A critique of the Hinkley Point C nuclear power plant decision
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DRAFT FOR CONSULTATION

This is a short position paper on the UK Government's recent accouncement to go ahead and permit development of a new nuclear power station at Hinkley Point (DECC, 2013a). The two atomic fission reactors and power generation plant are to be guaranteed an above-market rate for the electricity to be generated (Guardian, 2013a; WNN, 2013).

This paper has been prepared to support a proposal for an organisation to take a public position on this project decision. As presented here it is a draft for discussion.

Essential references have been given. Full references for the numbers and other data quoted are available by email.

1. Expensive electricity from a minor energy provider

- **Power from Hinkley Point C is likely to be at least 50% more expensive than the average wholesale price of electricity.**

- **Hinkley Point C would only produce around 2% of the UK's total energy needs (excluding transport fuels).**

The announcement on 21 October 2013 means that Hinkley Point C will be able to sell electricity energy at a minimum of £92.50 per megawatt hour (MWh) - the so-called "strike price" agreed (BBC, 2013a). If Électricité de France (EdF or EDF Energy), the energy company managing the project, also agree to build the planned nuclear power plant Sizewell C, the strike price would be reduced to £89.50 per megawatt hour (MWh), to reflect the understanding that building a second power plant of the same design should be cheaper than building the first (Utility Week, 2013a).

Ofgem's Supply Market Indicator for Electricity indicates that for the average household consumption of 3,800 kWh (kilowatt hours) per year, the wholesale costs as of October 2013 are £225 out of the total electricity bill of £600, meaning that energy companies are buying electricity from producers at £59.21 per MWh (one megawatt hour is a thousand kilowatt hours) (CF, 2013; Ofgem, 2013a). This means that if Hinkley Point C were generating power now, the power would be £33.29 more expensive, adding roughly half to the cost of wholesale power.

The strike price for Hinkley Point C is to be index linked to consumer price inflation (CPI) (IET, 2013; IMechE, 2013a; NEI, 2013; Spinwatch, 2013; Utility Week, 2013b; UK Govt 2013); which means that even with subsidies, wind power and solar power should cost far less than this new nuclear power by the time Hinkley Point C comes online, around about 2023 (Utility Week, 2013d). One estimate puts the strike price at £121 per MWh for 2023, double today's average wholesale price (Guardian, 2013b; Utility Week, 2013c).

For 2012, nuclear power plants provided just 7.4% of total energy supplied to consumers in the UK, and the average over the latest five years of figures was 6.8% (DECC, 2013b). However, nuclear power plants provided 13.88% of total primary electricity produced in the UK in 2011, averaging at 10.56% over the latest five years for which data is available (IEA, 2013). So, nuclear power is fairly significant within the production of electricity, but not so important when looking at the total energy the country consumes.

Efficiency in the use of electricity is an important policy direction in the UK, and a range of measures will be employed to rein in growth in power demand. According to official UK Government statistics, the UK consumed

376.241 TWh of electrical power in 2012 (DECC, 2013c). According to the recent announcement, Hinkley Point C should come into service in 2023 (UK Govt, 2013), by which time, UK power demand should have reduced. According to the National Grid's UK Future Energy Scenario projections, for “Gone Green”, power consumption in 2020 will be 317 TWh, or under “Slow Progression”, 303 TWh, so an average consumption of 310 TWh (UKFES, 2013) .

The design for Hinkley Point C has two 1,750 MW steam turbines, one for each of two nuclear reactors, and so its theoretical maximum output capacity would be 3,500 MW or 3.5 GW (IMecHE, 2013b). However, the two reactors are each projected to be able to produce 1,630 MW of output energy, so the total capacity of generation would be closer to 3.26 GW (EDF, 2013). If Hinkley Point C operates at full power 90% of the time, it would generate 25.229 TWh on average each year. By 2023, this would represent roughly 8% of all the electricity that the UK consumes. However, the total power that reaches the customer would be less, because of losses in distribution and transmission.

The total gas and power used by end consumers in 2020, is likely to be in the region of 1,112 to 1,178 TWh, so taking the mid-point, 1,145 TWh (UKFES, 2013). Before system losses are accounted for, Hinkley Point C would be providing only 2.2% of the UK’s total energy demand (excluding transport fuels).

The National Grid anticipate that over time, more thermal comfort for buildings will come from electrical heating, which explains why the “Gone Green” scenario has higher power consumption than “Slow Progression”. However, this isn't inevitable, and total power consumption in the 2020s could be considerably less than they anticipate. Thermal comfort in buildings could come from increasing levels of building insulation, rather than electrical heating, if measures such as the Green Deal and ECO (Energy Company Obligation) are improved; and efficiency in the use of electricity could lead to a much higher reduction in power demand than anticipated. Therefore it is necessary to ask the question whether power from Hinkley Point C would be needed by the time it starts generating. It seems likely that Hinkley Point C would not be built without the guaranteed price subsidy, but it can be questioned whether this expenditure is justified.

