# Novel UV-C Emitting Phosphors for Hg Low Pressure Discharge Lamps


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**20th JCF-Frühjahrssymposium, March 2018, Konstanz, Germany**


## Introduction

Water disinfection with UV-C radiation gets more and more important over the last 20 years. Hg-low-pressure discharge lamps are typically used as artificial UV-C sources. The main emission (85%) of these lamps lays at 254 nm, 12% lays at 185 nm (VUV-region) and 3% in the visible range of the electromagnetic spectrum. Therefore, the majority of the emitted radiation is UV-C light, which can be used directly for water disinfection. The 12% of VUV emission, become absorbed by water under formation of OH-radicals, already in small layer thicknesses. To increase the disinfection efficiency of Hg-low-pressure discharge lamps it is necessary to convert the emitted VUV-radiation into UV-C-radiation. Therefor phosphors are needed, which can be excited with 185 nm and emits radiation between 200 and 310 nm. In addition to disinfection purposes, UV-C radiation can also be used for so called "advanced oxidation processes" (AOP). AOP is a fast growing field in the area of water treatment, in which OH•-radicals are used to break C-C and C-H bonds to decompose organic pollutants [1].

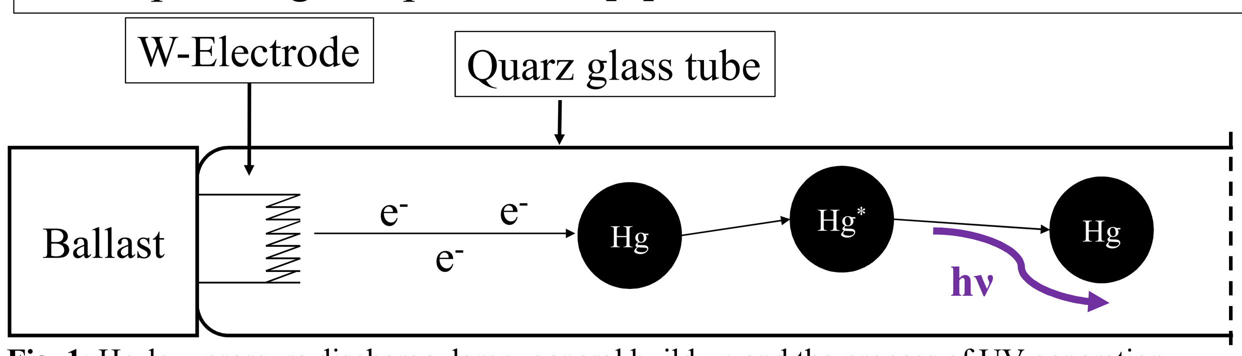



**Fig. 1**: Hg-low pressure discharge lamp, general build up and the process of UV generation

## Processes inside the gas discharge

1. Emission of electrons: Cathode → $e^-$
2. Excitation of Hg-atoms: $Hg + e^- \rightarrow Hg^* + e^-$
3. Relaxation of excited Hg-atoms: $Hg^* \rightarrow Hg + h\nu$

