When safety is relative: Ecological Modernisation theory and the nuclear safety regulatory regimes of France, the United Kingdom and United States

By David Toke

Abstract

This paper analyses the differences in nuclear safety regulation between the USA and two European countries, France and the UK, using ecological modernisation (EM) as a theoretical framework. The EU aims to apply the precautionary principle to nuclear safety regulation. This may encourage greater public acceptance of nuclear risks which will benefit the nuclear industry economically through allowing continued operation and deployment. This may fit in with EM's discourse favouring environmental regulation that increases economic efficiency. However, this is a weak version of EM since it involves negotiations with the industry rather than a 'strong' version of EM involving engagement with leading environmental NGOs who wish to avoid nuclear power altogether in favour of renewables. By contrast, the USA's nuclear safety regulation is constrained by adherence to cost benefit analysis and not the precautionary principle which is associated with EM. The Nuclear Regulatory Commission is dominated by political appointees in its leadership. Attempts to strengthen nuclear safety regulations are often opposed by Republicans who argue from a general position that stricter environmental regulations involve major increases in industry's costs. However, this can lead to increased public argument about the regulations and resulting regulatory uncertainty may, paradoxically, increase regulatory costs.

Key words: ecological modernisation; nuclear power; safety; precautionary principle; cost benefit analysis

Introduction

This paper studies the differences between the safety regulatory approaches to nuclear power in the USA compared to two Western European countries (UK and France). Safety regulation in this context means those rules and/or processes legitimised by the state with the aim of assuring that nuclear power stations do not cause significant harm. Ecological modernisation (EM) is used as an analytical device to understand these differences. The central question is the extent to which the different countries' approaches to nuclear safety regulation are consistent with ecological modernisation (EM). This will be measured by the extent of the application of the precautionary principle and whether regulation is consistent with industrial economic efficacy.

Since EM is associated with western European cultures, two different European countries, that is the UK and France, are chosen as a basis for comparing European nuclear safety regulations with that of the USA. The focus is on the safety of nuclear

reactors since this is the preserve of the nuclear safety regulatory bodies themselves. The UK and France have nuclear power programmes and have been, at least until 2021 (during the period of collection of empirical information), subject to laws of the European Union and, by extension and association, therefore, the EU's EM policies [1].

Perhaps France on its own could be a suitable comparator to the USA given the size of the French nuclear programme. However, it may be useful to include a second European case in order to determine whether France was merely an outlier in comparison to the USA. The UK is an appropriate choice here for a second European country since its culture may be thought to be closer to that of the USA than France and therefore involve fewer confounding variables to help us understand the contextual differences between Europe and the USA on the nuclear regulation issue.

This is an important topic given the relative lack of recent analytical political focus on nuclear safety policies, and also a shortage of attempts to analyse the issue in terms of EM. Jasanoff and Kim [2] analysed a comparison between the USA and South Korean nuclear policies, implying that the US nuclear programme has been constrained by a socio-technical imaginary involving 'containment'. However, a relevant issue is to compare US policies on nuclear safety with European countries and the interaction between safety and economic outcomes. The nuclear safety regimes of other states are studied elsewhere [3].

Ecological modernisation (EM) will be discussed next, and then its particular application to nuclear power. Then this will be applied to nuclear safety regulation in the three countries.

Theory:

1. Different types of EM

According to Machin [1, 211] a key aspect of EM is that 'the market can benefit from environmental challenges by implementing strategies and tools to protect the environment, industries and businesses enhance their efficiency and the rising demand for green technology drives innovation and development'. She analyses EM as a hegemonic discourse in the EU, to such an extent that 'EM is presupposed and promoted as the only feasible option' [1, 214].

Hajer [4, 29] said that (in Western Europe) 'ecological modernisation became the dominant discourse between governments, environmental movements and key expert organisations' and involves seeing 'the existence of a comprehensive environmental problem' [4, 28]. It is an approach which 'conceptualises environmental pollution as a matter of inefficiency' [4, 33]. Hajer describes the 'precautionary principle', as 'one of the principal storylines that structured the discourse of ecological modernisation' [4, 67]. Environmental objectives are achieved through market means with the state giving a guiding hand through a mixture of regulations, incentives and agreements with industry [5]. The polluter pays principle is central to the EM concept [6, 240]. The European Commission defined the precautionary principle as being applied 'where preliminary objective scientific evaluation, indicates that there are reasonable grounds for concern that the potentially dangerous effects on the environment, human, animal

or plant health may be inconsistent with the high level of protection chosen for the Community' [7, 2].

EM can be viewed simply as a suite of policies or, in addition, a set of processes or at least a set of actors which drives the formation and implementation of ecological policies [8, 89]. Szarka [8] focussed on technological means of implementing EM in the EU and the USA. A further distinction has been made between 'strong' and 'weak' ecological modernisation [9]. According to Szarka [8, 89] 'Christoff proposed a distinction between a "weak" variety of EM, understood as technocratic instrumentality directed to technical innovation, and a "strong" variety providing effective ecological protection through a high level of deliberative democracy'. 'Strong' ecological modernisation is generally associated with grass roots action by green activists to promote their green visions and take action, including a dispensation to engage in anti-nuclear activity in the example of Germany [10, 189]. 'Strong' EM advocates have a claim to improve economic efficiency by avoiding nuclear power entirely and adopting what are now widely seen as cheaper renewable energy technologies [11]. These advocates could argue that the precautionary principle would rule out nuclear power entirely, especially in view of the interests of future generations in having to deal with nuclear waste.

