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THE ROLE OF NUCLEAR POWER IN A SUSTAINABLE FUTURE

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ABSTRACT: In an era where global warming is a major threat, nuclear power offers an alternative to fossil fuels that has a number of advantages. In this paper, the advantages and challenges associated with this source of energy are reviewed.

Keywords: nuclear power, nuclear safety, nuclear structure, quarks, global warming

It is a little over 110 years since Rutherford discovered the atomic nucleus. At the time physicists could not explain how such a small system could be made from the particles (electrons and protons) then known. It took another 20 years to discover the neutron and to realise that a new force, the nuclear force, far more powerful than electromagnetism, was at play.

We now know the properties of thousands of nuclei, with many thousands still to be discovered before we meet the limits of stability. The majority of these are isotopes, with the number of neutrons accompanying a fixed number of protons varying over an enormous range. If we think of the periodic table, there are now 118 known elements, with the last 9 'super-heavies' (nuclei with atomic number 100 or greater) made artificially. The race to make even heavier elements is underway at a number of laboratories around the world but it is extremely challenging as they live for only a very short time. The holy grail is the possibility that there may be a region of relative stability somewhere beyond element 118.

We have sophisticated theoretical treatments which can accurately predict the binding energies of known nuclei but become less reliable in the superheavy region. While nuclear theory usually involves solving the many-body problem in terms of two- and three-body forces between protons and neutrons, there are hints that nuclear structure may be even more interesting. We know that the protons and neutrons are themselves made of more fundamental particles, the quarks, and that the quark structure of the protons and neutrons may be modified inside an atomic nucleus. This is an area of research dear to my heart and it has led to a remarkably accurate description of nuclear properties (Thomas 2021).

In spite of the tremendous progress in finding more nuclei and describing their properties, it is only in the last five years, more than 100 years after their discovery, that we have found where in the universe naturally occurring nuclei are forged. For many years it was thought that the heavier nuclei were formed in supernova explosions. However, the calculations never quite matched the observed abundances. Then, just five years ago, the remarkable observation of gravity waves, tiny fluctuations in space time, resulting from the merger and subsequent explosion of a pair of neutron stars finally resolved the issue. We now know that almost all of the heavier nuclei, including gold and platinum, were made this way. It is stunning that the gold in our jewellery is the ash of explosions resulting from the merger of pairs of neutron stars (or pulsars)!

Because of the huge scale of energies associated with nuclei, a million times larger than those of atoms, there was excitement and concern about the possibility of nuclear energy. Rutherford is famously quoted as suggesting that it was not feasible, classifying talk of extracting nuclear energy as 'moonshine'. Yet well before the discovery of fission by German scientists in 1938, the public domain included frightening speculation of doomsday scenarios involving nuclear energy. We set aside the extremely important issues of nuclear weapons that currently beset the world and in keeping with the theme of this meeting, namely sustainability, turn to the generation of energy.

The conversion of mass to energy using Einstein's famous $E=mc^2$ means that the scale of energy released in nuclear reactions is astonishing. The energy generated by the decay of 1 kg of plutonium is equivalent to that of 2.7 million tonnes of coal. In addition to the CO_2 released, a coal-burning plant releases huge quantities of other pollutants, including radioactive material. On the other hand, nuclear energy releases no greenhouse gases and if safely operated no pollution. The advantages, especially in a world where the threat of global warming is so real and so frightening, are extremely attractive. France has led the way in exploiting nuclear power with 50% of its electricity produced that way. Indeed, 10% of the world's electricity comes from nuclear power. Solar and wind power are being exploited in impressive ways but reliable back-up power is essential when the sun doesn't shine or the wind blows too weakly or too strongly. The demands on raw materials associated with batteries and the impact on the environment of energy storage in reservoirs mean that nuclear power has very real attractions.

However, there are two major problems: safety and waste (Londergan & Vigdor). Let me deal with the issue of waste first. A nuclear reactor produces significant quantities of extremely dangerous radioactive materials, the worst with very long lifetimes, technetium-99 over 200,000 years and iodine-129 15.7 million years. The safe storage of such long-lived waste presents tremendous problems, and so far only Finland and Sweden have agreed storage methods. When we realise that just 2000 years ago the Romans ruled the world, the challenge of managing dangerous materials responsibly over hundreds of thousands of years becomes clear. It was inconceivable to me that just a few years ago the South Australian government seriously suggested taking the world's nuclear waste for short-term gain. Fortunately, the South Australian population proved smart enough to say no.

