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Nuclear renaissance, public perception and design criteria: An exploratory review

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ABSTRACT

There is currently an international drive to build new nuclear power plants, bringing about what is being termed a "nuclear renaissance". However, the public perception of nuclear energy has historically been, and continues to be, a key issue, particularly in light of the Fukushima nuclear incident. This paper discusses the disparity between perceived and calculated risks based on the last four decades of research into risk perception. The leading psychological and sociological theories, Psychometric Paradigm and Cultural Theory, respectively, are critically reviewed. The authors then argue that a new nuclear-build policy that promotes a broader approach to design incorporating a wider range of stakeholder inputs, including that of the lay public, may provide a means for reducing the perceived risk of a nuclear plant. Further research towards such a new approach to design is proposed, based on integrating expert and lay stakeholder inputs and taking into account broader socio-cultural factors whilst maintaining the necessary emphasis on safety, technological development, economics and environmental sustainability.

1. Introduction

Around the world, a number of countries are investing in or considering building new nuclear power plants. This new-build activity, the so-called "nuclear renaissance", is in stark contrast to muted nuclear build activity over the last 20 years.

The main drivers for this renaissance include climate change, an impending electricity generation gap and security of fossil fuel supply; however, a number of barriers to constructing new nuclear power plants also exist, with one of the most significant being public perception (Greenhalgh and Azapagic, 2009).

Public perception of nuclear power has been an active research topic for decades, with numerous studies reporting on the level of public support for, or opposition to, nuclear power (Eurobarometer, 2010; Poortinga et al., 2005) and how this support has varied over time (MORI, 2009). Investigations into the underlying psychological (Fischhoff et al., 1978; Slovic, 1987) and sociological (Douglas and Wildavsky, 1982; Wildavsky and Dake, 1990) factors that govern these attitudes have also been carried out.

The recent events at the Fukushima Daiichi nuclear power plant in Japan have resulted in a renewed focus on understanding both the safety of nuclear power and the public understanding and level of acceptance of nuclear power. Whilst it may be some time before the full impact of the Fukushima incident on the public perceptions of nuclear power become clear, research carried out shortly after the event suggests that there has been a slight negative impact (FoE and GfK NOP, 2011). The potential causes of such shifts are described in Section 3 of this paper.

Negative public attitude toward nuclear power has often had far-reaching consequences for the nuclear industry. For example, the previous proposals for construction of new nuclear power plants at Sizewell B (O'Riordan, 1984; O'Riordan et al., 1985) and Druridge Bay (Baggott, 1998) in the UK have led to significant delays and cancellation of the whole project, respectively. These and other similar examples around the world highlight the importance of understanding why the public objects to nuclear plants to help address these objections in a more informed and strategic way.

In an attempt to contribute to this aim, this paper focuses on new nuclear build, using the UK case as an example. It first compares and contrasts the *calculated* versus *perceived* risks from nuclear plants. The paper then proposes how the current body of knowledge on calculated and perceived risks could be integrated within a novel decision-support framework to influence changes to the design, or design process, of nuclear power plants. It is

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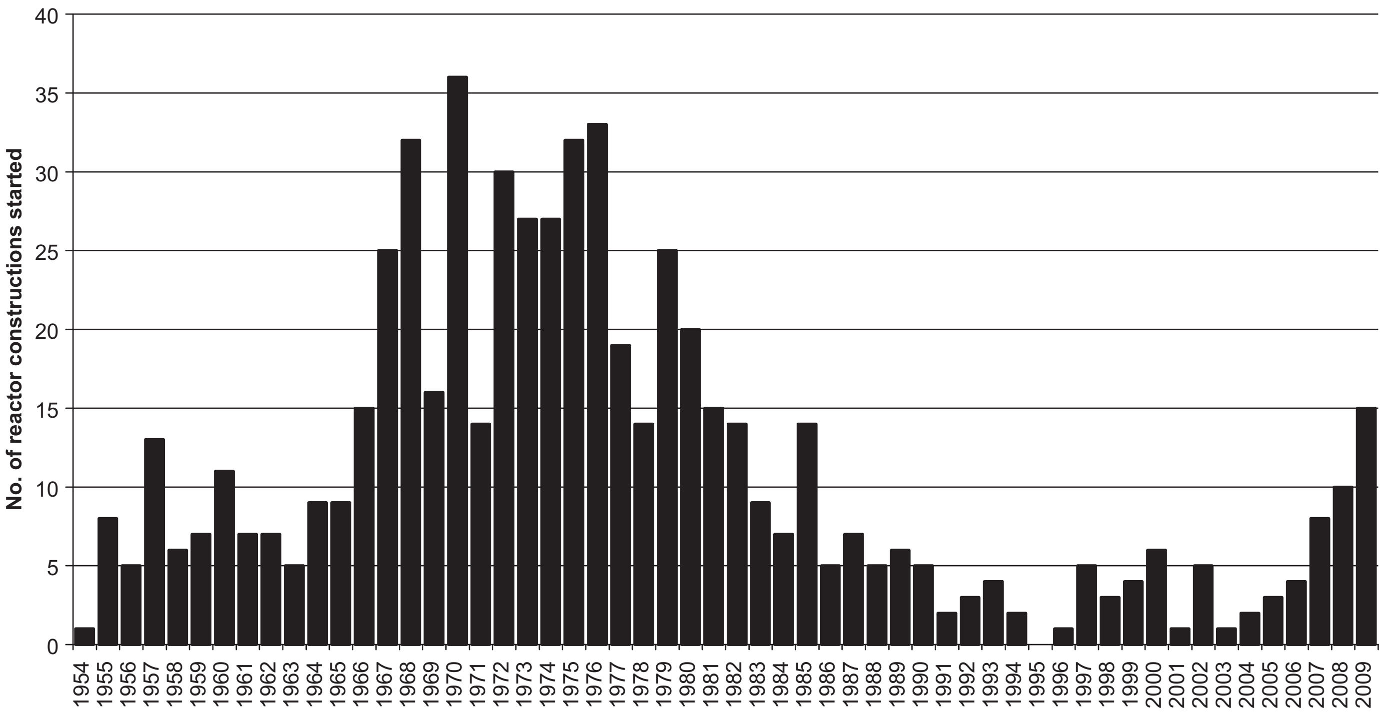

Fig. 1. Nuclear new build from 1954 to 2009 (based on the data from IAEA (2009)).

intended to go beyond simply proposing better communication or education programmes, aiming instead to provide a socially informed approach to design that could potentially help towards addressing social concerns about nuclear power plants. However, to understand better some of the social concerns related to new nuclear build, it is important first to appreciate the influence of the previous nuclear build. This is discussed in the following section.

