Can life harness nuclear power? The biomolecular perspective

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Abstract

Nuclear power sources are very reliable and high-density, and there are surprisingly many possible methods for its harnessing in nature. I examine the plausibility of each method, citing natural analogues where appropriate, and basing my assessments on the theoretical limitations of biomolecular mechanics. I conclude that there are a number of reactor designs that are compatible with these limitations, but only fission reactor designs have plausible evolutionary paths.

1 Introduction

Biodiversity has a reputation for very, very consistently exceeding expectations and defying previously established limits on what living organisms can do. Though we may have developed a good grasp on what what is easy and hard for life to accomplish, few can give confident answers as to the boundaries of what is *possible*. The most confident analyses perhaps come from biomolecular physics: while it is hard to say whether there's a way for evolution to create a particular macroscopic trait, the mechanical and chemical properties of biomolecules are much less under question. Lipid membranes cannot exist above 500 °C, because all known lipids undergo pyrolysis at that temperature [1]. Liquid, water-based cytoplasm cannot exist too far outside the bounds of 0 °C to 100 °C, since those are roughly the freezing and boiling points of water at the range of pressures accessible on Earth. As long as the qualifications are phrased precisely enough, they will be universally true, and of fair utility as well.

This makes biomolecular physics an excellent lens through which to explore whether nature can duplicate one of humanity's greatest and most terrifying feats: harnessing nuclear energy. The search for energy has driven an endless variety of fantastical evolutionary innovations, from single impressive biomolecular mechanisms, such as ATP synthase's dynamo; to obscure and complex chains of reactions, such as photosynthesis's ability to turn CO_2 and water into sugars and oxygen, with the help of light; to the countless offensive and defensive strategies employed in the warfare that heterotrophs wage on each other. Practically every source of energy on the Earth, from the Sun to deep-sea vents, from the wind to the waves, from wood to *bones*, has been turned to somebody's advantage. It would almost be more amazing if nuclear energy were *not* harnessed by any organism.

Nevertheless, there is very little record of this. The only unambiguously confirmed case of radiotrophy in nature is that described in Dadachova et al. [2], in which three fungi, *Cladiosporium sphaerospermum*, *Wangiella dermatitidis*, and *Cryptococcus neoformans*, grow the fastest in the presence of ionizing radiation 500 times that of ambient levels. These strains were first isolated from the reactor water of the Chernobyl Nuclear Power Plant in 1991, five years after its

infamous disaster. Their postulated mechanism of radiotrophy is the promotion of melanin-mediated electron transfer by the ionizing rays from the reactor slag.

This certainly counts, but it is a little anticlimactic, given the immense potential of nuclear power. Organisms use their comparatively meager chemical energy reserves to perform counterintuitively powerful physical feats, travelling extreme distances by land, sea, and air, tearing apart or disintegrating wood, bone, skin, and even metal, colonizing a vast variety of substrates. What sort of terrifying things might nature be capable of, if endowed with an energy source of that magnitude? Is the fact that there is no fungus or bacterium that metabolizes our tissue indiscriminately for fusible or fissionable nuclei a sign that this is not a mechanism that can plausibly be implemented by biomolecules? Or is it just a sign that evolution hasn't managed to crack that niche yet? I aim to give a speculative, but well-informed guess at the answer to this question.

2 Plausible reactor types

While there are many different kinds of nuclear reactors that humans build, the majority of designs, particularly for fusion reactors, run at temperatures vastly outside the range at which biomolecules can even *exist*, never mind at which life can survive. Though reaction chambers with metallic components are plausible and will be covered here, if there are plausible designs to be found, they still probably do not lie in the extreme temperature regimes of molten salt reactors and stellarators. Confining our scope to the liquid water regime (for our purposes, −25 °C to 125 °C) will still turn up all the most interesting and relevant designs.

