

Institution: The University of Huddersfield
Unit of Assessment: 9 Physics
Title of case study: An Alternative Nuclear Future
<p>1. Summary of the impact (indicative maximum 100 words)</p> <p>The University of Huddersfield leads the UK in the development and advocacy of the thorium nuclear fuel cycle as an alternative to the uranium/plutonium cycle. We have set the design parameters for feasible thorium fuelled accelerator driven subcritical reactor assemblies for power generation and waste management and for fertile to fissile conversion of thorium [A]. Our high media profile [G,H] and extensive interactions with the public [I] and policy makers both in the UK and US [B,C,E,F] has led to growing acceptance of thorium as a realistic, safer, cleaner and proliferation resistant alternative fuel for nuclear fission reactors. Consequently our research is now influencing nuclear policy both at home and overseas [D,F].</p>
<p>2. Underpinning research (indicative maximum 500 words)</p> <p>Prof Cywinski and Dr A.Bungau (who have been at Huddersfield since September 2008) initiated research on the novel deployment of thorium as a nuclear fuel. They were joined by Prof Barlow and Dr C.Bungau in early 2011. Initially we developed an innovative thorium-fuelled Accelerator Driven Subcritical Reactor (ADSR) based on thorium [1] and explored methods of effecting the fertile to fissile conversion of thorium to provide fuel for conventional reactors [2]. ADSRs have the potential to fill the gap of carbon-free nuclear power stations with a safer, cheaper, more sustainable form of nuclear power. Moreover, the significantly greater neutron flux at energies $>2\text{MeV}$ provided by accelerator-driven spallation allows ADSRs to transmute legacy actinide waste, burning it as fuel and turning a liability into an asset.</p> <p>Drawing upon the expertise in Huddersfield's International Institute for Accelerator Applications we have carried out research on appropriate proton drivers for ADSR systems, concluding that our newly demonstrated non-scaling fixed field alternating gradient accelerator can provide the required proton energies, currents, and reliability. The compact nature (and hence reduced cost) of a nsFFAG enables multiple proton injection and spallation to be considered, thereby mitigating against accelerator trips and homogenising the spallation neutron density in the core. Cywinski and colleagues have now secured a patent on the multiple injection principle [3].</p> <p>In parallel projects, molecular modelling has been carried out by Cywinski and colleagues to confirm the physical stability, thermal conductivity, expansion, and diffusion of thorium fuel in a reactor [4]. Cywinski has also collaborated with LPSC and CEA in Grenoble to measure the mass and isotopic yields of the $^{233}\text{U}(\text{n}, \text{f})$ reaction using the Lohengrin spectrometer at ILL [5], producing the most complete and accurate data to date on fission cross sections of ^{233}U (ie the fuel's fissile component resulting from neutron capture by fertile ^{232}Th).</p> <p>Since 2011 we have simulated the behaviour of reactor configurations using the Monte Carlo MCNPX program. In order to confirm the accuracy of the results they have been benchmarked against those from GEANT4. This is a modern and very general simulation code originally developed for particle physics but now finding many applications as it is much more adaptable than MCNPX, particularly for complex geometries such as those of an ADSR. As part of the research programme, C.Bungau has successfully added several new classes to the GEANT4 simulation code which have allowed the code to be used for nuclear reactor criticality calculations for the first time. These modified codes greatly extend the capabilities of GEANT4 and will be made generally available.</p> <p>As a part of our research programme we explored pathways to the exploitation of thorium energy and the delivery of the relevant technologies. These are reported in detail in "<i>Towards an Alternative Nuclear Future: Capturing thorium-fuelled ADSR energy technology for Britain</i>", a 71pp policy document prepared at the request of the former Minister of Science, Lord Drayson in 2009 [1]. Here we showed that it is possible, through a public/private partnership, to realise thorium</p>

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ADSR technology by 2025 ahead of GEN IV. We also showed that ADSRs could be cost competitive, with a complete 600 MW reactor ($k_{\text{eff}}=0.985$) being of a comparable cost to a conventional system, whilst generating costs would be ~£3/MWhr lower than that of a U fuelled system. Radiotoxic waste production would be substantially less. These figures are similar to the estimates made by Jacobs E&C Ltd who, in collaboration, developed a comparable system (the ADTR™) [6].