2. Too late and uncertain to keep the lights on

- **Hinkley Point C would not be generating power in time to protect the National Grid from low energy supply margins in the next few years.**

- **Despite claims that the EPR nuclear reactor design is inherently safer than current designs, there is currently no working EPR yet anywhere in the world.**

- **EPR projects in Finland and France are late and over-budget, and there is no guarantee this would not happen in the UK.**

Ofgem, the UK Government's energy regulator has said that the margin between electricity demand and supply could become very slim in the next few years (Ofgem, 2013b). Hinkley Point C is only expected to be operational some time around 2023, and so cannot answer these short-term energy security concerns.

Professor David MacKay says that in order to meet the generation gap needs of the next few years as we close down coal-fired power stations (and some nuclear power plants will close too), we only need to build a “a few more new gas power stations” (BBC, 2013b).

The EPR (European Pressurised Reactor) units of the Hinkley Point C plan are novel reactor designs, and are as yet untried anywhere in the world (Areva, 2013a; Greenpeace, 2012). The two projects to build EPR nuclear power plants in Europe are both dogged by delays (WNN, 2010; WNR, 2012) and cost overruns (Nuclear News, 2013; WNN, 2012). However, two EPR plants are under construction in Taishan, Guangdong province in China, and are expected to be running within four years' time, and costs are apparently being kept to budget (Areva 2013b; FT, 2013; WSJ, 2013). Even so, there is no EPR power plant in production anywhere in the world as yet. And there are no guarantees that the British project will not cost more than expected and take longer than anticipated to build.

3. Not responding to the demands of climate change at the right pace

- **New nuclear power cannot help us meet our carbon budgets in a timely fashion**

The United Nations Framework Convention on Climate Change (UNFCCC) has the challenge of accepting and responding (UNFCCC, 2013) to the latest International Governmental Panel on Climate Change (IPCC) report showing that the global "safe" carbon budget hasn't slackened since 2007 with the evidence from more recent science – if anything, it's got tighter (IPCC, 2013). The urgency for carbon emissions control means that adopting any strategy with a time-to-completion of more than five years runs the risk of overshooting our carbon budgets. This means that the ambitions for a nuclear power renaissance should not be pursued. We need guaranteed carbon control in a much shorter timeframe than the project lifetime of Hinkley Point C.

4. The money could be better used elsewhere

- **The estimated £16 billion required to build Hinkley Point C could build 8 times as much generating capacity in gas-fired power stations.**

- **The estimated £16 billion, could be used to build a mix of flexible, low carbon gas-fired production and power plant facilities, producing the same amount of power as Hinkley Point C, and still have money left over.**

- **The estimated £16 billion, if used for an energy efficiency scheme in buildings, such as the former CERT, could save energy equivalent to 60 years of the output of Hinkley Point C, a plant with a reported lifetime of 60 years.**

If the Hinkley Point C nuclear power plant runs at 90% of its rating, and 5% of this power is lost in transmission and distribution, it stands to make electricity sales of something like £2.44 billion each year in today's money (with a strike price of £92.50 per MWh), and some have estimated that this could amount to before tax profits of the order of £1 billion each year (Guardian, 2013b). It is not clear if this profit would be re-invested in new energy generation plant, or used in energy conservation projects.

The Hinkley Point C project was before 21 October 2013, said to be likely to cost £14 billion (Process Engineering, 2013). Since then, it is said that it will cost £16 billion to build (Reuters, 2013). What else could one get for £16 billion ? Norway have just agreed a plan to build a further 1.3 GW (gigawatts) of wind power for 20 billion kroner (crowns), around £2.1 to 2.3 billion, which would produce roughly 3,400 GWh (gigawatt hours) a year operating at 30% "load factor" - how much of the wind the turbines can turn into usable power. The developers claim 3,700 GWh (Energy Live News, 2013; Power Technology, 2013; WindPower Monthly, 2013). If this investment were repeated for 7 years, the total cost would be £14.7 to £16.1 billion and the amount of power from the new wind farms would amount to roughly 25.9 TWh (terawatt hours - a terawatt is a thousand gigawatts) per year, which can be favourably compared to the predicted output of Hinkley Point C of 25.229 TWh per year. The wind power would be fully available by 2020, at least 3 years before Hinkley Point C comes online, and it wouldn't have end-of-life costs such as radioactive waste disposal and plant decommissioning hanging over the project.

Liberum Capital, the stockbrokers, said in a press release on 30th October 2013, that for the £16 billion that it will cost to build 3.2 GW of Hinkley Point C nuclear power capacity, the UK could build 27 GW of gas-fired power plant, "solving the 'energy crunch' for a generation" (Utility Week, 2013c). An alternative proposal would be to spend around £7 billion on new Natural Gas-fired power plant (12 GW) and £4 billion on low carbon substitute or synthesis gas (SNG) production and power plants, to provide the same amount of power as Hinkley Point C (25 TWh per year) and have £5 billion left over to pay for the difference between gas fuel and nuclear fuel. Gas-fired power generation is very flexible, and the capacity for flexibility in the electricity supply grid is going to become increasingly important as the amount of true renewable electricity increases, to fill in gaps in demand, because the sun does not always shine and the wind does not always blow.