2. The nuclear renaissance

2.1. Drivers for new nuclear power plants

The historical rate of nuclear plant construction around the world is shown in Fig. 1. The pronounced drop in new build activity during the 1980s may, at least partially, be attributed to various national government policy shifts following the Three Mile Island and Chernobyl incidents in 1979 and 1986, respectively. The legacy of these events may be seen continuing throughout the 1990s and early 2000s with only a small number of new power plants. However, predictions by the nuclear industry foresee an increase in nuclear capacity from the current level of 373 GW_e up to between 1100 and 3500 GW_e in 2060, depending on the level of priority and political commitment given to new nuclear power (WNA, 2010d).

The countries in Europe with current significant nuclear power capacity are France, Germany, Russia and the UK. Several Scandinavian and Eastern European countries such as Sweden, Finland, Ukraine and Hungary also have nuclear programmes. The UK and a majority of the European countries that currently have nuclear energy programmes have announced their intention to expand, or at least extend, current operations. This is with the notable exception of Germany, which has declared that it will phase out all nuclear power generation over the coming decades (von Weizsacker, 2005), although more recently there have been some indications that the existing power plants may see a life extension (Nolan, 2009). However, following the recent events at Fukushima, this decision has been called into question (Harding, 2011).

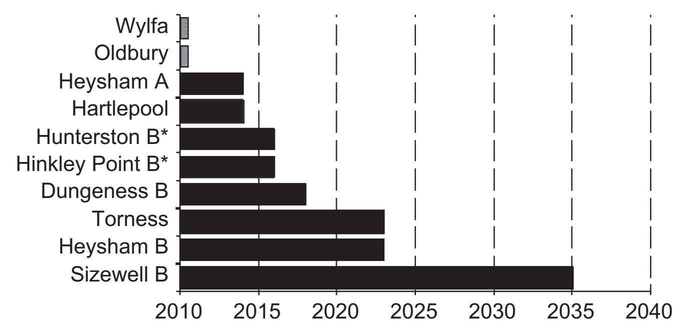

Fig. 2. Predicted UK nuclear plant lifetimes (DTI, 2006) (* denotes life extensions are already in place (WNA, 2010c)).

Looking at the new build situation in the UK, for example, one key driver for new nuclear power is the shutdown timescale associated with the existing fleet of nuclear power plants (Greenhalgh and Azapagic, 2009). The timescale for the shutdown of the present generation of nuclear reactors in the UK is shown in Fig. 2. The decision to decommission these plants largely relates to technology lifespan. Where technically and economically viable, life extensions for some of these plants will be sought, but the Oldbury and Wylfa plants are scheduled to shutdown in 2012 (NDA, 2011a, b). Both plants use Magnox[1] fuel, which is no longer in production (Tynan, 2010).

A second driver for new nuclear build to consider in the UK is the Government's commitment to reduce national carbon emissions in an effort to address climate change. The Climate Change Act 2008 (DECC, 2008) legally commits the Government to reducing the UK's carbon emissions by 35% by 2020 and by 80% before 2050. Meeting these ambitious targets will require low-carbon technologies across all sectors, but particularly in the

[1] MAGnesium Non-OXidising alloy clad assemblies containing natural (non-enriched) metallic uranium fuel.

power industry. Fossil fuel plants have historically provided the majority of UK electricity generation and whilst Carbon Capture and Storage (CCS) retrofits to these plants have been proposed, CCS remains unproven on a commercial scale (DTI, 2007). Nuclear power on the other hand is already part of the UK energy mix and its increased generation could help towards meeting the climate change targets in the medium term.

A third factor relates to energy security. During the 1990s, the UK Government de-regulated national electricity generation which led to the so-called "dash for gas". Between 2003 and 2007, UK changed from exporting 91,000 GWh of gas to now importing 215,000 GWh (BERR, 2009). This has left the UK highly reliant on foreign gas supplies, reducing the nation's energy security. Besides, stability of gas supply depends heavily on the source and any fluctuations in supply can rapidly affect the price and availability of gas-generated electricity (Watson, 2010).

With plant lifetimes, greenhouse emissions and energy security in mind, the UK Government presented a review of the energy situation in its 2007 white paper, "*Meeting the Energy Challenge*" (DTI, 2007). This was followed by a white paper on nuclear power (BERR, 2008) which laid out the Government's plan to include new nuclear power stations in the future energy mix. In these documents the Government also laid out how it intended to make the process of building new nuclear power plants more streamlined, by having a single national consultation on nuclear power, and then narrowing the remit of the local planning procedures to include only local issues. This streamlining was intended to establish industry support for new build right at the outset of the new build programme with the aim of making investment in nuclear power less prone to risk, and therefore more attractive to industry. The Government also stated in the above white paper that it believed that any new nuclear power plants must be built, managed and decommissioned by the private sector and that no subsidies for such activities would be made available (BERR, 2008). This in turn means that a lack of subsidies or financial guarantees places the burden of financial risk on the private sector, potentially raising a significant barrier to new build.

The May 2010 UK General Election saw a Conservative/Liberal Democrat coalition take power. The coalition government has stated that it supports the previous policy of removing 'unnecessary' barriers to new nuclear plant construction in the UK, while emphasising that there will be no public subsidy for any new nuclear build (Hendry, 2010). It remains to be seen if the influence of the historically anti-nuclear Liberal Democrats will change this stance over time.

The nuclear plant licensing process is key to nuclear new build. This process involves an in-depth justification of the safety of the nuclear plant to satisfy regulatory bodies. An overview of licensing is covered in the following section, as an introduction to risk discussed later in the paper.

2.2. Licensing nuclear plants

Responsibility for nuclear plant licensing rests with national regulatory agencies. The International Atomic Energy Agency (IAEA) publishes a variety of safety requirements, standards and guidelines that can be applied by national regulators. The IAEA does not function as an overarching international regulator but does foster international cooperation on safe application of nuclear energy (IAEA, 1956). There is no single international design standard for nuclear plants and different national regulators require reactor designers to demonstrate the safety of their designs via different approaches.

In the UK, for example, the nuclear regulator is the Office for Nuclear Regulation (ONR) (Podger, 2011). Under the UK regime, the onus is on the plant designer and operating utility to demonstrate a thorough analysis of the design against a series of high-level safety objectives and a limited number of numerical targets. This is a direct influence of the UK health and safety law and the As Low As Reasonably Practicable (ALARP)[2] principle. First, the risk of death or radiation dose is calculated and compared against numerical target Basic Safety Levels (BSL) (HSE, 2006). If unacceptable, this risk is further reduced by design to be as low as reasonably practicable (HSE, 1992). The regulator will expect the designer to make significant improvements against the BSL, justified by some form of cost-benefit analysis. A target termed the Basic Safety Objective (BSO) defines a risk that could be considered "broadly acceptable"—providing it had been shown that further improvements incurred "grossly disproportionate" cost (HSE, 2009).

In the United States, the Nuclear Regulatory Commission (NRC) issues explicit numerical and design standards for aspects of nuclear plant design, from individual sub-systems to overall calculated probabilistic safety goals. Reactor designers and operators must demonstrate via analysis and/or test that these prescribed targets are met.

