Nuclear Energy in the UK: Safety Culture and Industrial Organisation

Book Section

Nuclear Energy in the UK: safety culture and industrial organisation

William J. Nuttall and John E. Earp

Summary

In this paper we seek to explore the relationship between professionalism and nuclear safety in the UK. We consider the history of civil nuclear energy in Britain and the near complete shift in emphasis from state owned enterprises to the private sector. We show how in recent years government has acknowledged that a truly liberalised electricity industry is unable to deliver the construction of new nuclear power stations as part of a future low carbon electricity system. Throughout, however, the intention has been for policy merely to incentivise the private sector rather than to steer industry strategy directly. Having said that, the line between strong incentives and weak control can be hard to see. We present illustrative examples, real and fictional, that give insight into the UK nuclear safety culture and we discuss the wider nature of UK society with respect to corruption. We conclude that the unique basis of safety regulation in the UK, essentially permissive rather than prescriptive, has a key role to play in promoting and maintaining nuclear professionalism.

1. Introduction

This paper is tasked with exploring the professionalism and the integrity of nuclear procurement in the UK. It is an interesting question rarely considered in Britain. Much attention has been given to building and maintaining a strong safety culture within the UK. Much of this has related to mitigating the risks and consequences of accidents. There has been little discussion, however, of the risks or impacts that would arise from self-interested criminal behaviour. Perhaps the closest that the UK has come to such issues in the nuclear sector has been acts of negligence and data falsification designed to hide negligence. These issues are explored via case studies later in the paper. We have also been asked to consider the role of state-owned enterprises and the relationship, if any, between: on the one hand industrial organisation and ownership; and corruption or criminality on the other. In this paper we describe the profound journey that the UK has taken in recent decades from state-owned industrial national champions to private sector firms in a liberalised market. Today many of the firms operating in the UK nuclear energy sector are foreign entities. Again we see little, or no, evidence of impacts from criminality. As the UK admits more international companies into its domestic nuclear services market it exposes British companies to global competition. As UK nuclear energy firms are progressively serving global markets, general anti bribery legal measures become increasingly relevant and important. We shall consider these issues briefly later in the paper. Finally, we suggest that the main effect of internationalisation on British industry is that British firms improve their global competitiveness.

In this paper we suggest that a key driver of British nuclear professionalism is non-prescriptive nuclear licence via which individuals and organisations are given high degrees of formal responsibility and discretion for nuclear safety. With responsibility and discretion comes professionalism.

The UK was one of the first countries in the world to develop civil nuclear energy, following earlier efforts dedicated to the production of plutonium-based nuclear weapons. That history provides an important context for this paper, and we shall consider such things further in the next section.

2. UK historical context

While much of this paper will deal with issues facing civil nuclear electricity generation in a Twenty-first Century Britain defined by liberalised markets, globalization and private sector led innovation, it is important at the outset to make clear that Britain was not always such a place. In the middle of the Twentieth Century the United Kingdom faced an existential threat from Nazi Germany far graver than anything in historical memory. Germany was a continental-scale engineering-oriented superpower and somehow, and by the narrowest of margins, Britain triumphed. In winning, however, national weaknesses and shortcomings were revealed for all to see and the returning troops demanded change. 1946 saw the election of a strong and radical Labour Government under the leadership of Clement Attlee.

Attlee's Government inherited no money, but it inherited victory and a mandate for deep reform and a major part of that would be industrial reorganisation. Attlee in the 1940s, and later Harold Wilson in the 1960s, took Britain to the point that it was a country in which fuel from state-owned coal mines would be transported on state-owned railways to be burned in state-owned power stations generating electricity transmitted and distributed over state-owned wires to be used in state-owned factories making cars and airplanes (1). There were also state-owned nuclear power plants. The consequence was that by 1975 Britain was a temple to state-owned enterprise. Three state-owned enterprises vied for influence over the post-war nuclear power programme: the Central Electricity Generating Board owner-operator of the power stations (of all types) and also of the transmission grid; the UK Atomic Energy Authority operator of an extensive network of nuclear national research laboratories and research reactors and finally, a UKAEA offshoot, British Nuclear Fuels Ltd (BNFL) provider of a full complement of fuel cycle services and associated research. In addition to these three state-owned enterprises the British Government held a one-third share (with Germany and The Netherlands) in the uranium enrichment company URENCO. All the nuclear power stations operating today in the UK are, in various ways, a product of this post-war economic model. While it is true that the most modern British nuclear power plant, Sizewell B (a modified Westinghouse SNUPPS plant) was completed in the mid-1990s, and hence after Britain had turned away from the model of state-owned-enterprises, it was also very much a product of statist thinking. It had been intended to be the first of a fleet of CEGB-led projects built for Britain with American help in the form of design (Westinghouse) and construction know-how (Bechtel).The successor plant proposed for Hinkley Point near Bristol in western England received planning approval and had substantial public acceptance, but it was never built for reasons we shall explain later. We suggest that more than anything else the British nuclear programme ground to a halt in the 1990s, not because it was "nuclear", but because it was statist. Or alternatively one might say that British nuclear ambitions were not undermined by the actions of the green-left, but rather by the pro-market right with an agenda for electricity market liberalization.

Margaret Thatcher, first elected in 1979, was Britain's first and so far only female Prime Minister. She entered office with a powerful political majority and a strong belief that things had to change. Part of her change was to rid Britain of statist industrial policy and she embarked on a wide ranging programme of industrial privatisations including in energy. First to go was the government's stake in the oil company BP. More importantly, her second term government set about privatising British Gas which was sold off as a monopoly (albeit a contestable monopoly) missing an opportunity for true liberalization in the form of genuine market competition. In the lead up to the 1987 election Thatcher wanted to get it right for the next opportunity – electricity. Electricity privatisation featured in the 1987 Conservative Party election manifesto and her third term government went on to both privatise and break up the monolithic CEGB. Competing generator companies were established (albeit initially with a high level of market power) and the National Grid was sold off as a regulated private monopoly grid operator. The Thatcher government's intention was to bundle the nuclear power plants into the larger of two electricity generation companies, together they were known in the discussions as "Big-G" and "Little G", but it soon became apparent that such ideas frightened the merchant bankers tasked with delivering the privatisation and who had been hearing worrying noises from prospective institutional investors (2). The investor concerns focussed on the unknown economic risks associated with eventual plant closure and decommissioning. Later it would become clear that at market discount rates such costs are in fact small, even negligible, but in the febrile lead up to the planned sale there was great sensitivity to financial risk. Fearing that the privatisation would fail, the nuclear power plants were removed from the privatisation plans late in the process.

With the Conservative Party majorities eroded in the 1987 election there was a clear sense that electricity privatisation must be delivered before the next election, expected in 1991. The tight timescale was met. Interestingly if there had never been any intention to privatise the nuclear power stations it would have been possible to establish from the outset the greater than five generator companies that economic theory suggests is necessary for market competition to work properly. In fact it would take many years after the privatisations of 1991 for Britain's Big-6 Generator companies of today to be established in the market. The nuclear power plants were eventually privatised in 1996 in the form of British Energy. British Energy had a very difficult time essentially going bust and requiring a state bail-out in 2002 – see section 8. Today all but one of Britain's nuclear power plants are operated by a subsidiary of the largely state-owned French electricity company Electricité de France (EdF) which acquired the operations of British Energy in 2009. Today it is EDF that is leading the way with its plans for a nuclear renaissance in Britain.

Trained as a scientist Margaret Thatcher had a certain enthusiasm for nuclear energy and much esteem for the leader of the CEGB, Sir Walter Marshall, who was bitterly opposed to the break-up of his empire. Despite her affection for the atom and for "Dear Walter" her love of the free market was even deeper and it was her leadership that caused Britain to turn away from coal-fired electricity generation (where Thatcher, in the mid-1980s utterly crushed her bitter foes in the National Union of Mineworkers) and nuclear power which frankly frightened her less-technically minded friends from the financial sector. Thatcher's government sowed the seeds of the 1990s "dash for gas" in British electricity generation and the first serious steps towards renewable electricity generation (in which context it must be acknowledged that Margaret Thatcher had an early personal belief in the risks from anthropogenic climate change). The "dash for gas", made use of a flexible fuel in stations which could readily regulate output to suit market conditions (in particular operating on the margin) hence giving it a significant economic advantage compared to the nuclear fleet that typically operated at base load. The advantage of natural gas really emerged after the ending of the Pool market and the move to New Electricity Trading Arrangements (NETA) in March 2001. Prior to that shift all Pool generators (including nuclear) received the market clearing price. The ending of that pricing system with the shift to NETA allowed flexible generators at the margin to receive higher prices per kWh and this contributed to the commercial difficulties of British Energy referred to above.

