entX

CLEAN ENERGY TECHNOLOGIES

# HARNESSING THE ENERGY OF RADIOACTIVE PARTICLES

The large amount of energy carried by radioactive particles can be harnessed to useful effect in a number of societal applications, including Medicine, Chemical Catalysis, Remote Power Sources.

## Medical

Energetic radioactive particles are recognised for their potential to treat (*ie*, destroy) cancerous tissue in a highly localised fashion, minimising damage to surrounding healthy tissue -- in contrast to the shotgun approach of classic chemotherapies.

A number of radioimmunotherapy cancer drugs have already been approved and these employ β-particle emitters attached to peptide molecules that selectively bind to the surface of particular cancer cells. α-particle emitters are even more effective in terms of short-range cancer cell-killing potency.

It so happens that the production of the ideal medical α-emitter ($^{212}Pb$) is reliant on the availability of a parent radioisotope ($^{228}Th$) that is present in the radioactive waste accumulated by various mineral producers, most notably those producing rare-earth elements. entX is running a project to extract this valuable medical isotope from mineral waste streams.

## Catalysing Important Chemical Reactions

Radioisotopes can be incorporated into catalytic materials, *ie*, substances that facilitate specific chemical reactions. When this is done, the radioactively-excited electrons create an energised surface on which desirable chemical reactions proceed at an accelerated rate.

Radiocatalysts can be applied to chemically transform carbon dioxide, or to produce hydrogen. They are ideally suited to using the unwanted radioisotopes commonly designated as 'wastes'[1]. Thus, radiocatalysis technology offers an appealing technological endpoint, *ie*, driving the conversion of waste $CO_2$ into valuable products using unwanted radioactivity.

entX has performed a number of experimental demonstrations of the radiocatalytic conversion of $CO_2$ into useful organic compounds. The company sponsored a body of work at ANSTO in which a ceramic catalyst was made radioactive (in the OPAL reactor) and then used to successfully convert $CO_2$ to chemical compounds of industrial significance (*eg*, formic acid). Another larger set of experiments will be carried out in 2023.

## Producing Remote Power Sources.

When β-particle emitting radioisotopes are incorporated into semiconductors they create many electric charge carriers and these can be captured into an external circuit, thereby producing electric power. This 'betavoltaic' method of electricity generation is akin to photovoltaics, but does not require exposure to an external source of photons.

Betavoltaic power units operate continuously for long periods, without the need for recharging. Their operational life depends on the half-life of the radioisotope driver, thus can run to many years. Compact units will find numerous applications, in particular in extreme environments where battery change-out is expensive or impossible, such as in ocean-floor devices, space vehicles, etc.

entX is building small prototype betavoltaic devices and scaling these up in collaboration with several industry and academic partners using private capital with welcome support from a Commonwealth "*Collaborative Research Centre - Project*".

1 Including: $^{210}Pb$, $^{90}Sr$, $^{125}Sb$, $^{14}C$.

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## IMPLICATIONS FOR THE NUCLEAR POWER DEBATE

Each of the technologies outlined in the previous Section is a manifestation of the industrial and societal utility of the energetic particles emitted by radioactive isotopes. This includes particles emitted in material regarded as radioactive 'waste'. Some radioisotopes can be manufactured artificially, but most of the radioisotopes needed by entX can be preferentially accessed from 'waste' streams in the nuclear fuel cycle, or from naturally-occurring radioactive material streams in the minerals industry.

If a nuclear power capacity is established in Australia, entX will welcome the opportunity this creates in terms of supply options for the radioisotopes that are essential components of the company's emerging products. Such supply options would emerge by virtue of: (i) the radioactive by-products resulting from nuclear power operations, and; (ii) the possibility for producing valuable radioisotopes by irradiating precursor materials with neutrons in a reactor core.

### Radioisotope Value from Nuclear Power by-Products.

The generation of nuclear power leads to a few radioactive by-product streams, most of which are designated as 'wastes', yet they comprise radioisotopes that have considerable technological value when harnessed as described herein. For example, the management of reactor coolant water results in useful radioisotopes (*eg*, $^{45}Ca$, $^{60}Fe$, $^{3}H$, $^{63}Ni$, $^{14}C$) that accumulate over time.

