/s throughout the experiment. The solar radiation rate began at 264 W.m-2 at 07:00, with the following temperatures recorded: ambient temperature of 25.12 °C and water temperature of 34.1 °C. The temperature of the outer glass remained lower than the water temperatures of the distiller's absorber plate.

During the experiment, the water temperature in the absorber plate varied, reaching its maximum value at 1:00 p.m., with 70.1 °C. The highest incidence of solar radiation recorded on this day was 1080 W.m-2, which contributed to the significant increase in water temperature, favoring the evaporation process. Tiware and Rathore (2022) found that, in a waterfall-type solar distiller, the maximum temperature reached from the water was 58 °C at 2:00 pm, with solar radiation of 855 W.m-2. Comparatively, the present study obtained a maximum water temperature of 70.1 °C at 1:00 p.m., indicating a higher temperature in relation to the research of these authors. The values obtained demonstrate a higher incidence of solar radiation, which directly contributed to the increase in temperatures and, consequently, to a more effective heating of the water.

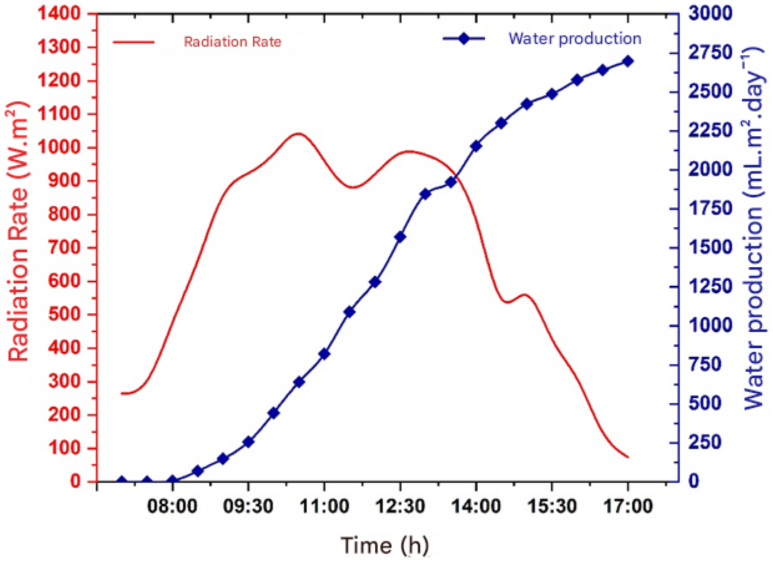
Figure 4. Distiller Temperature Profiles



Source: The authors, 2025.

Figure 5 demonstrates that the levels of solar radiation to which the system was exposed were satisfactory, reflected in an increasing production of distilled water throughout the day. It is observed that at 12:00 p.m., solar radiation reached 1080 W.m-2, with water production at this time reaching 1279 mL.m-2. It is also noteworthy that the production of distilled water varied in accordance with solar radiation, reaching a total of 2654 mL.m-2 at the end of the day. This increase in production can be attributed to the overheating of the absorber plate due to the prolonged time of exposure to solar radiation, which raised the temperature of the water, favoring the evaporation process. The peaks of solar radiation occurred at 10:30 a.m. and 12:30 p.m., when the maximum values of 1080 W.m-2 and 1000 W.m-2 were recorded, respectively. This experiment demonstrated a good production of distilled water, corroborating the study by Khechekhouche *et al*. (2020), who highlight in their research that the productivity of the solar distiller increases with the addition of solar radiation.

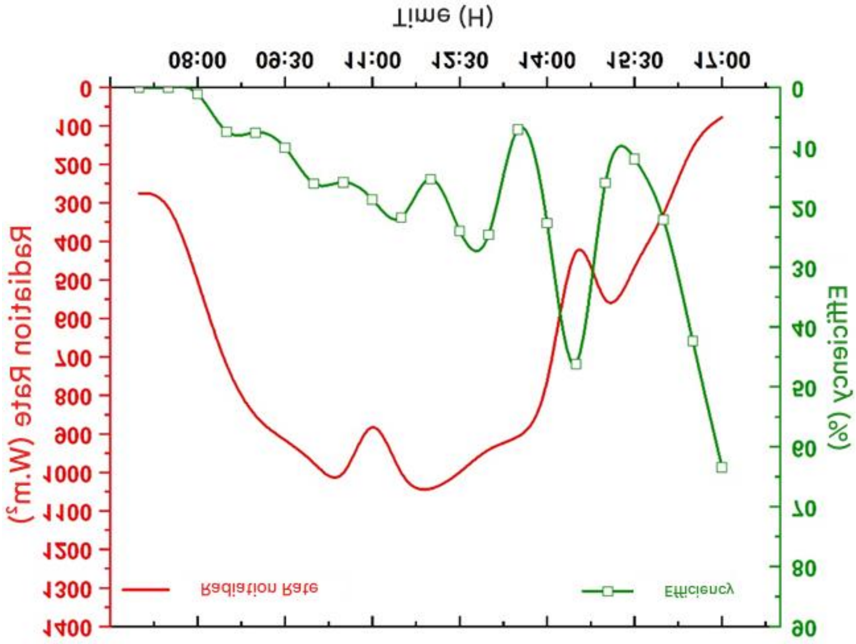
Figure 5. Distiller's Water Production



Source: The authors, 2025.

Figure 6 shows the hourly thermal efficiency as a function of the incidence of solar radiation in the experiment carried out. During the experiment, the distiller achieved an adequate efficiency at the end of the day above 60%. This performance is due to the high incidence of solar radiation recorded on that day, which presented an average of 810 W.m-2. For comparison, Sharshir *et al*. (2018) reported an hourly efficiency of 35.56% in a conventional distiller under similar conditions. These results highlight the effectiveness of the experimental system, especially under favorable solar radiation conditions.

