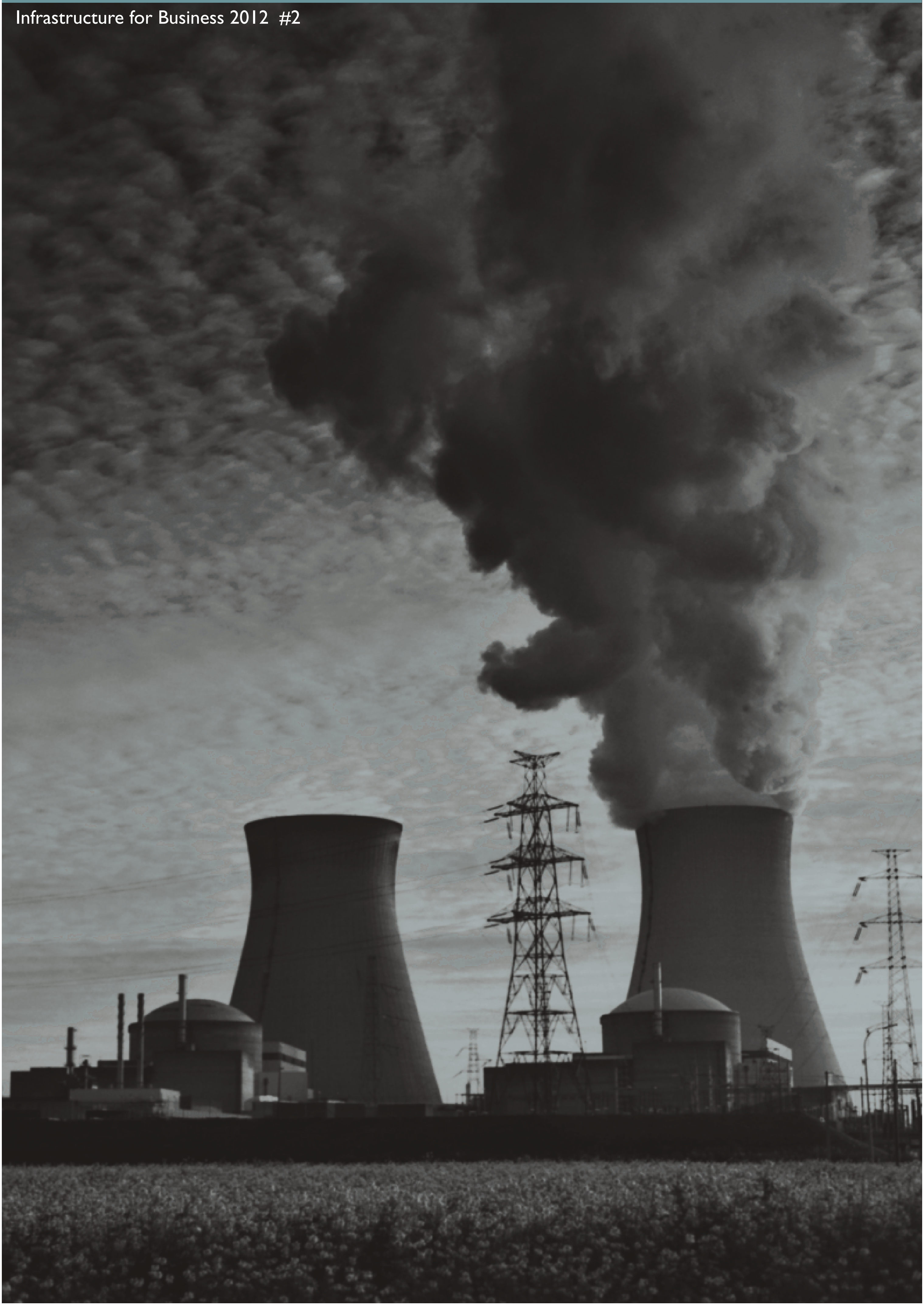
Infrastructure for Business

Britain's Nuclear Future



Britain's Nuclear Future

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Contents

Executive summary

Clean, cheap and safe. These words are not often linked with nuclear power. But they accurately describe a vital baseload energy supply. This report sets out a positive case for nuclear energy and explains why IoD members are so strongly in favour of a new nuclear programme in Britain.

"84% of IoD members want to see a new nuclear programme in the UK."