By the start of the Twenty-first Century, Britain had firmly turned its back on state-owned enterprise in energy and the nuclear power industry had to recognise that fact or perish. In the first few years of the new Century, say up to 2006, there was a sense that electricity market liberalization had worked – consumers, both industrial and domestic, were switching suppliers in ever increasing numbers, power supply reliability was good and prices fell. But there were also growing voices of concern because energy policy had by this time evolved to require progress in two emerging areas: decarbonisation motivated by concern for global climate change and energy security involving concerns for both fuel supplies and power generation capacity. With both challenges in mind, concern was growing more generally regarding the need for major energy infrastructure renewal. While it was clear that the liberalised market could supply electricity it was far from clear that the market would ever be able to build new power stations, once the initial dash for gas was done. By the second half of the decade of the 2000s there was much concern for UK "Generation Adequacy". It was far from clear whether renewable capacity represented any form of comfort in that regard. Major blackouts in 2003 and fractious gas disputes between Russia and Ukraine (2006 and 2009) forced policy-maker attention towards an established and reliable source of low-carbon electricity: nuclear power. But how could the liberalized market of the 1990s be incentivized to build such things? The short answer is by a retreat from liberalization and towards a socialisation of economic risks, but without a return to nationalisation and state-owned-enterprise. The policy changes are summarised in the next section, but suffice it to say that in 2014 Britain is, once again, a place with strong government intervention in the energy sector, albeit largely free of state-owned-enterprises.

2. UK Nuclear Renaissance

The UK was one of the first countries to develop civil nuclear energy. While the Soviet Union was the first country to make civil use of nuclear energy with a small reactor at Obninsk in 1954, the UK was the first to connect a large capacity generator to a power grid. The four unit nuclear power station at Calder Hall in the northwest of England was opened by the Queen in 1956 (3) (the site in Cumbria is adjacent to Windscale, now called Sellafield). The second four reactors were at Chapelcross in Dumfries. All eight of these reactors had an original dual mission of supporting the need for military materials and electricity generation although they progressively transferred to a solely electricity generation mission in their final years. These two sites were the fore runners of the programme of Civil/Commercial Magnox reactors constructed only for electricity generation which began at Berkeley in Gloucestershire and Bradwell in Essex both of which commenced operations in the early 1960s. These early natural uranium-fuelled graphite moderated and carbon dioxide cooled reactors were followed by a fleet of "Magnox" power stations operating on very similar principles. The title "Magnox" refers to the magnesium/aluminium non-oxidising alloy used for cladding the metallic natural uranium fuel.

In the 1970s the UK had the chance to switch to what was already an emerging global front-runner technology – light water reactors. Indeed a very wide range of reactor types were considered at that time, but it was the higher temperature graphite-moderated and gas-cooled concept the Advanced Gas Cooled Reactor, or AGR, that was selected for deployment. The AGR concept was technically advanced and severe problems were encountered in construction (e.g. Dungeness B – required 23 years to construct and commission) and operations (revealed by relatively poor reliability). As noted earlier, by the late 1980s it had become clear that Britain's AGR concept could not compete with light water technology for reliability. It was resolved that the next plant, commissioned in 1996, would be a pressurised water reactor built at Sizewell on the Suffolk coast. Sizewell B was intended to be the first of a fleet of new Westinghouse developed power stations, but the political and economic events described earlier conspired to scupper such plans. For the next ten years there would be very little talk of nuclear power and over the same period electricity market liberalisation was consolidated, as described in the previous section.

As noted earlier, by 2006 it had become clear that while the liberalised market could indeed provide retail consumer choice and through competition put downward pressure on retail prices, it could not raise sufficient capital for nuclear new build. UK energy policy would need major structural reform if policy goals relating to the environment and energy security were to be met.

Since 2006 UK policy has moved consistently and strongly towards incentivising a nuclear renaissance. Along the way some long-standing axioms of policy have been quietly dropped. For example the axiom *no subsidy for nuclear power* was adjusted to be *no special subsidy for nuclear power*. In the former case a conventional interpretation would suggest that no subsidy could be paid to those planning nuclear investments or generating nuclear power. Following the adjustment to a situation of *no special subsidy,* nuclear power would be allowed to receive subsidies as long as they were not only available to nuclear power. For example the UK might subsidise low carbon electricity generation technologies. Nuclear power would be eligible for such a subsidy, as would renewables. As such, the measure would not be a special subsidy for nuclear. Government suggested that the policy had merely been clarified, but arguably the logic for subsidies had been fundamentally redefined. The shift made possible the later moves that are enabling recent progress towards a British nuclear renaissance. While policy is deliberately incentivising new nuclear build the formal power of initiative remains with private companies and importantly, in energy at least, the UK has seen no sustained return to strong state-owned enterprises reminiscent of the former CEGB. While there was a relatively short-term intervention to rescue British Energy (described later in section 8), fundamentally the UK has a situation in which government has policy goals and government achieves those goals by incentivising private firms via market arrangements and risk guarantees. Actual investment decisions continue to be made by private companies. Government incentives include long-term subsidies (for renewables and new nuclear build) in a form known as contracts for difference. There is indeed an irony that the UK, which led the EU into energy market liberalisation and which for years spoke out against opaque long-term pipeline gas contracts is now seeking (and winning) EU state aids approval for a 35 year long-term contract for nuclear power. The UK is in some ways retreating from liberalisation recognising that stronger intervention is needed to ensure infrastructure renewal and decarbonisation. For further information on the policy underpinnings of the UK Nuclear renaissance see report by W.J. Nuttall (3).

While there has been clear progress over the last ten years towards a nuclear renaissance in Britain there have been some exceptionally difficult events along the way. Most notably these have been the global financial crisis of 2008 and 2009 and the severe nuclear incident in

March 2011 at the Fukushima-Daiichi plant in Japan[1]. The fact that UK policy enthusiasm for highly capital intensive nuclear power plant investments has remained firm in the face of such pressures is quite remarkable (4). It is even more remarkable that UK public opinion, while divided, has on balance remained resolutely pro-nuclear through these difficulties. Arguably it is the powerful investor communities who have been most troubled by the external events mentioned earlier, thereby continuing the trend that in the UK it is not political concerns that raise the most difficulties for new nuclear projects.

It was originally expected that the lead investors for new nuclear power projects in Britain would be large European electricity generating companies, and indeed prior to the Fukushima-Daiichi accident three competing teams had expressed interest in new nuclear build. These were:

- NNB Generation Company a collaboration between EDF and Centrica
- Horizon Nuclear Power a joint venture between RWE and E.ON
- NuGeneration Limited a collaboration between SSE, Iberdrola and GDF Suez

It is noteworthy that all seven investing companies were large European energy companies. It was such companies that were originally expected to lead a UK nuclear renaissance. However, following the impact of the external pressures alluded to above these ventures have now evolved greatly.

- NNB Generation Company is now collaboration between EDF, two Chinese generating companies, the French technology vendor Areva[2] and with some remaining space for a new entrant investor.
- Horizon Nuclear Power is now led by the Japanese technology vendor Hitachi
- NuGeneration Limited is now led by the Japanese technology vendor Toshiba

Noting the diminished role for energy companies UK nuclear new build (at least in the project planning and build phase) is less directly connected to the liberalised market than it once was. Furthermore if one wants to point to the return of state-owned enterprises in the UK nuclear story, then one observes that they are not enterprises owned by the British state. The front-runner nuclear new build project in the UK is led by NNB Generation formed from enterprises the majority of which are owned by either the French or Chinese State. Arguably therefore the UK is benefitting from the cheap capital enjoyed by state-owned enterprises, but is willing to forgo the political and state control that usually accompanies the use of domestic state-owned enterprises and national champions (1).