Instead of spending the £16 billion on energy production, if the same capital were used on energy demand reduction, such as building insulation, it could permanently remove the need to purchase energy. The current Green Deal aims to help homes become lower carbon. The current Energy Company Obligation (ECO) scheme to help insulate hard to heat homes costs £1.3 billion every year. One of the predecessor policies, the CERT (Carbon Emissions Reduction Target) scheme was good value for money. The CERT scheme over its lifetime cost £5.3 billion and made lifetime energy savings of 500 TWh, and its parallel policy, CESP (Community Energy Saving Programme), 32 TWh, according to one calculation (Rosenow, 2012). If £16 billion were to be spent on energy conservation using similar methods, it would avoid the need to consume 1,509 TWh, equivalent to nearly 60 years of the anticipated output energy from Hinkley Point C, a plant scheduled to have a total lifetime of 60 years (although the subsidies will only last for 35 years).

5. Inflexible generation from the largest generation units

- **As more renewable energy enters the grid, we need all new generators to be flexible, but nuclear power is not.**
- **The Hinkley Point C design means that the National Grid will need to increase their amount of emergency backup, known as STOR.**
- **The growth in wind power and the STOR mean that Hinkley Point C is redundant.**

It is often claimed that we need nuclear power to act as "baseload", that is, power generation capacity that is "always on". However, as the amount of renewable electricity comes on to the grid - wind power and solar power being the most important - other forms of generation need to be flexible to "fill in the gaps" for the variability in renewable generation - when the sun is not shining or the wind is not blowing. With current nuclear power plants, it is not desirable to turn a nuclear power plant off or on too often, and it is expensive to reduce or increase the amount of power coming from a nuclear power plant - something that is done in France, for example. By contrast, gas-fired power generation is easy to turn off and on, and using gas to backup wind generation makes the sum total cost of power cheaper, as the wind power is essentially free. The amount of gas-fired generation capacity and other capacity used in emergency that we already have is plenty enough to cope with the UK's projected growth in wind and solar power over the next 15 to 20 years. Just to note : renewable power is not the reason why we need spare capacity. Even if there were no renewable sources of power feeding the grid, as the operation of the National Grid becomes less energy wasteful and more "lean" in future, backup capacity will be essential in balancing the nation's power supply.

The EPR is claimed to be designed to ramp up and down in power output, (WNA, 2013), but the costs and consequences of attempting this are not yet proven or disproven. Importantly, damage to the EPR nuclear fuel could be higher from cycling the power output down and up, if there is high burn-up fuel in the reactor cores.

If there is an emergency powerdown by a large electricity generator, either because of an accident or the need to service the units, the National Grid have a method of dealing with this, known as STOR - Short-Term Operating Reserve. It issues orders to spare generators standing by to start producing power within minutes, and others within hours. During the St Jude's storm on the night of 27th / 28th October 2013, two units of the Dungeness B nuclear power plant were shut down owing to weather-related complications, adding up to a sudden loss of roughly 800 MW of power, during which time the STOR brought on hydroelectric power (HEP), pumped water storage power and open cycle gas turbine (OCGT) power, all standing by for just such an eventuality.

Currently, the largest power generation unit on used in the UK National Grid for power is Sizewell B, with one reactor and two turbine generation units nominally each at 660 MW, although total plant output since 2005 has only been at 1,195 MW (dependent on seawater temperature). In September 2013, one unit was operation at 600 MW and the other at 601 MW. The National Grid must have emergency backup for the combination of these two units, owing to the design of the electrical control equipment. If Sizewell B were to suddenly stop working, the National Grid would have to start up alternative power plant equivalent to the 1,201 MW lost.

The Hinkley Point C nuclear power plant design has two nuclear reactors, each projected to produce heat equivalent to 1,630 MW (megawatts) through conversion of the heat via two Arabelle steam turbines supplied by Alstom, each capable of generating 1,740 MW of electrical power. The total electricity that would be produced by the plant is reported to be in the region of 3,260 MW, although electrical power used within the plant itself - known as "parasitic load" - may bring the total available for supply to the National Grid down to around 3,000 MW from the two units.

If the Hinkley Point C power plant is completed, either one of the units going offline would require National Grid to provide emergency power of around about 1,500 MW, or perhaps more, ten times as much as any wind power outage could be. Having this nuclear power plant on the grid would mean that National Grid have to have a bigger emergency response capacity than at present.

Existing plans to develop STOR capacity, using a range of methods, combined with the increase in wind power capacity, mean that Hinkley Point C will be redundant before it's even opened.

6. Extra safety measures, but the prospects of more dangerous fuel, and higher accident risks

- **The EPR nuclear power plant design has had more safety measures included, owing partly to the Fukushima Dai-ichi multiple nuclear reactor accident.**

- **The EPR reactor design could be tailored to use dangerous mixed oxide fuels - reprocessed from radioactive waste.**

- **Ramping the power output of the EPR up and down will be dangerous because of high burnup fuel.**

- **Damages to the nuclear fuel rods cannot be quantified, and extra emissions allowances have been requested.**

The design for Hinkley Point C includes two concrete reactor containment walls, each more than a metre thick; and a six metre thick concrete floor under the reactor vessel, with channels for meltdown dispersion, and a cooling system. After a total lost of power, cooling systems failed at Fukushima Dai-ichi and the reactors overheated - so to avoid this, the design for Hinkley Point C will have six separated flood-proofed independent power generators. But the official documents looking at the design consider only the use of normal uranium oxide fuel, as mixed oxide fuels are said to be "out of scope". The EPR could potentially be partly loaded with MOx (mixed plutonium and uranium oxide) fuel, and this would increase the risks of any potential accident. Although the only MOx fuel production facility in the UK has been closed, other reactors in Europe are fuelled with MOx, which comes from international nuclear waste reprocessing.

