

 SCIENCE AND CULTURE

Could a bacterium successfully shepherd a message through the apocalypse?

Gayathri Vaidyanathan, *Science Writer*

For more than a decade, Canadian poet Christian Bök has been toiling on a book of poems. But his is not the typical authorial angst: Bök intends his poems to outlast human civilization, and indeed the planet itself. And his authorial palette is not typical either: rather than inscribing his poems on paper, he's attempting to put them in a bacterium.

Bök, a visiting artist at the Massachusetts Institute of Technology's Center for Art, Science & Technology, got the idea for microbial time capsules in the early 2000s after completing a book of experimental poetry (1). It was such a big commercial hit that he felt he had the artistic license to do something truly weird.

Bök came across an article in a computer science journal in which computer scientist Pak Chung Wong at the Pacific Northwest National Laboratory, along with his colleagues, had contemplated a data-preservation problem of

apocalyptic magnitude (2). What would happen to our cultural and scientific legacy if nuclear war or a natural disaster wipes out all of our information-storing infrastructure?

Wong was looking to outlast natural disasters, citing practical concerns about national security. Bök took it a step further, initiating a project meant to outlast both humans and the planet while transmitting a sense of humanity and its customs, something like the Voyager spacecraft's famous golden record purports to do for alien life.

Locked Away

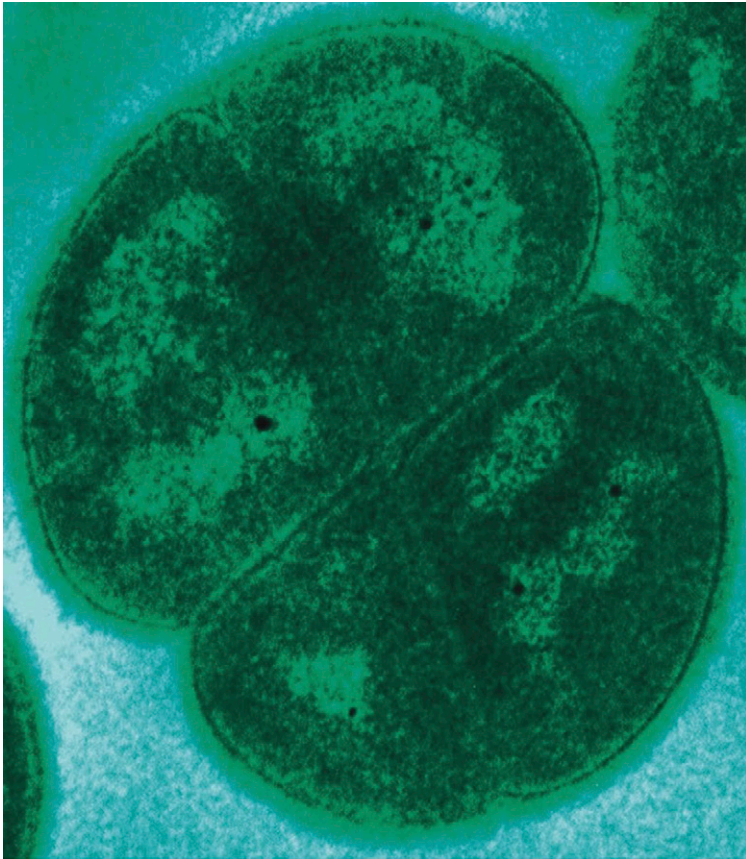
Without adequate maintenance, all manmade information storage devices—hard drives, silicon chips, stone tablets, Palmyra—would be destroyed over time. Wong and his colleagues proposed a longer-lasting solution: store the information in the genome of an extremophile bacterium that can survive inhospitable environments.

The key to bacterial messages, Wong found, lies in the vessel itself. Drop the extremophile *Deinococcus radiodurans* in acid and it survives. Eject it into outer space and it thrives. Desiccate it; store it for a million years and pull it out, and the bacterium would go back to normal.

Remarkably, the genome of *D. radiodurans* suffers few—if any—mutations, even when blasted with ionizing radiation. It's been nicknamed Conan the Bacterium by NASA. As a proof of concept, Wong and his colleagues inserted a tiny message—the lyrics of the song "It's a small world after all"—encoded in DNA into the genome of this bacterium and allowed it to multiply for 100 generations. The embedded song survived without mutations, according to work published in 2003 (2). Although 100 generations isn't many for showing genetic stability, Wong had offered up proof-of-principle that *Deinococcus* messages could persist unaltered.

Around the same time, Bök read an article by astrophysicist Paul Davies, who suggested that extraterrestrials might venture to send humankind messages encoded in the genome of spores, viruses, and bacteria rather than in radio signals (3). This seemed a wonderful sci-fi premise to Bök and he wondered why our civilization should not embed messages similarly in living cells. "Poetry should be at the ground floor of this activity," he says.

So began *The Xenotext* (4). When completed, it will be a book of poetry crafted not of paper and glue but of DNA and protein, bound within an extremophile. The organism's genome would encipher a 14-line poem by Bök, named "Orpheus." The bug's replication machinery would read the DNA and assemble a protein. The sequence of amino acids would encipher another 14-line poem, called "Eurydice." Hence, the bug would be both a storage vessel and a poem-generator. The protein would also make the bug fluoresce red via an mCherry red fluorophore tag.