3. Development of the Generic Design Assessment Process

Within the UK and throughout the world nuclear power plant construction projects have been subject to construction delays. A prime cause of this referenced in many reports has been the practice of commencing build before the design was finalised, leading to changes being required during the build. (5). Fortuitously this situation was alleviated at Sizewell B because the length of time taken over the Public Inquiry provided sufficient time for the design to reach a mature stage prior to construction commencement.

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[1] We use the term "incident" rather than "accident" because unlike all earlier severe nuclear accidents (e.g. at Chernobyl), the incident at the Fukushima-Daiichi plant was a consequence of an independent external disaster (the earthquake and consequent tsunami) and did not arise from an initiating event within the plant itself.

[2] At the time of writing the commitment of Areva to the Hinkley C project appears to be in some doubt as a consequence of financial difficulties at the company.

We note that the Sizewell B Public Inquiry was conducted under arrangements now superseded, which allowed inquiries into large infrastructure projects to be wide ranging. The older arrangements had the consequence that at the Sizewell B Inquiry only 30 of the total 300 days were associated with local issues, such as the impact of the project on local infrastructure and related potential transport problems such as traffic delays. The rest of the time was taken up with national policy matters (6). As a result the Government has instigated, for the nuclear renaissance, changes to the legal arrangements surrounding inquiries in the UK and it is no longer the case that they are "wide ranging". Station design and safety, national need, and siting are now handled by policy processes at a national level. Public Inquiries now are restricted specifically to local issues. That these new arrangements work successfully is evidenced from recent the much shorter duration inquiry into the proposed construction of Hinkley Point C.

The safety and environmental impact of a proposed power plant are now largely handled via a national and site-independent process known as "Generic Design Assessment" (GDA). The GDA process was introduced to reduce the risk of UK nuclear new build construction starting before project design had reached sufficient maturity (7). The GDA process is operated jointly by the regulators engaged in nuclear energy matters in the UK, specifically the Office of Nuclear Regulation ONR (who lead the process) the Environment Agency and the security regulator – the Office for Civil Nuclear Security (an autonomous part of ONR).

In order for a nuclear design to be sanctioned for build it must first go through the GDA process. Designs are submitted by a sponsor – generally a reactor vendor and are subject to detailed scrutiny by the regulators leading to an extensive dialogue on nuclear safety matters before the design is accepted for construction to start. The process, which can typically take up to 3 years, requires the sponsor to submit a significant number of design reports covering the detail of the proposed design set against a generic site. Hence the only design issues not assessed are those which are site specific. Utilising this approach it is hoped that construction delays deriving from design changes will be limited.

Currently in the UK the Areva European Pressurised water Reactor (EPR) has reached the stage of sanction for build having received a "Statement of Design Acceptability" (SODA), and the AP1000 is part way through awaiting its selection by a constructor before finalising the process. The Advanced Boiling Water Reactor (ABWR) is a late entrant into the GDA process motivated by the shift of technology choice following the acquisition of Horizon by Hitachi.

Because the GDA process is new and only recently introduced for the proposed nuclear new builds planned for the UK, we are not able to cite specific examples of where and how the process has reduced construction delays. However we have already mentioned that serious delays occurred at Dungeness B in the UK. Similar, but shorter, delays occurred on the other Advanced Gas-cooled Reactors. It is well reported in the technical press that delays due to design changes have beset the recent EPR projects at Olkiluoto in Finland and Flamanville in France. Also we have mentioned the fortuitous benefit of a delay to the commencement of planned construction of Sizewell B brought about by the extensive Public Inquiry. The delay allowed time for the design to reach a high level of maturity with the benefit that design change delays were significantly minimised. As a result there is a degree of confidence in the UK that the introduction of the GDA process, which ensures this higher level of design maturity as agreed with the regulators before commencement of construction, will mitigate construction delays due to design changes. It is also worthwhile noting that the COL (Combined Operating Licence) approach adopted by the Nuclear Regulatory Commission (NRC) in the US for their proposed new builds has a similar intent (8).

4. Development of the UK Nuclear Regulatory arrangements

With the drive to construct a large programme of civil reactors in the early 1960s it became clear that there needed to be a set of regulatory arrangements vested within a civil authority charged with ensuring the safety of this unique technology. Following deliberations this lead to an act of parliament The Nuclear Installations Act 1959 which was redrafted as The Nuclear Installations Act 1965 as Amended (9) to take account of international arrangements and which is still in force today, although some changes have taken place since, notably in 1969. The Act established the Nuclear Installations Inspectorate (NII) as a specialist body to enforce matters related to nuclear safety on civil nuclear sites in the UK. This body, although effectively a standalone organisation, was integrated into the Health and Safety Executive (HSE) formed following the Health and Safety Commission of 1974.

The creation of the HSE formed part of a wider philosophy to health and safety at work that emerged in the UK in the early 1970s as a result of world-leading ideas and initiatives. Central to the new thinking were the ideas of Alfred Robens in his capacity as chairman of the Committee on Health and Safety at Work established in 1970 at the initiative of Barbara Castle the Labour Government's Secretary of State for Employment and Productivity (10). Central to Robens' thinking was a desire to make use of the fact that those who know most about industrial safety on a given site are usually those operating that site. As such he sought to avoid prescriptive and generic national checklists issued by a central safety regulator, but rather make it the law that owners and operators of facilities should be able to justify their safe compliance with requirements specified by the regulator. The requirement would be to meet a required level of safety, and usually not a specific intervention. Operators have a level of discretion in choosing how to demonstrate the required level of safety.

Resulting from the modernisation of British arrangements all aspects of health and safety on a nuclear site in the UK were regulated by the NII which established a Nuclear Site Licence granted to a body corporate in order for them to own and operate a nuclear facility (a Power Station or other facility such as irradiated fuel reprocessing or fuel manufacture) (11). Subsequently in 2008 a review of the nuclear regulatory arrangements commenced in preparation for potential new nuclear builds. It recommended that the structure of the NII change and that it be returned to being a standalone organisation rather than being under the umbrella of the HSE. At that time it was renamed the Office of Nuclear Regulation (http://www.onr.org.uk/) and it assumed responsibility for all aspects of nuclear safety and security, some aspects of which had previously been outside of the NII. Notwithstanding these structural changes to the basis of regulation; the Nuclear Site Licence, although slightly modified, remains essentially the same.

The Nuclear Site Licence has 36 licence conditions (originally 35 but the last one was added in the 1990's to cover the "control of organisational change" when it became apparent that this aspect if not appropriately managed could have significant impact on nuclear safety). The 36 conditions cover all aspects of activities on a nuclear site which could impact nuclear safety. It also links closely with related aspects of the Radioactive Substances Act 1933 and the Ionising Radiations Regulations (IRR's) 1999 and has strong connection to the Environment Agency and their regulation of radioactivity released to the environment. Importantly this document, and the way it is enacted and enforced, is closely allied to all other safety regulatory arrangements in the UK in that it is permissive and not prescriptive. It requires Licensees to produce "Adequate Arrangements" to cover the detail of their activity and to be wholly responsible for them. Once adequate arrangements are produced these are approved by the ONR who then assess compliance with those arrangements in the regulation process and where appropriate give specific "permissions" for actions to take place (e.g. a consent/approval to re-start a reactor following a shutdown). This approach is very different from most other regulatory regimes where the regulators produce mandatory guidance documents (e.g. the Nuclear Regulatory Guides, or "NUREGs", issued by the Nuclear Regulatory Commission in the USA) with which a nuclear facility and its operators must comply. The US documents are a prescription of what, and how, activities must be conducted.

The implications of this for a nuclear facility owner/operator in the UK is that they need to have "in house" staff with the necessary skills and experience (Suitably Qualified and Experienced – abbreviated to SQEP) who are initially able to draft the "Adequate Arrangements" and the associated operating and maintenance instructions and supporting systems and to ensure that they are worked to. To do this they must clearly understand the nature of the plant its risks and associated hazards under all normal, abnormal and emergency conditions. They must also understand the original design intent of the plant as a base line for any future changes; this role has evolved to be the "Design Authority". Similarly they need to retain in house the ability to be an "Intelligent Customer" such that they can clearly specify for contractual purposes the plant or services they need, or any changes to it recognising the impact this may have on the overall risks and consequent hazards (or changes to them). The focus is on the Nuclear Site Licence holder who is totally responsible for nuclear safety, but this way of working also has major implications for those in the supply chain, who need to have clarity of understanding in the way the Licence works. As there are no clear mandatory regulations to follow, they need to be sufficiently SQEP to fully understand the impact on nuclear safety of any work they may be engaged to carry out. In this context having the right nuclear safety culture in the organisation is vital for success. Hence all people working on a UK nuclear site need to have a clear understanding of the impact of what they are tasked to do concerning nuclear safety. This understanding, usually necessary down to first line supervisor level, means that staff are conditioned to follow procedures and stop and ask for clarification if processes and procedures do not seem to meet the standards required. This way of working is generally termed "conservative decision making".

