FEASIBILITY OF SMALL MODULAR NUCLEAR REACTORS FOR IRELAND

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Electricity generation in Ireland contributes to almost a quarter of Ireland's overall greenhouse gas emissions and at the moment Ireland is the most import dependent country in Europe. In future markets Ireland's electricity generation will consist of a large supply coming from renewable sources. However, these sources are variable and still require a base load supply from a power plant to meet demand for the entire year. These power plants are currently being run by fossil fuels, however to reduce our emissions a more environmental source for base load supply such as nuclear must be considered. Due to the nature of Ireland's electricity grid, large nuclear reactors are considered too large. However, in recent years a new type of reactor has been designed for small electricity grids such as Ireland, the small modular nuclear reactor (SMR). These reactors are scalable in outputs up to 300 MW and have many advantages such as significantly lower capital costs, enhanced safety features, factory fabrication and can be built modularly to meet the demand. Some barriers pointed out by the research to deploying the technology in Ireland include dealing with the waste from the spent fuel, which no permanent solution yet been found, and overcoming the anti-public perception particularly the "NIMBY" syndrome. The proposed research study aims to determine if the technology is viable for Ireland by taking an open minded view and weighing up the advantages against the disadvantages of introducing nuclear power in the form of SMR's to Ireland. This paper focuses on a review of the literature on the economics, social and environmental impact of SMR's. In order to develop a clear insight into the feasibility of the technology, a case study has been adopted as the research strategy. The proposed methods include interviews with members of BENE, a senior member of ESB and a reactor supplier and also a focus group with members of BENE. The findings of this exercise highlight that introducing SMR's to Ireland would promote energy security and offset significant amounts of greenhouse gas emissions, however, an evaluation must be made to deal with the spent fuel and anti-public perception. Therefore, it is believed that there is an opening for such a dissertation for academic research into the feasibility of SMR's for Ireland.

Keywords: economic impact, electricity generation, environmental impact, small modular reactors, social impact.

INTRODUCTION

In 2007, the global primary energy consumption increased by 2.4% to 11,099.2 million tons of oil equivalent (mtoe). The majority of this energy consumption was obtained from the combustion of fossil fuels such as oil, gas and coal, with nuclear energy and renewable sources accounting for a significantly less share (Boyle et al., 2009). Electricity generation in Ireland contributed to a staggering 23.33% share of Ireland's overall greenhouse gas emissions (GHG's) in 2005 (Crilly and Toshko, 2008).

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In 2006, Ireland saw its import dependency rise to 91%, consequently making it the most import dependent country in Europe (Boyle et al., 2009). Reducing our reliance on fossil fuels by turning to alternative technologies such as renewable and nuclear energy will reduce our GHG's, while at the same time decrease our import dependency. In future electricity grids, renewable energy sources will have increasing shares of unpredictable supply that will affect the grid operation and will require a back up approach such as nuclear (Shropshire, 2009).

The maximum peak demand of electricity in Ireland in 2010 was 5090 MW (Megawatt) (EirGrid, 2011). There is a general consensus that the Irish grid is therefore too small to incorporate a large reactor >1000 MW (Carelli et al., 2010, Kessides, 2009, Kuznestsov, 2008). According to Kessides (2010, p. 3858), these considerations suggest that, "there is merit to analyzing the economics of smaller nuclear plants."

The International Atomic Energy Agency (IAEA) define small reactors as those with power <300MW (Ingersoll, 2009). As highlighted above large reactors are too substantial for the Irish grid, as stated by Kessides (2010, p.3858), "power systems engineering dictates that no single unit should be larger than about 10% or at most 15% of the demand." Crilly and Toshko (2008, p.1498) recognize that in selecting an electricity generation technology, "guidelines should not only be from the most common viewpoint of least cost, but also equally from the least intermittent, the most reliable, the least variable, the most publically/socially acceptable, the most secure etc., point of view."

Small type reactors have been around for decades and have often been used to power military submarines (Ahearne, 2011). This research, however, will focus on the feasibility of some of the advanced small reactor designs that aim to be deployed in the coming decade that would have, "sealed cores and could be assembled at factories and shipped fully assembled" (Ahearne, 2011, p577). A renaissance in interest of SMR's is due to GHG's, economics, job creation and new international market opportunities (Shropshire, 2009). An example of an advanced small reactor design is the International reactor innovative and secure (IRIS). The IRIS design, based on advanced light water reactor (LWR) technology, is being developed by over 20 organisations from 10 different countries including the United States. The design is scalable in power between 100MWe (Megawatt electric) and 350 MWe and its features include a 3.5 year re-fuelling cycle and allows modular construction. The reactor began pre-licensing with the US Nuclear Regulatory Commission (NRC) in 2005 and is likely to submit an application for design certification in 2012 (Ingersoll, 2009).