The 2008 UK Government White Paper "Meeting the Energy Challenge A White Paper on Nuclear Power" concluded that “our view remains that in the absence of any proposals from industry, new nuclear power stations built in the UK should proceed on the basis that spent fuel will not be reprocessed. As a consequence, plans for waste management and financing should proceed on this basis”. However, this does not rule out the practice.

Nuclear power plants are usually expected to run all the time. Most of Britains nuclear power plants were built with the assumption that they would run producing a constant level of power. The output of electricity from a nuclear power plant can be reduced and increased, but there are risks and financial penalties for doing so unless it is absolutely necessary – for example under emergency conditions. Some nuclear power plants in Europe are used to follow peaks and troughs in power demand, and it is possible that the Hinkley Point C power plant would be expected to do the same. However, given the stated plans for the nuclear fuel in the reactor, this increases the risk of plant failure. The UK EPR (TM) is expected to have some high burn-up fuel rods in its reactor core, and studies have shown that repeatedly stopping and starting nuclear fission in such fuel rods, such as by removing them from a reactor core and then replacing them, or bringing the output power of the reactor down and then up again by inserting and removing control rods, causes high physical stress in high burn-up fuel rods, and could compromise fuel and fuel rod integrity. It is not yet known if "power cycling" of the EPR can be done safely, and it could be shown that it is risky to do so. In this case it would mean that the reactor would not be fully flexible.

The EPR Pre-Construction Safety Report explains that EDF Energy have requested high tolerances for Xenon and other noble gas emissions, presumably as they cannot tell how easily it will be for high burn-up fuel rods to develop leaks of fission gas (see Appendix A). This suggests that the safety of this type of nuclear fuel is not yet fully quantified.

7. Transparency issues

- **Secrecy and lobbying have dogged this decision**

There are a number of areas surrounding the Hinkley Point C announcement that are unclear. For example, on 29th October 2013, in the House of Commons, Paul Flynn MP received a reply from the Nicky Morgan on behalf of the UK Treasury that "non-disclosure agreements have been signed ahead of commercial discussions with potential investors in Hinkley Point C. A [loan] guarantee has not been approved and a security package has not been agreed. At this early stage of discussion with investors it cannot be said what will be published however the Government will disclose information within the bounds of the confidentiality agreement." (Hansard, 29 Oct 2013, Column 432W)

This demonstrates that this deal is far from completion, and raises questions of confidence. It also throws up the lack of transparency surrounding the negotiations between Government, the energy industry and the investor groups. The exact nature and size of all the subsidies that will be made by the UK Government to the investors and project managers is still uncertain.

The deal apparently guarantees the subsidy payments, even if the project goes into administration, according to wording in the "Notes to Editors" of the Press Release from the Department of Energy and Climate Change on 21st October 2013 : "Compensation to the Hinkley Point C investors for their expected equity return would be payable in the event of a Government directed shut down of Hinkley Point C other than for reasons of health, safety, security, environmental, transport or safeguards concerns. The arrangements include the right to transfer to Government, and for Government to call for the transfer to it of, the project company which owns Hinkley Point C in the event of a shutdown covered by these provisions. The compensation arrangements would be supported by an agreement between the Secretary of State for DECC and the investors."

The Press Release also raised the prospects of challenge to the announcement : "The commercial agreement reached today on key terms is not legally binding, and is dependent on a positive decision from the European Commission in relation to State Aid."

Since the project is scheduled for completion at least a decade away, and it is not possible at this time to accurately project the prices of fossil fuels, or fossil-fuel generated electricity that far into the future, it could be that market forces enhance the role of energy conservation and the development of renewable electricity in that timespan, making the power from Hinkley Point C redundant. Another possibility is that the electricity market becomes subject to further reforms to enable stronger competition, and so it could be envisaged that power from Hinkley Point C could remain unsold.

Those who work in the nuclear power sector, whether employees or contractors, are constrained by the conditions of their contracts to keep strict secrecy on a number of aspects of their work that could risk national security. This means that whistleblowing on the health of the industry is fraught with complication, and although a number of failings in nuclear power plant operation and nuclear engineering have come to light, it is not clear what else may emerge.

8. Security matters

- **The Hinkley Point C project will be mostly foreign-owned and controlled.**
- **Proliferation risk**

As part of the Hinkley Point C project, a radioactive waste repository will need to be built on the site that will hold contaminated material for a 100 years before permanent disposal is made. This is just one of a number of security issues raised by the plans for this plant. The announcement on 21st October 2013 signalled the drawing in of Chinese investors to the project consortium, the company to build the plant are French, and the technology is from another French company. This means that the plant will be largely built, owned and controlled by foreign companies.