It is in the orientation towards technology, maximisation of business efficiency and market expansion that EM differs from sustainable development (SD), as well as the lack of the emphasis on equity and building international movements that is a hallmark of SD [12]. EM itself acts as a discourse that creates a nexus connecting ecology, technology and business that encourages environmental regulation, in this case about nuclear safety. It creates a language and involves actors that distinguishes this political space from other debates about business regulation. EM involves an ecological imperative and is an area in which ecologically interested civil society groups are active.

Ecological modernisation could be said to be present according to the extent of the adoption of the precautionary principle and also the reconciliation of stricter environmental regulation and economic competitiveness. EM is also characterised by there being a political zone in which environmental groups are active, although their role in the policy process will vary between 'weak' and 'strong' EM. It is the combination of these measuring rods that makes EM a suitable and useful means of analysing a comparison between nuclear power safety regulation in the three selected countries. A key indicator of economic efficiency will include the extent to which regulatory certainty, involving stricter regulation, can provide benefits (including meeting some demands made by nuclear critics) without incurring excessive costs.

2. EM and differences between the USA and the EU

There is a major cleavage of opinion within the USA on the issue of environmental regulation. For example, the GOP (Republican) official website states, on the subject of energy-environmental regulation: 'Decades of excessive government regulations and lobbying have cost us tens of billions of dollars, diminished the production of American energy, and wiped out thousands of jobs' [13]. On the other hand, actors in Europe may argue that, in the case of nuclear safety, extra safety measures involve no more than slight increases in cost, but with considerable gains in public confidence.

The former Secretary of State for Energy and Climate Change (at the time of the Fukushima accident), Chris Huhne commented:

'We asked Dr Weightman, a former nuclear regulator who was familiar with all of the issues and above suspicion, to make recommendations (note: about safety improvements). I thought that the key thing in terms of the public particularly given what was going on in Germany, was that the public knew they were going to be dealing with a family of low carbon energy that was absolutely safe. …….Nuclear safety is like a hygiene factor, in that you do not eat in a restaurant that you think is dirty. It needs to be absolutely established, even if it slightly increases the cost' [14].

This quote perhaps epitomizes the key EM nostrum, that perceptions of consumer quality are increased by environmental regulation that improves product quality, thus resulting in greater sales and thus economic efficiency. Implicitly this discourse defends stricter regulatory policies from attacks such as made by Republicans mentioned earlier. The Republican Party's argument, that environmental regulation is costly, is said to have been influenced by extra-party pressure groups led by the organisation 'Americans for Prosperity' in particular [15].

Differences on the application of the precautionary principle between the US and the EU may vary between policy issues, as noted by Wiener and Rogers [16]. However, Wiener and Rogers may be wrong when they claim that the is US more precautionary than the EU on the issue of nuclear power, something that is clearly at odds with the evidence produced in this paper. Indeed, it can be argued that the analysis of Wiener and Rogers fails to distinguish between those issues (eg nuclear safety) where environmental groups are active and where EM analysis applies, and other issues that do not involve substantial ecological issues and pressures from environmental groups.

There appears to be much less of a consensus on global green challenges, including climate change, in the USA compared to the EU, given the lukewarm attitudes of Republican presidents in the 21st century towards taking action on climate change. According to Schlosberg and Rinfret [16, 254] there has been some evidence of limited ecological modernisation in the USA but they also 'note the many elements of the European discourse that have not become part of the US framework. These include a focus on the precautionary principle……'. [17, 268]. Implicitly the authors were referring to the precautionary principle being applied to environmental issues in an EM context. Here it is argued that the public's support for environmental objectives will mean that products designed in accordance with the precautionary principle will be regarded as being higher quality compared to those that are not so regulated. That will make such products more cost-competitive in ecologically aware markets.

Cost-Benefit Analysis (CBA) was installed as the central means of assessing regulatory efficacy during the 1980s, under President Reagan [18], [19, 190]. Indeed such policies can be seen as a reaction against what was seen as an overzealous precautionary approach in environmental policy. Shapiro stated [20, 386] 'Reagan had campaigned on a deregulatory platform' ……'Supporters of regulation have blamed CBA for deregulation and for playing an important role in reducing environmental protections and American health and safety. Opponents of regulation have regularly called for greater use of CBA, citing the immense cost that regulation imposes upon American business' [20, 385]. The use of CBA is ensconced in nuclear safety regulation in that proposals for improvements in nuclear safety at existing installations

have to pass a cost-benefit analysis, i.e. that benefits (avoidance of calculated radioactivity escapes) must exceed costs of retrofit measures. In a report rejecting the need to fit PAR devices to existing PWRs the NRC defined cost benefit analysis as involving 'comparison between the monetary cost (the "impact") of the system and the benefits (the "value") it produces by way of reducing radiation exposure' [21, 1-1].

The EU set out its approach to the precautionary principle in a Communication issued in 2000 [7], which contains the basic definition of the precautionary principle discussed earlier. In this Communication the EU argues that CBA can be used as part of the application of the precautionary principle. However, unlike US regulatory usage of CBA which implies that regulations can only be justified if benefits exceed costs the EU argues that: 'Decision-makers need to be aware of the degree of uncertainty attached to the results of the evaluation of the available scientific information. Judging what is an "acceptable" level of risk for society is an eminently political responsibility' [7, 3)……'The Commission affirms, in accordance with the case law of the Court that requirements linked to the protection of public health should undoubtedly be given greater weight that economic considerations' [7, 19]. This implies that the 'benefits' of avoiding negative environmental impacts can be given more weight compared to the cost of avoiding such impacts.