The most concentrated source of radioisotopes in the nuclear fuel cycle is the irradiated uranium fuel discharged from power reactors (often called 'spent' nuclear fuel (SNF)). When uranium is cheap (as now) it is not economically feasible to chemically process SNF for its useful radioisotope contents[2]. Nevertheless, entX contends that the radioisotopic value of SNF should be recognised in any approval process for establishing a nuclear power generation capacity – as supported by the following facts:

» in the time (>10 years) it will take to establish a NP capacity in Australia, the technologies of entX and others will have progressed to the point where they represent a real demand for various radioisotope emitters present in SNF (*eg*, $^{125}Sb$, $^{93}Nb$, $^{63}Ni$, $^{147}Pm$, $^{121m}Sn$).

» the radiochemical processing of irradiated uranium is already well-established in Australia. It is undertaken on a ~daily basis as part of the production of the $^{99}Mo$ medical isotope, at ANSTO. This capability is one of Australia's key nuclear assets. It is directly relevant to reprocessing SNF and would de-risk any project to build a SNF reprocessing facility.

» in addition to industrially useful radioisotopes, valuable metals such as ruthenium, palladium and neodymium could credibly be extracted from SNF[3] if a reprocessing capability was established as part of a 'life-cycle' nuclear power infrastructure investment. Such an undertaking would also help minimise volumes of radioactive waste needing long-term storage.

» it is not out of the question that an Australian power reactor would use an advanced metallic form of fuel – this could dove-tail well with an emerging AUKUS nuclear submarine fleet. Also, such fuels offer thermal advantages which can lead to better safety margins when load-following an electricity distribution grid. Metallic fuels are easier to chemically process so would facilitate the recovery of valuable radioisotopes from SNF.

In the event that a nuclear power reactor can be established in Australia, entX would seek to establish access arrangements for the routine radioisotope 'waste' streams associated with the plant. Furthermore, entX would advocate for building a SNF processing capability for extracting and re-purposing a wide range of constituent radioisotopes having industrial/ technological value.

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2 When only a single product (plutonium) is recovered from SNF for recycle – as in France – the chemical processing effort is economically viable only if carried out on a large scale.

3 Mass estimates have been published, *eg*, in: S. Bourg & C. Poinssot, *Prog.Nuc.Energy*, v94, pp 222-228 (2017).

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Radioisotope Products from New NP Reactors

Nuclear reactors can produce radioisotopes by virtue of the large numbers of neutrons present in their cores. A radioisotope production run involves inserting/holding a small sealed capsule of a target material in a core for a designated period, after which it is discharged and the radioactive product retrieved in a suitable manner.

Indeed, entX used ANSTO's OPAL reactor to produce a radioactive strontium isotope within a ceramic that served as a radiocatalyst for $CO_2$ conversion experiments, and the company is planning a new irradiation to produce a radioisotope sought after by the fabricators of certain satellites and space vehicles. OPAL is an excellent and versatile research reactor, however, it is quite small and is alone on this continent. Both factors limit the ability to reliably produce key technological radioisotopes in a scaled-up manner.

In the event that a nuclear power reactor can be built in Australia, entX would counsel that the selected reactor-type has the capability for performing in-core radioisotope productions.

SUMMARY

This Submission has made the following important points:

» Radioisotopes are a vital energy-component in numerous existing and emerging technologies. Their use is set to expand as new applications are being found in the medical, clean-energy and chemical sectors.

» Technologically useful radioisotopes can be produced from radioactive 'wastes', including spent nuclear fuel and radioactive byproducts generated from nuclear reactor operations. Thus, such 'wastes' can be said to have radioisotopic value.

» Technologically useful radioisotopes can be produced in nuclear power reactors.

» Establishing a nuclear power generation capacity in Australia would provide much-needed radioisotope supply options – this would support both the users and developers of technologies that harness the unique energy value of radioactive particle emitters.

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