2.1 Ambient pressure and temperature fission reactors

Ambient pressure and temperature fission reactors represent the easiest, most immediately available method of accessing nuclear energy for sessile organisms. Ambient pressure can vary from virtually none, around the fringes of the atmosphere, to 110 MPa [3]. Ambient temperature is more restricted, as noted in §1, topping out at 122 °C [4]. As for combinations of both extremes, the water around deep-sea "black smoker" alkaline vents is supercritical, at pressures of roughly 25 MPa and temperatures of roughly 370 °C [5]. While there are no organisms known to live in this regime, there is plenty of multicellular life, such as shrimp and polychaetes, living just millimeters away, capable of dipping appendages into it temporarily [6]. Any organism that treats them as "ambient", however, even only intermittently, will have to be very well-equipped.

The only natural nuclear reactors known to have ever formed were exposed to the atmosphere: the Oklo reactors, in Gabon [7].[1] They were famously self-regulating: they were lakes where the surrounding rocks had an especially high uranium content, and the lake water served as a neutron moderator. Like clockwork, the water would boil off for the thirty minutes or so that the reactor was operational, and then would be fed back by a stream over the next one and a half hours. The water-soluble fission products would be carried downstream to the ocean, while the non-water-soluble products became trapped in the surrounding aluminum phosphate. They lasted for 10^5–10^6 years, and produced a continuous 100 kW.

The energy they generated was thermal, however, which is next to impossible for an organism to harness as a primary energy source. However, temperature gradients *are* an exploitable source

[1] There is, of course, something to be said for sampling bias, the Earth's surface being vastly easier to excavate than the seafloor. This is outside the scope of this article, however, and most of Earth's biodiversity would agree with humans on the oceanic crust's relative inaccessibility, anyway.

of energy. If there is a temperature gradient, particles, charged or otherwise, will flow down it. If the temperature gradient can be maintained somehow, with a hot sink and a cold sink, then it's possible to extract energy from the system, since the particles will keep flowing.

One simple way humans exploit this to create power sources from radioactive material is the thermoelectric effect, where electrons will flow from a hot sink to a cold sink.[2] This is typically done without any nuclear reactions occurring other than the decomposition of a radioisotope, as these "radioisotope thermoelectric generators" (RTGs) are most often deployed in spacecraft, where simplicity is preferred over raw power. However, in the presence of a natural nuclear reactor, this is a much more exploitable phenomenon.

Before we attempt to hammer out the details of how it would be exploited, we should briefly consider whether nature has not already solved the issue for us. Are there not already such sharp temperature gradients in nature? Undersea vents certainly count. There's much convincing literature on life originating in alkaline vents in particular: their natural networks of micropores are thought to have produced the proton gradients that ATP synthase, and subsequently all cellular respiration, evolved to exploit [8]. This is usually explained as just a diffusion gradient, but, given the above reasoning, the temperature gradient must have helped as well.[3]

A less promising analogy is the temperature difference between hot springs and the surrounding air and stone. A gradient exists, certainly, but nothing is known to exploit it, not so much as plants that feed by dipping their roots into springs and exploiting the thermal gradient to drive their vascular systems. Perhaps we only have yet to find these, but hot springs are well-studied ecosystems.

In any case, it would be interesting to attempt an *a priori* mathematical appraisal of how much energy would be available to an organism attempting to exploit such a gradient, but unfortunately, it is not a well-described area. The equations usually used for evaluating membrane potentials, the Nernst and Goldman equations, assume uniform temperatures, an assumption that can be traced back to Fick's laws of diffusion themselves. There is no readily apparent way to generalize those without resorting to modelling the solutes as gases, which still greatly complicates things, while simultaneously making the model near-uselessly inaccurate. The other side of the coin is the equations used to describe the thermoelectric effect, which are the Seebeck, Peltier, and Thompson flux equations. These, on the other hand, assume metallic wires rather than membranes, and the "Seebeck coefficients" used to calculate the magnitudes of the fluxes are very difficult to determine *a priori*, and only available *a posteriori* for various metals. The models that do exist involve statistical mechanics and phonon-electron interactions [10, 11]. The best I can do is note that the practical limit on how much energy can be harnessed is much more dependent on the maximum temperature the organism can withstand than on the total energy output of the reactor. Since the Oklo reactors boiled water very quickly, they must have had solid parts well above the roughly 125 °C limit we previously established for life [4]. If there is a limit, it is cooling, and that is less well-studied in the Oklo reactors. As a comparison, however, we can note that it must be more efficient than the convective cooling of present-day hot springs, since we don't see those getting exploited for their gradients.