In general, the differing philosophies of the UK and US regulatory approaches can be considered as the cases at the opposite ends of the spectrum, with the majority of other countries following a prescriptive regulatory format closer to the US approach. It is unusual though for a nuclear plant design approved by a regulator in one country to be accepted in another country without some modification being required. Harmonisation of design standards is being pursued (WNA, 2010a) but is still some way from being realised.

Two nuclear plant designs are currently undergoing assessment by the ONR for suitability for new build in the UK: Westinghouse's Advanced Passive 1000 MW_e plant (AP1000) (WEC, 2008) and Areva's Evolutionary Pressurised Reactor (EPR) (AREVA, 2008). Both designs have already been approved in their countries of origin (US and France, respectively) and are currently in the Generic Design Assessment (GDA) phase. GDA consists of a safety and environmental impact assessment of the nuclear plant design; site-specific assessment will form part of the next phase. Technical reports and comprehensive descriptions of plant features are available via the HSE website (HSE, 2010), and the public are invited to comment on the designs via the internet.

Much of the evidence provided in the licensing process is presented in the form of calculated risk. As shown in the following section, calculated risk is a highly technical subject used in engineering and there is much evidence that suggests that the lay person is unable to comprehend its meaning (Carlisle, 1997; Kahneman and Tversky, 1974, 1979; Slovic, 1987; Tversky and Kahneman, 1992). This is arguably one of the reasons why the public continue to object to nuclear power despite the very low calculated risks. This disparity between the *calculated* and *perceived* risk is discussed in the next section, with the aim of understanding better the way in which the nuclear design process could be changed to take into account lay-public views and perceptions of risk.

3. Calculated and perceived risks from nuclear plants

There is no simple way to define the difference between calculated and perceived risk, as perceived risk is difficult to define. However, the main difference is that calculated risk represents an attempt to define risk 'objectively' using various mathematical approaches (as, for example, expressed by Eq. (1) in

[2] ALARP is a legal regulatory test which is applied under UK law to matters of health and safety. In short, operators and designers must be able to demonstrate that risk levels have been reduced to a level "as low as reasonably practicable", where "practicable" may be considered in terms of the amount of time, money or "effort" expended to reduce risk levels further.

Table 1
Probabilistic risk application levels (US NRC, 2007).

PRA level	Description	Typical outputs
1	Considers individual reliabilities of components and sub-systems of plant in a fault or event tree format to determine what events might result in damage to the reactor core, usually due to overheating.	Core Damage Frequency (CDF) [a]
2	Using events leading to core damage (Level 1 PRA) as a basis, the probability, magnitude and timing of a significant release of radiation to the environment is determined. This is usually the combination of core damage and a failure of the containment summarised into a large (or 'early') release frequency. Essentially this is a radiation release that requires an off-site emergency response.	Radiation Release Frequency [b]
3	Taking the radiation release frequency and characteristics as an input, environmental dispersal and public exposure is used to determine the health or economic consequences. This can be expressed in a number of ways, but commonly as the frequency of death caused in the first few hours after a radiation release (short-term health effects) or by considering longer term health effects such as increased incidences and mortalities of various types of cancer.	Early death frequency (Short-term) or Excess Mortality rate/Latent Cancer fatality (Long term effects)

[a] Core Damage Frequency (CDF) is the frequency expected for an accident or event occurring that damages the reactor core. It is often expressed as a probability per year, e.g. 1×10^{-5} (or 1 in 100,000 years).
[b] Radiation Release Frequency (RRF) is the frequency expected for an accident or event that leads to radiation being released from the containment structures of a nuclear plant. This often follows a CDF event and is often expressed as a probability per year, e.g. 1×10^{-6} (or 1 in 1,000,000 years).

Table 2
Summary of results from PRA studies on nuclear reactor plants (*all values represent probability per reactor per year).*

	Safety goals		***PRA of operating plants***		**PRA used in New Nuclear Plant Designs**	
Date	**US NRC** (US NRC, 1990) ***1991***	**UK HSE** (HSE, 2006) **2006**	**Wash-1400** (US NRC, 1975) **1975**	**Nureg-1150** (US NRC, 1990) **1991**	**Areva EPR** (HSE, 2007) ***2007***	**WEC AP1000** (WEC, 2009) ***2007***
Core Damage Frequency (CDF) (Level 1)	N/A		$\sim 1 \times 10^{-4}$	$\sim 5 \times 10^{-5}$	6.1×10^{-7}	2.41×10^{-7}
Radiation Release Frequency (Level 2)	N/A		$\sim 5 \times 10^{-4}$	$\sim 5 \times 10^{-5}$	3.9×10^{-8}	1.95×10^{-8}
Early Death Frequency (Level 3)	5×10^{-7}	ALARP	$\sim 10^{-5}$	$< 10^{-7}$ [a]		
Excess Mortality or Latent Cancer Fatality (Level 3)	2×10^{-6}	BSL 10^{-4} BSO 10^{-6} [c]		$< 10^{-7}$ [b]		

[a] Typical mean probability between 5×10^{-11} and 2×10^{-8} but report suggests all results below 10^{-7} should be viewed with caution.
[b] Typical mean probability between 1×10^{-8} and 4×10^{-10} but report suggests all results below 10^{-7} should be viewed with caution.
[c] Basic Safety Level and Basic Safety Objective define limits on 'tolerable' and 'broadly acceptable' risk. PRA results must be supplemented to show risks are ALARP.

Section 3.1) while the perceived risk tries to account for subjective factors of psychological and sociological nature calculated risk does not include. This is discussed in more detail below.

3.1. Calculated risk

Nuclear plants consist of complex sub-systems with many components, often with various layers of 'redundancy' in an effort to increase safety. Components or sub-systems may function continuously, intermittently or only in an emergency situation. In normal operation, components or sub-systems are almost certain to be taken off-line for maintenance periodically. Components may fail in service by a number of different modes, for example a pump may cease to function, may fail to switch off or may leak even when not required to run. Whilst not mathematically infinite, it is easy to see that the combinations of failure modes in different operating regimes make obtaining a single numerical risk figure extremely challenging.

Probabilistic Risk Assessment (PRA) is one of the methods most often used to calculate risk from nuclear plants. In PRA, risk is characterised by the probability or likelihood of occurrence of an adverse event and the severity or magnitude of the possible adverse consequences of that event. It is calculated as

$$R = \sum_{i=1}^{n} p_i \bullet C_i \qquad (1)$$

The above equation states that the level of calculated risk R associated with an event is the product of the probability p_i of a risk event occurring and the magnitude of the consequences C_i of such an event, summed over all occurrences of the event. For the purposes of this paper, this is termed "calculated risk" to differentiate it from "perceived risk" discussed further below. The implication of this definition is that a simple probability is not a risk, since it does not take account of a consequence. In the nuclear context, the magnitude of consequences might relate, for example, to fatalities or a reduction in life expectancy associated with a given radiation dose.