3. References to the research (indicative maximum of six references)

- [1] Cywinski*, Barlow*, Towns-Andrews* and 11 others, *Towards an Alternative Nuclear Future: Capturing thorium-fuelled ADSR energy technology for Britain*, (ed Cywinski) (2009/10) A policy report prepared at the request of Lord Drayson, Minister of Science
<http://www.thorea.org/publications/ThoreaReportFinal.pdf> #
- [2] C.Bungau*, Barlow* and Cywinski*, *Optimisation Studies of Accelerator Driven Fertile to Fissile Conversion Rates in Thorium Fuel Cycle* (2012). In: Proceedings of IPAC2012, New Orleans, Louisiana, USA. IEEE, London, pp. 4112-4114. ISBN 978-3-95450-115-1
- [3] Cywinski* and 5 others, *Charged-particle-generator* (2011) International Patent WO2011077082 (plus CN102668723A, EP2517539A1,US20120257703) #
- [4] Martin*, Cooke*, and Cywinski*, *A molecular dynamics study of the thermal properties of thorium oxide* (2012). Journal of Applied Physics, 112 (7). 073507. ISSN 0021-8979, DOI: 10.1063/1.4754430 #
- [5] Martin, Cywinski* and 16 others, *Measurements of the mass and isotopic yields of the $^{233}\text{U}(n, f)$ reaction at the Lohengrin spectrometer* (2011) pg 1-7 DOI: 10.1109/ANIMMA.2011.6172920
- [6] Peggs, Barlow*, Cywinski*, Seviour* and 13 other international authors, *Thorium Energy Futures* (2012). In: Proceedings of the International Particle Accelerator Conference IPAC 2012. JACoW, New Orleans, Louisiana, USA, pp. 29-33. ISBN 978-3-95450-115-1 (lecture presented by Cywinski – available from the University Repository <http://eprints.hud.ac.uk/15980/>)

papers selected to indicate quality of underpinning research.

* denotes Huddersfield author, non-Huddersfield lead authors are given in refs 5 and 6 for bibliographic completeness.

Grants

Barlow, Cywinski Edgecock et al: EPSRC grant EP/E032869/1 *The Non Scaling Fixed Field Alternating Gradient (NS-FFAG) Accelerator* 01.4.07 to 31.3.11 £ 7,472,363
(The applications work group of this project developed ADSR technology following Cywinski's and Bungau's appointment at Huddersfield)

Barlow and Cywinski: EPSRC grant EP/F028121/1 *Innovative Accelerator Technology for Accelerator Driven Subcritical Reactors* 1.10.07 to 31.3.09 £142,341

Barlow and Cywinski: STFC PNPAS award: *Using Thorium as a Fuel in Conventional Reactors* 1.7.09 to 30.6.11 £424,447

4. Details of the impact (indicative maximum 750 words)

Impact on industry

At an early stage of Huddersfield's thorium research programme (2009) Cywinski and Barlow created ThorEA, initially as the Thorium Energy Amplifier Association, currently extended in scope to the Thorium Energy Association. ThorEA is a learned, not-for-profit, society that brings together academics, industrialists and politicians to discuss all aspects of thorium deployment technologies. Meetings with 30-50 participants are held twice annually at venues around the UK, often attracting overseas attendance. Siemens, Jacobs E&C Ltd, the Norwegian company Thor Energy, NNL, and

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the Nuclear Institute have participated. As a result Cywinski was invited to address the Nuclear Institute's Midlands, Cumbria and North East branches, and in 2012 gave the NI North West R V Moore memorial lecture. These interactions have showcased Huddersfield's research and led to a publication with Thor Energy and Jacobs [6], with the latter confirming that our research has "...had an impact on our own designs for the ADTRTM which won the prestigious IChemE 2010 Innovations and Excellence Energy Award." [A].

Impact on government and policy makers

Given the current position of the nuclear industry, the public and governmental perception of that industry, and issues involved with the scale of financing, licensing, and build time, it is clear that influence on policy is a crucial first stage in exploiting our research.

Following ThorEA's inception in 2009 Science Minister Lord Drayson requested a report on our research on thorium technology, defining the financial investment necessary for the UK to deliver the enabling technologies for the construction of a thorium-fuelled ADSR, whilst additionally appraising the commercial opportunities arising for the UK. The report [1], edited by Cywinski, showed that the technology would allow the UK to compete aggressively in existing nuclear markets, open up new nuclear markets, directly impact other high technology industries including medicine and enable the UK to meet carbon reduction targets. The Government left office before the report, delivered in late 2009, could be acted upon. However the report has been recognised and supported by IAEA as "...a positive contribution to the international effort to secure eventual global deployment of sustainable thorium fuelled ADSR power generation systems." [1].

In 2013, under Cywinski's chairmanship, ThorEA was granted full membership of Europe's Sustainable Nuclear Technology Platform – SNETP – in recognition of its reputation for bringing academia and industry together.