[2]Thermoelectric generators create current loops rather than unidirectional flows, so they need to provide a less expensive return path, in the form of a wire made of a material less susceptible to the effect, but this is a detail that is not relevant to the mechanisms we are about to consider.

[3]Pedantically, one may even claim that this would count as an example of organisms harnessing nuclear energy; at least half of all geothermal energy is radiogenic [9]. It is, however, a very unhelpful revelation.

We can still speculate. If our chosen mechanism is establishing proton gradients across micropores downstream from the nuclear heat source, then respirating prokaryotes are already perfectly suited to the task. It's conceivable such organisms even colonized the Oklo reactors, back when they were still active. If there are porous structures around the most radioactive parts of the Chernobyl reachor pool, we might find some there as well. Over longer periods of time... who knows? Plants and fungi can make their own pores. They may well fill the niche, too.

Are there other plausible mechanisms? Yes and no. Yes, there are plenty of other forms reactors can take. As much as any environment, if it is capable of occurring geologically, reactors are also capable of being made intentionally, especially on smaller scales. While ^{235}U is no longer abundant enough for the conditions at Oklo to arise again, there is no reason it couldn't be accumulated biologically, whether through the vascular processes of plants and fungi, or even through diligent hoarding by colonial organisms such as ants. When one adds the possibility of symbiosis between accumulators and metabolizers from very distant taxa, it starts to seem almost strange that this is not a known phenomenon. ^{235}U isn't even the only possible substrate; ^{232}Th is present in the crust in appreciable amounts, which can absorb a neutron to become the fissionable ^{233}U and participate in a sustained chain reaction of its own,[4] and the equally abundant crustal radon, while not fissile, can still be used as fuel for RTG-style mechanisms [12].

However, there are not many other plausible ways of harnessing the energy. The ersatz photosynthesis employed by radiotrophic fungi is clearly metabolically helpful, but does not seem to constitute their primary energy source; it is hardly more than a catalyst for their electron transfers [2]. Directly capturing ionizing radiation may have potential as a strategy, but we have yet to see it realized. I have my reservations, considering how dangerous ionizing radiation is if it hits nucleic acids or proteins. Precisely positioning the radiation source would help a lot with this, which is easier with the next two kinds of designs.

2.2 Pressurized fission reactors

This is not much different from the above design; the only thing that pressurization accomplishes is that it can unlock more lucrative reactions with more easily available nuclides, circumventing the need to gather rare fissionable or fertile isotopes such as ^{235}U and ^{232}Th. The best candidates for these are the isotopes that represent the ends of various decay chains, which can be re-enriched—given sufficient neutron economy—into fissionable isotopes. In nature, these take the form of all naturally-occurring isotopes of lead except for the lightest (altogether, more than half of all lead), and a modest portion of thallium and bismuth [13, 14]. The non-fissile but fertile ^{238}U also qualifies, which is vastly more abundant than fissionable uranium, and can be enriched into ^{242}Pu, among other fuels. Up until now, we have been treating "fissionability" as an inherent quality of a fuel, but it is relative to neutron temperature. The faster (i.e. more energetic) the neutrons in a reactor are, the more reactions are favorable, and both higher temperatures and higher pressures can help.

The simplest extension of our previous lines of thinking is the introduction of supercritical water to the reactor pool. This enhances the neutron economy considerably, as supercritical water is vastly less dense than liquid water, while still moderating neutrons more effectively than steam, and at a potentially lower temperature as well [6]. This allows one to "breed" certain lighter isotopes up. Unfortunately, this does not negate the need for radioactive inputs entirely, and in practice, not even fissionable inputs; the

[4] This is called "breeding", and will be discussed in more detail in §2.2.

energy of the reactor must still come from decay processes. Barely-supercritical water is not an especially versatile medium, and the only practical, naturally-occurring substrates for a supercritical breeder reactor are ^{232}Th, which breeds into ^{233}U, and ^{238}U, which breeds into ^{242}Pu [15].