CLEAN, CHEAP AND SAFE

Nuclear power is clean:

- IoD calculations, averaging out the findings of a number of studies, show that life-cycle CO_2 emissions from nuclear are around 50 tonnes per GWh, compared with nearly 500 tonnes from gas and over 900 tonnes from coal.
- Nuclear also emits far less Sulphur Dioxide, Nitrogen Oxide and particulate matter than gas and coal, over the life-cycle.

Nuclear power is relatively cheap, when costs are levelised over a lifetime:

- For a 2017 project start, including the impact of a rising carbon price, levelised costs are projected to be around £70/MWh for nuclear, £95/MWh for gas, £130/MWh for coal, £145/MWh for onshore wind and £180/MWh for offshore wind.
- Excluding a carbon price, gas and coal are the cheapest energy sources, at £60-70/MWh, although nuclear is not far behind.

And nuclear power is safe:

- According to estimates from the European Commission and the Paul Scherrer Institute, nuclear is the safest electricity generation technology, with a death rate of 0-0.2 per gigawatt year of electricity generated, compared with 0.2 per gigawatt year for wind, 0.1-0.4 for gas, 0-0.8 for hydro, 1.4 for peat and biomass, 2.2 for lignite, 2.8 for coal and 4.1 for oil.
- It is now clear that concern over the effects on health of the accident at Fukushima have been overestimated. There has been no serious casualty from the radiation and none is expected in the future, a view further supported by newly published work at MIT.

IoD MEMBER VIEWS

IoD members overwhelmingly want to see a new nuclear programme in the UK:

- An April 2012 survey of 1,117 IoD members found that 84% are in favour of new nuclear in Britain. In February 2010, a similar survey of 1,798 IoD members found that 85% thought that new nuclear power stations should be built in the UK. These results show that the Fukushima accident has had little impact on IoD members' enthusiasm for new nuclear.

- The April 2012 survey also found that, on average, IoD members think that nuclear should account for around 30% of the UK's electricity supply, a sizeable increase from its current 20% share.

NUCLEAR 2.0: GLOBAL CONSTRUCTION AND TECHNOLOGICAL REVOLUTION

There is no question that Fukushima was a very public disaster for the nuclear industry, although there was no loss of life. A number of countries – including Japan, Germany, Switzerland and Italy – appear to have turned away from nuclear power. But globally, nuclear energy is thriving:

- As of 22 February 2012, almost a year after Fukushima, there were 63 reactors, with a combined power output of 60GWe, under construction; 161 reactors, with a combined output of 179GWe, planned; and 334 reactors proposed, with a combined output of 379GWe. These are very similar numbers to March 2011, before the Fukushima accident.

- China currently has more than 25GWe of new nuclear under construction, with a further 180GWe planned or proposed. In a recent announcement, the Chinese Government set out plans to accelerate the development of nuclear power, slowing down on solar and wind expansion.

A major amount of innovation is currently taking place that could revolutionise the development of atomic power:

- In the next few years, new suppliers are likely to go global. Russia's state-owned Rosatom recently announced it was ready to take the place of RWE and E.ON and construct nuclear plants in Britain; France's nuclear industry was undercut by 30% by the Korea Electric Power Corp for a $20 billion contract to build four plants in the United Arab Emirates; and China is likely to make a concerted effort to export its own nuclear technology.

- Small Modular Reactors (SMRs) are being developed at a rapid pace, and will start to arrive over the next decade. Earlier this year, the US government made $450 million available to support first-of-a-kind engineering, design certification and licensing for up to two SMR designs over the next five years. SMRs will cost less than big power plants, will particularly appeal to countries that don't have large national electricity grids, and are likely to replace more expensive off-grid diesel generators.

- Thorium, which is more abundant and safer than uranium, could also be seen in nuclear plants, although a number of years of concerted R&D effort would be needed before the thorium fuel cycle could be established in current reactors and much longer for any future reactor systems

- Nuclear fusion has been the future for a long time. But a considerable degree of progress has been made in plasma containment and the ability to create extreme heat – both vital to make fusion power work. Fusion is the holy grail of energy – producing abundant and 100% clean power – and its future is starting to look a little closer.

WHY RADIATION FROM CIVIL NUCLEAR POWER PLANTS SHOULD NOT BE TREATED AS EXCEPTIONALLY DANGEROUS

Nuclear radiation is far safer than many people imagine:

- The chance of survivors of Hiroshima and Nagasaki dying from the after-effects of radiation exposure was 0.7% over the next 50 years – about the same as the chance of dying in a road accident in the US.
- Workers whose employment regularly exposes them to mild doses of ionising radiation have a 15-20% lower chance of dying of cancer before age 85 than other workers.
- Radiation is used in medical treatment to save lives. In a monthly treatment a radiotherapy patient will typically receive to some healthy tissue more than 10,000 times the additional annual dose recommended as safe for the public by the International Commission for Radiological Protection (ICRP).

