ADSR ACTIVITY IN THE UK

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A review is given of present and planned involvement in ADSR research in the UK, and the activities of the ThorEA association.

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1. Introduction

The UK currently emits approximately 10 tons of CO_2 equivalent per person per year, broadly in line with the European average.[1] The government has set ambitious targets, including the cutting of CO_2 emissions by 80% by 2050 from the 1990 baseline,[2] but there is no firm plan as to how such goals will be met. There is some scope for development of wave and tidal power and for offshore wind farms, less for onshore wind and solar power, however it appears virtually impossible to meet such targets without the use of nuclear power.

Although the UK currently obtains about 20% of its electricity from nuclear power, the reactors are old and are all but one due to be out of service by 2023. Steps are being taken to replace and even expand these plants, though progress is slow as there still considerable public opposition.

The Thorium ADSR (accelerator-driven subcritical reactor) system is well placed as a match between the pragmatic need and the distrustful public: it is manifestly safe, as switching off the accelerator switches off the reactor, it produces no (or almost no) long lived waste, and it is highly proliferation resistant. Although there has been little UK activity in this area until recently, this is changing very rapidly and the number of groups and people interested in, and working on, the topic has grown greatly in recent years.

2. ThorEA

ThorEA (Thorium Research for the Energy Amplifier) is a not-for-profit organisation and learned society. It aims to promote thorium-fuelled energy amplifier systems as a safe, sustainable and publicly-acceptable form of nuclear power. Its goal is the construction of a thorium-fuelled ADSR in the United Kingdom. It provides a framework within which individuals and organisations can co-operate in pursuit of this.

There are over 80 individuals on the mailing list, and some 40 names appear (with permission) as members on the organisation website. They cover a very broad range of disciplines: Accelerator Scientists, Particle Physicists, Nuclear Physicists, Nuclear Engineers, and Economists. They also come from many different institutes. The UK Accelerator Institutes, Cockcroft and John Adams, are well represented, as are the Rutherford Appleton and Daresbury Laboratories. There are members of 10 different universities, and several from industry. Although most are UK based there are several from continental Europe, the US and elsewhere that use this as a way of keeping in touch, and they are very welcome – we are aware that we are behind in many areas. Anyone who wishes to join should send an email to the author.

It maintains a website `http://www.thorea.org` as a central point of information and contact, which includes details of the organisation, a news feed of relevant stories, links to other sites, and details of meetings. These open and informal workshops take place 3-4 times a year, and normally get around 30 participants and about 10 talks, covering all aspects of ADSR systems from the accelerator to the economics.

It also acts as a forum for partnerships to respond to funding opportunities. There have been several small successful bids: further ones are in progress. It seeks out and exploits opportunities to publicise Thorium and ADSRs, through the web, in the press, by public talks and private lobbying.

3. Design Choices

In order to focus ideas one has to propose a particular system. In doing so we are aware that choices may need to be reconsidered as circumstances change and more knowledge is obtained.

- We propose a Thorium fuelled fast reactor. Uranium ADSRs do not solve the waste or proliferation problems, and thermal Thorium reactors do not produce the fast neutrons needed for transmutation.
- We emphasize energy production, with transmutation as an extra benefit, as we think this will have a stronger political appeal (in

the UK situation) than a system purely for waste disposal.

- We propose a 1 GW Thermal power station, large enough to make an appreciable contribution to the electricity generation capacity.
- We propose a production reactor as the first system, rather than a prototype, which would be expensive with no return on investment.
- We operate at a criticality k of 0.985. We believe that this is low enough to be safe.
- For this we require an accelerator (or multiple accelerators) delivering $\approx 30\,mA$ at 1 GeV This would be a 3 stage process, with a conventional cyclotron to 35 MeV, a ring accelerating protons to 400 MeV, and another for the final acceleration to 1 GeV.
- We use lead as target, coolant and moderator, and operate at a high temperature for high Carnot efficiency. We have benchmarked different simulation codes (MCNPX, FLUKA, GEANT4 and models within these) for the spallation process, and shown how target optimisation can increase the neutron yield.[3]
- Fuel must be recycled. ^{233}U must be reclaimed not only as fuel but also as it will be a proliferation hazard after a few hundred years, when the ^{232}U has decayed. There is also a long term waste problem from the ^{233}U decays. The design of fuel elements to survive in high temperature lead is a challenge, but should be possible.

The FFAG is our preferred accelerator.[3] Its DC magnets are cheaper and more reliable than those of a synchorotron. The acceleration rate is limited by the RF rather than the magnets, and we envisage acceleration up to 1 GeV in around 1000 turns, which would take 1 ms for a 50 m ring. The beam energy of 1 GeV is very hard to attain using a cyclotron, and 10 mA is very hard to attain using a synchrotron. A Linac can achieve both, but its capital cost is inevitably large due to its length. We are currently engaged in construction of EMMA, first nsFFAG, at Daresbury, which will start operating in 2010[4] and hopefully this low energy electron accelerator will show the viability a high current proton machine.

At 1 KHz, if an FFAG is run with a ‘synchrotron style’ duty cycle, in which individual pulses are injected, accelerated, and extracted, then a 10 mA current requires $\approx 6\,10^{13}$ protons/bunch. This is well over typical space charge limits, which are of order 10^{13}. A large harmonic factor (several bunches per turn) can only help slightly. However if it can be run ‘cyclotron style’ with a 100% duty cycle the bunch is only $\approx 6\,10^{10}$ particles which presents no space charge challenge, however the sweeping of the RF frequency (in itself an unsolved problem) limits the duty cycle.

4. Reliability: the Next Accelerator Frontier

The accelerator for an ADSR must attain levels of reliability far beyond those of present accelerators. Requirements stated in the literature vary between 3 and 1000 trips per year, with varying definitions of a 'trip'. We urgently need more investigation to harden up the actual requirements. Thermal stresses in the window and target are directly beam-related, thermal stresses in the core and its components are moderated by the time constant of the reactor and cooling, and there are also limits from economics: a 1 GW plant cannot just drop out of the Grid with impunity.

Reliability can be achieved by redundancy, robustness, under-rating and planned maintenance. These have a cost penalty, and the design must include them only where necessary. Ion Sources are known to be fallible and two or more should be used. The DC magnets will probably be sufficiently reliable. RF components will fail, and the design must cope with this: this probably rules out clever designs such as the Separated-Orbit Cyclotron, Recirculating Linear Accelerators, and Harmonic number jumping, as these require the bunch to have a specified energy at a specified point in the cycle. There are also mundane components such as vacuum and power. Multiple accelerators may be needed to provide adequate reliability.

5. Conclusions

ADSR involvement in the UK is increasing rapidly. We have a wide range of specialists working together across discipline boundaries. Activities are increasing in many areas, and those interested are welcome to browse the ThorEA website and help us towards the goal of establishing Thorium powered ADSRs as the sustainable carbon-free energy source of the future..

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