Figure 6. Thermal efficiency of the distiller



Source: The authors, 2025.

PHYSICOCHEMICAL AND BACTERIOLOGICAL PARAMETERS OF CONTAMINATED WATER

The efficiency of the distillation system is directly related to the quality of the distilled water, which is one of the main objectives of the solar distiller. In this context, both contaminated water and distilled water were subjected to tests to evaluate relevant physicochemical parameters, as established by the potability legislation of the

Physicochemical tests of contaminated water

Analyzing the raw water sample, high levels of the parameters were observed and when analyzing the water after the distillation process, results compatible with the potability parameters were obtained, which confirms the efficiency of the distillers, since the pH, electrical conductivity, color, chlorides, total hardness, alkalinity, turbidity, sodium, potassium and TDS, did not exceed the standards of potability after distillation. Table 1 shows the results and physicochemical parameters of the distiller's raw and distilled water.

Table 1. Result of the physicochemical analysis of raw and distilled water samples.

Control Parameters	Raw water	Distilled water	V.M.P.*
ph	7,8	6,7	6,0 – 9,0
Electrical conductivity (µScm-1)	164,0	1,5	–
Apparent color (uH)	46,4	3,4	15,0
Chloride (mg Cl-L-1)	163,9	4,7	250,0
Total hardness (mg CaCO3 $^{L-1}$)	259,5	0,0	300,0
Alkalinity (mg CaCO3 $^{L-1}$)	923,0	32,4	–
Turbidity (NTU)	8,0	0,6	5,0

Sodium (mg Na+ $^{L-1}$)	300,0	0,0	200,0
Potassium (mg K+ $^{L-1}$)	31,0	0,0	–
TDS ($^{mgL-1}$)	843,3	0,0	500,0

V.M.P.*= Maximum amount allowed according to Ordinance GM/MS No. 888, of May 4, 2021 of the Ministry of Health. Source: Propria, 2025.

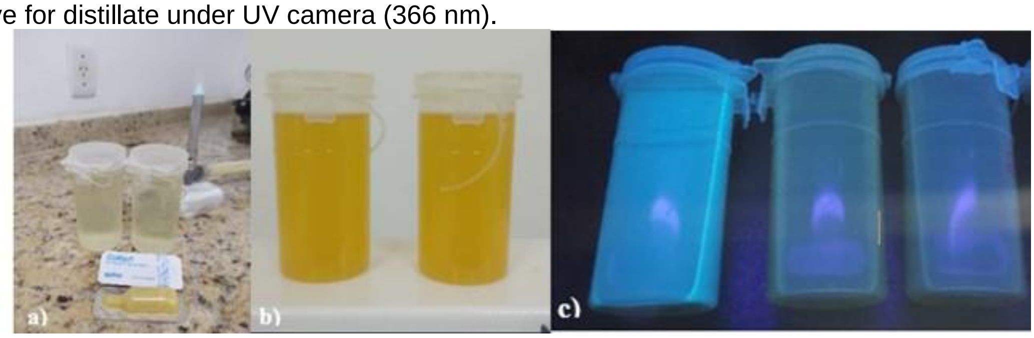
Bacteriological tests of water

The solar distiller intended for the production of drinking water must ensure a 100% removal efficiency for total coliforms, in addition to the complete absence of *Escherichia coli*. To evaluate the bacteriological quality of raw and distilled waters, the presence/absence test was used. The results indicated that the crude samples showed positive results for total coliforms and *Escherichia coli*. However, after the distillation process carried out by the distiller, they confirmed the complete removal (100%) of these microorganisms, demonstrating the effectiveness of the process.

Presence Test - Absence (P/A)

In the (P/A) test, the samples positive for total coliforms showed cloudy yellow in the cells. In the presence of *Escherichia coli*, a blue fluorescence was formed in the dark chamber under UV light (365 nm). As shown in Figure 7 and Table 2, with the results referring to the bacteriological analyses of the samples of raw water and distilled of presence/absence. The distilled samples showed 100% inactivation of total coliforms and Escherichia coli.

Figure 7. P/A test for identification of total coliforms and Escherichia coli from the raw and distilled sample. (a) the test for P/A was inserted. (b) positive for total coliforms (c) positive for Escherichia coli in the raw sample and negative for distillate under UV camera (366 nm).



Source: The authors, 2025.

Table 2. Results referring to the bacteriological analysis of raw and distilled water samples of presence/absence of total coliforms and *Escherichia coli* in 100ml of water.

Essay	Raw water	Distilled water
Microorganism		
Total coliforms/ *Escherichia coli*	Gift/Gift	Absent /Missing

Source: The authors, 2025.

FINAL CONSIDERATIONS

The proposed objectives were achieved in this study, as the solar distiller was operated and presented satisfactory results in the water temperature profiles of the heat absorbing plate, resulting in a high production of distilled water and efficiency. In this experiment, the water temperature in the heat-absorbing plate was 70.1 ºC, the productivity at the end of the day reached a distillate volume of 2833 mL.m-2 and the efficiency was above 60%.

In the results obtained from the physicochemical analyses of the distilled water, the values were within the standards of potability for human consumption according to the parameters analyzed. The bacteriological results indicated that the raw samples showed positive results for total coliforms and *Escherichia coli*, however, after the distillation process carried out through the solar distiller, there was a complete removal (100%) of these microorganisms, demonstrating the effectiveness of the process.

Therefore, it was possible to conclude that the solar distiller under study is a promising option for the production of distilled water for communities where the water demand is not high and where there is a high incidence of solar radiation to provide water within potability standards.

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