A new tolerance of more realistic radiation exposure levels would bring large cost savings to any nuclear programme, without compromising people's safety:

- Much of the damage arising from nuclear accidents is caused by over-zealous rules based on radiation exposure levels that are too restrictive.
- In 1951 the radiation safety level was set at 12mSv per month, and has since been reduced by a factor of 150 to appease popular aversion to radiation. Current regulations for the public are set to be As Low As Reasonably Achievable (ALARA), 1mSv per year, a small addition to natural background radiation. These levels are recommended by the International Commission for Radiological Protection.
- A new AHARS (As High As Relatively Safe) level might consist of a maximum *single acute dose* of 100mSv; a limit for *chronic or protracted doses* of 100mSv in any month; and a *whole-of-life* limit of about 5,000mSv.
- While no corners should be cut in respect of the control of reactor stability and its heat output, with fresh justifiable safety standards many costs of nuclear power could be reduced dramatically and safely. Nuclear waste, reprocessing and decommissioning should take their place alongside other environmental problems requiring responsible and transparent solutions like the disposal of hazardous chemical and biological waste. They should not be major problems.

"According to estimates from the European Commission and the Paul Scherrer Institute, nuclear is the safest electricity generation technology."

Dounreay, Scotland. Decommissioning of Dounreay is planned to bring the site to an interim care and surveillance state by 2036

NEW NUCLEAR IN THE UK

At the very least, the UK needs to replace the nuclear reactors that are coming to the end of their lives:

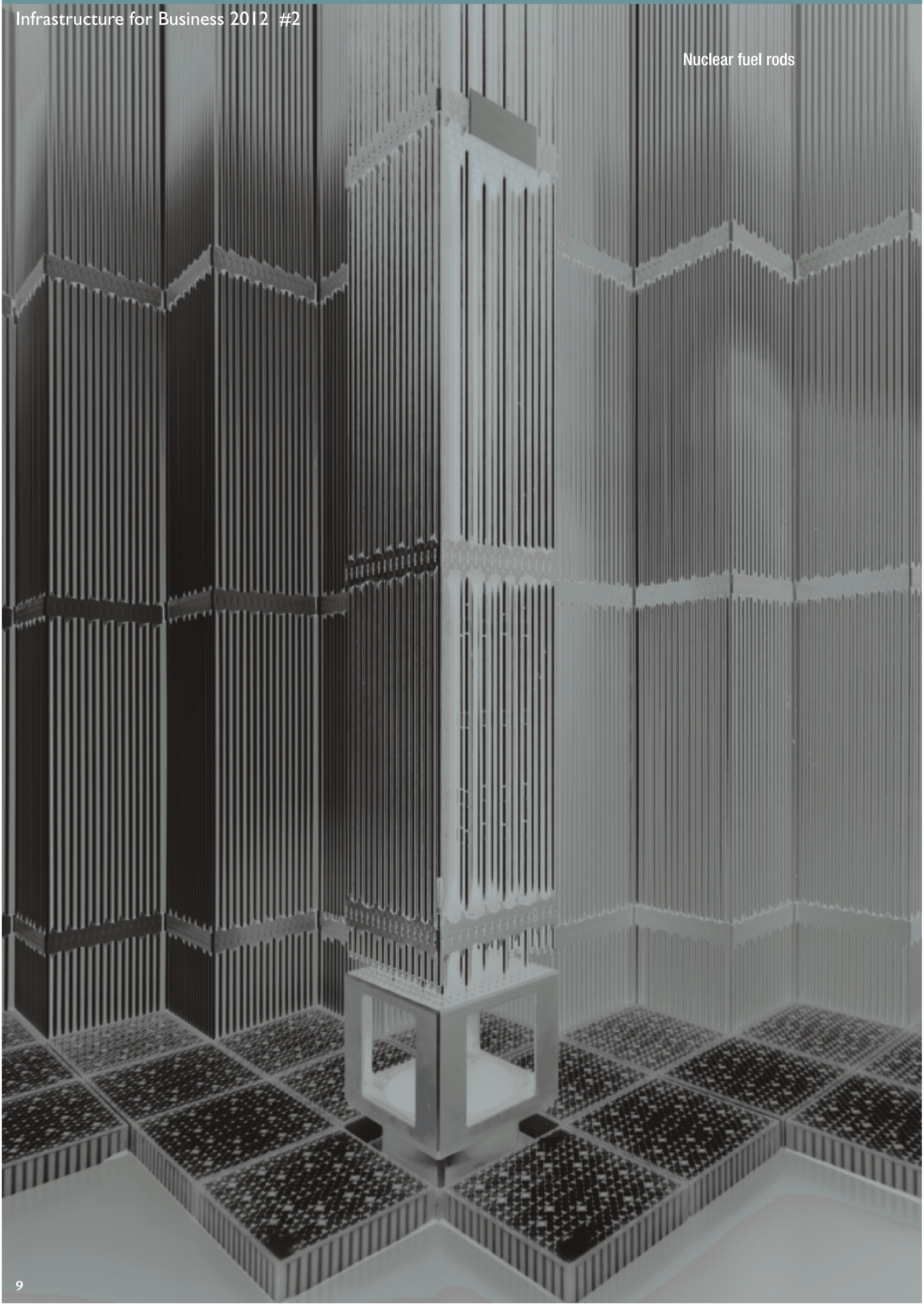
- With the closure of existing coal and nuclear power stations over the coming years, the UK has a large energy gap to fill. Although shale gas looks very promising, gas and renewables may not be sufficient to fill it.