Sunstein [22] discusses the EU's regulatory preference for the precautionary principle in contrast to the USA's preferred alternative, cost benefit analysis (CBA).
Sunstein rejects the precautionary principle as such as too vague, but instead Sunstein [22, 363] discusses Posner's [23] advocacy of 'a form of CBA with risk aversion'. He argues for the adoption of an 'Anti-Catastrophe Principle' [23, 384). However, in practice, it may be difficult to separate this principle from what the EU actually states in its previously quoted documentation – indeed it may be that the EU's moderately phrased version of the precautionary principle is closer to Sunstein's ideas than those of the USA's strict adherence to CBA principles.

Hence this paper will study the extent to which these regulatory regimes dealing with nuclear power are closer to the EM discourse involving the precautionary principle and the maximisation of economic efficacy through environmental regulation. However, in order to do this there has to be an argument that EM can be applied to the case of nuclear power safety.

3. Nuclear safety and ecological modernisation

Although there has been considerable discussion of the politics of opposition to nuclear energy [eg 24 , 25, 26, 27] there has been little discussion of the relationship between ecological modernisation and nuclear safety. Perhaps a key reason for this is that nuclear power might be regarded as a controversial topic if considered as a positive environmental technology in the sense that leading environmental NGOs such as Greenpeace, the Sierra Club and Friends of the Earth have had a history of hostility to the technology. As the previous discussion says, the environmental movement is very important in setting environmental goals (in EM discourse) and so development of nuclear power, it might be argued, cannot be a subject of ecological modernisation.

On the other hand, some analysts have contended that development of nuclear power as a technology can fall within the remit of ecological modernisation. Lengefield and

Smith [28, 21] argue that ‘many environmental activists who have embraced ecological modernization do NOT advocate nuclear energy; however, many institutions that have enacted policies consistent with ecological modernization and/or environmental reform have, in fact, adopted nuclear energy production as a mechanism for environmental reform’. Certainly, governments such as those in the UK and France have supported nuclear power, yet they also have been associated with the EU and ecological modernisation policies.

However, regardless of such a debate, it may be less controversial to say that the narrower issue of nuclear safety regulatory arrangements is a candidate for discussion of EM. After all, the pollution consequences of industrial capitalism in general are considered to be the key subjects for ecological modernisation processes [29]. The task of preventing the escape of radioactive pollution from civil nuclear operations may be seen to be part of this. That having been said, there may be distinctly different approaches to this issue of nuclear safety in ‘weak EM’ as opposed to ‘strong EM’, as discussed earlier.

It may thus be plausible to argue that weak EM is likely to encompass negotiations about nuclear safety. Weak EM is associated with elite bargaining between corporations and Government to achieve environmental regulatory outcomes through technological means [4]. The topic of nuclear safety regulation falls within this discussion. Environmental groups will act as outsider, perhaps oppositional, groups in the policy process under the ‘weak’ version of EM.

Whilst civil society groups such as the Union of Concerned Scientists may put resources into arguing for nuclear safety measures, in the case of anti-nuclear green activists the arguments about safety may often focus more on them being a reason for phasing nuclear power out rather than arguing for detailed reform [30]. Some allege that there are continuing links between civil and military uses of nuclear energy [31].

So, this paper focuses on the issue of nuclear safety rather on the extent to which nuclear power can, or cannot, be analysed as a positive environmental technology. The improvement of nuclear safety can be said to be a widely shared objective and, also one that is in the interests of environmental protection. So, what is possible is to examine and to compare the differences in nuclear safety regulatory policies in the USA and countries such as France and the UK. It is therefore possible to examine the extent to which the distinction between the use of CBA and the precautionary principle has consequences for nuclear safety techniques. This can help us to understand the extent to which ecological modernisation is applied in the USA and European countries such as France and the UK.

Method Used

Methods included: First, quantitative analysis was conducted, where feasible, on nuclear regulations in terms of their period of promulgation with the aim of studying trends in numbers of new, and changes in, safety regulations. This proved to be only possible on a consistent basis in the case of the USA.

The prime emphasis was on qualitative analysis of documents issued by the three nuclear regulatory agencies of each country, and technical documents on nuclear safety prepared by the IAEA and the OECD. The research included a study visit to the IAEA's HQ library in Vienna. From this, key regulatory issues and technologies were identified to be used as measures for the decisions taken by the three national regulatory agencies. These included differing philosophical and legal approaches to the relationship of costs to safety measures as well as key technical issues.

Specific technological issues are studied using safety technologies which have featured especially prominently in the technical literature on nuclear safety. This is done for the purposes of analysis of any correlations with differences in safety regulatory philosophy. These are: Filtered Containment Venting System (FCVS), Passive Autocatalytic Recombiner (PAR), emergency power and water provision, earthquake and flood risk analysis, and aircraft protection for new reactors. The regulatory codes, rules and decisions made by the three country's nuclear safety regulators were examined for such issues, as well documents issued by bodies such as the IAEA and OECD. FCVS is technology that, in the event of a nuclear accident, permits gases to be taken away from the reactor whilst removing the more dangerous radioactive particles that might otherwise escape from the reactor. PAR technology neutralises hydrogen gas build-ups in the aftermath of 'meltdowns'. Hydrogen gas accumulations can result in explosions, such as occurred during the Fukushima accident in 2011.