Applying Eq. (1) to each component in a nuclear plant is difficult due to the amount of data required to understand the probability of every potential component failure. The level of redundancy and diversity in components means a sequence of events must occur for an event causing measurable consequence to occur. Two most common methods for PRA are fault- and event-tree analysis (Bedford and Cooke, 2001) which provide a calculated risk, often expressed as a probability but implicitly incorporating increasing levels of consequence as described in Table 1.

A selection of PRA results for some nuclear plants is presented in Table 2. One of the first probabilistic risk analyses of a nuclear plant was carried out in the USA and is commonly known by its document name, WASH-1400[3] (US NRC, 1975). The report focused on the risks associated with commercial Pressurised Water Reactors (PWR) and Boiling Water Reactors (BWR) in the USA. WASH-1400 stated that the frequency of deaths caused by nuclear power in a country the size of the USA, with 100 operational reactors, would be around 100,000 times lower than the total frequency of deaths caused by all natural disasters in the USA per year. The report was criticised by non-governmental organisations (NGO) such as the Union of Concerned Scientists (UCS) who accused it of lacking clarity

[3] Now NUREG-75/014, or commonly known as the Rasmussen Report.

and presenting long-term fatality predictions in a misleading manner (UCS, 1977).

In 1991 a new report, NUREG-1150 (US NRC, 1990), was published as an update of WASH-1400. NUREG-1150 compared its results to WASH-1400 and demonstrated that in many ways nuclear safety had improved and concluded that this was a direct result of improvements in both the design of the plants and the operating procedures in place at the plants studied.

The Level 3[4] calculated risk of around $\sim 10^{-7}$ fatalities per plant per year published in NUREG-1150 (US NRC, 1990) is broadly in agreement with results determined for similar plants in Europe (Slaper and Blaauboer, 1998), although the later study focused solely on long-term health effects. For reference, this level of calculated risk is similar to the probability of death caused by other "rare" events, such as being struck by lightning, which was calculated (for the USA) to be 4.2×10^{-7} per person per year (Curran et al., 2000). The UCS (and others) again raised serious concerns about the validity of the NUREG-1150 study, criticising assumptions made such as "zero violations of safety regulations" as unrealistic (Lochbaum, 2000).

Based on the criticisms of NUREG-1150, the NRC has instigated a further study, State of the Art Reactor Consequence Analyses (SOARCA), which aims to take into account for a much wider range of accident initiation factors in order to provide an improved assessment of the risks (US NRC, 2009).

The above-described PRA studies were conducted retrospectively, whereas the PRA process is now integral to the design of new plants. Levels 1 and 2 PRA can be conducted at the generic design stage and the full Level 3 PRA becomes more appropriate once a specific site is chosen. For example, Table 1 shows the Level 1 and 2 PRA results for the AP1000 and EPR presented in the manufacturers' safety documentation during the GDA phase. These data indicate a further fall in calculated risks that can be attributed to a variety of factors including the PRA method being used and the incorporation of plant operating experience into the designs.

The key conclusion of this section is that integrating operational experience and improved PRA methods with plant design has resulted in significant reductions in calculated risk levels (three to four orders of magnitude over a period of 30 years as shown in Table 2). However, as with any analytical method, there is always uncertainty as to the accuracy and completeness of the models used, especially for events of very low probability. In spite of the many safety improvements made and the fact that nuclear power is calculated to be significantly safer than many other everyday activities, the following section shows that the public still perceives nuclear power as a high-risk activity.

3.2. Perceived risk

3.2.1. Public support for, and opposition to, nuclear power

A great deal of research has been undertaken into the public perception of nuclear power, in part because the controversy of nuclear power has been present since the inception of the technology (Kasperson et al., 1980). Of recent surveys, the pan-European *Eurobarometer 324 – Europeans and Nuclear Safety* (Eurobarometer, 2010), and its predecessor Eurobarometer 271 (Eurobarometer, 2007), are significant owing to the size of the samples used. In both surveys, around 27,000 individuals across 27 European countries were questioned face-to-face on a wide variety of nuclear issues.

Eurobarometer identified a spectrum of beliefs relating to the advantages and disadvantages of nuclear power. People were asked to state what first came to mind when they thought of nuclear power—that the advantages outweigh the risks, or the risks outweigh the advantages. People living in countries that have existing nuclear power generation capacity tended to be more positive about nuclear power than those from countries without existing capacity, stating that the advantages outweigh the risks. People in France, Germany and Spain were the exception to this result, displaying a more negative viewpoint (risks outweigh advantages), in spite of the presence of current nuclear power plants. Since France generates over 75% of its electrical power from nuclear plants (WNA, 2010b), it is perhaps surprising that 53% of the country's population believes that the risks of nuclear power outweigh the advantages (Eurobarometer, 2010). Research into cross-cultural risk perceptions has identified a number of underlying reasons that might explain such disparity, such as cultural collectivism, or the bias between individual and societal influence in determining values and goals (Weber and Hsee, 1998).

Eurobarometer also found that a substantial proportion of people (74%) in the EU felt they were not well informed in relation to nuclear plant safety. Additionally, 46% of people in the UK believed that construction of new nuclear plants was already underway in the UK; in reality, it is likely to be at least two or three years before any construction work begins.

Results obtained in the UK by Ipsos MORI (MORI, 2007, 2008, 2009) using samples of approximately 2000 people showed a downward trend in how well the public felt they knew the nuclear industry—down from 27% of "know very well/a fair amount" in 2007 to just 17% in 2009. However, in a wider context, it appears that nuclear issues are not of great concern to the British public, with a consistently low proportion, $\sim$3% or less, of respondents mentioning nuclear issues as a concern when asked (MORI, 2007, 2008, 2009).

In the UK, the number of people supportive of nuclear power has grown steadily, from around 20% in 2001 to around 33% in 2009 (MORI, 2009). What is more notable according to the same survey is that the number of people opposed to nuclear power has significantly decreased, from nearly 50% in 2001 to around 20% in 2009. It should also be noted that 2001 represented a peak in opposition to nuclear power, with the historical level being much closer to a figure of around 25% (de Boer and Catsburg, 1988).

This swing in opinion requires some explanation, and research carried out by Poortinga et al. (2005) and Pidgeon et al. (2008), may help to provide it. The authors explored the public perception of nuclear power placed in the context of climate change. The research took the form of a survey of a randomly selected stratified sample of around 1500 people in the UK and it found that there was a reluctant acceptance of nuclear power as a method to reduce the level of greenhouse gas emissions, but that other, non-nuclear options would be preferable if possible. It is possible that the re-framing of nuclear power as a "green" technology has led to the steady growth in support and reduction in opposition to the technology seen by the annual Ipsos MORI polls.