There are two aspects to the risk of proliferation. Any use of uranium in a nuclear reactor has fissile plutonium as a by-product – the stuff of nuclear bombs. Even reprocessing spent nuclear fuel to extract the plutonium to make mixed oxide fuel does not solve the problem of plutonium, as burning mixed oxide nuclear fuel in a nuclear reactor will create more fissile plutonium as a by-product (although a bit less than went in). Plutonium that has already been separated from spent fuel is a particular risk, should it be acquired by those who would want to utilise it for its explosive criticality. It may therefore be better to make mixed oxide nuclear fuel – at least the final result would be plutonium locked into spent fuel – more difficult to make use of. However, spent fuel is dangerous in and of itself. It is not expected that spent fuel will be under any form of strong containment, and will sit in cooling ponds in insecure warehouses. Draining a fuel pool would at the very least cause a fire in the superheated fuel rods left exposed – and could possibly cause a “dirty bomb” phenomenon if it also exploded. With superheated fuel rods in cooling ponds arising from high burn-up nuclear fuel, the danger is worse than other power plants. In addition, going ahead with the Hinkley Point C power plant will increase the number of dangerous spent fuel pools in the UK. Both of these issues proliferate risk.

There is also the question of double standards. There are some countries currently not permitted by the international community to operate nuclear power plants, such as Iran, but if they see the UK building a big new nuclear power plant, they may be able to make a stronger case for their own plan for civilian nuclear power. The more nuclear power plants there are, the more likely that plutonium could end up in the wrong hands.

9. Radioactive waste and spent nuclear fuel

- **The Hinkley Point C nuclear power station could increase the total radioactivity of the combination of the radioactive nuclear waste and spent nuclear fuel by between 87% and 93%.**
- **The volume of undisposed radioactive waste and spent nuclear fuel is still accumulating in the UK, even without the Hinkley Point C project. Although without the Hinkley Point C project, the**

radioactivity of the total anticipated at point of disposal is decreasing.

The EPR nuclear reactor design is said to generate more electricity from less fuel, however, there will still be significant radioactive and toxic waste from the plant. In the Pre Construction Safety Report (PCSR) of 30 May 2012, Section 2, it says "Spent fuel from nuclear power stations is not categorised as waste because it still contains uranium and plutonium which could potentially be separated out through reprocessing and used to make new fuel", but spent fuel does need to be counted when considering the total radioactivity burden, and the need to make arrangements to dispose of it.

The new EPR nuclear reactors would create radioactive wastes and spent fuel that would add to the UK's total inventory. Going from the Nuclear Decommissioning Authority's 2010 Inventory of radioactive wastes, combined with the report on radioactive materials not in the 2010 Inventory as a baseline, and using a worked example from three reports from the Committee on Radioactive Waste Management (CoRWM Document Numbers 1277, 1279 and 1531) as a guide to how to do the calcuation, it it is possible to estimate that the Hinkley Point C development of 2 EPR nuclear reactors would add between just a few percent to the total volume of radioactive waste and spent fuel; but increase the total radioactivity of the waste and spent fuel by something like 87% to 93%, which is close to **double** the amount of radioactivity to manage otherwise. The final volume for safe disposal would be between 634,000 and 644,000 cubic metres compared to the baseline of 631,000 cubic metres. However, the radioactivity would be between 127 million and 132 million TBq, compared to the baseline of 68 million TBq without the EPR development. The range of values depends on whether current stocks of plutonium and uranium are used to make fuel for the new EPR reactors - MOx fuel. The figures compare with a combined volume of spent fuel and radioactive waste calculated from the 2004 inventory baseline of 478,000 cubic metres, and a radioactivity burden of 78 million TBq.

Although there has been progress with the development of Low Level Waste facilities, much of the remainder of the UK's radioactive waste and spent fuel is not yet in safe, long-term storage, and the total is rising, even without the new Hinkley Point C nuclear power plant. It would seem wise to aim to reduce the total levels of un-secured radioactive materials, rather than create new waste.

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[Transcript by Jo Abbess]
[...]
[Tom Heap]
"Some of Ed Davey’s policies, not least the LibDem [Liberal Democrat Party] U-turn on nuclear, have been guided by DECC [Department of Energy and Climate Change] Chief Scientist David MacKay, author of the influential book “Renewable Energy without the Hot Air” [sic, actually "Sustainable Energy without the Hot Air"]. Does he think the lights will dim in the second half of this decade ?"
[David MacKay]
"I don’t think there’s going to be any problem maintaining the capacity that we need. We just need to make clear where Electricity Market Reform [EMR, part of the Energy Bill] is going, and the way in which we will be maintaining capacity."
[Tom Heap]
"But I don’t quite understand that, because it seems to me, you know, some of those big coal-fired power stations are going to be going off. What’s going to be coming in their place ?"
[David MacKay]
"Well, the biggest number of power stations that’s been built in the last few years are gas power stations, and we just need a few more gas power stations like that, to replace the coal, and hopefully some nuclear power stations will be coming on the bars, as well as the wind farms that are being built at the moment."
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"[...] some PWR types [...] designed for load-following. While most French reactors today are operated in that mode to some extent, the EPR design has better capabilities. It will be able to maintain its output at 25% and then ramp up to full output at a rate of 2.5% of rated power per minute up to 60% output and at 5% of rated output per minute up to full rated power. This means that potentially the unit can change its output from 25% to 100% in less than 30 minutes, though this may be at some expense of wear and tear. […]"

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Appendix A

Glossary of Terminology

Radioactivity

Each atom of each molecule of matter has a core (nucleus) and a shell (one or more electron particles). If an atom loses one or more of its shell of electrons, or gains one or more electrons, it is called an ion. The nucleus of an atom is composed of proton particles and zero, one or more neutron particles.