This is a much more exciting prospect, however, than it may first seem. While in isolation, it is not an especially favorable development, it can become the keystone of an entire *ecology* relying on the generation of certain "radionutrients",[5] and is a very likely development if organisms that collect and metabolize fissile isotopes already exist. The creation of ^{239}Pu in particular makes an entirely new series of decay products possible, and raises the upper limit of neutron energies. The web of nutrients can be expanded from there, one reaction at a time, until it encompasses the aforementioned terminal decay products of lead, thallium, and bismuth.

Whether cells can survive supercritical conditions, however, is another matter. As discussed above, it *is* an environment which some organisms can dip their toes into, literally speaking, but maintaining permanent contact with it, never mind building a nuclear reactor around it, is of much more questionable difficulty. Similar to how no organisms are known to have gaseous cytoplasm, none are known to have supercritical cytoplasm [4, 16]. I was unable to find literature providing evidence for organelles or biomolecules housing gaseous-phase or supercritical-phase matter, either. If an organism is to have a reactor chamber, realistically, it must be extracellular, or in a cell modified to an unprecedented degree.

This is not necessarily a problem; many organisms are capable of creating pockets of pressure and temperature extremes. The latter, however, are difficult to find literature on. Even very comprehensive review papers of violent and explosive mechanisms in nature, such as Sakes et al. [17], which we will reference repeatedly, neglect to cover thermodynamics and heat production. This is a shame, as while ambient pressures reach five times above the critical point of water (110 MPa versus 22 MPa), truly "ambient" temperatures fall 250 K, or about ⅜, short of the critical point (394 K versus 643 K) [3, 6]. Nevertheless, pressurization mechanisms can be repurposed as heating mechanisms trivially, and there is ample geothermal heat available in many environments, so we will take the principal difficulty with high temperatures to be structural stability, rather than reaching critical temperature in the first place.

Cataloguing the potential power of natural pressurization mechanisms is important for establishing the minimum plausible depth for pressurized reactors, and the maximum pressure at which a reactor can operate. Serendipitously, the highest turgor pressure cited in Sakes et al. [17] among all shooting mechanisms in nature, no others coming even close, is from a taxon familiar with deep-sea conditions, *Cnidaria*. The cnidocytes of a wide range of cnidarians have similar ranges of suitable pressures, with fire corals *Millepora alcicornis* and *Millepora complanata*, and hydras *Hydra magnipapillata* and *Hydra oligactis*, given as prototypes. The internal pressure of their cnidocytes can reach 15 MPa before they open the operculum and fire their tubules.[6] The additional 7 MPa of pressure can easily be provided by the surrounding ocean, corresponding to a minimum depth of roughly 700 m. Combined with the maximum amount of hydrostatic pressure known to be tolerated by life, 110 MPa, this yields a total potential pressure of 125 MPa.

[5] The physicist in me wants to say "nucleonutrients" or simply "nuclear nutrients", but given that in biochemistry, "nucleo-" and "nuclear" tend to refer to cell nuclei and nucleic acids, that name would be too confusing.

[6] For most cnidarians, the majority of this pressure is built up right before release, but hydras keep their cnidocytes at pressure. This does not negatively impact structural stability or performance in any way, so one can assume that the downsides are metabolic, either through passive maintenance or through compensating for misfired cnidocytes [18].

The walls of these cnidocysts are made of multiple layers of collagen-like proteins, a total of 1 µm to 1.5 µm thick, and the roughly 2000 µm^3 capsule of the cnidocyst is completely stable until the operculum opens to release the tubule [18, 19]. Collagen undergoes pyrolysis right around the supercritical transition temperature of 370 °C, and could with only a small amount of additional mineralization form the reactor wall of a more permanent supercritical reactor [20].[7] How such a wall would interact with heavy neutron radiation is uncertain, but mineralization can help contain the radiation, especially when incorporating neutron poisons such as xenon.

