Detecting Heavy Metals in Water

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Introduction

Problem

- Canada-wide investigations reveal harmful levels of toxic metals are present in tap water [1]
- Make sure public is aware of the quality of their water
- Test water for the heavy metal contaminants, mercury (Hg) and lead (Pb)

Solution

- A prokaryotic vector that is to be placed in a houseplant where fluorescent signals will indicate the presence of a heavy metal
- Yellow will be released when mercury is present, red will be released when lead is present, and yellow, red, and blue will be released when both are present

The Model

SBOL and Truth Table

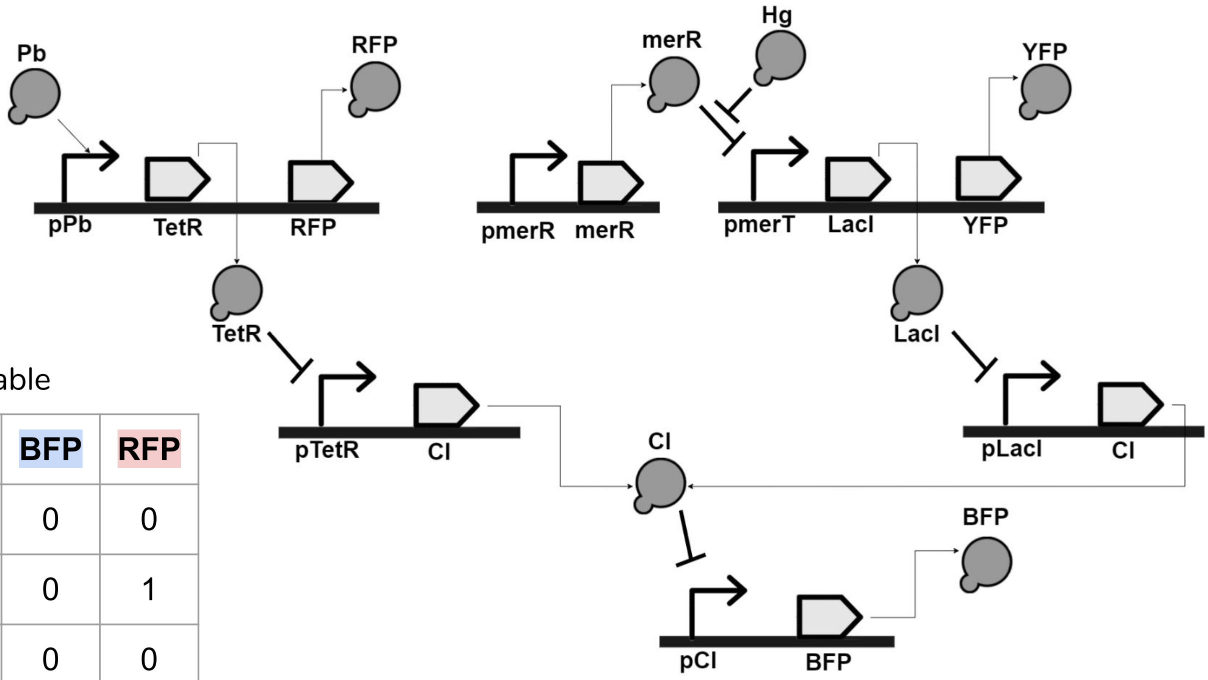


Table 1. Truth table

Pb	Hg	YFP	BFP	RFP
0	0	0	0	0
1	0	0	0	1
0	1	1	0	0
1	1	1	1	1

Plasmid

Host: Agrobacterium tumefaciens

Plasmid: Tumour-inducing (Ti) plasmid (pBBR1MCS)