If the core (nucleus) of an atom is unstable, the atom can potentially one or more of six things :-

1. It can emit an Alpha Particle consisting of two protons and two neutrons. This is essentially a nucleus of a Helium atom, a Helium ion. This is known as Alpha radioactive decay, or Alpha decay.

2. It can emit a Beta Particle consisting of an electron or a positron (a bit like an electron, but with positive electrical charge). This is known as Beta radioactive decay, or Beta decay.

3. It can emit a Gamma Particle consisting of a photon - the same kind of particles as sunlight - but at a much higher energy. This is called Gamma radiation.

4. It can split into pieces - normally two or three. This is called nuclear fission. When this happens, a lot of heat energy is given off.

5. It can emit a neutron particle. An atom can become unstable if it is bombarded (irradiated) by neutrons from the nuclei of other unstable atoms, and if one of these neutrons enters its nucleus. Having an extra neutron in its nucleus can make the atom a different chemical, but unbalanced, so that it is likely to be radioactive itself. The heavier the nucleus, the more likely it will be to undergo nuclear fission. Many unstable nuclei will emit neutrons.

6. It can emit a proton particle, a nuclear particle with a positive electrical charge.

The kind of radioactivity of a substance depends on its nuclear weight. Only the very largest nuclei are capable of nuclear fission - splitting into two, three or possibly more pieces. But most of the really heavy nuclei experience Alpha decay rather than nuclear fission.

All of these forms of radioactive decay give off heat energy, but fission gives off about 10 times as much as the other kinds.

When there are enough unstable atoms in a piece of material giving off neutrons, then there can be a cascade of neutron emissions, one after another, causing a large flow of neutrons, and a lot of heat energy is produced. This is known as a chain reaction. In order to achieve this, there must be at least a certain amount of the material in one place. This is known as the critical mass, and the material is said to have reached criticality. If this situation is not managed, the material can explode from the quantity of heat energy produced.

If material has been irradiated by neutrons, it is called an “activation product” and it will have a number of unstable nuclei throughout its bulk. Even when the neutron flux is removed, and nuclear fission stops, there will still be heat produced by the material, owing to the other kinds of radioactive decay.

Activation products can include the containers of the nuclear fuel, parts of the nuclear reactor, and part of the water or gas used to cool moderate the radioactivity of the reactor core.

Nuclear Power Plant (NPP)

A nuclear power plant uses the heat energy created by nuclear fission (and other forms of radioactive decay) to vapourise water into steam, which drives a steam turbine to produce electricity.

The centre of a nuclear power plant is a nuclear reactor, a special building which contains the nuclear fuel in its core. The nuclear fuel is in packaged in a specific way. First of all pellets of the nuclear fuel are put into a sealed tube of metal alloy. A collection of these fuel pins, or fuel rods, is then packaged into a container called a fuel assembly, which has an outer cladding. When the reactor is in operation, the fuel rods get hot, so water is passed through the core to cool it.

Important Fission Products and Activation Products

If an atom is made unstable, it may become a different chemical, or it may stay the same chemical, but with a different number of neutron particles in its nucleus – in which case it is known as an isotope of the chemical.

In terms of the safe operation of a nuclear power plant, the following are the key chemical end products of neutron irradiation (activation products), radioactive decay and nuclear fission (fission products) that need managing and monitoring :-

a. Plutonium

Plutonium is produced by the irradiation of Uranium with neutrons. There are several different isotopes of Plutonium that are of concern. These are activation products. They are formed inside the nuclear fuel.

b. Highly-radioactive short-lived chemicals

These include isotopes of Iodine, Caesium, Cobalt and Strontium. These are mostly fission products, but radioactive Cobalt can be produced as an activation product if there is a trace of Cobalt in the steel used in the nuclear reactor. These are mostly formed inside the nuclear fuel, apart from radioactive Cobalt. Radioactive Caesium is water soluble, so any leaks from nuclear fuel rods means that it ends up in the reactor coolant if the reactor is water-cooled. Also, if one particular isotope of Xenon is produced in fission gas, it can decay to radioactive Caesium.

b. Noble Gases

The most significant are isotopes of Xenon, Krypton and Argon. These are the most important of the gases known as “Fission Gas”, and are produced as a result of nuclear fission – fission products. They are produced inside the nuclear fuel, but end up being emitted to the atmosphere because leaks from fuel rods.

c. Tritium (3H)

This is an isotope of Hydrogen and forms a gas. It is mosty formed as a product of irradiation of the water coolant in a reactor core (an activation product), but can be a fission product. It can be formed inside the nuclear fuel, and would make its way out into the the reactor coolant if there are leaks in the fuel rods. Otherwise, it is generally produced in the reactor coolant.

d. Carbon 14 (14C)

This is mostly in the form of carbon dioxide (CO2) or methane (CH4). Because this isotope of carbon is radioactive, these are often referred to as radiocarbon dioxide and radiomethane. These are activation products.

e. Helium (He)

This is non-radioactive and a gas. It is mostly formed by Alpha radioactive decay, but can be formed by nuclear fission, and can also be used to create a gap between nuclear fuel and the fuel containers when the fuel rods are manufactured.