The purpose of this paper is to present the aims and objectives in determining the feasibility of small modular nuclear reactors (SMR's) for Ireland, to review literature relating to the economic, social and environmental impact of SMRs and to propose a research methodology for carrying out primary research.

**RESEARCH AIMS & OBJECTIVES**

The aim of this research is to determine if small modular nuclear reactors (SMR's) are a safe and economic means of providing emission free electricity to Ireland.

In order to accomplish this aim, the following objectives have been created:
1. To investigate the economic viability of deploying SMR's in Ireland.
2. To examine the technology behind SMR's.
3. To identify the environmental effects of SMR's including safety and waste management.
4. To investigate the non-financial parameters of SMR's applied to Ireland.
5. To compare the greenhouse gas emissions that can be offset using SMR's as opposed to fossil fuel based technologies in Ireland.

The hypothesis which will be tested by the research is as follows:

"Small modular nuclear reactors are a safe and economical means of providing emission free electricity to Ireland."

LITERATURE REVIEW

The following evaluation will review literature on the feasibility of SMR's for Ireland under the headings of "economics," "environmental impact" and "social impact."

Economics of SMR's

There is a widespread attitude that economics of scale (EOS) is the main driving force for nuclear reactors due to the main factor of buying resources in bulk resulting in a lower levelized unit of electricity cost (LUEC), and consequently that smaller sized reactors are not viable (Ingersoll, 2009). According to Ahearne (2011), Carelli et al. (2010), and Chen et al. (2010), one of the main barriers for investment in nuclear energy is the significant capital cost and high risk premium that follows. However the capital investment and risk premium of nuclear power plants may be significantly reduced by means of using smaller reactors as, according to Ingersoll (2009, p.592), "their smaller physical size and plant "footprint" offer the potential for a number of improvements in the fabrication, transportation, and construction of DSRs (deliberately small reactors), which in turn provides improvements in plant safety and economics." Therefore SMR's, or DSR's, may be particularly suitable for the Irish market due to a more attractive investment scalability than large reactors and the fact that large reactors may be unsuitable for the Irish electricity grid. Another valuable characteristic of SMR's is the investor can build the plant at a rate that is closer to demand growth which allows the local grid capacity to be built in more modest increments (Ingersoll, 2009).

As highlighted by Ingersoll (2009), nuclear reactor economics are based on the EOS factor, so how can smaller reactors address this to be economically competitive? There are many factors independent of SMR's that may reverse the EOS factor such as modular construction, reduced construction times (lower risk premium) and factory fabrication (Carelli et al., 2010, Shropshire, 2011, Ingersoll, 2009). Another barrier for small reactors to overcome is standardisation. There are so many SMR's under development that it may lead to a decrease in effort and lack of standardisation (Ingersoll, 2009).

According to Kessides (2010), there is an abundance of natural resources of uranium, the primary fuel of most SMR's, in the earths crust and with advanced technologies could provide enough fuel to meet the world's energy demand for many centuries. Another economic issue is if additional countries decide to opt for nuclear power, this
will have an effect on oil and gas prices. According to Liao et al. (2010), if the "prices of oil and gas decline, then the incentives for developing nuclear power go down as well and this leads to uncertainty in any efforts to revitalize the nuclear energy industry." Ireland does not have an indigenous supply of uranium, nor does it have an indigenous supply of fossil fuels except for peat, therefore uranium would have to be imported from countries such as Kazakhstan, Canada and Australia that provide over 60% of total uranium supply from mines (Azapagic and Stamford, 2011, Crilly and Toshko, 2008).

The constant surge in fossil fuel prices allow nuclear power to compete economically with electricity generation from coal, natural gas and oil even though it includes a relatively high capital and maintenance cost (Ahearne, 2011). According to Ingersoll (2009), what makes SMR's particularly attractive is, their flexibility to enter traditionally non-nuclear energy markets. In Ireland for example an opportunity exists in replacing fossil fuel plants with SMR's in order to provide a competitive source of emission free electricity. Shropshire (2011) identifies that for countries where there may be no option to accommodate a large reactor due to grid stability (such as Ireland), SMR's could be introduced into small-medium sized transmission markets where coal/gas plants are at a disadvantage due to high carbon or fuel costs.