The relevance of FCVS and PAR systems increased following accidents such as Three Mile Island (1979) and Fukushima on account of a need to persuade the public that if nuclear accidents do occur, then their worst consequences can be mitigated. These features have been prominent in the nuclear safety discussions about the needs for retrofits sand design changes for new reactors. This has been alongside other issues such as: checks on resistance to flooding and earthquakes; the assurance of provision of emergency water and power services in the event of a severe accident, and aircraft protection. The latter issue increased in importance following 9/11.

By focusing on these technical/regulatory issues a clear set of measurements is established allowing the relative strictness of nuclear safety standards to be assessed in the three country cases.

Second, interviews were conducted with the following actors in all three country case studies to study the issues mentioned earlier: a) officials who are, or have been involved, with the nuclear regulatory authorities in all three country cases. b) independent nuclear consultants in all three cases, with including consultants who worked in the nuclear industry and those who worked with anti-nuclear groups c) civil society groups concerned with nuclear regulatory activities in all three countries. d) it proved practical to interview one former minister with responsibility for nuclear power (in the case of the UK), but not ministers from the other two countries. A limitation was that there were no interviews made with the nuclear power companies themselves, but to compensate for this, pro-nuclear consultants in the US and the UK, and an energy specialising political representative of the French state, were specifically sought for, and interviewed. There was also a study of documents issued by nuclear power companies and trade associations, as well as documents issued by regulatory agencies and civil society groups. The aim of the interviews was to understand overall

institutional, philosophical and regulatory points of controversy and act as a guide to relevant technical issues.

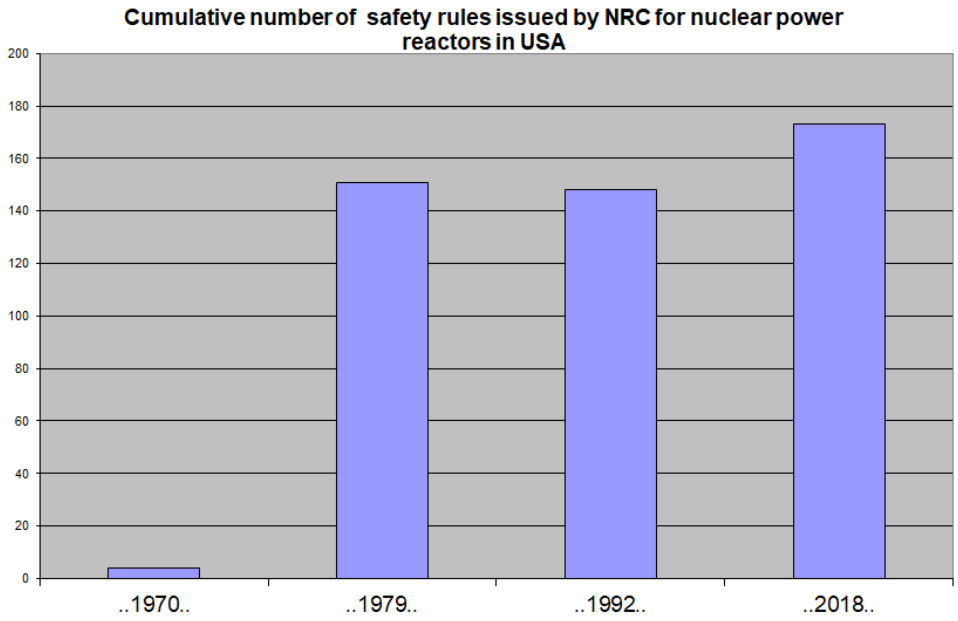
Results of empirical analysis

1. Nuclear safety regulation in the USA

By the end of 2020 nuclear power in USA was generating, on an annual basis, around 20 per cent of US electricity from 94 nuclear reactors [32]. The majority (64) of these are Pressurised Water Reactors (PWRs). The USA's nuclear safety regulation is overseen by the Nuclear Regulatory Commission (NRC). Safety is governed by a series of technical rules called Commission Federal Regulations (CFRs) detailing precise safety measures. These are set by the NRC following consultations, although the NRC has the authority to issue orders without consultation.

The number of safety rules dramatically increased in the 1970s, as can be seen in Figure 1. This increase was, according to Komanoff [33], associated with a sharp increase in construction costs for nuclear power plant. What is less clear is a) whether the regulations caused this increase in cost, or b) whether the regulations were developed to mirror the increases in safety made by the nuclear designers and constructors themselves who tried to meet heightened public concern about nuclear safety. The increase in number of nuclear safety regulations stopped towards the end of the 1970s, although there has been a slight increase in more recent years in order to deal with the expected new types of nuclear power plant that would come online in the 21stcentury. Almost all of the additional safety rules introduced during the 1970s came into force before the Three Mile Island accident in March 1979 [34]. The absence of net new rules in the 1980s coincided with the anti-regulatory discourses of the Reagan era.

Figure 1



Source: author's analysis of NRC safety rule data

The increase in safety rules in the 1970s was associated with the 'inclusion of multiple barriers to prevent or contain potential release of radioactive materials created within the fuel by the fission process' [35, 4]. The NRC was given authority to ensure what was called 'adequate protection to the health and safety of the public' in respect of nuclear power processes [36]. Hence the safety rules are, in effect, to be decided by the NRC's interpretation of what constitutes 'adequate' protection.