Our strong engagement with politicians and policy makers, for example through the All Party Parliamentary Group on Thorium, has "...significantly informed the UK debate on clean, low carbon, but safer and more sustainable, nuclear power." [B] whilst assisting "...in DECC's consideration of possible future scenarios for nuclear power generation..." [C]. We are also informing policy, as demonstrated by the inclusion of the thorium fuel cycle in the recent Beddington Review document "Nuclear Energy Research and Development Roadmap: Future Pathways" [D] recognising that thorium fuel could play a key role in the future pathways to nuclear power in the UK and is worthy of further research - a remarkable turnaround with respect to an earlier negative NNL policy statement on thorium.

We have also interacted closely with the Weinberg Foundation (an NGO operating from Somerset House) and its patron, Baroness Bryony Worthington (Shadow Minister for Energy and Climate Change) [B], since its launch in 2011. The WF recognise that our research has been "...instrumental in changing scientific, political and public opinions on thorium energy..." [E].

In the US our ADSR research on waste transmutation carried out in collaboration with PAC has led to "...a legislative bill in the Illinois State General Assembly based on the Huddersfield-PAC ADS model that would permit construction of a pilot plant to demonstrate this approach to dealing with nuclear waste. This bill has passed out of committee with bipartisan support and is now up for vote in the full Illinois House of Representatives." [F].

Internationally, we are represented on the programme committee, alongside Carlo Rubbia and Hans Blix, of the international thorium energy conference THEC13. This conference series successfully brings together academics, industrialists, politicians and policy makers. Huddersfield has given invited lectures, and chaired sessions and discussion panels, at this and previous THECs.

Media impact

Our research on thorium has generated significant media interest in thorium, starting with The Times science supplement Eureka in October 2009 which featured our ADSR as one of the 15 projects researching technologies of tomorrow which "...promises to change the way we live for the better.....". Since then Huddersfield's research has featured many times in national newspapers including the Guardian, Telegraph, Financial Times, a major colour supplement article in The Mail

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on Sunday [G] and even featured in House and Garden (8/2012). Internationally we have been asked to write an editorial for The Australian and have been featured in many international newspapers and blogs, always attracting tens and sometimes hundreds of feedback comments. Our research has featured prominently on the BBC [H]: in Radio 4's *Material World* (15/9/2011), and "*Costing the Earth*" (29/2/2012), whilst on television it featured in the pre-election *Politics Show* (April 2010), and other news items. BBC World's Horizons Business in 2013 broadcast a whole programme dedicated to Huddersfield's thorium ADSR work (viewing figures ~100M). In October 2013 Cywinski was interviewed live on Australian ABC News (reach 2M viewers). We are often asked for live comment on nuclear issues on local BBC radio news programmes.

A Google search for Huddersfield and thorium generates 218,000 hits linking to articles, blogs, comments, and interviews.

Public Engagement

We have given dozens of invited talks at Public Lectures, Café Scientifique, TEDx, Philosophical Society, Schools and other public events across the UK, including an invited lecture at the British Science Festival in September 2011 where we also partnered Jim Al-Khalili in a public debate on nuclear power, and an invited appearance at Beacons Rock Festival in August 2013. Each event has drawn audiences of between 50 and 200. Feedback at and from the presentations is always positive with each presentation invariably leading to several new invitations to speak.

Finally, recognising how much our thorium research had attracted the attention of the public and was impacting perceptions of the potential of alternative nuclear power and waste management, the Science Museum in London launched a 3 month exhibition in the Antenna Gallery in October 2012 dedicated entirely to our research programme. Visitor numbers exceeded 775,000, and the associated Topic Zone stimulated 464 visitor comments and an article in the Dutch Newspaper NRC Handelsblad (22/11/2012) [I].

5. Sources to corroborate the impact (indicative maximum of 10 references)

[A] Endorsement from the ADTR Project Manager at Jacobs E&C Ltd

[B] Endorsement from the Shadow Minister for Department of Energy and Climate Change, House of Lords

[C] Endorsement from the Department of Energy and Climate Change

[D] Nuclear Energy Research and Development Roadmap: Future Pathways (2013) BIS-13-262

[E] Endorsement from the Chairman and co-founder of the Weinberg Foundation

[F] Endorsement from the President of Particle Accelerator Corp

[G] <http://www.dailymail.co.uk/home/moslive/article-2001548/Electron-Model-Many-Applications-Technology-save-world.html>

[H] Material world <http://www.bbc.co.uk/programmes/b014gdxv>, Costing the earth

<http://www.bbc.co.uk/programmes/b01cjwv1>, Horizons Business

www.bbc.co.uk/mediacentre/worldnews/horizons-episode-20.html

[I] http://antenna.sciencemuseum.org.uk/?page_id=18430