In seeking to understand the underlying causes of the trends observed in quantitative research by Eurobarometer and Ipsos MORI it is important not to ignore qualitative research. This is particularly true for communities that are close to nuclear plants where qualitative research has observed deeper, subtler trends in risk perception (Wynne et al., 2007). The researchers discovered that people living close to nuclear plants do have a tendency to be supportive of nuclear power, but with several caveats attached. Observed local issues ranged from feelings of a lack of empowerment to influence nuclear issues (this also seemed to be synonymous with social class with lower class people feeling less powerful), to a sense that local people were being stigmatised for living near nuclear facilities (Slovic et al., 1991). Wynne et al. (2007)

[4] Early death frequency is defined as deaths that occur instantly or within a period of a few weeks of the event or accident.

also found that there was a feeling amongst local people that they deserved more back from the nuclear companies and the government in exchange for their tolerance of the nuclear plant and a concern that they were perceived as gullible or mercenary by wider society for accepting nuclear installations into their communities. One conclusion in particular stands out from the rest:

> [Local] "People are much more realistic about risk and uncertainty than the industry and regulatory authorities seem to realise. Communications based on the assumption that the public is seeking 'zero risk' are misguided, and are undermining the credibility of the institutions involved." (Wynne et al., 2007)

A further exposition on risk perception by communities close to nuclear plants can be found, for example, in Azapagic and Perdan (2011).

The Eurobarometer and Ipsos MORI surveys discussed above attempted to explore the particular aspects of nuclear power that cause people the greatest concern. Although these studies provide a wealth of data on a range of nuclear issues, it is important to note that expressed preference studies of this type are only one experimental tool that can be used to understand public opinion. One drawback of using an expressed preference methodology is that the norm is for only around 3% of people to worry about nuclear power (MORI, 2009), which suggests that issues relating to nuclear power may not be particularly important to the lay public in general. A second drawback is that nuclear design is a complex area and the majority of the public are not qualified to assess plant safety levels on a technical level. The combination of these factors may reduce the usefulness of using expressed preference studies to survey public opinion of nuclear safety.

Early work by Kahneman and Tversky (1974) details tests whereby people without sufficient information or understanding of a subject would rely on various heuristic[5] judgement mechanisms to provide an answer. It is possible that in asking the lay public for their opinion on the nuclear hazards of greatest concern researchers may invoke these heuristic judgements, essentially leading to people 'guesstimating' an answer based on their previous experiences; this may not provide an appropriate background to the specialist nuclear issues in question.

It is important to recognise that despite such 'failings' the public perception of technical risk is informed both by what they *do* and by what they *do not* understand. Understanding the psychological and sociological processes that occur in rationalising aspects of risk that are not understood is key to understanding how risk perceptions are formed. This is explored in the next section.

3.3. Psychometric paradigm and cultural theory

A great deal of work has been carried out in an attempt to explain observations such as those discussed in the previous section. Two leading theories have emerged:

a) Psychometric paradigm,[6] which developed from the psychological perspective of how an individual responds to perceived risk, building on the work by (Starr, 1969); and
b) Cultural theory, which developed from the sociological perspective of how group behaviour responds to perceived risk.

3.3.1. Psychometric paradigm

This is a psychological model that attempts to explain risk perception by using an expressed preferences method (as for example, used by Eurobarometer discussed previously). The answers provided by people allow profiles to be constructed for different risks; these profiles are based on a number of dimensions that are said to be evaluated cognitively when a person attempts to evaluate a risk.

The psychometric paradigm developed from the early work on risk perception by Starr (1969) which used 'revealed preferences' to explore behavioural patterns across a diverse range of activities. Revealed preference studies rely on observing behaviour in an effort to uncover patterns that may suggest the presence of underlying factors driving the behaviour in question. Starr's work established four basic rules of risk perception:

- voluntary risk levels can be roughly 1000 times greater than involuntary risk levels and still be acceptable to the public;
- the underlying risk posed by death from disease appears to act as a baseline that other risk levels are compared to;
- acceptable risk levels appear to be roughly proportionate to the [mathematical] cube of the benefits of an activity; and
- public acceptance of risks appears to be directly influenced by the public understanding of the benefits of the activity in question.

These conclusions have been found to hold across a wide range of cases despite criticisms of the potential shortcomings of the revealed-preferences approach (Otway and Cohen, 1975). As a result of his work, Starr recognised that nuclear power is not positioned favourably against these conclusions: it is largely involuntary, it is generally perceived as potentially harmful and the benefits of nuclear energy have been debated since its conception in the 1950s.

Starr also arrived at a fifth conclusion, suggesting that the economic drivers for nuclear safety would lead to a higher level of safety and reliability than the drivers based on perceived risk. This is driven by the large capital cost of nuclear power which must be amortised by maximising plant availability and service life as much as is technically and safely viable in order to maximise their return on investment. Whether a plant makes a profit or not is particularly sensitive to events that curtail operating lifetime or reduces plant availability, such as a period of unscheduled maintenance (BERR, 2007).

The dimensions analysed in the initial model for the psychometric paradigm (Fischhoff et al., 1978) are shown in Table 3. This initial model was tested against a relatively small sample of 76 individuals, who were asked to rate 30 different activities and technologies that were deliberately diverse in an effort to obtain as broad a view as possible.

Statistical analysis of the results determined that two overarching meta-dimensions, which combine the effects of several dimensions, could be distilled from the answers provided. The first meta-dimension relates to dimensions 1–6 and is often termed "unknowness". The second incorporates dimensions 7–9 and is known as "dread consequences". Repeated empirical research has corroborated these findings (Slovic, 1987) as has the application of additional analytical techniques, such as three-way principal component analysis (Siegrist et al., 2005). Nuclear energy was shown to be highly dreaded and highly unknown by these studies. Nuclear energy also scores significantly higher in the dimensional terms than any other activity or technology surveyed, suggesting that it occupies an extreme position psychologically—almost a worst case combination of an unknown technology with fearful effects if something goes wrong.

[5] A heuristic judgment is based on a person's previous experiences. Such judgments may often differ significantly from a judgment made based on 'knowing all the facts', particularly in situations which are new or challenging to the person making the judgment.

[6] The psychometric paradigm is also often referred to as the psychometric model.

Table 3
Dimensions of risk as per psychometric paradigm (based on Fischhoff et al. (1978)).

	Scale (1–7)	Description
1. Voluntariness	1 = Voluntary 7 = Involuntary	Can the affected choose to participate in the risky activity/event?
2. Immediacy	1 = Immediate 7 = Latent	How immediate are the effects?
3. Known to exposed	1 = Precisely 7 = Not known	How well does the participant understand the risk?
4. Known to science	1 = Precisely 7 = Not known	How well does science understand the risk?
5. Controllability	1 = Cannot be controlled 7 = Complete control	How much control does the affected have over exposure, can exposure be avoided using individual skill?
6. Newness	1 = New 7 = Old	Is the risk new or old and familiar?
7. Chronic/Catastrophic	1 = Chronic 7 = Catastrophic	Do the consequences affect an individual (chronic), or many others?
8. Common/Dread	1 = Common 7 = Dreaded (unusual)	Is the risk "everyday" or something feared and dreaded?
9. Severity of Consequences	1 = Certain not to be fatal 7 = Fatal	If the consequences occur, what is the chance that death will result?