Such rules determine the type of license given to proposed nuclear plant operators. Once given such licenses the terms of the license can be altered by the NRC to require a backfit safety measure. However, this can be done only after any revisions will deliver 'a substantial increase in the overall protection of the public health and safety or the common defense and security to be derived from the backfit and that the direct and indirect costs of implementation for that facility are justified in view of this increased protection' [37, para a3)

Hence backfits are required to pass a cost benefit analysis (CBA) conducted in quantitative terms. Assessed benefits of protection to people's health from the prevention of an assumed amount of radiation leakage are set against the various costs associated with making the backfit [38]. It should be noted that no special 'precautionary' weight was attached to the prevention of radiation from serious accidents.

The NRC itself is run by Commissioners, who are political appointees (by the Presidency) with defined periods of office. The appointments have become increasingly partisan according to Nesbit and Dickman [39, 43]. Arguments about safety protocols are thus debated between Commissioners with strong ties to either Democrats or Republicans. A former NRC Chairman, Gregory Jaczko (a Democratic Party nominee), claims that the nuclear industry has used the courts to neutralise attempts to strengthen safety rules and reserve the interpretation of the rules to the

nuclear industry itself [40, 43-48]. He alleges that various of the NRC's initial recommendations for safety improvements in its report which followed the Fukushima accident were watered down or removed because of political backing for the nuclear industry's demands. According to Jaczko [40, 122] 'There is little doubt that the Republican Commissioners would oppose much of the report because they believed that Fukushima was a Japanese problem and that U.S. plants were sufficiently protected'.

Jaczko appears to question the reliance on numerical calculations of risk when he says: 'safety is not an objective statement of scientific truth. Safety is a subjective determination made by societies – or their designated representatives – about the acceptable behaviours that companies and individuals can engage in. There is no textbook that says how much radiation exposure is too much' [40, 60].

Yet the basis of CBA as practiced by the NRC in its assessments of whether safety measures should go ahead [21], contains a precise determination of the impact of radiation, expressed in costs (or benefits in avoiding such costs) set against whether this is greater than the cost of backfit measures. An alternative view is that there should be a 'subjective' judgement that specified risks should simply be avoided. Hence, under this logic, there should be a precaution against the danger that the costs of a particular risk could be much higher than the calculations used in CBA. This is on account of the existence of risks and contingencies that are unknown to the analysts computing the CBA calculations. This is not the practice in the USA nuclear safety system, although it is, on paper at least, a feature of the EU's approach to nuclear safety. There is a difference between assessing only quantifiable risk (the USA approach) and broader notions of uncertainty about risks. The EU's approach will leave some room for this, although not nearly enough as far as anti-nuclear critics are concerned.

Among those risks which are very difficult to quantify are the risks of terrorist attack on a given nuclear plant. After 9/11 there was a battle over whether and how safety measures at nuclear power plant should be increased so that they could be protected against aircraft strikes, a problem that was previously given less priority. However, the NRC's initial response was that such protection was not required [41, 24518 Col 1]. An anti-nuclear group called ''Committee to Bridge the Gap', organised a petition in favour of a rule requiring that all operating nuclear power plant be fully protected against aircraft strikes. The nuclear energy industry, represented by the Nuclear Energy Institute (NEI), rejected the need for such measures [42].

Eventually, after much public discussion a new rule was brought in (in 2009) to require developers of new nuclear power plant (but not existing ones) to build additional shells to protect against impacts by aircraft [43]. However, the delay did bring with it uncertainty and knock-on effects on costs for two schemes for building nuclear power plant. These were a new set of advanced PWR designs for twin sets of power stations in South Carolina, (Virgil Summer 2 and 3) and also in Georgia (Vogtle 2 and 3). The developers initially assumed that the new aircraft protection rule would not apply to them, and then argued with the NRC about the extent of shielding that needed to be put in place. The result was delays in achieving certification of a license with the NRC and increased costs on the projects. The developers (unsuccessfully) sued for the recovery of $900 million needed to complete the new shield [44]. In addition to this the

projects were delayed by arguments over whether the foundations had been built according to the regulations [45].

Even though these issues were settled and serious construction on the projects went forward, the construction of the plant at Vogtle and Virgil Summer were delayed by a considerable period, with the construction of the Sumner plant being abandoned whilst still partly built. Nevertheless, despite arguments with the NRC about the regulations, it is debatable whether the regulatory issues made a major contribution to the extent of the cost-overruns of the plant. A former NRC Commissioner commented that: 'The experience of the 1970s and 1980s was repeated at Vogtle and Summer. For reasons having nothing to do with environmental opposition or regulatory excess these plants and several others now cancelled experienced major costs that they were unable to manage' [46].Indeed it can be argued that if the regulations requiring aircraft protection for new plant had been established quickly after 2001 with legal certainty then the constructors would have saved money in not having to spend time re-designing their proposals as a results of years of wrangling with the NRC.

The Fukushima accident led to the establishment of a review of safety rules and practices under the aegis of the NRC. This review produced a series of recommendations. However, several key recommendations were resisted by the NEI on behalf of the nuclear industry. For example, the original Task Force Report set out a proposed instruction to 'Evaluate need to address risk of seismically induced fires and floods', (47, 5), but this was rejected by the NRC. The Report also recommended having a minimum period of 72 hours when alternative means of supplying power and water could be assured (to avoid Fukushima style meltdowns after loss-of-coolant problems). However, after lobbying by the nuclear industry such provisions were watered down, in effect, to 24 hours [48].