Breeches of the conservative decision approach have in the past led to the regulators taking legal action against the Licensee. A very good example is the so called Parasol Grab event which happened at Wylfa power station in July 1993 (12). Whilst operating at normal conditions and undertaking refuelling (a standard procedure) on 31 July 1993 at around 21:00hrs, and using the standard refuelling equipment, the operator noticed that a grab (known as a parasol grab due to its shape and configuration) was missing from the hoist part of the refuelling machine (a large shielded "crane") used to remove spent fuel and replace new fuel in the reactors fuel channels. There was no indication where the grab had gone and there were no alarms, so the reactor was held at power - generating electricity until about 04:00 the next morning. In practice the grab and its counterweight had become detached and had slid down a connecting chute (part of the refuelling equipment) into the top of one of the reactors 6150 fuelling channels blocking the gas flow in that channel.

As a result of the blocked channel, cooling gas flow was compromised and fuel was damaged; although at the time no high temperatures or indication of contamination in the gas system were detected. However given the potential seriousness of a lost refuelling grab the conservative decision should have been to enter a controlled shut-down immediately, not several hours later with the final decision being affected by the loss of revenue from generation. This experience resulted in the regulator (NII at the time) seriously questioning the nuclear safety culture on the plant and to take legal action under the licence. The case was heard in Mold Crown Court in Cheshire and resulted in a fine for the then plant owner /operator Nuclear Electric of £250,000 with £138,000 costs.

It is important to emphasize that the regulator brought this case not on the basis of a failed weld (subsequently determined to be the cause of the dropped grab) but rather on the issue of concern about the safety culture exhibited by the actions of the staff following the dropping of the grab. In this context it is important to appreciate that the Office for Nuclear Regulation is concerned with issues of nuclear safety and security. It is not tasked with preventing crime and corruption within the nuclear sector except in so far as such issues might affect safety or security[3].

Readers interested in learning more about the UK Licence and, in particular the relationship to International Atomic Energy Agency fundamental safety principles are recommend to consult a recent paper by Buttery and Vaughan (13).

5. The UK Liability Regime

An important issue relating on the one hand concerns of nuclear safety to, on the other, the power of national governments is the issue of nuclear liability insurance. Insurance of nuclear sites in Organisation for Economic Co-operation and Development (OECD) countries tends to be divided into two main types of loss. The first, known as material damage insurance, is of greatest day-to-day significance to nuclear power plant operators while the second is third party liability insurance.

Material damage insurance protects the operator from losses arising from any incident on-site (perhaps even as small-scale as an employee falling of a ladder), through losses relating to damage to the plant itself, and in addition possibly including protection against risks arising from the operator's contract position in the market. In the event that a plant becomes unavailable it is likely that it will be subject to ongoing base-load contracts to supply electricity. In the event that the plant is no longer available the contract must still be honoured and substantial losses can be incurred needing to buy power in the open market in order to meet previously agreed base-load commitments to sell power (7). Material damage insurance can include protection against such risks. Such nuclear material damage insurance is an important business for both plant operators and specialist insurers, but fundamentally it is a private matter between companies.

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[3] There is perhaps an interesting parallel to be drawn with the Food Standards Agency. In 2013 there was a national scandal in the UK when it became apparent that horsemeat was illegally being passed off as beef in food products. This was a crime, but it had no implications for human health. Initially FSA representatives went on TV saying effectively "don't worry – there is no problem for human health". It was only some time later, and presumably following advice, the FSA realised that they were in fact the body formally responsible for preventing food crime. They were not just a safety regulator, but it appears that fraud prevention was a responsibility that they did not immediately know that they had. Despite this comment, to our understanding the ONR has no role in preventing economic crime. We expect that such matters would fall to the police and specialist crime agencies.

The second major aspect of nuclear insurance is third party liability insurance and it is here that governments have a stronger role. This insurance importantly includes the risk of a severe nuclear accident with off-site consequences. In this case losses can arise in both the country in which the plant is located and, depending on geography, neighbouring countries. The United Kingdom manages nuclear liabilities according to a set of core principles:

- A liability regime of "strict liability";
- Operator Subject to a Limit of Liability; and
- Subject to the 1960 Paris Convention and 1963 Brussels Supplementary Convention which is legislated in the Nuclear Installations Act 1965 (9).

At the heart of third-party liability regimes is the notion of strict liability (i.e. the victim does not need to prove fault or negligence against the operator) and exclusive liability (i.e. all claims are legally channelled to the operator). The channelling principle means that the operator is responsible for all third-party losses arising from nuclear activities on their licensed site, even if the fault is traced to an external supplier. An example might be a severe nuclear accident in which a significant failure related to coolant pumping. Imagine if the pump failure was later found to be an error in design by the pump manufacturer. In that scenario the nuclear power plant operator cannot shield themselves from formal liability by pointing to the failure of a component supplier. The operator is responsible for, and hence incentivised to ensure, good quality component supply.

Strict liability is a cost burden placed upon nuclear power plant operators beyond the burden placed on other industrial systems operators including those in the energy sector. There is sometimes said to be a quid-pro-quo in that the nuclear industry receives a special benefit to offset its greater obligations. That benefit is that the operator is shielded from large-scale risk by a limit to its third party liability. Presently the United Kingdom is undergoing the process to ratify the 2004 Revised Paris Convention (14) by amending the Nuclear Installations Act 1965 through secondary legislation made under section 76 of the Energy Act 2004(15). Notably, this would raise the liability cap in the UK from £140 million to £1.2 billion. It would also affect the heads of damage (i.e. the definitions of loss, such as personal injury, loss of property, business continuity, etc.) that may be compensated, and may affect the priority and mechanism in which different heads of damage are subsequently handled. Third party losses above the threshold are not covered by the industry or their private insurers, but rather are covered directly by government. Some have argued that this represents a substantial public subsidy on nuclear power compared to other energy sources (16). Some countries (e.g. India) do not yet have strict liability and some channelling may be possible to suppliers following a nuclear accident. Such provisions can represent major obstacles to international involvement in nuclear projects especially in respect of the sale of components. Component manufacturers need assurance that third-party nuclear liabilities are subsumed by the operator via the provisions of exclusive liability. Otherwise, it may be impossible for these companies to obtain the necessary risk protection to enable a sale to take place.

Since the March 2011 incident at the Fukushima-Daiichi plant in Japan the European Union has been concerned with inconsistencies relating to third-party liability nuclear insurance between member states. Most notably the issues surround claims management (especially in instances where claims are trans-boundary); EU member states that are not members of any third-party nuclear liability conventions (as of 2014, there are 5); and the variation in the amount of financial security required across all member states that are party to the Paris or the alternative Vienna Convention, ranging from €5.6 million for Italy to €2.5 billion for Germany. It is also expected that member states who are party to the Paris Convention will ratify and enforce the Revised Paris Convention, although the original deadline (as mentioned in council decision 2004/294/EC) (17) has now lapsed.

The 2014 EU policy process has not sought to converge the whole of the EU to a single protocol (though this has been considered), rather the intention has been to achieve greater levels of harmonisation between member states on issues such as limits of liability and heads of damage. Internationally, one convention that aims at being a global nuclear liability regime is the 1997 Convention of Supplementary Compensation for Nuclear Damage (CSC) which is yet to be brought into force, although it has been signed by 18 countries including the USA and India. The CSC is a free standing instrument that aims to overarch the Paris Convention and the Vienna Convention. However, the provision in the CSC for legal channelling is at odds with for example India's Act on nuclear liability and there remains much debate as to the pros and cons of the CSC (18) (19). Overall, it is evident that civil nuclear liability regarding third party liability insurance at international and national levels remains a work-in-progress.