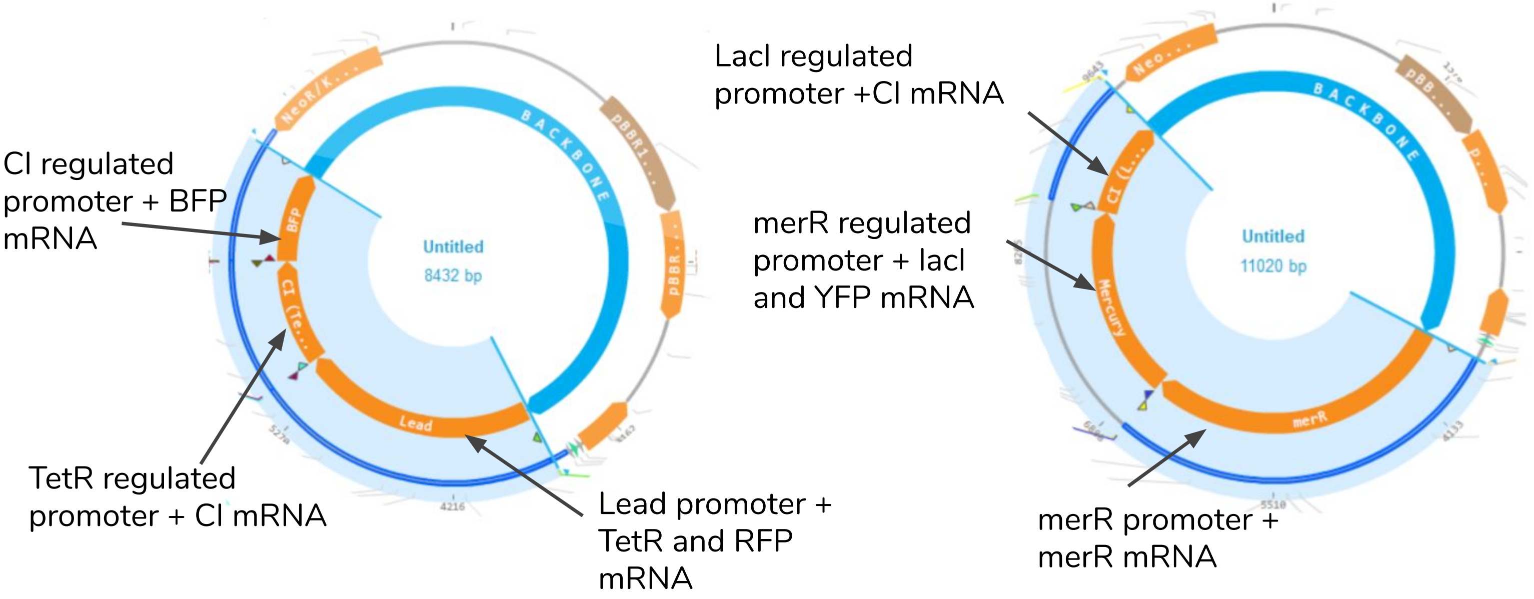


Figure 1. Tumor-inducing plasmid containing various parts that allow the visual response to mercury and/or lead.
The left plasmid contains the system for lead detection (RFP) and detection of both metals (BFP) while the right is

Assumptions

Zero Rate Assumption

- mRNA dilution << mRNA decay; mRNA loss dictated by mRNA decay
- Protein decay << protein dilution; protein loss dictated by protein dilution

Constant Rate Assumption

- Applies to decay, dilution, translation
- Processes occur at a constant rate ($\propto k$)

Mass Action Kinetics

- For merR + Hg binding
- Reaction rate proportional to product of reactants ($\propto k[merR][Hg]$)

Hill Kinetics + Hg-merR Dissociation

Repression of pTetR: $\frac{d[mRNA]}{dt} = \frac{K_{trsc}}{1 + (\frac{[TetR]}{K_{\text{hill repression}}})^H}$

Repression of pLacI: $\frac{d[mRNA]}{dt} = \frac{K_{trsc}}{1 + (\frac{[LacI]}{K_{\text{hill repression}}})^H}$