In addition to this the NRC has refused to order the fitting of equipment such as FCVS and PAR to Pressurised Water reactors to limit the impact of nuclear accidents [49].

2. Nuclear safety regulation in France

France has the largest proportion of electricity generated from nuclear power of any large nation, that is over 70 per cent, with 55 out of 56 operating reactors in 2020 being Pressurised Water Reactors (PWRs) [50]. Jasper [51] compared the nuclear programmes in the USA and France (and also Sweden). He argued that France's nuclear power programme was much better planned, and delivered at much lesser cost, compared to the US nuclear programme. Although his analysis needs to be updated from 1990, and he did not do detailed comparison of the technical aspects of nuclear safety regulations, his arguments complement those made in this paper in that he a) discussed the USA's particular focus on cost-benefit analysis and b) said that the French state's emphasis on emphasising nuclear risks 'may produce greater public safety' [51, 260]. This coincided with much more consistent support (in opinion surveys) for nuclear power during the 1980s compared to the USA [51, 261].

The Autorité de Sűreté Nucléaire (ASN) is the nuclear safety agency, and they are advised by the engineering agency the Institut de Radioprotection et de Sûreté

Nucléaire (IRSN). The ASN and the IRSN are independent of Government, although members of their boards of government are appointed by Government on the basis of their expertise in defined areas.

Nuclear safety in France is not conditional, as in the US case, on a cost-benefit analysis being conducted but rather, according to French safety officials, on a commitment to assure safety. French safety officials [52, 53] emphasise the wording of the EU law on the subject approved in 2014, which makes safety objectives a priority without there being any conditionality on satisfying cost/benefit criteria. Article 8a of the 2014 Directive on nuclear safety states:

'1. Member States shall ensure that the national nuclear safety framework requires that nuclear installations are designed, sited, constructed, commissioned, operated and decommissioned with the objective of preventing accidents and, should an accident occur, mitigating its consequences and avoiding:

(a) early radioactive releases that would require off-site emergency measures but with insufficient time to implement them;

(b) large radioactive releases that would require protective measures that could not be limited in area or time.

2. Member States shall ensure that the national framework requires that the objective set out in paragraph 1:

(a) applies to nuclear installations for which a construction licence is granted for the first time after 14 August 2014;

(b) is used as a reference for the timely implementation of reasonably practicable safety improvements to existing nuclear installations, including in the framework of the periodic safety reviews as defined in Article 8c(b).' [54]

Safety regulation in the nuclear sector is decided according to a series of decisions ('avis') on different issues issued by the ASN, rather than a set of discreet rules as in the case of the USA's NRC. There are no published standards, technical guides or specific principles, so trends in safety rules are not quantifiable. Safety reviews are conducted every ten years, and these can involve recommendations for safety improvements, again, with no justification required according to cost benefit analysis. For example, in the 2005 review, it was decided to fit PAR to existing PWR nuclear reactors [52]. Filtered Containment venting systems (FCVS) had been fitted to French PWRs following a decision in 1986 [55, 29].

The French policy avowedly goes beyond the US policy in the design of safety systems ‘In France and in parallel with the USA we considered beyond the design accidents. In France this means a SCRAM system and also to provide back-up to a failure of a safety system. In the USA this is just a SCRAM system’ [52]. (‘SCRAM’ refers to the emergency shutting down of a nuclear reactor by the immediate insertion of nuclear safety rods).

According to a French nuclear safety official from the IRSN, the engineering advisors to the safety agency (ASN): ‘We don’t take into account the cost, but there is an engineering cost – there are not enough engineers to do everything. It is important to prioritise modifications, so we might say leave something until next time. ASN will define the priorities. But always there are some discussions with IRSN about this. When they don’t agree it is often on the timing. The operators may try and lobby the ASN if they perceive that the IRSN is demanding too much. There are hearings which discuss these things, in a college, with EDF as the licensee’ [52].

In the light of Fukushima ‘stress tests’ were held and recommendations made for strengthening what is called a ‘hardened core’ safety system. This includes assuring water and power for the system ‘with a sufficient autonomy to maintain the safety functions at least until off-site provisions are set in place, i.e. during 72 hours’ [56, 44].

On the other hand critics of the nuclear industry say that the safety record and trust in the nuclear safety system is not as high as the official pronouncements might imply. There are historical allegations of malfeasance and cover ups among the operators and commercial contractors over nuclear waste transfers in the 1980s, failure to implement agreed safety improvements and also recently, falsification of records at the forge used to make equipment for the latest nuclear reactor at Flamanville [57].

In France the impact of the Three Mile Island and Chernobyl nuclear accidents was to increase the pressure to find safer techniques for nuclear power in both operating and also planned nuclear power plant. The plant being built at Flamanville is the European Pressurised reactor (EPR), which has been long time in development, originally a Franco-German project by Framatome and Siemens. ‘The entire process was backed up to the end of 1998 by the French and the German Safety Authorities which engaged into a long-lasting cooperation to define common requirements applicable to future Nuclear Power Plants.’ [58]. The aim was to meet increased inherent safety standards.

