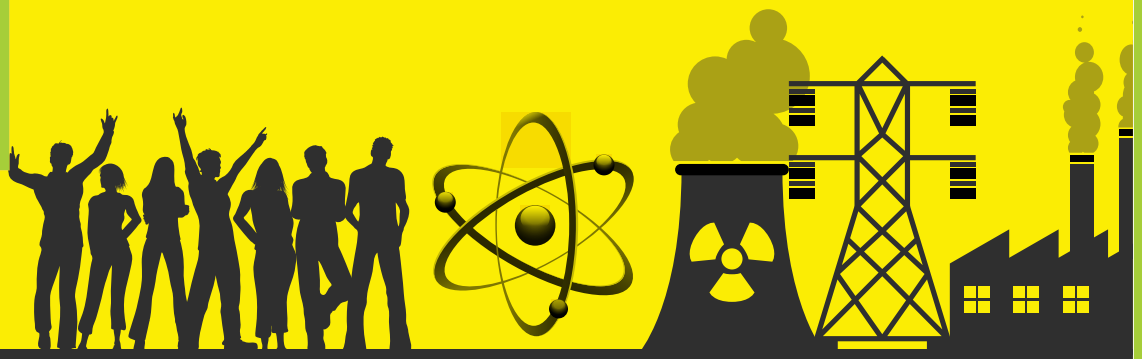
ENVIRONMENTAL SCIENCE JOURNAL FOR TEENS

JANUARY 2018

Nuclear waste = fuel of the future?



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Abstract

Nuclear power has the potential to be a climate-friendly energy source, but also embodies great threats to humans and the environment which requires dedicated safety precautions. Currently, safely handling large amounts of very long lived, dangerous *radioactive waste* created by nuclear power production makes it a pretty costly and *unsustainable* endeavor. In this study, we analyze if it is possible to redesign nuclear power stations so that they can run on existing *nuclear waste*. And here is the good news: our *feasibility* study shows that it can be done, and that the majority of current nuclear waste does not even have to be modified. These advanced nuclear power stations do not yet exist. However, with a focus on the generation of *sustainable* and climate-friendly energy in our research and development efforts, we believe we can make them happen in the near future.

Introduction

We need more climate-friendly energy sources if we want to reduce the negative effects of global climate change. Making electricity out of *fossil fuels* like coal, oil or natural gas releases lots of *greenhouse gases*, which accumulate in the atmosphere and heat up our planet.

Nuclear power – electricity generated from the forces that are released by *nuclear fission*, or splitting atoms – has the potential to be an almost unlimited and more climate-friendly energy source. That is because in contrast to fossil fuels, no greenhouse gases are released *directly* during the immediate use of the fuel.

However, there are several major problems with the current ways of providing nuclear power.

- First, the mining of nuclear fuel – mostly a natural substance called *uranium* – is costly and energy intensive and causes many environmental problems.
- Second, nuclear energy production generates significant amounts of radioactive waste, which is extremely dangerous for humans and animals for very long periods of time (several thousands of years) if not handled safely. In fact, in neither the US nor the UK have we found an acceptable method of disposing of this waste for good, even though we are already producing tons of it!

Figure 1:
Mining of uranium, the prime fuel for current nuclear reactors. The uranium ore has to be ground and then treated with chemicals to extract the uranium. These are harmful for the environment. Furthermore, uranium mines release a radioactive gas that is harmful for miners.

Rössing open pit uranium mine, Namibia

- Third, the power production creates *plutonium* as a *byproduct*, which can be used to make *nuclear weapons*. This means it needs to be strictly safeguarded from abuse.
- Finally, the entire process (building the power stations, mining and processing the fuel, as well as transporting and storing the waste) requires very complex and energy intensive infrastructure, which contributes to *indirect greenhouse gas emissions*.

Methods

We used computer and mathematical models to understand if it might be possible to redesign nuclear power stations in a way that they run on nuclear waste. (This is also called "spent nuclear fuel" or SNF). This would reduce the negative impacts of current and future nuclear power generation immensely. Our models were able to simulate how such new nuclear power stations could function. Our calculations were based on a single core cylinder reactor filled with fuel salt where both burning and heat transfer occur.

Results

Great news: our models show that it is feasible to redesign nuclear power stations in a way that they can run on spent nuclear fuel (currently a highly toxic radioactive waste product). Plus, the spent fuel does not have to be further modified before it is used. Even better, our advanced nuclear power stations do not produce any additional waste. While these *innovative* power stations do not yet exist, our research indicates that they are a real possibility for the future.