6. UK regulators

The UK separates safety and security regulation (held within ONR) and energy market economic regulation held within the Office for Gas and Electricity Markets (OfGEM). OfGEM's role is to monitor the trading markets for electricity and gas and to propose reforms where there is evidence that they are not functioning correctly. It ensures competition operates properly in electricity generation and supply and it regulates prices in the natural monopoly services of electricity transmission and distribution. OfGEM does not involve itself significantly in the organisation of manufacturing industry even in those cases where such capabilities affect national energy capacity. If such concerns feature anywhere in England it would be within central government in the Department of Energy and Climate Change (DECC) in coordination with the Department for Business, Innovation and Skills (BIS). DECC has, for instance, sponsored Technology and Innovation Needs Assessments (TINA) studies including of nuclear power but these do not look at the level of procurement and contractual procedures (20). TINA studies are more concerned for national capacity for maintaining critical infrastructures. TINA offers advice to government it does not necessarily reflect the opinion of government hence as such it has limited influence. We note that there is no single expert body outside government itself tasked with ensuring that critical national energy infrastructure projects are delivered efficiently and professionally. Here we mean to a quality that transcends merely safety, security an environmental protection. The need for such oversight is motivated by the fact that energy infrastructure projects (i.e. power station construction or Grid enhancements) are large complex projects which transcend electoral periods of office for members of the UK Government and hence also often the tenure of Members of Parliament.

We suggest that any attempt to seek to separate political risk (managed by government), economic risk (handled via the market) and engineering risk (responsibility of the constructor) is likely to fail as there are too many potential points of contact between these various risks. Hence we need a body that sits above all such concerns. We are not alone in thinking this way; such concerns have been whispered for several years.

Earlier this year the Guardian Newspaper hosted a UK wide event known as the *Guardian Big Energy Debate.* Bristol was selected as the centre for the South West of England part of this event. The debate touched upon similar concerns to those discussed above and noted that such issues were a significant "detractor" from achieving a sound footing for long term energy projects. As a result the meeting advocated that an independent cross party infrastructure commission be established, that this should be technically led and charged with taking major energy infrastructure development decisions ensuring that these were out with the influence of party political activity (21).

7. Engineering Codes and Standards

The nuclear reactor business in the UK, which was once world leading (in the 1950/60s), focussed on the use British Standards as the basis of the design and for installation. However the reactor supply business is now global with reactors potentially being built in the UK with their design origins in France, the USA and Japan.

Typically the UK is familiar with the ASME/ANSI codes as these were used for the Sizewell B reactor, or more specifically the standard nuclear unit power plant system (SNUPPS) comprising the reactor and its supporting primary circuit. However the secondary systems were built to British Standards, hence the key issue was one of ensuring that interfaces between plant systems were correctly configured. This situation must no doubt be repeated when Japanese originated plants are built in the UK.

In recent years there has been growing interest in harmonising or even standardising engineering codes internationally. This comes perhaps as a consequence of first: the prospect of Nuclear Renaissance and second: a sense that new build projects would be more international than was seen in the early nuclear power programmes of the 1970s and 1980s. The range of engineering codes (US, French, Japanese, Russian and others) can be bewildering and risks adding cost and perhaps even undermining safety. The US (ASME) and The French (AFCEN) have both been keen to explore prospects for greater simplification, albeit unsurprisingly with a preference for their codes to be the reference starting point. These issues matter acutely for the UK poised to construct French (EPR), Japanese (ABWR) and perhaps American (AP1000) nuclear power plant designs in the coming years. The question remains: what role, if any, will there be for UK engineering codes and standards?

The UK trade body for the nuclear sector is the Nuclear Industry Association (NIA). It celebrates the fact that it has more than 260 member companies spread across the supply chains of nuclear new build and decommissioning. The NIA has produced an import guide for companies entering the UK nuclear supply chain (22). We would recommend it to those seeking a second complementary perspective on some of the issues discussed in this paper. The NIA report for instance, says more about the role of engineering codes and standards than we have space to do here.

8. UK Case Studies – Learning From Experience

Although there appear to have been no examples of wilful self-serving fraud in the UK nuclear industry, there are examples of "innocent errors" at a working level due to working level staff being inadequately briefed by first line supervisors who themselves did not fully appreciate the implications of their activity on nuclear safety and the nuclear site licence. We provide two illustrative fictional stories loosely based on real events. They are intended to capture the key learning elements that apply to companies contracting to work on a UK nuclear licenced site.

One can envisage a situation where a competent electrical contractor was contracted to upgrade the lighting systems in a new fuel store at a nuclear power station. Such facilities are covered by the licence and criticality certificates (which form part of the licence). Let us assume the work to be correctly specified and that the work area has proper barriers. Let us further assume that the new fittings can be delivered on pallets to an outside area adjacent to the external store door (usually roller shutter type). This allows for unwrapping of the electrical items before transferring them to the facility itself. The reasoning behind this would be to prevent wrapping material being taken into the defined reactor zone and hence having to be treated as active waste. However as the work commences let us posit that a major thunderstorm occurs having the potential to seriously wet the electrical equipment (not a desirable position). One can imagine the electrician taking the initiative to protect the equipment and moving it rapidly into the fuel store simply to keep it dry. He keeps the wrappers on while he does this to help keep the items dry. However the wrapping would most likely be polythene a hydrogenous material which is banned from fuel stores under the criticality certificate (as it is a potential moderator).

Hence an action taken with good intent would immediately breach the licence. There is no doubt that any subsequent investigation would clearly indicated that with the amount of moderator material involved there would be no real nuclear issue. However it highlights how a contractor electrician and his supervisor could adversely impact the site licence as a result of not clearly understanding the potential implication of their work on nuclear safety. Although in this envisaged situation the electrician could be praised for taking an initiative that in any other non-nuclear facility would have been the right thing to do, in this case it would highlight the need for enhancing the training for all future contractors.

In a similar way one can envisage a second separate fictitious scenario in which a Mechanical Craftsman (a contractor) is asked to a service a sump-pump in the turbine hall (non-reactor area) of a nuclear power station. Finding the sump level controller faulty he replaces it with an equivalent (better) unit and successfully re-commissions the pump. This, as in the example above, might be an action which on a non-nuclear site would be praiseworthy. However on a UK nuclear site, replacing a unit with a non-identical spare becomes an unauthorised plant modification and breaches licence condition 22 (11). In this case the position could be even more confusing since the plant item is outside of the reactor area; however sump pumps are "claimed" as part of the flooding defence systems within the nuclear safety case.

These illustrative fictional examples demonstrate how contractors at working level UK environment need to have a good understanding of the nuclear licence and its implications. They further illustrate the importance of incorporating such matters into the training programmes. Contracting organisations that do this tend to be favoured over those which do not. This commercial preference helps drive the UK safety culture forward.

The Wylfa parasol grab event discussed earlier also illustrates a situation where regulatory legal action was taken. The legal action was not in response to any mechanical failure or failure to follow instructions but rather simply because of a lack of nuclear safety culture. The issue of nuclear safety culture remains a major feature of any work both by owner operators (as was the case at Wylfa) and also by contractors. Hence this aspect features highly in any training for work on a UK nuclear site and is a feature of any contractual arrangements. Specifically a contractor who can demonstrate an understanding of, and evidence of, practice in nuclear safety culture will have an advantage in tendering situations.

A further example of the impact of the Nuclear Site Licence on new builds can be taken from the Sizewell B build in the early 1990s (23). This plant was built to time and cost. Its cost was £1.9bn, when envisaged as part of a larger fleet, but when the rest of the planned fleet was cancelled a First Of A Kind (FOAK) cost of £390,000 was “back fitted”, making it appear to be overspent. The design was a Standard Nuclear Unit Power Plant System (SNUPPS) and a copy of the successful US plants at Callaway (Missouri) and Wolf Creek (Kansas), hence a proven design. However evaluation under the UK Nuclear Licence system led to changes (in some cases related to the siting position) such as the addition of an ultimate reserve heat sink; an emergency boronation system to ensure shutdown under certain emergency conditions and a hardwired (rather than software-based) nuclear safety protection system.