Repression of pCI: $\frac{d[mRNA]}{dt} = \frac{K_{trsc}}{1 + (\frac{[CI]}{K_{\text{hill repression}}})^H}$

Repression of pmerT: $\frac{d[mRNA]}{dt} = \frac{K_{trsc}}{1 + (\frac{[merR]}{K_{\text{hill activation}}})^H}$

Activation of pPb: $\frac{d[mRNA]}{dt} = \frac{K_{trsc} * (\frac{[Pb]}{K_{\text{hill activation}}})^H}{1 + (\frac{[Pb]}{K_{\text{hill activation}}})^H}$

Hg-merR Dissociation: $\frac{d[merR]}{dt} = -K_1 * [merHg]$

$$H = 1$$

$$K_{hill\ repression} = 1uM$$

$$K_{hill\ activation} = 1uM$$

$$K_{trsc} = 5.56 \text{ x } 10^{-14} \text{ M/s}$$

$$K_1 = 4.5\ x\ 10^4\ mM^{-1}s^{-1}$$

Figure 2. The Hill kinetics equations for the system, in which H is the hill coefficient, and K is a coefficient representing either activation/repression or transcription.

Translation & Dilution Rates

Protein translation: $\frac{d[protein]}{dt} = k_{trsl} * [mRNA]$

mRNA degn: $\frac{d[mRNA]}{dt} = k_d * [mRNA]$

Protein dilution: $\frac{d[protein]}{dt} = k_{d\ prot} * [protein]$

Figure 3. General equations for translation and dilution of the proteins used.

Results and Discussion

Simulation Output: Pb Present, RFP output

Figure 4

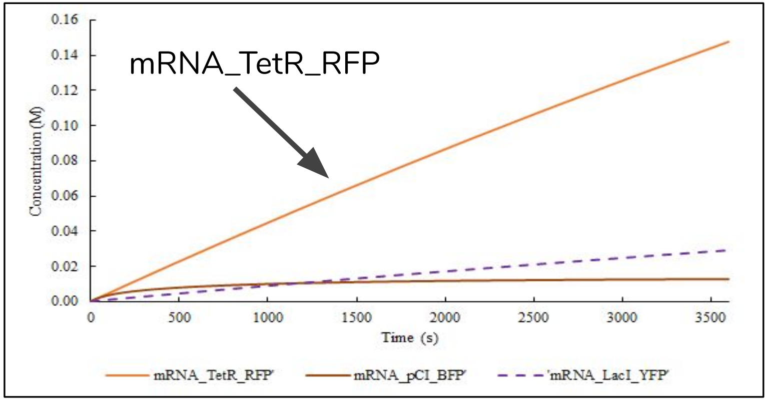
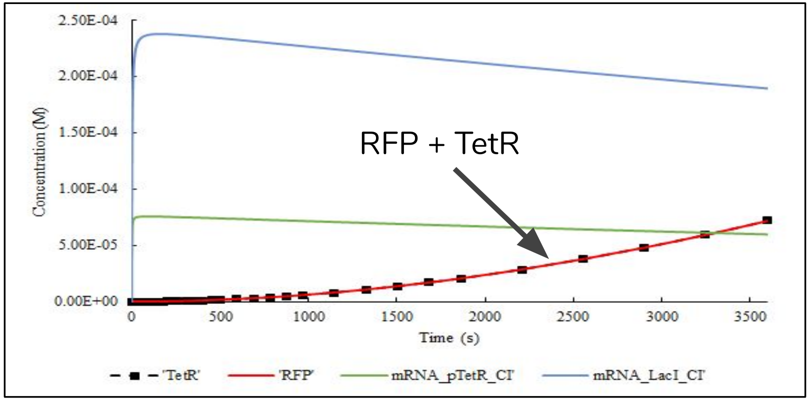