**Social Impact of SMR's**

One of the main barriers for nuclear power is anti-public perception, particularly for countries such as Ireland who have always had a strong anti-nuclear culture (Beken et al., 2010, Goodfellow et al., 2011, Liao et al., 2010). Public perception is the attitude of the public towards the deployment of the technology. According to Locatelli and Mancini, (2011) "even if the technology is intrinsically safe and there are no externalities, the public in many countries does not support nuclear energy." Due to the recent events at the Fukushima Daiichi nuclear plant in Japan and beforehand at Three Mile Island and Chernobyl in 1979 and 1986, there is now a renewed focus on the public understanding and level of acceptance of nuclear power. Failing to understand public perception can lead to significant consequences for the nuclear industry. For example, the proposal for construction of a new nuclear plant at Druridge Bay in the UK led to significant delays and eventually cancellation of the entire project due to public objection (Azapagic et al., 2011).

The main social barriers in relation to nuclear power, according to Ahearne (2011, p. 574) are, "whether the public will accept new nuclear plants, whether sites can be found where the public will accept a geological repository for their spent fuel, and whether future development should be based on the once through or the closed fuel cycle." Another social issue to address when initiating a nuclear power programme is "NIMBY" (not-in-my-back-yard) syndrome. For instance, if the general public does accept nuclear power the local community who have to host them may express fierce opposition and therefore to find several different sites for SMR's may be much more difficult to find one for a large reactor. Furthermore, the "NIMBY" syndrome will also have an effect when choosing a disposal site for the spent fuel (Locatelli and Mancini, 2011, Schaffer, 2011). However, Azapagic and Stamford (2011) highlight that local opposition may be overcome by winning local support through hiring staff from the local community, sourcing supplies from local suppliers and by directly investing in the local community. To help overcome "NIMBY" when choosing a site, methods
include spreading the risks (3-4 sites), limiting the term for storage e.g. 100 years and monetary incentives (Schaffer, 2011).

In the coming years it is predicted that the world will face a reduction in the number of qualifications in the nuclear field. There are two types of operators in a nuclear plant, high level operators who work in the central control room and medium level operators who carry out routine checks under supervision of the high level operators. However, the training of high level operators could be difficult for a country such as Ireland if it was to begin a nuclear program (Locatelli and Mancini, 2011). For countries where there are no nuclear plants in operation, such as Ireland, a native workforce would have to acquire training abroad, they may have to hire foreign workers, or rely on reactors suppliers to provide a workforce. For example, the United Arab Emirates hired a former U.S nuclear regulatory commission official to undertake the role of their director general for its federal authority for nuclear regulation, when the country initiated their nuclear power programme (MacFarlane, 2010). SMR's have an advantage over large reactors in that they have the potential to have lower training requirements than larger reactors. However, some high level operators will still be required which may prove difficult to be acquired for countries initiating a nuclear programme (Locatelli and Mancini, 2011).

Another social issue related to nuclear power is the security concern, as MacFarlane (2010, p.41) notes, "one of the main security concerns about nuclear programs is their connection to nuclear weapons development." This issue is commonly referred to as "proliferation."

The three main concerns in proliferation are:
- how easy nuclear weapons material could be produced from an SMR,
- how easy nuclear weapons material may be acquired from the chosen fuel cycle, and,
- the effect of a country that possess certain technologies in producing nuclear weapons (Azapagic and Stamford, 2011).

According to MacFarlane (2010), there is little proliferation threat from running a nuclear reactor, but more of a threat at the "front end" of the nuclear fuel cycle (fuel production), and the "back end" (reprocessing spent fuel). Therefore it is essential that when initiating a nuclear programme, countries such as Ireland, must demonstrate intense security measures in order to win public acceptance. One method for Ireland to prevent the spread of proliferation if it began a nuclear program is to sign the Treaty for Non-Proliferation of Nuclear Weapons (Azapagic and Stamford, 2011).

Even though there may be little risk of a nuclear accident, in the public's opinion, a system with low probability of failure and high consequences can be seen as more risky than the opposite, hence the familiar fear of air crashes (Azapagic and Stamford, 2011, Locatelli and Mancini, 2011). Therefore, according to Locatelli and Mancini (2011, p.215), "the catastrophic potential of nuclear power is the major determinant of public opposition."