We now turn to another informative story from the British nuclear experience. In early 2000 a story emerged that revealed significant weaknesses in the UK nuclear safety culture at that time. The incident known as the Sellafield MOX Data Falsification arose within an international business operated by British Nuclear Fuels (BNFL). BNFL was a UK state owned enterprise responsible for fuel cycle research and policy implementation. It operated the large Sellafield site in Cumbria in the north-west of England, home to the Thermal Oxide Reprocessing Plant (THORP). Today, in 2014, BNFL no longer exists. It was broken up by the Labour Governments of Tony Blair and its former functions are now handled by the Nuclear Decommissioning Authority (NDA) and the National Nuclear Laboratory (NNL) while site operations are handled by private site management companies such as Sellafield Limited. The NDA acts as a policy interface to government and the sites themselves are managed on a Government Owned-Contractor Operated (GOCO) model. However, back in the 1990s, at the time of the Sellafield MOX Data Falsification, the situation laid within the domain of BNFL a classic state-owned enterprise (SOE).

The decision of the UK to embark on the reprocessing of thermal oxide fuels (coming from AGR and pressurised water reactors (PWR)) has its origins in the 1970s. Even at that time it was clear that the economics of such a project would raise special issues. The solution to perceived economic difficulties lay in scale. The proposed plant needed to be large, so large that its capabilities would almost certainly exceed UK needs, at least initially. The need for scale drove the UK into international reprocessing services, notably for Germany and Japan from which the country (noting BNFL was an SOE) earned substantial fees. Rather than returning separated plutonium dioxide to Japan, via maritime shipments that raised security and non-proliferation concerns in the United States, the policy adopted was to return useful fissile material to countries of origin in the form of uranium-plutonium mixed oxide (MOX) fuel.

While the UK has researched and developed MOX fuels since the late 1960s the British experience has faced many set-backs and obstacles including the story told here. A later difficult story concerns the building, problematic operation and eventual closure of the Sellafield MOX Plant (SMP). That story comes later than the data falsification problems and as such we shall not dwell on it in this paper. The MOX fuels at the heart of the data falsification events were manufactured at the older, and smaller, MOX Demonstration Facility (MDF) started in 1991 and commissioned in 1993 (24).

The supply of MOX fuel pellets to Japan was governed by a contract that included a clause inserted at the insistence of the Japanese customers. While all pellets would be tested by an automatic laser interferometer, 5% of the pellets that passed this automated test (and a visual inspection of all pellets) would also be subject to manual checking and data recording (24). The Parliamentary Office of Science and Technology (POST) has provided an excellent overview of the events providing more context and detail than we have space to record here. The POST report stresses that on 21 July 1999 a shipment of MOX fuel was despatched to Japan under the special quasi-military arrangements adopted to assuage global, especially American, concerns with international plutonium trade. One month later, on 20 August, a member of the MDF's quality control staff noticed that measurement records from the final manual measurements looked suspiciously similar between batches. A few days later a worker admitted that the measurement data had been falsified (copied from an earlier batch). A second worker admitted he had been aware of the wrong-doing. In September 1999 the UK Nuclear Installations Inspectorate (then the safety regulator) wrote to the Japanese Embassy advising them of a problem. Meanwhile BNFL had shut-down the MDF pending NII advice. In early 2000 the story broke in the public domain and soon after BNFL Chief Executive, John Taylor, resigned from the company. Five lower level workers were dismissed from their posts.

The MOX Data Falsification Incident involves a set of considerations:

- A task (final manual measurement) widely perceived to be unnecessary by BNFL and its staff, but insisted on by a third-party customer far away.
- The manual measurement task was tedious and boring.
- Workers were subject to insufficient oversight – quality control officials saw the problem too late.
- The incident damaged UK international relations with a key friend and ally, Japan.
- The incident had severe economic consequences, for the company, the country and caused the Chief Executive of the state-owned enterprise to resign.

More positively two things can be observed:

- Once the problem has been spotted by MDF quality control in August 1999, the matter was investigated transparently and conscientiously. International partners were fully informed within one month of first awareness.
- There was, and is, no suggestion that any workers had received financial or other gains as a result of their behaviour. Rather the core issue appears to have been a lack of a conscientious safety culture on the part of workers who did not respect the task given to them. Difficulties were compounded by staff reductions and a lack of staff training.

Importantly the official investigation into the incident concluded that while the fuel that was improperly approved was in fact safe, the failure of the agreed systems illustrated a major failure of the institutional safety culture (25). In addition to being a formal breach of the terms of the commercial contract with the Japanese customer it was also a breach of the Licence of the MDF site.

The MOX Data Falsification had several long-term consequences for BNFL and the UK. It badly affected plans that existed at the time for the privatisation of BNFL. It caused great damage to the UK-Japan relationship and it had significant economic consequences as it involved the temporary closure of the MDF and the return to the UK of MOX fuel that had already arrived in Japan. The Japanese insisted that the job be done right. In conclusion small things can matter enormously to both reputation and safety-culture even if in fact there is no direct safety issue at a narrow technical level. The UK learned this lesson clearly in 2000 as the extent of the data falsification story became clear. Our fictional, but realistic, examples are intended to reinforce this point.

Finally in this section we would like briefly to comment on the boom and bust of British energy from 1996 to 2002. The story of how, in the early years, the privatised nuclear energy company was the darling of the stock-market and following a change of market circumstances (and some unwise strategic decisions by management) the company ended up close to bankruptcy has been ably told by Simon Taylor (2). In this section we emphasise the reasons why the UK government did not simply allow the company to pass into administration and to be managed by a major accountancy company for a bankruptcy or a rescue process. Rather the government recapitalised the company effectively bailing it out and maintain management continuity and responsibility. This approach required the UK government to seek, and win, state aid approval from the European Commission in Brussels. In September 2002 The Guardian newspaper reported on the story with the words (26):

> *'The government said it was in emergency talks with the company with "paramount objectives ... to ensure the safe operation of BE's nuclear stations and security of supply."'*

Later the same report notes:

> *'A Department of Trade and Industry spokeswoman […] said: "British Energy asked us for help. We have started discussions with them to secure the government's priority to safety and security of supply. There are not going to be any blank cheques. There is a possibility of restructuring within the private sector. It is very early to say."'*

Safety was the clear reason, or excuse, invoked by government to justify a state intervention. That nuclear-related intervention was the first step in government's retreat from complete market liberalisation. Within the domain of nuclear power it is interesting to ask whether nuclear power is indeed special for safety reasons or whether Government's invocation of safety was merely an excuse. After all other critical infrastructures (such as the East Coast main railway line) were taken into state control after a failed privatisation (1). It is perhaps merely the rhetoric of safety as a reason that is special in the case of nuclear energy.

The final case study we would like to mention relates to the construction of Sizewell B in the 1990s. We tell this story because it reflects the UK experience of large CEGB (i.e. state owned enterprise) initiated projects. The story illustrates well the concerns of those making decisions regarding the supply of major components and systems.

Sizewell B was a project conceived and initiated by the CEGB in the dying days of state-owned enterprises in UK electricity industry. We suggest it followed the norms of the CEGB era despite extending beyond it. The project had some important and interesting points of principle: first that the UK should not introduce a new reactor and a new turbine at the same time and second that no first of a kind major systems or components should to be used in the project. The first idea was probably motivated by the bad experiences encountered in the introduction by the CEGB of 500MW turbines in the 1960s. These represented a doubling in scale of the established turbines and the change gave rise to a lot of problems. As a result the

CEGB established the Marchwood Engineering Lab which had a large turbo-machinery aerodynamics section. At the time there were a number of UK turbine manufacturers, but the problem was that they relied mainly on learning from experience and so if the CEGB ordered the first of a new machine it was, in effect, getting a prototype because the manufacturer could not afford to build a prototype of their own. The CEGB, as a state-owned enterprise usually found itself in the position that it would be expected to build the first of a kind to help iron out any problems which would also help British companies export. The net result of the research and development collaboration was the development of the 660 MW turbine sets which had become the standard for CEGB power stations (both the AGRs and fossil-fuelled stations). Given that the Government was requiring a high UK content, UK manufacturers were given preference. In addition there were other operational arguments for favouring two turbines. The first and probably the most important was associated with strategic spares holdings. The steam conditions at the front end of the Sizewell turbine are quite different from those at the other stations so the high pressure and moisture separator/reheater stages had to be redesigned, but the steam conditions going into the low pressure stages were more or less identical to the other 660s, so the majority of the large rotors are the same. If need be the operator (especially if as large and wide-ranging as the CEGB was) could exchange rotors amongst the different plants (including even mothballed oil-fired power stations). The other argument which is rather dependent on turbine reliability is that with two turbines the power plant load factor should be higher, since on a spurious turbine trip you only lose half the output. In early operation this was probably true since there were a number of teething troubles on the turbines and the plant suffered a number of turbine trips. Today it is highly reliable. Issues of single turbine failure also apply to the stability of the transmission grid. With two turbines the negative impact of a single turbine failure on the transmission grid would be less severe. In the late 1980s the transmission grid part of the CEGB was nervous of system oscillations that might be triggered by a large generator failure. Having two turbines at Sizewell B militated against that risk.