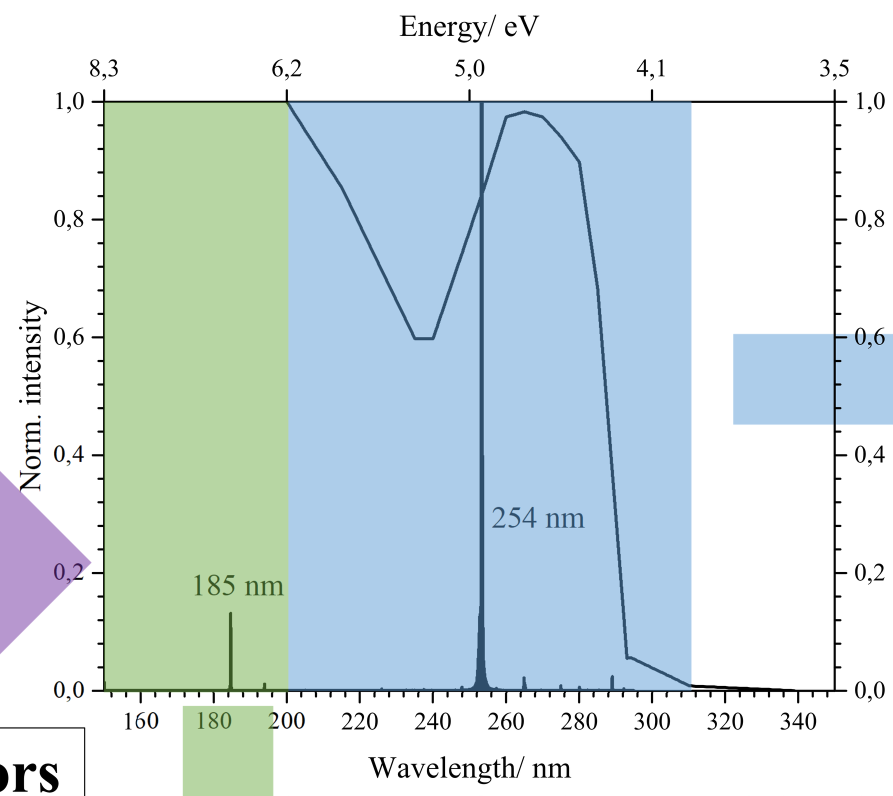
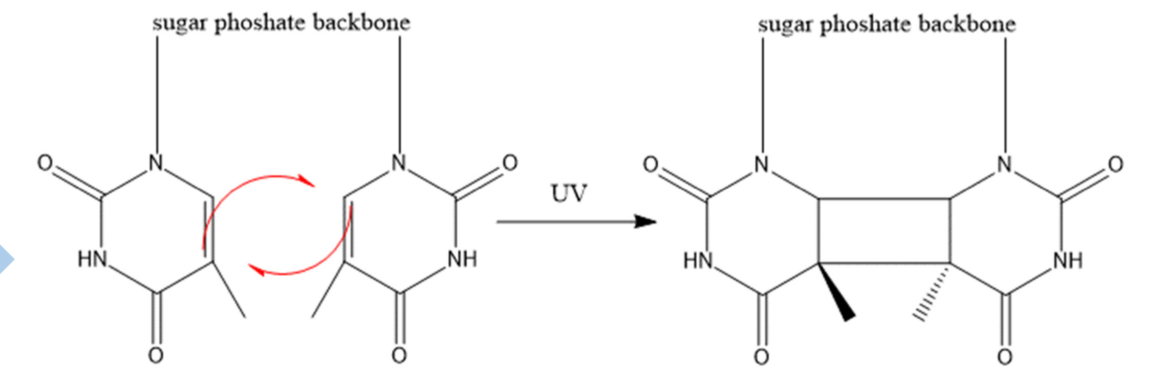
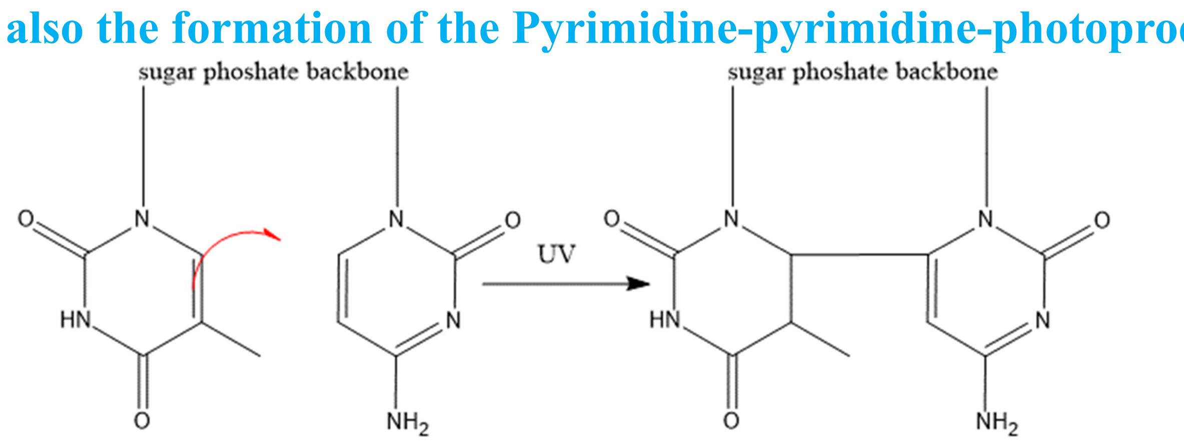



**Fig. 2**: Emission spectrum of a Hg-low pressure discharge lamp and germicidal action curve for B. subtilis (DIN 5031-10)

**Radiation between 200 and 310 nm induces the photochemical dimerization of two adjacent thymine bases by [2+2]-cycloaddition**