Life extensions of existing reactors are essential, but they cannot go on forever. And at present, the UK's nuclear replacement programme is in deep difficulties:

- E.ON and RWE have pulled out of the Horizon consortium, Scottish & Southern Energy has pulled out of NuGen, and EDF has delayed its final investment decision.
- The biggest hurdle to a programme of new nuclear power stations in the UK is finance – the weak balance sheets of the big utility firms, the "crowding out" effect of high levels of renewable subsidies, and the uncertainly surrounding long-term policy incentives.

Several measures could help to ease the obstacles for investors in new nuclear, including:

- A long-term government-backed financial indemnity, similar to that with Network Rail, would have a major impact on lowering the cost of capital which today is the most important input cost to nuclear power.
- Moving to technology-neutral auctions more quickly within the Electricity Market Reform would reduce any "crowding-out" effect of high levels of renewables subsidies and would better encourage lowest-cost decarbonisation.


Nuclear fuel rods

1. Why nuclear is a vital part of Britain's future energy mix

By Corin Taylor, Senior Economic Adviser at the IoD.

Clean, cheap and safe – words not often linked with nuclear power, but more than a year after the Fukushima disaster, they still accurately describe a vital energy source, and one that the UK must embrace.

"Nuclear is an ideal baseload electicity source."

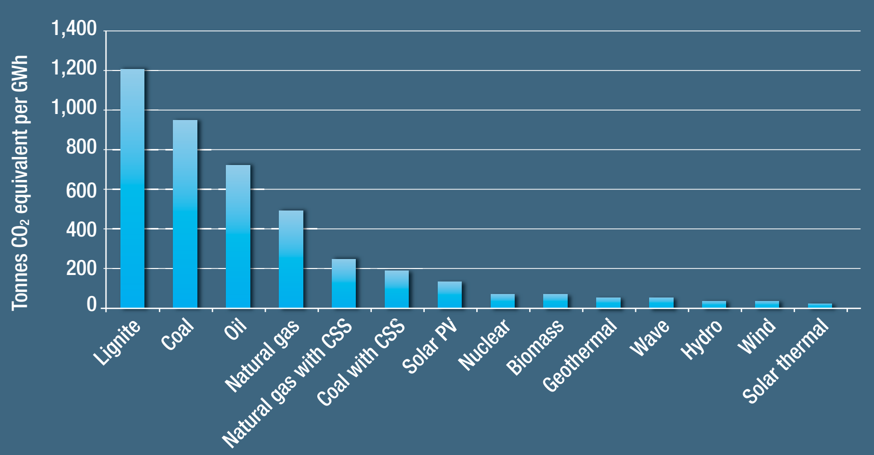
CLEAN, CHEAP AND SAFE

Nuclear energy is remarkably clean. Comparing life-cycle emissions[1] reveals that nuclear is as environmentally friendly as most renewables:

- A number of studies have estimated life-cycle CO_2 emissions from different electricity sources. There are numerous variables to consider, and the ranges given can be quite large, but averaging out the results of these studies shows that nuclear emits less than 50 tonnes of CO_2 per GWh of power, compared with nearly 500 tonnes for gas and over 900 tonnes for coal. Nuclear also emits far less carbon than coal and gas with carbon capture and storage (CCS).