Poet Christian Bök wants to use extremophile *Deinococcus radiodurans* (pictured here in a transmission electron micrograph) as a sort of information time capsule. Image courtesy of the Uniformed Services University (Bethesda, MD).

Poetry, Reimagined

"Orpheus" begins with these lines:

Any style of life
is prim
To which the organism responds by building a
protein that encodes "Eurydice":

The faery is rosy
of glow

The poems are a nod to a Greek legend, in which the son of Apollo descended to the underworld to try to bring his dead wife back. This apocalyptic overtone is appropriate to the venture, Bök says.

It took Bök 4 years to write the poems, which are basic cryptograms. He had to write two poems simultaneously: the DNA spells out one poem and the amino acid the other. The two poems are ciphers of each other.

Bök taught himself programming to build software that generated simple substitution ciphers, where each letter of the alphabet is paired with another letter. In his poems, "a," for example, maps to "t," "n" to "h," and so on.

Of 7 trillion cipher possibilities, Bök found one cipher that produced a lexicon that had enough useful words (about 120) that could be assembled into two poems that are also sensible and syntactical.

He next translated the poems into the language of living things. Each letter of the cipher maps to a DNA codon, the triplet of DNA molecules that encode an amino acid. The bug would read the codon and build an amino acid, which in turn would map to the original's letter-matching pair in the cipher.

Nano-novella

In some ways, Bök was uniquely suited to the task. He holds a doctorate in English literature, but doesn't shy away from science. While working on the poems, Bök taught himself not only programming, but genomic and proteomic engineering: requisite skills, he says, to be taken seriously by scientists and funders.

And his previous book, *Euonia* (1), was written under Herculean constraints, as Bök limited each chapter to words that contain a single vowel. Bök takes on such challenges because he wants to make discoveries about the limits and possibilities of the English language, he says. In *Euonia*, critics say that as the vowels get repeated and language gets stripped of its freedom, the sounds begin to convey mood and personality. "I think it is important for poets to range outside the catechism of their literary training in order to engage with discourse outside the mew of the poetic," Bök says.

When Bök approached molecular biologist Naomi Ward, at the University of Wyoming, in 2013 for help with the project, she marveled at his science-related accomplishments. Over the past 2 years, Bök had collaborated with scientists at the University of Calgary and gotten his idea to partially work in *Escherichia coli*, the workhorse of

genetic engineering, as a proof-of-concept. The next step was to place the poem in *D. radiodurans*.

The round, salmon-colored bug contains from 4 to up to 20 copies of its genome, which allows the bacterium to rapidly identify and repair DNA damage, leading to a low mutation rate. But even if the bug tolerates the foreign DNA, the synthetic protein it generates could cause metabolic burden, says Heather Rothfuss, a former postdoctorate in Ward's laboratory who worked with Bök. The protein may not fold properly or it may accumulate and sicken the host.

Building to a Climax?

After 6 months of experimentation, Bök's funding ran out. But on the final day of his grant, Bök received word from the Wyoming scientists: the bug had successfully incorporated "Orpheus" in its genome. It was also generating "Eurydice" in response. Still, their excitement was tempered; they only saw fragments of the protein poem during electrophoresis. Rothfuss speculates that the RNA was unstable, or perhaps the bug was stressed, and using media that reduces stress or adding-in a stress protein might help. The scientists have not yet solved the problem. It was, for Bök, the sort of censorship that he'd hoped to avoid.

Bök has three benchmarks of success for *The Xenotext*: the gene has to be properly introduced into *Deinococcus*; it has to generate a protein that fluoresces red, matching the opening lines of "Eurydice"; and the protein has to be stable enough to be detected.

The last criterion has not been met. Still, making use of a little additional grant money, Bök has planned two more experiments in which he hopes to make *Deinococcus* stably express the protein-poem. And with his Massachusetts Institute of Technology residency, Bök hopes to garner the expertise required to apply for more grants. "I've been scrambling to find more resources to see if I can finish my assay and struggling to rebuild the expertise I had before," Bök says.

Even if a microbe successfully shepherds information through the apocalypse, a big question remains: How would future humans or alien beings know where to look? In Wong's scenario, survivors of a catastrophe would be aware of the microbial repository. Failing this, Bök hopes that the messages would reach a sufficiently intelligent civilization that has fast computers and smart cryptographers.

But Bök doesn't feel as though his poems in particular deserve to survive as the sole representation of human culture. *The Xenotext*, he emphasizes, is not an expression of hubris. It is an aesthetic exercise meant to get people thinking about human extinction and to prompt poets to use living beings as a mode of artistic expression, he says. After all, even with *Deinococcus*' stellar DNA repair machinery, the "Orpheus" gene will likely mutate, given enough time, because of chance alone.

"It is much more of a conceptual work designed to inspire thought," he says. "Whether or not I actually produce something that is durable enough to persist billions of years into the future seems less important."

1 Bök C (2001) *Euonia* (Coach House Books, Toronto).

2 Wong PC (2003) Organic Data Memory using the DNA approach. Available at dl.acm.org/citation.cfm?id=602421.602426. Accessed December 1, 2016.

3 Davies P (2004) Do we have to spell it out? Available at <https://www.newscientist.com/article/mg18324595-300-do-we-have-to-spell-it-out/>. Accessed December 1, 2016.

4 Wershler DS (2012) The Xenotext Experiment, So Far. Available at www.cjc-online.ca/index.php/journal/article/view/2526. Accessed December 1, 2016.