Environmental Impact of SMR's

The issue where nuclear enthusiasts and opponents are perhaps furthest apart is the disposal and management of nuclear waste (Beken et al., 2010). According to Ahearne (2011, p.574), after much research into the issue of nuclear waste, "geological
disposal remains the only scientifically and technically credible long-term solution available to meet the need for safety without reliance on active management. Nuclear wastes are minute in comparison to waste from fossil fuel electricity generating plants (Beken et al., 2010, MacFarlane 2010). However, economically nuclear waste is big and is inclining to get bigger. These costs are due to the fact that radioactive wastes from electricity generation are highly dangerous over hundreds to thousands of years, with the appropriate means of disposal resulting in a matter of controversy (Beken et al., 2010). One method to try and reduce the volume of high level waste is reprocessing. Reprocessing is practiced by countries such as the UK and France and involves reprocessing the spent nuclear fuel, extracting the plutonium and uranium, and turning the remaining waste into glass logs which are transported to a repository (MacFarlane, 2010). This method does not get rid of the waste but may decrease it in volume by a factor of about 4-10 times. However, although reprocessing does reduce the waste it also causes a rise in plutonium separation that can be conceivably be used for creating nuclear weapons (Azapagic and Stamford, 2011, Schaffer, 2011).

Transport of nuclear waste is another issue, as nuclear waste is rarely stored or reprocessed at the location of its production this results in security risks as transportation could be subject to a terrorist attack. Even though there are issues such as disposal and terrorism, at the other end of the scale, according to (Beken et al., 2010) there are about 20,000 people employed in the nuclear waste industry in the UK involving production, reprocessing and waste handling. In developing a waste repository, a relatively small volume of waste, which would perhaps be the case for Ireland, may not justify expenditure involved in developing a repository, in conclusion, MacFarlane (2010) highlights that potential nuclear energy countries should have well established plans for waste disposal prior to acquisition of nuclear reactors.

Safety is the most important factor in selecting an electricity generation technology, particularly nuclear, which will have to be strongly emphasised after the recent events at the Fukushima Daiichi nuclear power plant. Smaller nuclear plants have the potential to improve plant safety further than large reactors for many reasons, according to Ingersoll (2009, p.51) they include: "(1) the reduced inventory of radionuclides produced from the fission process, (2) the potential to eliminate design features that introduce accident vulnerabilities, and (3) the opportunities to passively respond to unexpected transients." The total amount of radionuclides in a reactor core that are available for potential dispersion are referred to as the reactor "source term". There is a general consensus that a lower source term in an SMR will lead to safety advantages such as a reduced emergency planning zone (Carelli et al., 2010, Ingersoll, 2009, Kuznestsov, 2008). Eliminating accidental design features that can only be done in SMR's for example integrating the primary coolant system into a single common pressure vessel, is another way safety can be enhanced in SMR's (Ingersoll, 2009, Kuznestsov, 2008). Finally, most SMR designs are simply able to accommodate removal of the decay heat using passive, natural convection air ventilation systems. The latter is due to the fact that, "a lower core operating power will result in a lower decay power, the smaller core volume enables more effective conduction of the decay power to the reactor vessel" and "the removal of heat from the external surface area of the vessel is more effective" (Ingersoll, 2009, p.593).

The literature review has highlighted advantages of SMR’s, such as a possible economic form of electricity production that promotes energy security and employment, while also reducing our GHG's. The main barriers recognised by the
review were dealing with nuclear waste and anti-nuclear perception. In initiating a nuclear programme a country such as Ireland must be able to evaluate acceptable strategies to overcoming these issues. It may prove very advantageous in "coupling SMR's with wind turbines to stabilise the power grid." (Ingersoll, 2009, p.307) in countries such as Ireland, however the advantages must outweigh the risk due to safety and waste in order for the technology to be deemed acceptable for Ireland. If it is deemed acceptable, strategies must be evaluated to demonstrate to the public why it is so in order to gain public acceptance.

PROPOSED RESEARCH METHODOLOGY

It is vital, for the research, to be able to understand the feasibility of building a small nuclear power plant in Ireland. Issues that will influence building a reactor in Ireland, as highlighted in the literature review will be public acceptance, waste management strategy, the availability of resources (e.g. qualified workers), economics, safety and the size of the emergency planning zone needed for the reactor. In order to address these issues, it is proposed to use a qualitative methodology, a case study on the feasibility of deploying the IRIS reactor at a site in Ireland, as the overall research strategy. This strategy is deemed particularly suitable, as according to Robson (2003, p.146) it is "a strategy for doing research which involves an empirical investigation of a particular contemporary phenomenon within its real life context using multiple sources of evidence." Where this "contemporary phenomenon" i.e. the "case" could be almost anything. An advantage of the case study research is that it allows the researcher to use multiple sources and a range of different data types and research methods as part of the investigation. Also the case study can be particularly suitable to small-scale research that is focusing on one research site, which is the case in this scenario (Denscombe, 2003). The aim of a case study, as highlighted by Birley and Moreland (1998, p.36) is to "describe and understand the phenomenon "in depth" and "in the round" (completeness)."