In our simulations, so-called molten salt reactors seem a promising candidate for the new type of nuclear power station as they could be re-designed to run on SNF. Molten salt reactors operate on fuel dissolved in liquid salt. Over a lifetime of 60 years, one of these reactors would 'eat up' roughly 70 tons of SNF. This amount of SNF accumulates in 3 to 4 years of operation in a traditional nuclear power station of comparable size. Our suggested redesign would make nuclear energy generation much more efficient and sustainable, as it could 'squeeze out' up to 20 times more energy from already spent nuclear fuel. It would also eliminate any spent nuclear fuel as a source of highly problematic waste.

What differences do you see between the current nuclear power production and our version? What benefits can you think of?

All these points counteract all the climate benefits from the use of nuclear fuel mentioned above. That's why we propose to seriously re-think the way we provide nuclear power. Could we potentially make all of the energy available from existing radioactive waste? We undertook a feasibility study to find out.

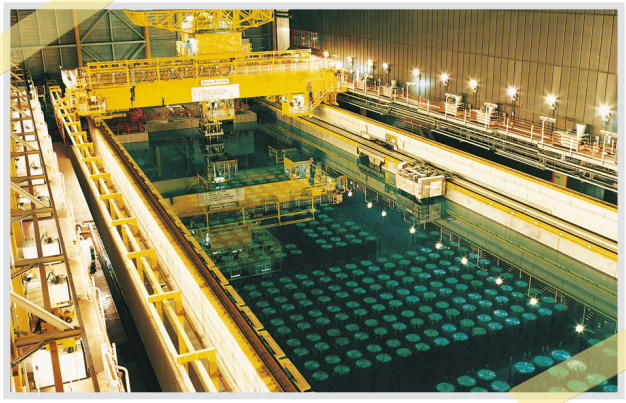

Figure 2:
A storage pool for spent fuel from current nuclear reactors. Spent nuclear fuel generate very intense heat and give off dangerous radiation, so it is very important to keep them under water.

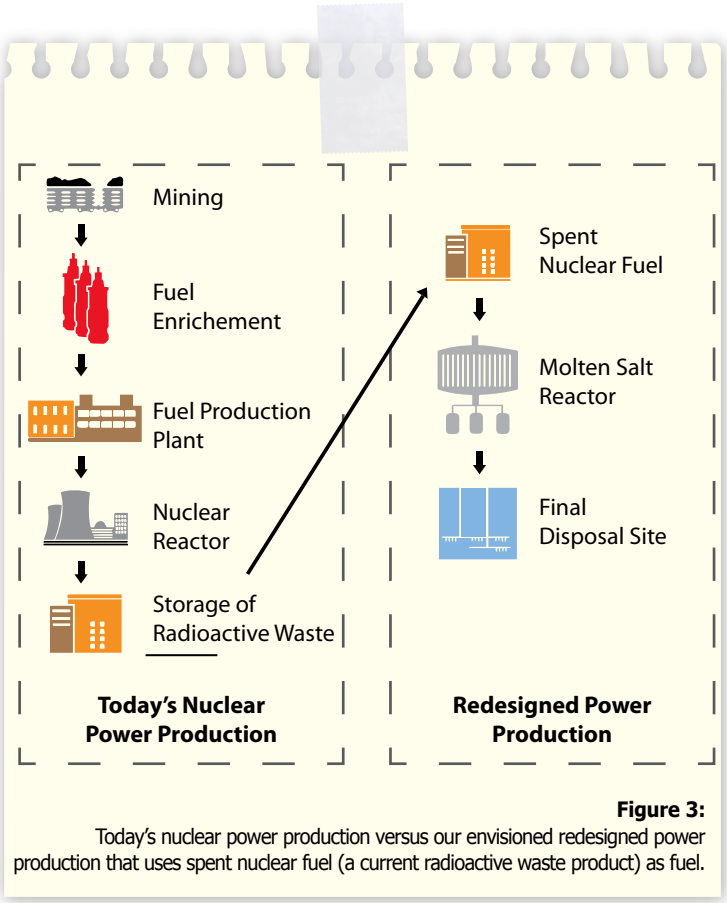

Figure 3:
Today's nuclear power production versus our envisioned redesigned power production that uses spent nuclear fuel (a current radioactive waste product) as fuel.