The techniques involved ‘robust containment’….to……’achieve a significantly lower core melt probability by appropriate prevention means, - achieve the 'preclusion' of accidents liable to cause early containment failure, such as core melt under high pressure conditions, - achieve a major reduction in the radioactive releases, which could result from low pressure core melt accidents’ [58]. Design innovations include double (rather than the usual single) walled containment to contain any radioactivity from an accident, ‘passive safety’ systems and a ‘core catcher’ to prevent meltdowns. In addition, there is an ‘aircraft shell’ to guard against aircraft crashes [59]. FCVS is not required for the EPR, according to EDF, because of the EPRs enhanced safety features.

However, construction of the EPR at Flamanville in northern France has been beset by problems. Although construction was started in earnest in 2007, it still had not been completed by the end of 2020.

3. Nuclear safety regulation in the UK

The UK's nuclear industry is much smaller than in either France or the USA in that in 2020 it had just 15 operating nuclear reactors [60]. Of these just one is a PWR, the others being older, British designs called Advanced Gas Cooled Reactors (AGRs).

The nuclear safety regulator in the UK is the Office for Nuclear Regulation (ONR). The ONR is a technocratic agency that was borne out of the UK's Health and Safety apparatus. Its Chief Executive is appointed by the Government but is statutorily independent in making judgements about its rules and specific safety decisions. As is the case with the French nuclear safety system, decisions are, it is claimed, made on a safety case by case basis according to what constitutes a reduction in risks 'as low as reasonably practicable' (ALARP). However, there are types of guidance in the existence of 'Safety Assessment Principles' (SAPs) and 'Technical Advice Guides' (TAGs). These are revised from time to time. The ONR was unable to comply with a request from the author to furnish earlier copies of the TAGs in order to analyse changes in technical advice and the SAPs tended to vary too much in the way information was presented to allow quantitative comparison of trends. This advice is used to evaluate new reactor designs in a lengthy process called 'Generic Design Assessment' (GDA).

The ONR was, until recently, governed by EU laws, but regardless of this UK health and safety legal traditions fit in closely with the EU's 'precautionary' approach. Common law established following a key legal case concerning a mining accident in the 1940s, says, in effect, that the costs of preventing adverse health and safety outcomes can be considerably higher than the assessed benefits of avoiding the health and safety problems. That, is, so long as that the costs are not 'grossly disproportionate' to the benefits [61, 2, para 1.3]. Indeed a statement from the Inspector at the enquiry for what is (to date) the UK's only operating PWR at Sizewell B is quoted by the ONR where costs to avoid consequences of nuclear safety problems can exceed benefits (of avoiding these problems) by 'a factor of about 2' for low risks 'whereas for higher risks the factor should be about 10' [61, 8, 5.4.8 (i)].

As a result, safety improvements will, according to this philosophy, be assessed on the basis of precaution rather than any simple cost-benefit calculation, although this does not, in practice, lead to all possible safety improvements being adopted. A case in point is an argument between EDF and the ONR about whether FCVS should be fitted to the (now being constructed) design for the European Pressurised Reactor, with EDF successfully resisting the ONR's initial desires [62, 18].

Anti-nuclear groups such as the Nuclear Free Local Authorities have engaged with the ONR, for example questioning, on safety grounds, decisions to allow the operating lives of AGR plant to be extended [63]. The NFLA made a detailed response to the consultation organised following the Fukushima accident [64]. However, rather than suggest specific safety improvements, the concern of the NFLA has been to point out specific dangers of nuclear power. They issued calls for better emergency planning and call for the nuclear power programme to be halted [65].

Following the Fukushima accident, the ONR set up a safety review. The review recommended a series of safety conditions [66, 67]. Chief among them was a) the necessity of providing back up power and water resources for at least 72 hours –which it is claimed was achieved later [66, 18-19]; b) the fitting of PAR equipment to mop up hydrogen in the event of a nuclear accident [66, 22); c) to provide information about, 'margins available for seismic, flooding and meteorological hazards' (in the original designs) and whether 'resultant risks are as low as reasonably practicable' [66,13]; also whether d) 'flood modelling improvements' were done [66, 13].

Unlike the USA there appeared to be no great controversy over aircraft protection. The ONR elected at an early stage to insist on aircraft protection against collisions with large aircraft in designs for new nuclear power plant (although not for existing ones to be retrofitted).

According to an ONR official: 'ONR recognised in late 2001 that there was a need to consider the effects of malicious aircraft crash on proposed new facilities. GDA Requesting parties were advised of this requirement in the early stages of planning for GDA entry.ONR's expectations were further amplified during the GDA process' [68].

Discussion of results in the light of the theory - Comparing outcomes in USA and France/UK

In terms of the philosophy of assessment of appropriateness of safety measures it is clear that there is a significant difference between the USA and the two European countries studied. The US has a bias against measures that, as measured through cost benefit analysis, fail to produce more (costed) benefits as opposed to the costs of implementing the safety measures. The US CBA procedure appears to make no explicit allowance for the unknown consequences of high consequence events.

On the other hand, both France and the UK are committed, in theory at least, to paying the cost of whatever safety measures are required to prevent high consequence nuclear accidents even when the costs of doing so exceed by a considerable margin the benefits of preventing the accidents. In practice there are some limitations on this latter propensity to guarantee safety in absolute terms. In the case of France some measures may be given greater priority than others. In the case of the UK costs for backfits will not be ordered if their costs are grossly disproportional to the benefits. The instance of the fitting of FCVS to the new Hinkley C EPR shows that it is possible for the nuclear company EDF to successfully resist effort by the ONR to insist on precautionary safety measures. In both France and the UK policymakers hope that slight increases in regulatory costs through a precautionary approach can benefit the long run economic development and operation of nuclear power.