So far, we have described the core of a reactor, but not the rest of it. It is strangely easy to imagine the rest of a coral playing the role. Its calcified tubules are ideal for transport of hazardous liquids, such as fuel, waste, and coolant. Its sessile, high-mass, highly mineralized exoskeleton is the perfect medium for embedded thermocouples to harness nuclear reactions directly, but there is just as much ecological room for corals that only perform isotope breeding, and obtain fissile isotopes from other sources. Undersea black smokers' vent fluids contain all of the aforementioned heavy metals suitable for fission reactors, as well as providing convenient conditions for reactions to start with [22, 23]. The main evolutionary bottleneck here, then, appears to be the invention of a thermocouple, and the necessarily subsequent repurposing of cnidocysts into reactor cores.

Given that our hypothetical cores can go up to 125 MPa and 370 °C, conditions more extreme than we first anticipated, it's worth asking: is nuclear *fusion* plausible under these conditions? In a word: absolutely not. Remember, similar conditions occur around hydrothermal vents. Fission reactions are uncommon there because of lack of substrate, but they do not lack deuterium ions; they constitute one thousandth of all hydrogen ions [13]. If it were possible, it would be happening at every vent, essentially all the time. If you still have doubts: the deuterium ions participating in a D–D fusion reaction must have relative velocities representing a solution at a temperature of 150 *million* K [15, 24]. It is not happening.

2.3 Particle accelerators

Particle-accelerator-like mechanisms are largely beyond the scope of this article. Unlike the above reactor designs, which rely only on neutron speed to achieve reactions, a particle-accelerator-like, or "railgun" design, would accelerate a *charged* particle at another charged target. If the particle is fast enough to break the Coulomb barrier, it will get close enough to its target to react with it, and undergo nuclear fusion. Sadly, natural shooting mechanisms don't reach even a fraction of the energy required to do this. To start with, the Coulomb barrier's height is directly proportional to the charges of the nuclei involved. Even the smallest possible barrier with natural substrates, the deuterium-deuterium fusion barrier, is 450 keV high [25]. This corresponds to a projectile velocity of roughly $6.6 \times 10^6\,\mathrm{m\,s^{-1}}$. The fastest speed achieved by any mechanism in Sakes et al. [17], achieved by the aforementioned cnidocysts, is a peak speed of $37.1\,\mathrm{m\,s^{-1}}$, which is five orders of magnitude smaller.

Any particle railgun built by nature must be of completely original, never-before-seen design, which cements it as an evolutionary impossibility. Is it, however, a design impossibility? Not necessarily. Linear particle accelerators work by a mechanism that is very familiar to both physicists and bacteria: by polarization of individual regions surrounding an inner layer the particle travels through. Since high-voltage electromagnetic waves cannot be made to travel as fast as the particle, an oscillating standing wave is used

[7] Another group, Bozec and Odlyha [21], found that collagen gelatinization temperature is (340 ± 10) °C, and gelatin pyrolysis temperature is (420 ± 10) °C.