**and also the formation of the Pyrimidine-pyrimidine-photoproduct**




## Prerequisites for potential UV-C emitting phosphors

- Suitable band gap (> 6 eV)
- High thermal, photo and chemical stability
- Redox stable activators
- High absorption cross section around 185 nm
- Emission band between 200 and 280 nm

**Radiation under 200 nm induces the photolysis of water**

$$H_2O + h\nu \rightarrow H^\bullet + {}^\bullet OH$$

## Examples for suitable host materials and activators

| Host materials: | Activators: |
|---|---|
| - Phosphates | - $Pr^{3+}$ |
| - Borates | - $Nd^{3+}$ |
| - Aluminates | - $Bi^{3+}$ |
| - Silicates | |

## „Advanced oxidation processes"

1. Formation of hydroxyl radicals out of hydrogen peroxide: $H_2O_2 + h\nu \rightarrow 2\ {}^\bullet OH$
2. Cleavage of C-C and C-H bonds via hydrogen abstraction or addition reactions [2]:
   a. ${}^\bullet OH + H_3C\text{-}OH \rightarrow H_2O + H_2C^\bullet\text{-}OH$
   b. $H_2C^\bullet\text{-}OH + {}^\bullet OH + O_2 \rightarrow H_2C{=}O + H_2O$
   c. $H_2C{=}O + {}^\bullet OH + O_2 \rightarrow HCOOH$
   d. $HCOOH + {}^\bullet OH + O_2 \rightarrow CO_2 + H_2O$
   or
   a. $H_2C{=}CH_2 + {}^\bullet OH \rightarrow H_2C^\bullet\text{-}CH_2\text{-}OH$
   b. $H_2C^\bullet\text{-}CH_2\text{-}OH + {}^\bullet OH \rightarrow HO\text{-}H_2C\text{-}CH_2\text{-}OH$