These different (country) approaches do have definite consequences in application of nuclear safety technologies themselves. For example, summarising some issues covered already, in the UK and France, there has been an effort to fit existing PWR nuclear power plant with devices to mitigate radioactive releases in the event of accidents. This has included recommendations, by the regulatory agencies in France and the UK to fit FCVS and PAR devices to existing PWRs, something that was not recommended by the USA's NRC. In France PAR was fitted to PWRs well before the Fukushima accident.

Moreover, the French and British nuclear safety regulators have requested that nuclear operators review their flood and earthquake risks of nuclear plant in the wake of the Fukushima accident, and that they should revise them, if necessary, beyond original design specifications. However, this has not been made necessary in the case of the USA. The arrangements decreed by the French and British nuclear regulators about guaranteeing provision of ancillary energy and water resources in the aftermath of a Fukushima-style nuclear accident has been rather more robust compared to the orders made by the USA's NRC. Although in all three country cases there is a requirement for aircraft impact protection on new nuclear power plant, in the case of the USA this proved more controversial than the other two countries, and implementation of such a rule was considerably delayed as a result.

Some key differences (already discussed) between the US, French and British approaches to nuclear safety regulation are shown in Table 1:

Table 1

Comparison of Nuclear safety regimes and selected measures in US, UK and France

	USA	UK	France
philosophy	Cost benefit analysis	Precautionary to avoid major accidents	Precautionary
Licensing practice for new reactors	Rules based	Generic Design Assessment advised by guidelines	Individual plant assessment
Retrofitting existing PWRs:			
FCVS	Not required or recommended	Recommended	Required
PAR	Not required or recommended	Required	Required
Autonomous water and power supplies for emergencies	Required for at least 24 hours	Required for at least 48 hours	Required for at least 72 hours
Post-Fukushima assessments of need to meet earthquake/flooding dangers	Not required	Required	Required
Status of ecological modernisation	No ecological modernisation	Weak ecological modernisation	Weak ecological modernisation

Source: earlier text

It is clear therefore that there are some differences between what can be called a West European ‘weak’ ecological modernisation approach to nuclear safety (at least as represented by the UK and French nuclear safety agencies) and the USA’s approach. However, despite Republican claims that stricter regulations involve high costs there is uncertainty about what effect of the different nuclear regulations have on costs resulting from regulation. Indeed, the experience of how aircraft protection regulation was dealt with could mean that the greater regulatory certainty in the British and French nuclear safety systems constrains the costs of safety regulation. On the other hand, in the US, the nuclear industry’s efforts to oppose extra aircraft protection for new nuclear plant resulted in delays and extra costs for the nuclear power plant being built in Georgia and South Carolina.

An additional point also becomes clear in that a ‘strong’ version of EM may involve a more critical stance towards nuclear power. This recognises that a strategy based more on renewable energy may achieve greater economic efficiency than one reliant on nuclear energy. Moreover a ‘strong’ EM approach may be more critical of the intergenerational consequences of nuclear waste. This discourse can be related to arguments to include environmental justice as a consideration [69].

Conclusion

At the start of this paper, it was stated that: ‘The central question posed is the extent to which the different countries’ approaches to nuclear safety regulation are consistent with ecological modernisation (EM). This will be measured by the extent of the application of the precautionary principle and arguments about the impact of regulatory costs on the economic operation and development of nuclear power’.

It is not possible to compile a direct comparison of the costs of regulation in nuclear safety in the USA compared to the UK and France, but what can be said is that the framing of the debate about precaution and regulatory costs in the EU fits the indicators for weak ecological modernisation. EM can be said to be operating in a weak sense in the UK and France in that application of the precautionary principle depends on negotiation between the regulatory authorities and the nuclear power industries themselves. Cost priorities will still be an issue and, as appears to be the case in France, the implementation of regulations involving excessive costs for specific reactors (which reduce the operating time of the reactors) may be deferred.

A prime motivation behind stricter safety regulations is to improve public relations with measures that will mollify fears about safety, thus allowing the nuclear industry to carry on generating and earning income. This is exemplified in the quotation set out earlier from the former UK Energy Minister in which he claims to trade off a ‘slight’ increase in regulatory cost for an increase in public confidence in nuclear safety. The result is economic benefit for the nuclear industry. This positive sum outcome, i.e. continued economic activity alongside attempting to meet increased demands for ecological protection, achieves key indicators of ecological modernisation.

By contrast, the USA nuclear safety regulation is hemmed in by a strict adherence to cost benefit analysis where 'unknown unknowns' are excluded from the cost accounting thus making an EM style precautionary approach to nuclear difficult to deliver. In practice attempts by the US NRC staff to strengthen nuclear safety regulation are often opposed by Republicans. The Republicans can exercise their influence through their appointees on the NRC to support the objections from the nuclear industry to stronger safety measures. Ironically this approach can lead to higher regulatory costs if, as has been the case in the instance of aircraft protection regulation, greater public argument leads to continued disputes and uncertainty about regulatory arrangements.

On the other hand, anti-nuclear NGOs may favour a different positive sum outcome involving substituting renewable energy for nuclear energy which they would argue is cheaper without having concerns about nuclear safety or nuclear waste. This dual policy mixture of economic gain and better ecological protection would also satisfy the criteria for ecological modernisation, but this can be called 'strong' EM.

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