Discussion

Creating nuclear power stations that can run on existing nuclear waste is a worthy endeavor, and our feasibility analysis shows that it can likely be done. However, we need a lot of *innovative* and *multidisciplinary* research to put this vision into reality. "Eating up" radioactive waste as fuel would eliminate the long-term storage problem of current nuclear waste as well as the accumulation of plutonium, and make nuclear power stations much more energy efficient. Also, it would relieve us from the costs and environmental damages done by mining current nuclear fuel (mostly uranium) and the complicated processes required for long term operation collectively called the *nuclear fuel cycle*. The new operational model would only consist of dissolving the SNF, operating the reactor, and cleaning the fuel salt (see Figure 3). All in all, it would reduce many environmental, social and political issues of current nuclear power production. Using our current nuclear waste as fuel would allow us to take full advantage of the climate-friendly aspect of nuclear power generation.

Conclusion

Even in science and technology, it's important to realize when we have to re-think our current approaches, and what our options are for improvement. Current nuclear power stations have been created with past technologies and goals in mind. Nowadays, some people claim, they might create often more problems than they solve. We need innovative alternatives to provide sustainable, safe and clean energy for generations to come. What creative solutions can you think of to make your energy consumption or your lifestyle more climate and environmentally friendly?

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Acknowledgement: Engineering and Physical Science Research Council provided funding (EP/R001618/1) for this adaptation and the Royal Academy of Engineering has funded the research chair position which allows re-thinking current approaches.

EPSRC Engineering and Physical Sciences Research Council

ROYAL ACADEMY OF ENGINEERING

Glossary of Key Terms

Byproduct – anything produced by a process which wasn't the main intended product. Nuclear power plants are meant to produce energy for electricity but also produce radioactive waste.

Direct greenhouse gas emissions – greenhouse gases that are released when using a fuel. For instance, burning of coal and natural gas creates a lot of CO_2 emissions.

Feasibility – the state or degree of being easily or conveniently done. We believe nuclear power plants that are fueled by nuclear waste are **feasible**.

Fossil fuels – natural fuels such as crude oil, coal or gas, formed in the geological past from the remains of living organisms.

Greenhouse gases – gases (like CO_2 and others) that contribute to global warming by trapping heat from the sun in the atmosphere close to the earth.

Indirect greenhouse gas emissions – release of greenhouse gases not directly by using a fuel, but by all the actions that are taken to make/refine/distribute the fuel or take care of its waste products. For instance, building power plants or waste storage facilities.

Innovative – creating new ideas or methods which are advanced and original.

Multidisciplinary – combining or involving several academic disciplines or professions (e. g. Physics, Chemistry, Engineering...) in order to find a solution to a problem.

Nuclear fission – a chain reaction where a neutron is reacting with an atom (usually uranium) and causes it to split into 2 different atoms. The process releases energy that was stored in the nucleus of the uranium atom and leads to new neutrons to produce new fuel and new fissions.

Nuclear fuel cycle – all processes required for the operation of a nuclear power station from start to finish, from mining of the fuel to the long term storage of the waste.

Nuclear power – is the power (in form of electricity) that is created by the energy that holds atoms together (nuclear energy). In most nuclear power plants, uranium atoms are split into two smaller atoms, and the energy released is used to heat up water. The water is turned to steam which then powers huge turbines that drive generators to make electricity. The steam is then changed back into water by cooling down via a cooling tower.

Nuclear waste – radioactive material that is created as a byproduct of using or processing nuclear fuel. We distinguish between low level waste and high level waste where the greatest portion is the spent fuel and a smaller portion is the remains from reprocessing of spent fuel.

Nuclear weapons – an explosive device that gets its power from the nuclear reactions.

Plutonium – a radioactive chemical element with the symbol Pu. It is not usually found in nature but instead created as a byproduct of nuclear power generation.

Radioactive/radioactivity – the emission of a kind of energy (also called radiation) from an unstable atomic core (the so-called nucleus). The radiation can be low or strong. The stronger it is, the further it travels, and the more harmful it is to humans and other creatures. (Strong radiation can travel through our body cells and do damage inside).

Sustainable – the quality of not being harmful to the environment or depleting natural resources, and thereby supporting long-term ecological balance.

Unsustainable – upsetting the ecological balance by depleting natural resources.

Uranium – a chemical element with the symbol U. It's a weakly radioactive, light silvery metal that can be found in nature. It's fairly rare and costly to extract in a process that is toxic to the environment.

Check your understanding

1 What do we mean when we talk about 'spent nuclear fuel'?

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2 Why would it be such a great idea to redesign nuclear power plants to run on spent nuclear fuel?

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3 What are the current benefits of making nuclear power?

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4 What are the drawbacks of current nuclear power generation?

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5 What do you think: is nuclear power an environmentally friendly power source?