Figure 5



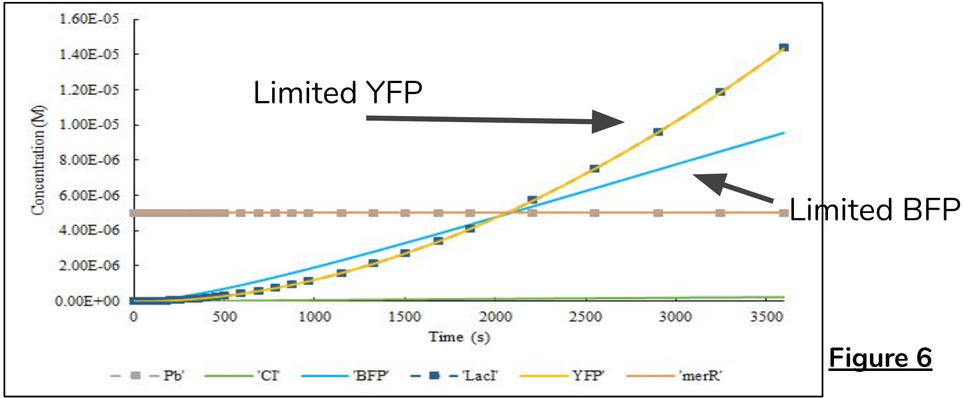


Figure 6

Simulation Outputs: Hg Present, YFP output

Figure 7

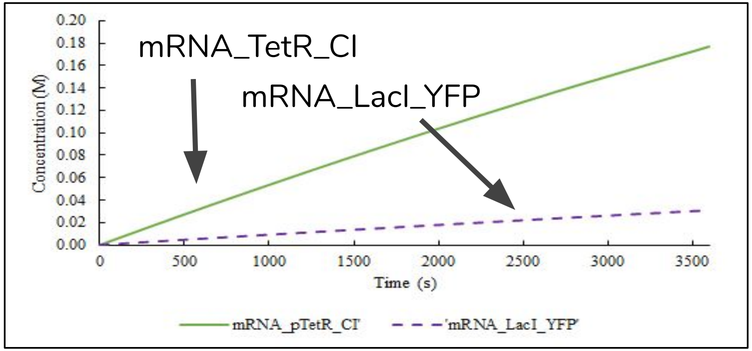
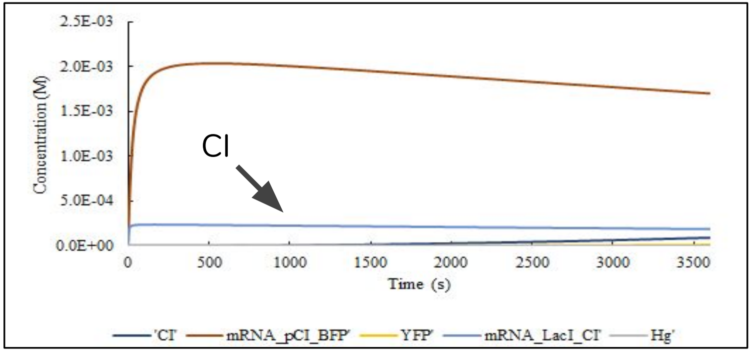