CHART 1.1

Life-cycle CO_2 emissions by electricity source



Source: IoD calculations using data from the following sources: Frans H. Koch, *Hydropower – Internalised costs and externalised benefits,* International Energy Agency, Implementing Agreement for Hydropower Technologies and Programmes, Ottawa (Canada), 2000; World Energy Council, *Comparison of energy systems using life-cycle assessment*, July 2004; Parliamentary Office of Science and Technology, *Carbon Footprint of Electricity Generation*, October 2006; The University of Sydney, *Life-Cycle Energy Balance and Greenhouse Gas Emissions of Nuclear Energy in Australia, 2006;* Oxford Research Group, *Secure Energy? Civil nuclear power, security and global warming,* March 2007; Benjamin K. Sovacool, *Valuing the greenhouse gas emissions from nuclear power: A critical survey*, Energy Policy 36, 2008

[1] For each electricity generation technology, life-cycle CO_2 emissions include, where relevant, emissions from extraction, transportation, processing, plant construction, operation, maintenance and decommissioning. For more information, see Parliamentary Office of Science and Technology, *Carbon Footprint of Electricity Generation*, October 2006 http://www.parliament.uk/documents/post/postpn268.pdf

TABLE 1.1

Life-cycle emissions of pollutants

kg per GWh	COAL		GAS		NUCLEAR	
	Low	High	Low	High	Low	High
Sulphur dioxide (SO_2)	140	3,600	1	324	11	157
Nitrogen Oxide (NOx)	500	2,350	100	1,400	9	240
Particulate matter	17	9,800	18	133	1	1

Source: World Energy Council, Comparison of energy systems using life-cycle assessment, July 2004

- A 2004 report from the World Energy Council also compared life-cycle emissions of Sulphur Dioxide, particulates and Nitrogen Oxide. The ranges given are extremely large, but again, nuclear is shown to be a clean energy source when compared with fossil fuels.[2]
- The IPCC has endorsed these findings, stating that *"nuclear power currently avoids approximately 2.2–2.6 $GtCO_2$/yr if that power were instead produced from coal… or 1.5 $GtCO_2$/yr if using the world average CO_2 emissions for electricity production in 2000 of 540 gCO_2/kWh."*[3]

Nuclear power is also relatively cheap, if the costs are levelised over a lifetime. A recent Civitas report found that, once a rising carbon price and other costs (including transmission) are taken into account, nuclear has among the lowest levelised costs of any of the main electricity sources in the UK:

- For a 2009 project start, levelised costs, including carbon and additional system costs, are estimated at around £80/MWh for gas, £95/MWh for nuclear, £100/MWh for coal, £150/MWh for onshore wind and over £200/MWh for offshore wind.
- For a 2017 project start, when the carbon price is projected to be far higher, levelised costs are estimated at around £70/MWh for nuclear, £95/MWh for gas, £130/MWh for coal, £145/MWh for onshore wind and £180/MWh for offshore wind. Gas and coal with CCS, if the technology proves to be commercially viable, are estimated to cost between £100 and £120 per megawatt hour.
- Excluding a rising carbon price, gas and coal are the cheapest energy sources, at £60-70/MWh, although nuclear is not far behind.[4]
- As the Energy Minister Charles Hendry told the Energy and Climate Change Select Committee on 15 May: "We recognise that different types of [low carbon] technology will have different costs... we would expect nuclear to be cheaper than others."

And despite widespread fears, nuclear energy is actually remarkably safe:

- According to estimates from the European Commission and the Paul Scherrer Institute, nuclear is the safest electricity generation technology, with a death rate of 0-0.2 per gigawatt year of electricity generated.
- This can be compared with 0.2 per gigawatt year for wind, 0.1-0.4 for gas, 0-0.8 for hydro, 1.4 for peat and biomass, 2.2 for lignite, 2.8 for coal and 4.1 for oil.[5]