3.3.2. Cultural theory

The cultural theory is the sociologically based alternative to the psychometric paradigm (Douglas and Wildavsky, 1982; Wildavsky and Dake, 1990). It begins by making two suppositions:

- people adhere to specific codes of social relationships and these relationships influence how the people involved view the rest of the world; and
- there are four basic modes of living within society corresponding to different levels of collective identity (group) and levels of personal freedom (grid).

Collective identity (group rating) is the extent to which a person identifies themselves as an individual or as part of a group. A high group rating means that a person not only feels part of a larger whole, but is also willing to make decisions based on group priorities rather than individual priorities. Conversely, a low group rating means that a person perceives themselves as an individual with no group identity and makes decisions based on their own, individual, priorities.

Personal freedom (grid rating) is the extent to which an individual can differ from an established norm and how much power an individual has to choose their own path, independent of others. A low grid rating means that they are only loosely constrained by wider society and are allowed a wide range of personal freedoms. A high grid rating means that an individual is constrained within society and has less personal freedom or control over his or her own fate. The four resulting archetypes can be seen in Table 4.

Table 4
Archetypes of cultural theory.

	Low grid	High grid
High group	Egalitarianism	Hierarchy
Low group	Individualism	Fatalism

Broadly speaking, egalitarians believe in a high level of freedom for all, but with an emphasis on societal well-being. Hierarchists share this view of societal well-being but are willing to restrict freedoms to achieve it. Individualists believe in freedom but with an emphasis on individual well-being, whilst fatalists believe that freedom is largely illusionary and that an individual's destiny is largely uncontrollable and is instead determined by fate.

The four different archetypes perceive and rank the same risks differently, based on the wider cultural influences that have shaped their outlook on the world and the beliefs that they then hold. Determining which archetype people belong to is generally achieved via the use of a questionnaire.

People belonging to different archetypes view nuclear power differently. Exactly who falls in to what category is complicated, based on the many different relationships that any individual possesses within the culture and society that surrounds them. However, some general trends have been drawn. From the basic criteria that underpin each archetype, arguably, nuclear power is likely to sit more favourably with hierarchists (it is ordered, structured and centralised) and less favourably with egalitarians (it is inequitable as it presents risks to the minority who live close to a plant and the technology itself is often imposed on them) and individualists (there is little personal freedom to choose nuclear power).

3.4. Critique of psychometric paradigm and cultural theory

Despite some apparent success, neither theory can explain perception of risk completely. Numerous reviews of the literature have identified a range of issues and aspects that the psychometric paradigm fails to explain. These include, but are not limited to:

- trust in regulators, operators, designers and scientists (Lidskog, 1996; Slovic, 1987);
- stigma effects associated with the history of nuclear energy (Gregory et al., 1995);
- expert versus lay judgements in matters of risk assessment (Fischhoff et al., 1982; Rowe and Wright, 2001);
- origin—natural versus man-made effects (Sjoberg, 2000b);
- demographic effects such as sex, education and racial background (Savage, 1993); and
- sample sizes and the representativeness of various surveys (Gardner and Gould, 1989; Sjoberg, 1996).

In response to these criticisms, Sjoberg has offered an improvement on the psychometric paradigm with the extended psychometric model (Sjoberg, 2000a, 2002). The model incorporates additional dimensions such as origin and attempts to analyse results at an individual level, rather than averaged across groups of people, as is generally the case with the classical psychometric paradigm. Whilst this had led to a slight improvement in the accuracy of the model, many of the previously mentioned problems with a psychometric approach remain.

The cultural theory has also been subject to criticism. In particular, the basic postulate that our perception of risk is informed by the imposition of wider cultural values on the individual is questioned by Boholm (1998). Additionally, several experiments into the ability of cultural theory to explain perceived risk have found that the theory correlates poorly with empirical results (Sjoberg, 1996) with only around 5% of observed results showing statistically significant correlations with theoretical predictions. A serious weakness of the cultural theory is that questionnaires have a tendency to show that the majority of people do not conform to one particular archetype. This leaves a 'silent majority' of people at the centre of Table 4 who are characterised by a blend of archetypes meaning their expressed preferences are difficult or impossible to analyse.

An empirical comparison of the psychometric paradigm and the cultural theory was presented by Marris et al. (1998), which suggested that whilst both approaches shed light on the mechanisms of risk perception, further work is required to mitigate disagreements between the different methods of analysis and to improve the ability of the two theories to deal with both groups and individuals. A number of reviews of risk perception research also call for more integration of individual (psychological) and group (sociological) factors (Boholm, 1998; Renn, 1998; Taylor-Gooby, 2002).

The Social Amplification of Risk Framework (SARF), first discussed by Kasperson et al. (1988) and discussed in more depth by Pidgeon et al. (2003), is an attempt to provide an integrating framework combining psychological, sociological, organisational response and risk communication theories to form an overall view of risk perception. A risk event is viewed by SARF as causing a risk signal. The signal is analogous to ripples on a pond, reaching and informing those closest to the hazard first and then spreading out. As the ripples spread out and move through society further from the source, it is likely that they will become distorted, amplified or attenuated. In SARF, it is the amplification of these risk signals, combined with other effects such as historical stigma which leads to the perception of risk of technologies like nuclear power becoming so different to the expertly calculated risk. The experts are located near the centre of the ripples, whereas the public is located very far away. Critics of SARF point out that, much like the psychometric paradigm, it is not a fully developed theory and that much more work is required before it can begin to predict the risk perception outcomes of risk events (Wahlberg, 2001).

In conclusion, the psychometric paradigm has demonstrated that there are specific themes underlying the perception of risks, with the meta-dimensions of dread-consequences and unknowness predominating. Nuclear power is found to rate highly on both these scales and this may go some way towards explaining its controversial history. The cultural theory expands on this by suggesting that within our society there will be pockets of more "extreme" groups with ideals that align positively or negatively with an activity such as nuclear power. This provides a theoretical background that places pro-nuclear industry and their diametric opposites in anti-nuclear NGO such as Greenpeace and the Union of Concerned Scientists. In particular, the work of Fischhoff et al. (1982, 1978), Slovic (1987, 1996) and Sjoberg (1999, 2002, 2004) on the psychometric paradigm has demonstrated that whilst further work is required, the current theories do allow us to understand the underlying themes and dimensions that drive our perception of risks, even if we cannot be as accurate as we would wish to be when attempting to quantify such underlying drivers.

Overall, there is broad agreement between the two theories that perceived risks increase when people feel their understanding of the topic is inadequate. As mentioned previously, since public awareness of the safety requirements and technical features of nuclear plants is generally low, this could be one reason for the difference between calculated and perceived risks. The following section therefore explores how it may be possible to expand the definition of risk to inform the design of nuclear power plants.