Figure 8



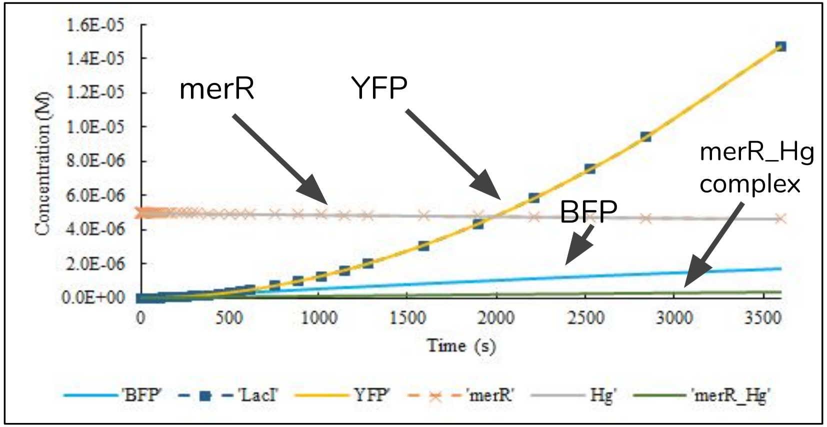


Figure 9

Simulation Outputs: Both Metals Present, All Colours output

Figure 10

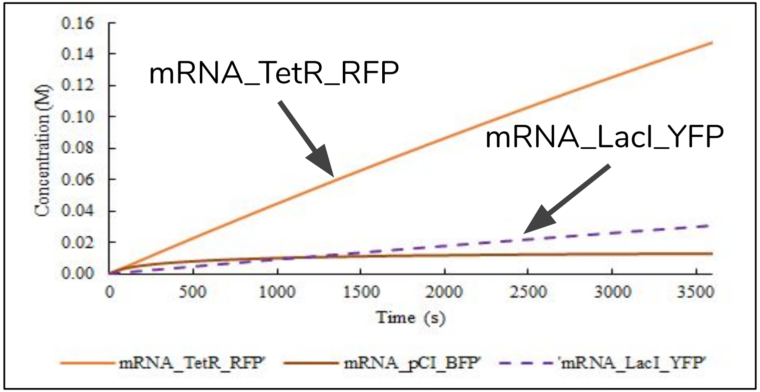
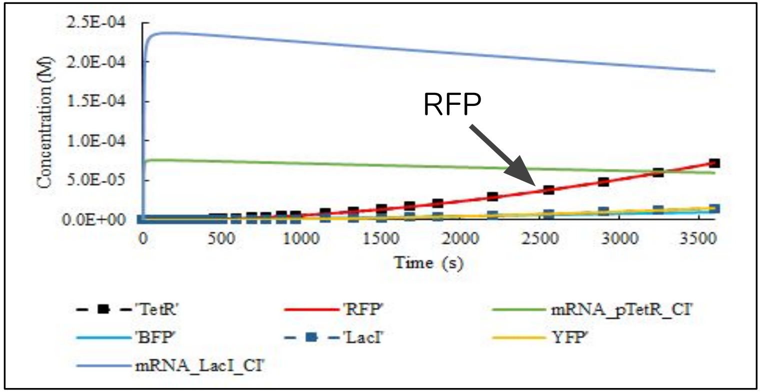


Figure 11



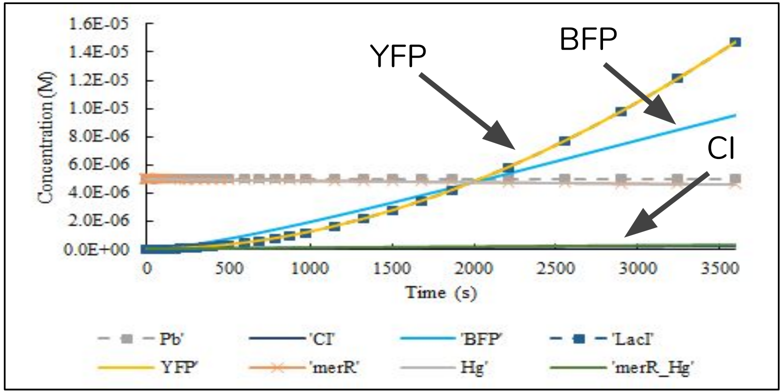


Figure 12

Limitations and Conclusion

Limitations

- Cannot sense the specific concentration of mercury or lead
- Colour prominence

Conclusion

- Give a visual alert to homeowners through colour outputs
- Can detect lead whether lead and/or mercury is present

Future Work

- Sensing contaminant concentration
- Detect additional contaminants

References

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