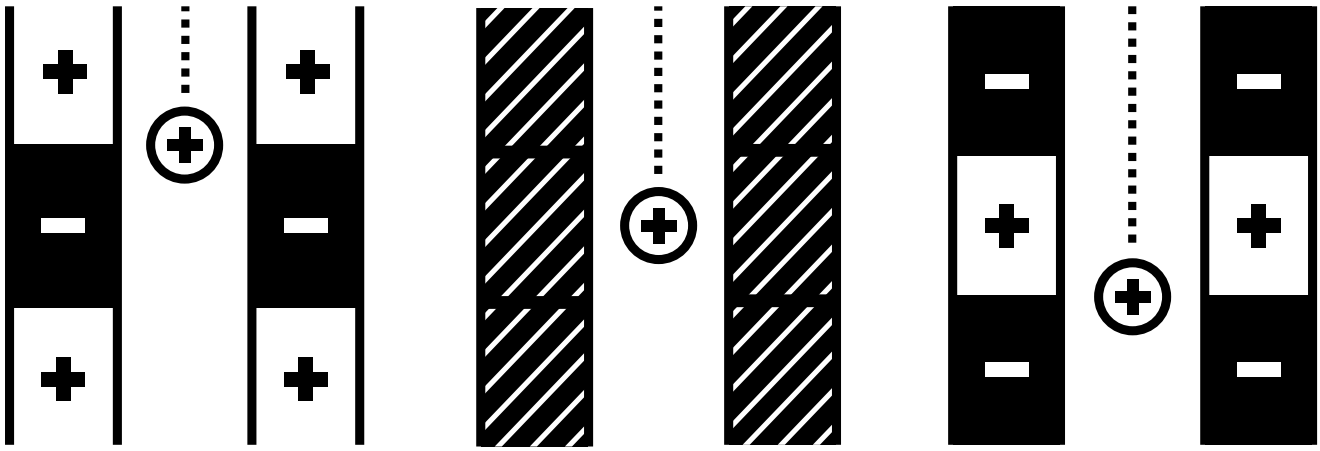

Figure 1: A schematic showing the three steps in the process of a positively-charged particle in a linear particle accelerator entering and leaving the region of a specific cell. The cells are not shown to correct relative scale.

instead. The polarized layer is divided up into individual "cells", which oscillate between positively and negatively charged, alternating charges along the path. The key is to time the oscillations so that the particle is always experiencing an *increasing* voltage potential around it. A positively-charged particle should always enter cells when they are *negative*, stay in the cell while it charges up to positive, and then exit it at its peak, entering another negative cell [26]. I have provided a schematic of the process in Figure 1.

The unfortunate catch is that the particle speeds up every time it crosses cells, caching its electric potential energy as kinetic potential energy. This necessitates *very* long tunnels, as each cell consequentially needs to be linearly longer than the last. The total length of the tunnel depends on the amount by which each cell can increase the particle's potential according to the power law $L \sim \Delta V^{-3/2}$, and linearly on the amount of time it takes to charge up each cell. The full equation, using the approximations $E_k \approx \frac{1}{2}v^2$ and $\sum_{k=1}^{n} k \approx \frac{1}{2}n^2$, is:

$$L = \sqrt{\frac{2\Delta E}{m}}\,\frac{1}{2}\left(\frac{E_{\text{tgt}}}{\Delta E}\right)^2 t = \frac{E_{\text{tgt}}^2\, t}{\sqrt{2m}\Delta E^{3/2}} \qquad (1)$$

Here, E_{tgt} is the target energy, ΔE is energy increment of each cell (equal to the voltage increment times the charge of the particle), m is the particle's mass, and t is the time it takes for a cell to charge up (while a particle is in it), i.e. the half-period of its potential oscillations. Note that this also includes the less significant result of the number of cells, which is simply $E_{\text{tgt}}/\Delta E$.[8]

For D–D fusion, we can substitute 2 Da for the particle's mass, and 450 keV for the target energy, simplifying the equation to:

$$L = 2.026\,185 \times 10^{15}\,\text{eV}^{3/2}\text{m/s} \times \frac{t}{\Delta E^{3/2}} \qquad (2)$$

This is where the trouble begins. First, the simpler part of the equation: cells are not known to change potentials especially rapidly. By far the fastest change in membrane voltage appears to be that of neurons during their refractory periods, which is limited to approximately 0.5 ms in

[8]This equation assumes that the starting kinetic energy of the particle is vanishingly small. On the scales I am considering, this is true; the most probable kinetic energy of any particle, by the Maxwell-Boltzmann distribution, is simply kT, which at a temperature of 37 °C, is equal to ∼25 meV.

a surprisingly diverse array of mammals, nervous system regions, and types of neurons, including oscillatory, self-stimulating ones [27, 28, 29, 30, 31]. Our putative polarizing ions, however, are not Na, K, and Cl; it is protons, which can associate much more closely to a thin tube full of vacuum, and for which nature has invented some of the most impressive pumps.[9] I was unable to find literature describing polarization times even *within an order of magnitude* within 0.5 ms. The only measurements of the time it takes ATPases that pump protons[10] to acidify any vesicle at all were for the creation of lysosomes and related endosomal organelles, which were on the order of one hour [32, 33, 34]. It seems the need to urgently acidify small chambers is not especially great in nature. Nevertheless, I will *very* charitably assume that an equivalent mechanism can be created to pump protons at similar speeds to the pumping that occurs during membrane repolarization, cyclically acidifying or repolarizing small cells with a half-period of 0.5 ms.