As regards the second principle: there was an intention to have no new technology and even the new smaller items were required to have an established pedigree at least at the component level if they were to be used. That was the strategy which was implemented in the procurement plan, but it proved impossible to hold to the plan. The protection and control system is a case in point. Westinghouse offered the Integrated Protection System (IPS), which integrated protection and control. Such approach was forbidden under CEGB rules (and we would suggest is now widely recognised as being contrary to the principles of independence of defence in depth). Thus the Sizewell project went for a Primary Protection System (PPS) which was the protection system from the IPS. To get the control system a choice was made to use the control portion of another integrated system: the one being used on the French N4 plants being developed by CEGELEC. At the time of ordering, Sizewell would have been the second application of each of these so it complied with the no first of a kind technology aim. However the first application of the PPS was to be as part of the IPS for the Italian plants, which were all cancelled following Chernobyl. This made the PPS a first of a kind which made licensing more difficult and forced a break with the hoped-for project philosophy, but was not an insuperable problem. The control system was more of a problem.

Control room design in the past has always had a large customer input and is the responsibility of the Architect Engineer (CEGB PPG in Sizewell's case) rather than the nuclear steam supply system or turbine vendor. The N4 control room was seen as being very innovative and was designed around a particular approach to operating procedures. The

CEGB did not want to go down that route and was against the use of "soft" controls, so the Sizewell B control room design was based on UK operating philosophy and was subject to extensive ergonomic review including the construction of a full sized mock up. The CEGELEC control system could be interfaced with this more conventional control room approach as well as to the more innovative N4 control room. The problem was that CEGELEC ran into difficulties in delivering the N4 computerised protection and control system and eventually EDF decided they were not going to achieve what was required on a reasonable timescale and so cancelled the order. This led to a two year delay in Chooz B. CEGELEC argued that they could still deliver the control portion for CEGB on the required timescales, but the Sizewell team had concerns and chose to look elsewhere. Following the N4 route (developing a new system) would have introduced unacceptable delays. Westinghouse came forward offering their control system, which was the control part of IPS but as a non-integrated separate system. The system would again be a first of a kind (because of Italian policy developments) but the Westinghouse idea had some pedigree. Westinghouse was able to implement the system to interface with the existing control room design and although time pressures were acute the changeover was achieved without delaying the construction and at a cost that was still within the overall project budget.

9. The European Dimension

We now consider nuclear power plant contracts within the UK as part of the European Union. Contracting for new power station build works in the nuclear sector is a function of the structure and organisation of the builder (who may or may not be the owner and ultimate operator). There are a number of commercial models which can be used, such as the owner/operator acting directly as Architect /Engineer and letting contracts for aspects of the build and undertaking the coordination directly. This is the general approach used by EdF at Hinkley Point C where the plant configuration is broken down into many contract areas and individual contracts let to cover each area either singly or in groups. This model requires the owner/operator to coordinate all of the packages of work.

An alternative approach is for the owner/operator to let an EPC (Engineer, Procure, and Construct) contract with a large recognised contractor skilled in delivering large nuclear projects. The EPC contractor then issues all of the plant area contracts and ensures their coordination.

A "half way house" arrangement is also possible where the owner/operator lets an EPC contract for significant aspects of the work but then manages other aspects of the work directly.

Currently in the UK only the plant at Hinkley has progressed sufficiently for these types of decisions to be taken. The other prospective builders have yet to declare their contract strategies. As the UK is a member state of the EU, the UK contracting environment is governed by EU regulations established to ensure that bidding for work is conducted in a transparent way and provides opportunities for companies to compete on an equal footing from across the European Economic Area. These regulations are extensive and are best appreciated from the European commission's document PRAG "PRocurement And Grants for European Union external actions – a Practical Guide" – 07/04/2014. This document outlines the steps necessary for procurement of goods and services within the European Union. It defines the processes governing at what financial level Contracts (tenders) should be invited internationally (>300,000 Euro), or locally (>100,000 Euro and <300,000 Euro), and where competitive negotiation is appropriate (>20,000 <100.000Euro). It also explains when a single tender approach may be acceptable. The document also prescribes timelines for announcing the tender intent, through issuing the tender documents, the contract tender period, the tender evaluation period and the contract award. From the level of estimated contract values quoted it is clear that virtually all nuclear power plant contracts fall within the scope of these regulations.

In addition to the above regulations in the UK the Office of Government Commerce (OGC) around 2006 and following an EU Public Sector Procurement Directive in 2004 introduced the concept of "Competitive Dialogue" - a procurement policy for use in tender situations where the tasks were large and complex. Practical guidance on this approach was issued in Information Note 04/06 31 July, 2006 "Practical Guidance on the use of Competitive Dialogue". The approach was adopted extensively by the UK's Nuclear Decommissioning Authority (NDA) for all of its major tenders for the management of the decommissioning of nuclear facilities throughout the UK. The process provides for the contracting organisation to enter into open dialogue with all potential bidders to ensure that subsequent tenders are all on the same basis. Again it ensures transparency. The document also provides a timeline for the process and how it complies with overall EU procurement regulations. This method of procurement is now established in appropriate sections of the UK's nuclear sector.

The above paragraphs refer to the "legal and commercial" aspects of tendering for work in the UK's nuclear sector however there are some practical matters which stand out as success criteria in acquiring contracts in the UK nuclear sector:

I. Because nuclear construction projects are large undertakings they significantly impact local communities, therefore some of the larger contracts have requirements for engagement with the local communities and investing in local projects such as improving amenities at say schools and colleges.
II. In common with most other countries there was a slowdown in nuclear construction over the period from say 1990 to 2005 hence recruitment was limited resulting in a skills shortage today. As a consequence companies demonstrably supporting training either directly or via local colleges tend to be successful in gaining nuclear contracts. A good example here is the dramatic growth of Bridgwater College (Local to the new build at Hinkley Point in Somerset) which has been funded to set up training facilities in support of the construction activities.
III. Contractors who can demonstrate a high nuclear safety culture, preferably with some specific nuclear site experience tend to be more successful than others.

10. Bribery and Whistle blowing

Although not developed with the nuclear industry in mind, there are two pieces of UK Legislation that relate strongly to professional integrity and which are worth mentioning here. The first is the Bribery Act 2010 (27). This bold piece of legislation repealed all previous statutes relating to bribery and has domain over the following crimes:

- Paying bribes

- Being bribed
- Bribery of foreign public officials
- Failure of a commercial organisation to prevent bribery on its behalf.

For the UK nuclear industry the greatest concern would appear to relate to the third and fourth listed items and the activities of a firm engaged in UK nuclear work but also operating in overseas territories. The final provision motivates strong anti-bribery measures within the firm. Sanctions for infractions can be severe including up to 10 years in gaol and unlimited fines. The legislation includes important incentives for companies to disclose their own wrong-doings. In many ways the UK Bribery Act of 2010 mirrors equivalent US provisions.

Another piece of general legislation driving good practice is the Public Interest Disclosure Act. 1998 (PIDA) (28). PIDA is sometimes known as the "Whistleblower's Charter". This protects employees from aggressive actions of employers if the employee makes disclosures in the public interest, subject to some restrictions. One restriction is that the employee must not benefit financially from the disclosure – that is: they cannot sell their story to the newspapers. Generally in this paper we argue that the public or private status of organisations is of little material difference concerning nuclear professionalism. As regards PIDA there is an interesting and important distinction which proved contentious as the original Bill was being planned and debated. The issue is the status of civil servants under the Act. Their free disclosure is not protected, as they remain bound by the Official Secrets Acts. The most that they can do is report any concerns to the Independent Civil Service Commissioners. Civil servants can never go public revealing state secrets, even in the public interest.