4. Transforming negative perceptions

4.1. Expanding the definition of risk

Current risk analysis procedures could be defined as being technocratically driven, with the absolute authority of science and expertise dominating political decision making (Fischer, 1990). Fischer (1999) challenges this ideal in the context of a democratic society, where all stakeholders, regardless of their "expertise" are, by definition, entitled to contribute at some level. A particular concern is the fact that it is far too easy for experts to simply define the values relating to risk analysis based on PRA without also accounting for the public perception of risk.

Bohnenblust and Slovic (1998) postulated a quantitative approach to expanding the fundamental definition of risk in an effort to provide a broader method for evaluating risk levels:

$$R = \sum_{i=1}^{n} p_i \cdot C_i \cdot \varphi(C_i) \cdot \omega_i \tag{2}$$

As can be seen from Eq. (2), the authors have modified Eq. (1) to incorporate the "risk aversion factor", $\varphi(C_i)$, which is a function of the consequences of the risk occurring, and the marginal cost, ω_i, which is defined as the amount of expenditure that people are willing to make to eliminate the risk. Unfortunately, this risk aversion factor is not fully described, stating only that it should incorporate factors such as "historical precedents" (stigmatisation factors), the "nature of a risk" (hinting at a psychological connection) and other such factors. Whilst marginal cost may shed light on how much money the public is willing to spend on safety, what it does not tell us is if the public has a preference for the method to be used to create that improvement in safety.

The additional factors in Eq. (2) are an attempt to quantify the various factors listed in Tables 3 and 4. Quantifying such factors is difficult, as many are not easily captured by numerical evaluations. The consequences of an event, in whatever way they are evaluated or defined, do seem to be a dominant factor in psychological and sociological terms. This may be due to the fact that in many cases the consequences of an event are much easier to understand at a lay level compared to the complexity of probabilistic evaluations of initiating events and the costs (financial and otherwise) of preventing or mitigating a risk.

Slovic (2001) attempted to redefine risk in terms of a game. He states that risks, just like games, are characterised by sets of differing attributes, in analogy to the situation where a game of Snakes and Ladders is dependent on the layout of the board and how the die falls, whilst Scrabble is dependent on the board, the skill of the player and the letters they are dealt. In essence, one risk might be evaluated predominantly on "voluntariness" and dread, whilst another risk may be more strongly influenced by whether the risk is human-made or natural. In his discussion of the "risk game", Slovic also stresses the importance of developing participatory processes for involving the public in risk analysis activities. He focuses on the issue that all too often the 'official' definition of risk is limited in scope to a pure relationship between probability of occurrence and magnitude of consequences (as calculated by experts), ignoring a great number of psychological, sociological, and cultural factors that have been demonstrated to be important. He goes as far to say that probability and consequence are no different to factors such as perceived dread, novelty and the various other psychometric factors investigated by risk perception researchers (in particular, the exponents of the psychometric paradigm such as Slovic himself).

Both Fischer and Slovic believe that by incorporating lay input into risk analysis decision-making at an early stage many of the problems encountered in later technological development may be avoided entirely. By having the lay-public help to define the rules of the "risk game", they are "bought in" at an early stage and they become part-owner of the game, with the power to influence decision making and so alter the course of any future developments and outcomes. This potentially reduces the possibility that they will oppose the results, as they helped create them.

Efforts by the government and industry to transform the public perceptions of an issue often simply revolve around 'getting the right message out', whether that be via press releases and the media, education programmes or public consultations. Whilst these approaches are carried out with the needs of the public in mind, they rarely incorporate public input into their procedures or methodology. An approach to design based on such grounds was suggested by (Krieg, 1993) who discussed the potential for improved acceptance of nuclear reactors by simplifying containment-building designs to assist the public in understanding the design criteria. The author argues that this has the potential to reduce negative perceptions of nuclear plants but also stresses the need for a transparent and balanced communication of risk to minimise misunderstandings. Krieg's approach does not involve full public participation in the design process; it merely champions extending the consideration already given to the public as a minor stakeholder. Unfortunately, very little research has been carried out following on from this work to either determine if the conclusions have merit, or to broaden the scope to deal with other aspects of nuclear plant design (Krieg's work focuses on just one aspect of nuclear plant design—containment).

An alternative approach to design would be to follow the ideology of Fischer, Slovic and others and take a proactive approach to incorporating the lay-public's views at the earliest stages. This proactive approach would result in a plant that is not only designed to the highest engineering and safety standards, but is also based on a wider, socially accepted design that may allow for easier integration of the plant within society.

4.2. Participatory design

Consultative activities are becoming more commonplace within society, with risk communication activities in particular seeking to incorporate lay-public input. However, these consultative processes are yet to influence significantly the design of systems and technologies, with the notable exception of participatory design processes that exist within the Information Technology (IT) sector (Schuler and Namioka, 1993). Participatory Design (PD) in this sector was born out of conflict between workers and managers over the use of IT to automate work functions. Initial efforts to introduce automation were beset with issues relating to stakeholder rejection by blue-collar workers and Trade Unions in particular, who felt that the new technology would threaten their jobs. An overview of the genesis of PD is provided by Kensing and Blomberg (1998). The ethos of PD is that by involving workers from the very early stages, they are woven into the project and are able to define their own rules and goals, much as Slovic suggested with his "risk game" (Slovic, 1998).

Research also points to a number of challenges that any participatory procedure must overcome, including (Hansen, 2006):

- the conflicting agendas of various stakeholders;
- differences in the amount of credence attributed to the input provided by different stakeholders; and
- the lack of a widely accepted standard format for such consultative activities to follow.

The nuclear industry has attempted on several occasions to engage the public at a more fundamental level through consultative processes with varying degrees of success, although it has never gone so far as to incorporate direct public input into nuclear plant design. Green (1973) provides insight into the fact that during its early years the nuclear industry was not successful in consultative efforts. A more recent example of a consultative process in the UK where significant mistakes were made would be the attempts by Nirex to obtain planning permission in West Cumbria for a rock-characterisation facility (RCF) to aid in research into the long-term disposal of radioactive waste (Folger, 1993). The RCF was designed with the public in mind, but not with the public involved, a subtle and ultimately costly mistake. The public, feeling distanced and disenfranchised, rallied against the project resulting in the refusal of the planning permission, an indefinite postponement of the project and a long-term review of the UK's entire nuclear waste-disposal strategy (NDA, 2006).

Lessons continue to be learned from incidents such as the Nirex affair, where a lack of clear communication and consultation had significant consequences (Dalton and Atherton, 2002). Despite this, issues still arise, as seen in similar circumstances in 2007 when the UK Government consultation on new nuclear build, after being challenged by Greenpeace, was ruled unlawful by the High Court (Sullivan, 2007). More effective consultation procedures have been carried out in Canada where extensive public engagement activities were carried out in the early 2000s prior to the adoption of the Adaptive Phased Management (APM) radioactive waste disposal plan (NWMO, 2005). Reinvigorated efforts in the UK by the Nuclear Decommissioning Authority (NDA) to select sites for long-term radioactive waste disposal have begun to adopt similar consultative processes to those used in Canada (NDA, 2006).