## Examples for the photoluminescence of UV-C emitting phosphors

### ns² luminescence

$[Xe]4f^{14}5d^{10}6s^2 \rightarrow [Xe]4f^{14}5d^{10}6s^16p^1$

### 4f-5d luminescence

$[[Xe]4f^2 \rightarrow [Xe]4f^15d^1$

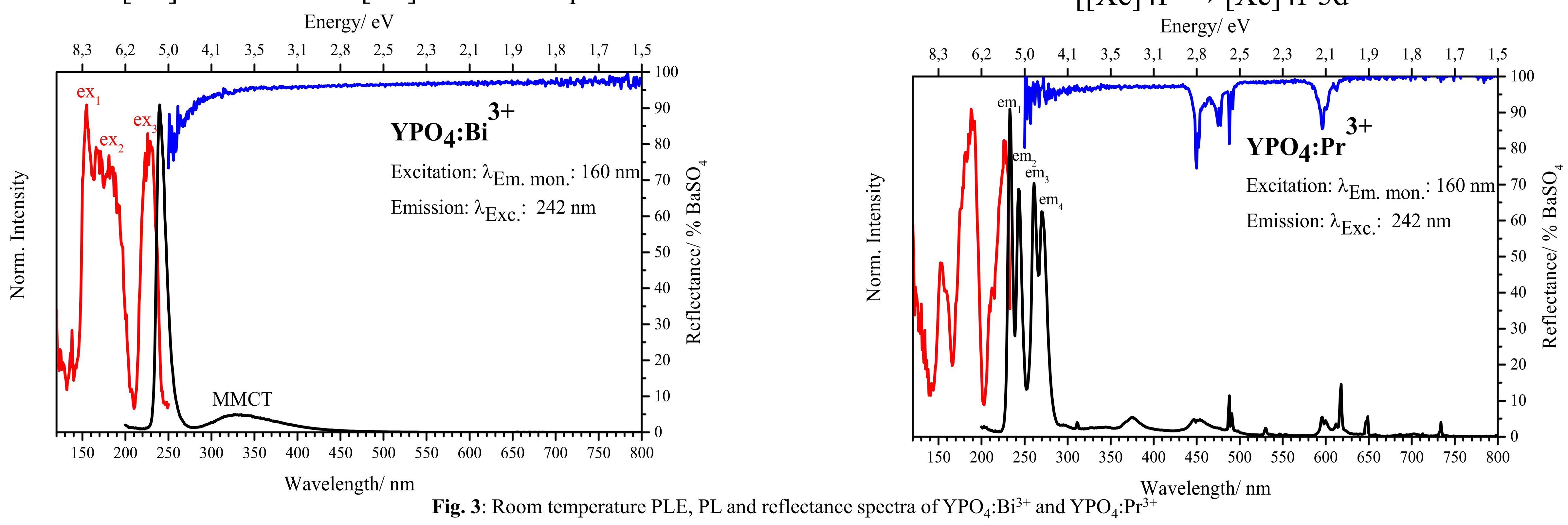



**Fig. 3**: Room temperature PLE, PL and reflectance spectra of $YPO_4:Bi^{3+}$ and $YPO_4:Pr^{3+}$

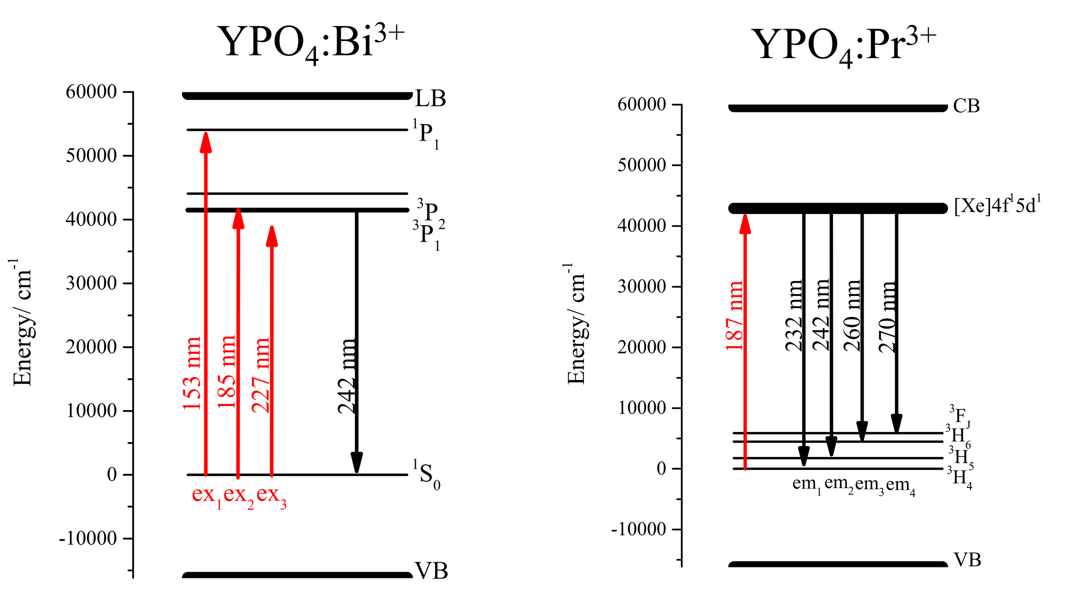



**Fig. 4**: Energy level diagram of $YPO_4:Bi^{3+}$ and $YPO_4:Pr^{3+}$ [3,4]

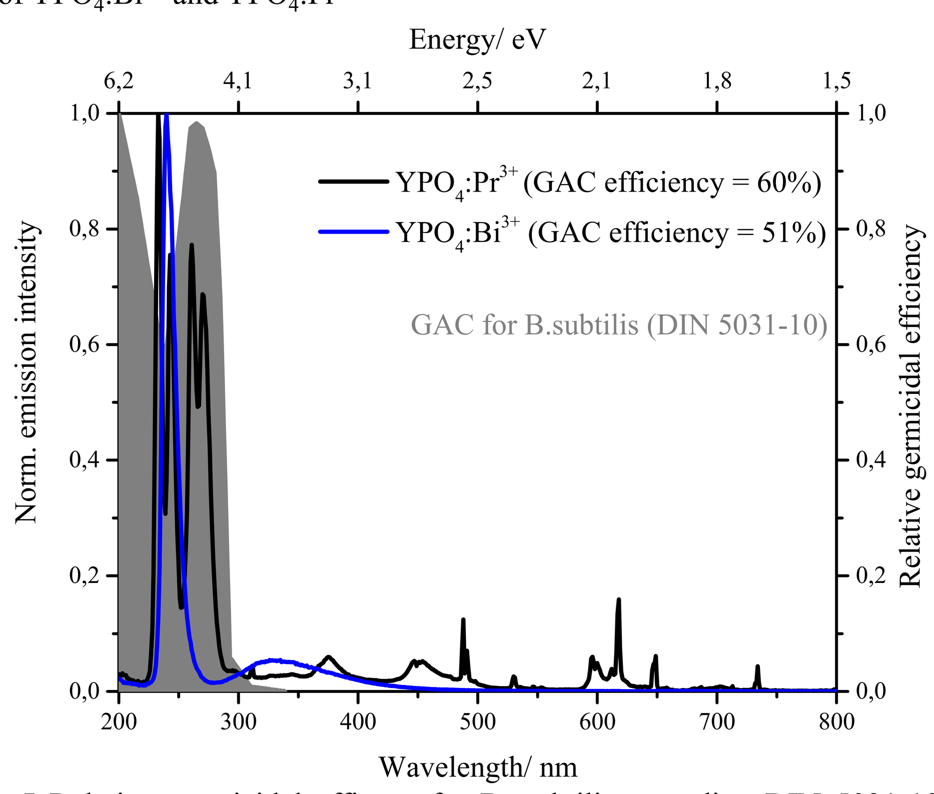



**Fig. 5** Relative germicidal efficacy for B. subtilis according DIN 5031-10 and photoluminescence emission spectra of $YPO_4:Bi^{3+}$, $YPO_4:Pr^{3+}$ ($\lambda_{Exc.}$= 160 nm)

## Example for the efficiency increase

Common values for big disinfection devices:

Lamp power: 50 kW
Efficiency 185 nm: 10 %
Efficiency 254 nm: 40 %