A much greater problem is the maximum potential difference that can be created within a cell, using proton pumps. For this, we have chosen V-ATPases as our champions of proton pumping. While ATPases are very efficient proton pumps in general, V-ATPases in particular have a uniquely versatile mechanism that is efficient enough that it is frequently found coupled to a very wide range of actions, such as, most famously, rotary motion. Their mechanochemistry is also very well-studied, and Grabe et al. [35] explain its mechanical performance characteristics in meticulous, exacting detail. They conclude that the thermodynamic limit to the ΔpH that V-ATPases can create under broadly physiological conditions is $3 \times (21 k_B T)$, which at 310 K is roughly 4.6. They however do cite an example of V-ATPases surpassing this limit anyway, in Futai et al. [36], in which a cell building a vacuole with V-ATPases was able to create a gradient from cytoplasmic pH ~ 8 to lumenal pH ~ 0.1, giving ΔpH ~ 7.9. The corresponding membrane potential difference given by the Nernst equation at 310 K is:

$$\mathcal{E}_{\text{mem}} = \ln 10 \times \frac{k_B \times 310\,\text{K}}{q_e} \times 7.9 \approx 486\,\text{mV}$$

This is *very* underwhelming. It is certainly impressive by biomolecular standards, as membrane potentials are more typically found at limits of $\sim$100 mV [34], but as we will see, this has very unfortunate consequences for our particle accelerator. A possible way to improve this number includes positioning the protons very close to the shaft, in a configuration that maximizes their interaction with the fired particle. This has the potential to multiply this figure by at least an order of magnitude, if done right. However, this would be an extremely complicated design task, and not one that can easily be calculated for.

Substituting these two rather optimistic numbers, 0.5 ms and 486 meV, into Equation 2 yields us the comically large number of 2.934×10^{12} m. Wolfram|Alpha offers such helpful distance conversions as: 19.6 astronomical units, 2.72 light-hours, and approximately half the semimajor axis of Pluto. I believe this figure tells us everything we need to know about the feasibility of particle accelerators assembled from existing biomolecules.

3 Conclusion

The radiotrophy currently seen in nature is evidently just a superficial flirtation compared to what could be accomplished on longer evolutionary timescales. The reason we are not familiar

[9] I speculate that a tube made of proteins in the shape of alpha-helices, similar to existing channels, would be suitable for such a purpose. It's easy to get protons to rapidly bind to and unbind from the surface amino acids of alpha helices, without critical loss of stability.

[10] With no other effects, such as motion or luminescence, which ATPases are known for.

with nuclear-powered biota today is that the environments in which radiotrophy is an evolutionarily viable strategy are far removed from us, either temporally in the case of the uranium-235-rich environment of the distant past, or spatially in the case of deep-sea vents. The evolution of life on Earth could, earlier on, have taken a different path, developing ecosystems of different fertile and fissile isotopes, with natural reactor cores an unusual but extant trait in nature, perhaps best exemplified by nuclear coral, if not more advanced species. However, nuclear fusion would have remained far, far out of reach, and the terrifying indiscriminate decomposers, leveraging their nuclear-fuelled metabolisms to tear apart all sources of mass-energy, would never have evolved.

There is only so much we can learn from this as humans. We have already investigated the use of radiotrophic fungi as a form of self-replicating radiation shielding in space travel, with promising results [37]. But it's a much more significant leap to trying to design biological nuclear reactors by re-engineering corals. One would have to repurpose multiple kinds of tissues from the inside out. Human tissue engineering is not there yet. But, one day, it will be.

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Further reading

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