Nuclear Fuel

Uranium oxide. Uranium has a heavy nucleus and so more likely to undergo nuclear fission.

Mixed Oxide Fuel (MOx)

Plutonium oxide from reprocessed nuclear fuel is mixed with uranium oxide (either reprocessed or from refined ores) to make nuclear fuel pellets.

Spent Fuel and Spent Fuel Ponds

When nuclear fuel has been in a nuclear reactor, and then becomes less energetic, it is removed from the reactor core, and it is then known as spent nuclear fuel, or spent fuel. It is either prepared for permanent disposal or reprocessed to separate out useful or dangerous chemicals. Besides emitting high levels of radiation of all kinds except neutrons, spent fuel gives off about 10% of the heat that it did when it was in the reactor core, and both the radioactivity and the heat are major concerns. Spent fuel normally goes into a cooling off pond of water for up to ten years, where it needs to be actively cooled, much like in the nuclear reactor. After this time, it is usually stored in a spent fuel pond until it can be reprocessed or disposed of. Most fission products (products of nuclear fission) in the spent fuel are a lot more safe to handle after 100 years, owing to the rate at which they give off radioactivity. It is expected that after 100 years, spent fuel will be much more safe to store in a geological disposal facility (GDF).

Nuclear Power Plant Accidents

The most serious accidents in a nuclear reactor are :-

a. **LOCA – Loss of Coolant Accident**

This is a situation where it becomes impossible to keep the nuclear reactor or the spent nuclear fuel at a safe temperature. There are “small break” LOCA, for example from a pipe or pump, and “large break” LOCA, which would include the reactor being punctured or drained of coolant with no ability to inject more. In the case of water-cooled reactors, if the reactor gets too hot, the water can turn to steam, which cannot keep the reactor core cool.

b. **Problems with Fuel Rods and Control Rods**

Most nuclear reactor designs have a frame, and the fuel rods are slotted into it. To control the output of the nuclear reactor, control rods are also slotted in. When nuclear fuel has been in a reactor for some time, it can swell up or become deformed, or even have a leak, due to a build-up of fission gas inside, or corrosion of the metal containers. This can make it difficult to remove the fuel rods. Control rods can also become warped over time and be hard to manage. In addition, a mechanical fault can mean that fuel rods or control rods cannot be slotted in or out of the reactor core in the way that the plant manager wishes. In some rare cases, the pressure of the coolant in the nuclear reactor can prevent control rods being properly inserted.

Fission Gas and Fission Gas Release (FGR)

Nuclear power reactors work by setting up conditions where there is a build-up in the flow of particles called neutrons. These neutrons cause the central parts (nuclei) of atoms in nuclear fuel to split up into smaller pieces (fission), giving off energy. This energy is in the form of heat, which can be used to generate electricity. The end result of the nuclear fission is smaller nuclei that are different chemicals or elements than the original atoms. Some of these "fission products" are solid, but some are gases. While the nuclear reactor stays working, this "fission gas" generally stays inside the package covering of the nuclear fuel (cladding), even though it increases the internal pressure in the fuel packages (rods in assemblies). Fission gas increases the internal pressure in the fuel rods, and can cause swelling or deformation, which limits the amount of time the fuel rods can safely stay in the reactor. Fission gas can contribute to holes in the fuel cladding, which will then leak the gas and maybe some of the fuel. If there is a nuclear reactor accident which causes a large change in temperature, or the nuclear reactor is partly or fully turned off, or fuel rods are damaged, this gas can be released. Fission Gas Release can also occur when fuel rods are removed from the nuclear reactor, and if they are chemically processed after being used in the reactor. Sudden or high volumes of fission gas being released is a chaotic scenario that may have a range of consequences. It is possible to reduce the amount of fission gas released from a fuel rod, either by adding special chemicals to the nuclear fuel, or arranging for the fuel to have different physical properties, or by changing the design of the fuel cladding. However, reducing the amount of fission gas released simply means that the fission gas will build up inside the structure of the nuclear fuel, which has its own risks when the spent fuel is removed from the reactor (upon change in external pressure), reprocessed or conditioned for disposal. In addition, should the fuel package become damaged - either during an accident or during reprocessing or conditioning of the fuel at the end of life, the higher levels of fission gas inside the fuel could cause problems. Fission gas that is released from leaking or damaged fuel rods when they are in the reactor core ends up in the reactor coolant and must be filtered out. It is normally vented to air after filtering, allowing some time for it to lose some of its radioactivity.