The participants in the case study research will include members of Better Environment with Nuclear Energy (BENE) to include:

-Denis Duff: The reason for selecting this participant is due to the fact he is a mechanical engineer working in the power generation sector with wide experience of different electrical generation systems.

-Ian MacAulay: The reason for selecting this participant is because he has a background in health physics and has been extensively involved in measurements of radioactivity in the environment and in radiation protection. Ian was also deeply involved in the nuclear debate thirty years ago and was one of the Irish scientists trying to correct imbalances in the media coverage.

-Frank Turvey: The reason for selecting this participant is because he is a fellow of many professional bodies such as the Irish Academy of Engineering and the Institute of Nuclear Engineers and has been involved in Irish nuclear for many years back to the proposal at Carnsore in the 1970's.

-Philip Walton: The reason for selecting this participant is because he has widespread experience in radiation including serving for seven years on the Board of the Radiological Protection Institute of Ireland.
Other participants in the case study research will include a senior representative from the ESB (Electricity Supply Board) and a representative from the supplier of the IRIS reactor of the Westinghouse Electrical Company. The representative from the ESB would have experience in the Irish electricity grid and be able to provide information on how easily a small nuclear reactor can adapt to the Irish grid and also give a perspective of their view on nuclear as a electricity generation technology. A participant from the Westinghouse Company would be able to provide information on the deployment of the technology to Ireland and an insight into the costs involved. The proposed data collection methods are semi-structured interviews and a focus group.

According to Yin (1994, p.84) "one of the most important sources of case study information is the interview." A semi-structured interview has a clear set of issues to be covered and questions to be answered. However, as opposed to a structured interview the interviewer can be more flexible and let the interviewee speak more freely on the topic (Denscombe, 2003). Interviews will be conducted with all practitioners on an individual basis. For the interview with the supplier an over the phone interview will be used as the interviewee is in a different country. The aim of the interviews is to identify the key areas around the safety and economics of the reactors and also on their viability to be deployed in Ireland. Particular emphasis will be placed on the safety of the reactor due to the radiation levels and also on the ability of the reactor to adapt to the Irish electricity grid.

Following the individual interviews it is proposed to carry out a focus group with members of BENE. The findings of the interviews will form the basis of a knowledge exchange seminar in which senior members of BENE will sit with the academic researcher in a face to face environment. Focus groups consist of a small group of usually six to nine people who are brought together by the researcher to explore ideas, attitudes and feelings about a topic and are regarded as a useful method of exploring opinions on non-sensitive and non-controversial topics (Denscombe, 2003). Using the focus group to bring the interviewees together "the synergy of the group can then enable a much livelier discussion than would be possible in a one-to-one interview situation" (Birley and Moreland, p.51 1998). The focus group shall be moderated by the academic researcher who will formulate a suitable agenda based on the findings of the interview. The knowledge sharing seminar will be video-taped to allow observation by the researcher at a later stage for more detailed analysis.

CONCLUSIONS

Having explored issues related to the feasibility of SMR's for Ireland there are a number of conclusions which can now be drawn:

1. Energy security and climate change appear to be the key drivers towards an electricity mix with a significant contribution from emission free sources, however, renewable energy will not meet 100% of the demand due to fluctuations in supply, therefore an emission free base-load supply that promotes energy security such as nuclear power should be considered.

2. Due to the nature of the Irish grid large nuclear reactors are deemed too large and it is therefore necessary to analyse the feasibility of smaller nuclear reactors which have many advantages including enhanced safety, modular
construction, significantly lower capital cost and their smaller output allows them to adapt more easily to small electricity grids such as Ireland.

3. The main barriers identified in deploying the technology are dealing with the spent fuel and anti-public perception particularly the "NIMBY" syndrome. There is no permanent solution to dealing with nuclear waste with geological disposal been recognised as the most credible solution after many years of research. Reprocessing does reduce the waste, but doesn't reduce it entirely and also gives rise to the risk of proliferation by separating nuclear weapons grade plutonium from the spent fuel.

4. Carrying out a case study as part of the research methodology will allow the researcher to develop a detailed perspective into the feasibility of the technology for Ireland by focusing on issues such as safety, economics and sustainability of the technology.

5. Members of BENE possess a wide range of expertise ranging from radiation safety to electricity generation systems and it is believed that an effective case study can be achieved by means of interviews and a focus group with members of BENE and also interviews with a reactor supplier and senior member of the ESB.

It is believed that the primary research, backed up with academic literature, will allow an open minded research study to be completed on the feasibility of small modular nuclear reactors for Ireland.

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