In my view the key issue is whether one can change the long-lived waste into waste that has a much shorter lifetime. Two methods have been proposed for this. The fast breeder reactor is capable of destroying the nuclei with very long half-lives, converting them into lighter nuclei that we can hope to store until they are no longer dangerous on the scale of a human lifetime. No doubt this technology will continue to be developed but so far the safety of fast breeder reactors is seriously in question.

The alternative method is accelerator driven transmutation, where a beam of particles is accelerated to high energy and then fired into a target containing long-lived waste. The nuclear reactions can destroy these dangerous nuclei, converting them to waste that needs to be stored for decades rather than millennia. The physics of this has been well understood for more than 50 years. The major question is whether it is cost effective — at least if you discount the cost of generating deadly material that lasts hundreds of thousands of years. There are hopes that not only can transmutation of nuclear waste be made a reality but that it may even generate energy in the process. Sadly, the amount of effort devoted to this problem appears very small, with Europe supporting one laboratory in Belgium and by far the most serious effort in China. Given Australia's production of nuclear fuel it is amazing that we have no involvement whatsoever in these research programs. Even more amazing, this possibility was never considered in the efforts to turn South Australia into a nuclear waste dump for the world.

In summary, at the present time there is no satisfactory solution to the problem of dealing with the waste from nuclear reactors but serious dedicated research could very well provide a solution.

Next we turn to the safety of operation of a nuclear plant. There have been a few well-known disasters involving nuclear power plants, notably Chernobyl and Fukushima. Both cases involved human error compounded with additional problems and could have been avoided. In the case of Fukushima, the back-up power system to drive pumps and keep the system cool was not sufficiently waterproof, a remarkable choice when flooding was a known potential problem.

In my view, the systems needed to operate a nuclear reactor safely and to reassure the public living nearby that this is in fact the case have not been invented and certainly, in Australia, this is the major challenge to the acceptance of nuclear power.

Nuclear reactors present the challenge of terrorism aimed at obtaining dangerous materials and that requires a serious security presence. Unfortunately, this typically leads to a lack of transparency. In South Australia the outstanding example of this is provided by the British nuclear tests at Maralinga between 1956 and 1963. Those tests generated clouds of radioactive material that drifted over South Australia and Victoria. Those were the days when the dairy industry was subsidised to provide free milk to school children, a group especially sensitive to the radioactive iodine for which milk is an ideal method of delivery. Was the population warned? Were iodine tablets to mitigate the effect on children distributed? No. The tests were covered by the Official Secrets Act and it would have been a crime to warn people of the dangers they and their children faced. That was simply disgraceful and should have been a criminal act but it was a natural consequence of the secrecy associated with matters nuclear.

The Australian people are suspicious of nuclear power, some for poor reasons and others for good reasons. In order to convince the rational opposition, one must solve the problem of operating a secure facility in a way that is both open and responsible. One needs to be able to have oversight that ensures that problems are found and fixed quickly and without regard to convenience or cost and that lets the public know what is going on in a timely manner. This is not just a problem for scientists, although scientists and engineers must be involved. Rather it is a problem of governance, that also touches social, legal and political challenges which go far beyond anything our society has yet solved.

In short, some of the key conditions under which one might accept nuclear power include:

- There must be an Oversight Committee (OC) which exists to ensure that the facility is operated safely and to keep the public informed on safety issues.
- The OC needs to include nuclear scientists and engineers as well as members of the general public who are respected by the community.
- The members of the OC must have access to all safety reports in a timely manner and have the power to request and receive timely answers regarding any issue relating to the safe operation of the facility.
- The members of the OC must be able to communicate directly with the general public and be protected by law in doing so.
- In order to be effective, the members must be appointed for fixed terms long enough to gain familiarity with the operation of the facility and their appointments must be protected from interference either from management or the political sphere. That is, they must have real tenure for the term of their appointments.
- The only area where the OC will not have oversight concerns potential terrorism but this must explicitly be forbidden from interfering with the requirement for full safety oversight.

No doubt, this initial list is incomplete and one needs a serious discussion between representatives of the scientific, engineering, social science and legal communities to prepare a framework that can work effectively. I am not aware of any such system of oversight having been developed, let alone implemented, anywhere. It will not be easy. Until this issue is resolved, convincing the Australian population to accept nuclear power, attractive as it may be in the light of global warming, is an impossible task.

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Conflict of interest
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