4.3. Changing the approach to design

The existing design process for a nuclear plant takes around 10–15 years and strives to optimise the design on safety, performance and costs. Public consultation is only initiated after the design has been completed and it seeks to facilitate a smooth transition between no plant existing and a plant being built, operated and eventually decommissioned. Therefore, existing consultative processes do not encompass nuclear design which means that if any part of the design is of particular concern to the public, it is often too late to take any remedial action without great expense and delays. If on the other hand, the public is consulted prior to the design stage, during the 'requirements analysis',[7] this could be by far the most cost-effective way to incorporate their concerns and alleviate any future problems with the siting and building of new nuclear plants.

Thus, there is a need to explore the potential for combining expert knowledge of plant design and calculated risks with the lay-public's perception of risk to arrive at a novel, socially informed, approach to design. Such an approach to design would be able to provide guidance to the nuclear industry on the potential effects of plant design changes on the public perception of risk from nuclear plants.

However, any changes in the approach to design for nuclear power plants that goes beyond the current practice of combining

[7] Requirements analysis or requirements capture is the first stage in the life cycle of any engineering system, aimed at helping to determine the requirements for a new product or a plant, taking into account views of various stakeholders, including the public.

calculated risk with technological and economic aspects must adhere to a number of different criteria. For example, it must:

- strive to continuously improve overall safety levels;
- incorporate information from many different stakeholders, both expert and non-expert;
- accept quantitative and qualitative inputs from both engineering and social science disciplines;
- structure these inputs in a clear, logical and unbiased fashion;
- interface with established systems engineering techniques right through the life cycle of nuclear power;
- be robust enough to be modified and updated as our understanding of risk and engineering expertise develop;
- provide a basis for practical designs that are economically, socially, and technically viable; and
- be simple to apply and follow.

This list of criteria is by no means exhaustive, and significant further work is required in order to develop the full set of criteria.

It is conceivable that some aspects of procedure or design will be more dominant than others. An early stage activity should be to evaluate the range of aspects associated with the design of a nuclear plant and attempt to prioritise areas for further study. Research into revealed and expressed-preference could help identify the design features that should be modified. Further research is also required on how to integrate the various results showing how different design aspects influence the overall perception of the nuclear plant.

A potential pitfall of expanding the approach to design is that by incorporating the views of a wide variety of stakeholders may lead to any conclusions becoming at best an approximation of reality and at worst vague and meaningless. In order to avoid this, careful consideration will need to be made in terms of assessing the various stakeholder inputs on an equitable basis. Additional stakeholder requirements will also impose an additional cost, but if incorporated at the requirements analysis stage, this should be much lower than the cost of re-design at a later date.

Ultimately the new, expanded, socially informed approach to design must be evaluated on its ability to generate meaningful and useful system requirements, design features and procedures that can provide measurable benefits to both the nuclear industry and society as a whole. Metrics for measuring such factors may also require development as established methods for evaluating the financial cost of negative public perception and the societal advantages created by a reduction in level of perceived risk do not currently exist.

4.4. Policy implications

The UK Government has carried out several consultations on nuclear power including the role that nuclear power should play in the UK energy mix (BERR, 2007), the suitability of the licensing process (DECC, 2010), the suitability of various sites (DECC, 2010) and the options available for the long-term disposal of nuclear waste (BERR, 2007). Further detail on UK policy on nuclear power can be found in, for example, Azapagic and Perdan (2011) and Greenhalgh and Azapagic (2009).

The UK Government's latest National Policy Statements for Energy Infrastructure recognise that there may be positive and negative effects from the construction of new nuclear plants and that organisations applying for site licenses should identify these effects in their license application (DECC, 2011), although there are no specific comments on mitigating or avoiding these effects. The UK Health and Safety Executive has invited public input into its Generic Design Approval (GDA) process for the assessment of new nuclear reactor designs (HSE, 2009). However, any design changes that are considered now must be balanced and justified against the cost of making the change. As the designs are almost finalised, such changes are potentially very costly and time consuming, and therefore it is perhaps less likely that any changes that are not critical for the safety will be made, even if they might enhance the socio-economic benefit of the plant. Therefore, making changes earlier in the design process would be less costly as the previously mentioned example of Sizewell B (O'Riordan, 1984; O'Riordan et al., 1985) demonstrates clearly.

Furthermore, the case of Fukushima has shown yet again the influence the public can have on nuclear policy. Although at the time of writing it is too early to determine the global long-term consequences for new nuclear build, it is already evident that some countries are changing their policies on nuclear power. A number of countries (such as China, the UK and USA) have instigated safety reviews. Germany, which had recently decided to re-consider new nuclear as a bridge to renewable energy generation, has shown signs of reverting to its previous policy of phasing out nuclear power as quickly as possible (Harding, 2011). This is perhaps as much a socio-political decision as it is one of safety; incumbent Chancellor Angela Merkel faces significant public and political opposition on the issue of German nuclear power (BBC-News, 2011).

5. Concluding remarks

Our understanding of risk, both from a technical and lay perspective, has developed significantly over the last 40 years. There now exists a large body of evidence around the issue of public perception of nuclear energy, in both quantitative and qualitative forms, that continues to expand. Research has shown that there are highly complex factors at work, influencing and shaping the perception of nuclear energy in many different ways. These factors go beyond simple direct interactions with government and industry and incorporate a whole spectrum of interactions within local communities and within wider society.

Policy makers must recognise the importance of public perception of nuclear power as a significant factor within global nuclear new build. This paper suggests that by involving the public at an earlier stage than is currently common, a nuclear plant can be built on a foundation of social consensus. Currently, interactions between the public and nuclear industry start with the licensing process and continue through to decommissioning. By extending this interaction to earlier stages, specifically during requirements analysis and plant design, it ought to be possible to increase public understanding of nuclear power and minimise the probability for disruption to new-build activities caused by misunderstanding and mistrust. It may not be possible to integrate all of the public views into a nuclear plant design, however the process of dialogue involved in such discussions can only reinforce current educational campaigns and help in building mutual trust.

Thus, this paper has argued that implementing approaches and policies which include an increased integration of lay-public risk perceptions into the design process for nuclear plants could result in a broader, socially informed nuclear plant design. The methods for carrying out early-stage design interactions between nuclear engineers and the public are still being investigated by the authors. To this end, further research is ongoing to understand the degree to which different aspects of nuclear plant design affect the overall perception of the risk posed by nuclear plants. It is also proposed that this socially informed approach to design, which retains the technological development and safety emphasis of the current design basis, would provide designs and processes that are more widely accepted by the general public. This in turn has the potential to reduce the capital cost and financial risks of new nuclear build.

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