11. Nuclear Professionalism in the UK

In this paper we have sought to consider the role of state owned enterprises in civil nuclear power and issues of safety relating to operators and the supply chain. We have attempted to learn from interesting and difficult British experiences and fictional scenarios typical of the issues faced in Britain. We have also been asked to consider issues of financially motivated self-interested crime and corruption, but we are unable to point to any such examples. Why are we in such a position? Perhaps because such criminality exists, but has not been uncovered, but we suggest that is unlikely. In order to make that suggestion, i.e. that such crimes are not occurring, we point to a wider literature on professionalism and corruption.

Extensive literature on corruption exists and cross-country comparisons are frequently made. There are several well established indices of corruption including the International Country Risk Guide (ICRG), a measure widely used by economists. Other well established indices include: the German exporter Corruption Index (GCI), an index from Transparency International (TI), the Global Competitiveness Survey (GCS) and the World Competitiveness Report (WCR). In 2012 Transparency International ranked the UK 17th best of 176 countries in its Corruption Perception Index. The UK scored 77/100, the same score as Japan. The UK tends to perform similarly well across a range of ranking measures. Much effort has been devoted to understanding why this is the case. Ali and Isse summarised the factors in 2003 with the words (29):

> *"The empirical results are consistent with the theory that higher judicial efficiency, higher level of schooling, greater economic freedom, smaller government, less foreign aid and decentralized government will lower corruption. Ethnicity has no significant impact on corruption."*

Only a subset of academic research on corruption has dealt with the behaviour of state officials. We suggest that we have no strong sense of a difference in professionalism between those working on nuclear matters under state control and those operating in the private sector. Today the vast majority of UK workers associated with nuclear new build work for private companies. Academic work on bureaucratic professionalism indicates that the UK is in a relatively strong position (at approximately the 15th percentile position on a ranked list of countries) (30).

We also note the experimental work of Barr and Serra who studied the attitudes of those living in the UK but originating overseas. They show a correlation of high tendencies to corruption with those arrived from territories ranked highly for corruption, but also show that such attitudes are socialised away over an extended period living (and in the case of the sample, studying) in the UK (31).

Finally we comment in relation to the UK power industry. As stated elsewhere in this paper, the electricity sector was originally nationalized operating as a state monopoly until 1991. The CEGB operated essentially all generation plant including both nuclear and fossil (predominantly coal) plants. In the early days there were examples of corruption in coal-fired plants and senior personnel had their contracts terminated. However recognizing the requirements necessary for nuclear plant management the CEGB carefully selected senior personnel using a competency-based model with the aim of ensuring that those engaged were of the highest integrity and recognized the uniqueness of the nuclear technology they were managing within the legal framework of the licence.

This approach was reinforced by the training arrangements, which majored on the importance of the individual in ensuring that the permissive nature of the licence was internalized by all senior personnel. All personnel knew that if they allowed transgressions, whether from corrupt practices or not, they were then themselves liable to face legal proceedings. Furthermore any such transgression would also significantly damage the nuclear industry, an industry which received much respect from those tasked with serving it.

We hope by these remarks to have evidenced our suggestion that the UK enjoys relatively high levels of professionalism and low levels of corruption and this is related to factors such as education, societal openness and flexibility and culture. We further suggest that the nuclear energy sector should have even higher-than-typical levels of professionalism. In large measure this can be expected to be a consequence of the nature of UK safety regulation and the nuclear licence regime in particular.

12. Closing Observations and Policy Recommendations

Each country around the world generating nuclear electricity has a different set of experiences and lessons learned. In this paper we have sought to explore some of the key learning points around UK nuclear safety. We were asked to give special consideration to the role of state-owned enterprises. In the UK, today, such enterprises have only a minor role in nuclear electricity generation. Prior to the privatisation of British Energy in 1996, however, it was a very different matter.

We are unable to point to an example where state or private ownership makes a material difference to nuclear safety and we are not aware of any significant difference in law relating to ownership in the civil energy sector.

We relate the story of the near-collapse of British Energy in 2002 because it is an example of direct state economic/ownership intervention justified by concerns for safety. As described earlier the government was not willing to see the company enter into administration and be operated by an accountancy firm as an administrator. Citing concerns for safety the government bailed-out the company, before later supporting its sale to the French national champion electricity company EdF.

In many ways all nuclear power producing countries face similar issues; as such it can be hard to identify uniquely British lessons. One important lesson, however, is that nuclear licensing (and national safety legislation more generally) operates permissively rather than prescriptively. As such operator actions are presumed to be permitted on the basis that the operator can justify to the regulator that the chosen actions are indeed safe and environmentally responsible. The goal of UK safety policy is to achieve safety levels As Low As is Reasonably Practicable (ALARP). This aligns with the concept of ALARA or As Low as Reasonably Achievable as used in most other countries around the world in relation to their nuclear sectors. The difference relates in part to the principles of the nuclear safety legislation described elsewhere in this paper. Specifically the use of the word “Achievable” implies ‘achieving a specific prescriptive level’ whereas “Practicable” means ‘able to be achieved in practice’ and hence the UK use of ALARP aligns better to the permissive nature of the UK regulations. For all practical purposes there is no significant difference between ALARP and ALARA in terms of outcome. Typically examples of the application of these principles relate to exposure to radioactive dose when undertaking particular tasks where the aim would be to reduce dose uptake for the worker. Dose can be minimised by changing the working practices or by additional shielding or a combination. An ALARA or ALARP assessment of the task would address both considerations. The ALARA route would target a specific low dose level whereas the ALARP approach would require incremental dose reduction set against the costs/benefit balance. Hence if a significant dose reduction can be achieved for little additional expenditure then it can be justified. While we recognise that the British approach to safety is unusual when compared to internationally widespread practice, we believe it to be superior. While there would be clear benefits in more strongly harmonised arrangements internationally, e.g. within the European Union, it would be unfortunate if that forced the UK to retreat from arrangements that were developed so carefully and which have been found to work so well.

We endorse the emerging idea for a strong infrastructure oversight body, the remit of which should extend further than merely safety regulation, security procedures, environmental protection or crime prevention. The body should also be able to anticipate delays and other problems impacting on infrastructure development. One could argue that the Office for Nuclear Regulation already has many, but not all, of these powers for the civil nuclear power sector. In principle the powers proposed could be applied to critical national infrastructure generally.

We have heard the suggestion of a new standing parliamentary committee and if that is the path taken we would recommend it to be given investigative powers (e.g. power of subpoena). Locating the proposed body inside parliament could lock-it to government election periods which already have enormous power in setting the timescales of policy decisions – not always in helpful ways (e.g. the rushed privatisation of the CEGB in the late 1980s). More than most other infrastructure projects, major nuclear projects are sufficiently large that they involve successive governments and span election periods. Hence, nuclear energy policy risks becoming a political issue. It is interesting to note, however, the resilience in the UK parliament of cross-party support for new nuclear build, matching widespread public support (3).

In respect of building and enhancing nuclear professionalism there has been much activity in recent years. For example the National Skills Academy Nuclear (NSAN), an industry-funded body tasked with skills development and human resource awareness, has been instrumental in developing, with The Open University, the Certificate of Nuclear Professionalism. Meanwhile, more focussed on new entrants to the industry there has been the Nuclear Graduates Scheme. The various engineering professional bodies such as the Institution of Mechanical Engineers, the Institution of Engineering and Technology and the Nuclear Institute (among others) are all actively engaged in continuing professional development in the nuclear sector, Following British tradition these institutions are private legal entities independent of government. They have been granted special privileges (by Royal Charter) and they have charitable status.

In closing we would like to say that in our experience there has been little or no difficult history of workplace crime in the British nuclear industry. We are not aware of corruption or acts of bribery. This leads us to ask: what militates against workplace crime? We suggest it must be a strong professional culture, and strong enforcement, or perhaps both. We speculate that perhaps the nature of interpersonal relationships in the UK workforce and organisational design help? The UK nuclear workplace is serious but relatively informal with short power distances and little deference to hierarchy. Workers operate as responsible individuals and the UK safety culture encourages this including in its formal aspects (the licence). We note that the UK nuclear industry appears to lack the sense of the elite *corps* seen in some other nuclear countries. Perhaps this militates against hubris and reinforces professionalism mixed with humility. Lastly the fact we are not seeing crime means we must be vigilant in our continuous search for it, and we must never become complacent.

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