Fuel Rods

The centre of a nuclear power plant is a nuclear reactor, a special building which contains the nuclear fuel in its core. The nuclear fuel is packaged in a specific way. First of all pellets of the nuclear fuel are put into a long thin sealed tube of metal alloy. A collection of these fuel pins, or fuel rods, is then packaged into a container called a fuel assembly, which has an outer cladding. The fuel assemblies are loaded into the reactor core. When the reactor is in operation, the fuel rods get hot, so water or gas is passed through to cool it. Theoretically, the coolant should not come into direct contact with the nuclear fuel, as they are contained, however, most nuclear power plant operators recognise that it is possible that they can have leaking fuel rods. Regular inspection and surveillance programmes are therefore necessary.

High Burn-Up Nuclear Fuel (Burnup, Burn up)

It is possible to make nuclear fuel that “burns up” more than normal. This does not mean that the nuclear fuel is used up faster. What it does mean is that a higher percentage of the same volume of nuclear fuel can be fissioned by the reactor. The net result is that the same amount of nuclear fuel carries on producing energy for longer, so theoretically it can be in the nuclear reactor for longer before it needs to be replaced by fresh fuel.

Nuclear fuel can be high burn up if it has higher levels of uranium enrichment, or if it has plutonium added, as in the case of mixed oxide nuclear fuel (MOx or MOX).
There are five main reasons why high burn-up nuclear fuel is potentially more dangerous than normal enriched uranium oxide nuclear fuel.

First of all, at high burn-up, the structure of the nuclear fuel changes, and this has implications for fission gas release, potentially making it easier for fission gas to be released if there is damage to a fuel rod. This can create problems with the safe management of the power plant.

Secondly, high burn up fuel can be more easily damaged by the changes in temperature and pressure caused by a nuclear reactor partially or completely shutting down and starting up again, or by a fuel rod being removed from the reactor temporarily or permanently.

Thirdly, higher burn-up nuclear fuel will remain in the reactor core for longer, and the operators will resist removing it, for example to check its integrity, as doing so will risk its performance. This means that visual and other inspections of these fuel rods could be delayed. It may be that unless fission gas levels start rising in the reactor coolant, it will not be possible to know that a fuel rod is compromised. Also, if fission gas levels in the reactor coolant rise, it might not be possible to know which fuel rod has been compromised.

Fourthly, there will be more fission products in the high burn-up fuel rods when they are removed from the reactor core, as more of the nuclear fuel will have been fissioned. This means that the nuclear fuel will be hotter, and stay hotter for longer than other kinds of fuel rod. This will be true for not only radioactivity, but also heat output, and will impact on how the fuel needs to be treated after it has been used.

The fifth reason why high burn-up nuclear fuel is a liability is because of the risk of sudden material failure, either from rapid break-down of the fuel rod, because of chaotic fission gas release, or ejection of nuclear fuel from the fuel rod under conditions of high temperature or pressure. If a chaotic failure occurs inside a nuclear reactor, it can damage more fuel rods. If a chaotic failure occurs outside the reactor, it could cause a major release of radioactivity, or fire.

Using what is known as mixed oxide fuel – a mix of uranium oxide and plutonium oxide nuclear fuel – is currently being considered as the recommended option by the UK Government for a plan to “safely” deal with plutonium stocks. However, if MOX fuel is used, these fuel rods will be automatically high burn-up, and in addition to the risks already mentioned, these rods will contain plutonium, which is highly chemically toxic, and many of its istopes are radioactive. If a MOX fuel rod were to disintegrate, either in a reactor core, but more specifically, in fuel rod cooling and storage ponds after use, when it is still hot, and internally stressed by fission gas, there is the added risk of plutonium fuel ejection – a highly dangerous fallout.

As a note, using the UK's plutonium stocks, by reprocessing into MOX fuel will not “eat up” or “burn up” all the plutonium, as fission in the combined fuel will produce other isotopes of plutonium, some of which will be radioactive, particularly close to the start of its use.

Having high burn-up nuclear fuel rods in a reactor core or a spent fuel pond would increase the risks of meltdown in the event of a LOCA – Loss of Coolant Accident, because the nuclear fuel will continue to produce higher relative levels of heat than other kinds of fuel through the radioactive decay of its higher levels of fission products, even when there is no nuclear fission taking place because neutron flux has been stopped.

It is thought that the hotter MOX fuel in the Fukushima Dai-ichi Reactor 3 unit might have contributed to the severity of the accidental explosion and meltdown there, following loss of reactor coolant, even though the plant managers retained use of some of the safety equipment for some time after the earthquake and tsunami on 11 March 2011.

Appendix B

French Nuclear Power

According to data from the International Energy Agency (IEA) and the World Nuclear Association (WNA), nuclear power generates just under 76% of all French electricity production, on a trend towards 78%, based on data in the period 1990 to 2012. This represents an average of roughly 106% of final electricity consumption in the period 1990 to 2012, after taking into account imports, exports, electricity use within the energy industry (parasitic load at 10.5%) and system losses. The IEA calculates that nuclear power represents 81% of primary energy production in France, by applying the average of nuclear power plant conversion efficiency of 33% from heat to electricity. France has become more dependent on nuclear power to meet its total energy demand in the period 1990 to 2012, and this has had the side-effect that winter imports from Germany have been high during winter cold snaps, as nuclear power is not flexible to cope with the much higher demand for heating.