Without phosphor conversion of the 185 nm emission:
**20 kW (40%) for disinfection useable**

With phosphor conversion of the 185 nm emission, using a hypothetic phosphor with a quantum efficiency of 90%:
**24.5 kW (49%) for disinfection useable**

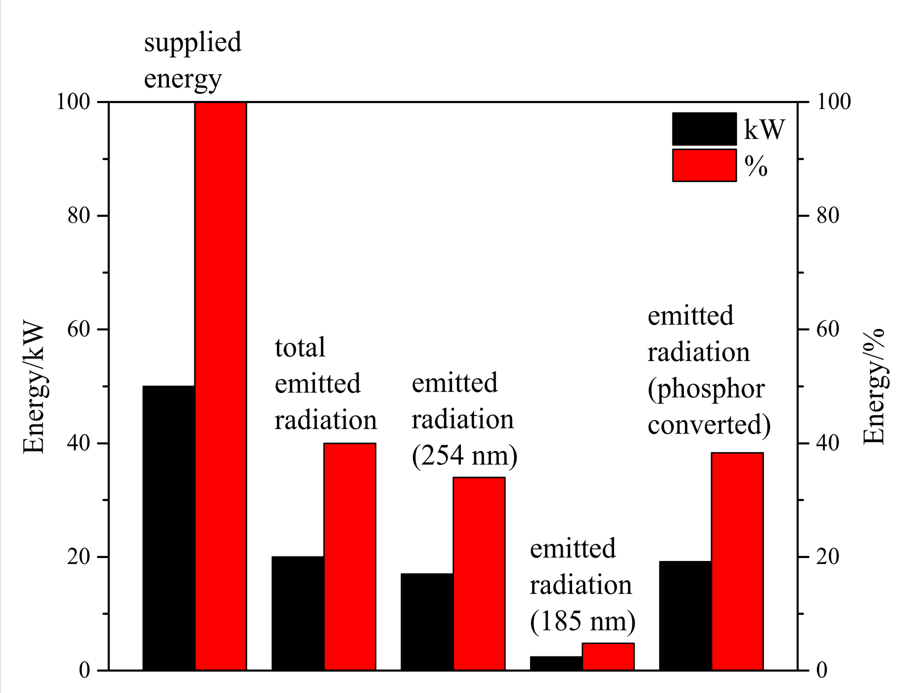



**Fig. 6**: Overview energy distribution for a big disinfection device with and without phosphor conversion of the 185 nm line

## Conclusions

Future work will deal with the more UV-C emitting phosphors. The herein presented phosphors are already known and multiple studies were dedicated to them.

## Literature


[1] R. Andreozzi et al., Cat. Today, 53, 2008, 51-59
[2] System SE. The UV/oxidation handbook, 1994
[3] R.H.P. Awater, P. Dorenbos, J. Lumi., 184, 2017, 221-231
[4] A.J.J. Bos et al., Rad. Measure., 43, 2008, 222-226



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