[2] NB: The data also reveals the potential for fossil fuel plants, especially coal, to become less polluting.
[3] Intergovernmental Panel on Climate Change, Fourth Assessment Report (AR4), Working Group III report: Mitigation of Climate Change, 2007, p.269 http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg3_report_mitigation_of_climate_change.htm
[4] Ruth Lea, *Electricity Costs: The folly of wind power,* Civitas, January 2012 http://www.civitas.org.uk/economy/electricitycosts2012.pdf. The costs in the Civitas report were based on estimates in Mott MacDonald, UK electricity generation costs update, June 2010
[5] Estimates from the European Commission ExternE (Externalities of Energy) project and the Paul Scherrer Institute, cited in David JC MacKay, *Sustainable Energy – without the hot air,* 2008, Figure 24.11 http://www.inference.phy.cam.ac.uk/sustainable/book/tex/sewtha.pdf

- And as Chapter 3 shows, nuclear radiation is far less dangerous than many assume. Current radiation exposure standards permit only tiny doses above the natural background level.
- Chapter 3 also concludes that matters of nuclear waste, reprocessing and decommissioning should take their place alongside other environmental problems requiring responsible and transparent solutions such as the disposal of hazardous chemical and biological waste. They should not be major problems.

IoD MEMBER VIEWS

IoD members overwhelmingly want to see a new nuclear programme in the UK:

- In February 2010, a survey of 1,798 IoD members found that 85% thought that new nuclear power stations should be built in the UK.[6]
- In April 2012, a survey of 1,117 IoD members found that 84% were in favour of new nuclear in Britain.[7]
- The same April 2012 survey found that, on average, IoD members thought that nuclear should account for around 30% of the UK's electricity supply, a sizeable increase from its current 20% share.

NEW NUCLEAR IN THE UK

In 2010, nuclear accounted for 20% of the UK's, and 13% of the world's, electricity supply.[8] It is an ideal baseload electricity source and a vital part of the overall energy mix.

A sizeable chunk of the UK's existing electricity generating capacity will be shut down over the next decade. Closure of around 12GW of old coal and oil-fired generating plants by 2015 is mandated by the EU Large Combustion Plant Directive, with further shut-downs to follow by 2020 under the Industrial Emissions Directive.[9] All but one of the UK's nuclear stations are set to reach the end of their life by 2025, although recent reports suggest that a number may be kept open for a little longer.

The UK has a large energy gap to fill, and, although shale gas looks very promising, gas and renewables may not be sufficient to fill it. At the very least, we should be replacing the nuclear reactors that are due to come to the end of their lives.

The biggest hurdle to a programme of new nuclear power stations in the UK is finance – the weak balance sheets of the big utility firms, the "crowding out" effect of high levels of renewable subsidies, and the uncertainly surrounding long-term policy incentives. Capital costs make up around 80% of the overall costs of nuclear energy,[10] and with a decades-long payback period, these upfront expenditures are a big hurdle for investors.

At present, the UK's nuclear replacement programme is in deep difficulties:

- In late March 2012, E.ON and RWE pulled out of the Horizon Consortium, just a few months after Scottish & Southern Energy pulled out of another called NuGen, citing the lack of nuclear expertise and construction risk.
- EDF, the French utility that only a few years ago promised a new nuclear plant online in Britain by Christmas 2017, has delayed its "Final Investment Decision" until the end of this year – perhaps in the shrewd pursuit of additional subsidies.

[6] IoD Policy Voice survey, February 2010
[7] IoD Policy Voice survey, April 2012
[8] BP, *Statistical Review of World Energy,* June 2011 http://www.bp.com/sectionbodycopy.do?categoryId=7500&contentId=7068481
[9] Peter Patterson, *Electricity generation – will the lights go out?*, Big Picture Q4 2009, Institute of Directors, pp.41-53
[10] See, for example: US Energy Information Administration, *Levelised cost of new generation resources in the Annual Energy Outlook 2011*, November 2010, Table 1

- **The ratings agency, Moody's, recently confirmed that it would downgrade EDF and Centrica if they decided to build four reactors in the UK.**

We should not be too surprised by this. Moody's warning was not really about the cost of nuclear power but the weak starting positions of the combined balance sheets of EDF and Centrica. It takes real balance sheet strength to shoulder the financial risk of a nuclear programme that could easily run over budget and past the construction deadline. And in Western Europe, this has been the case with the only two plants under construction: Flamanville 3 in France (originally due 2012, now delayed until 2016 and EUR 3 billion over budget) and Olkiluoto 3 in Finland (due in 2010, now set to open in 2014 and EUR 2.7 billion over budget). Construction risk comes at a high financial premium and Moody's have noticed.

The recent Draft Energy Bill may well fail to deliver the clean, secure and affordable energy businesses need, and with many details still to be finalised (for example, the "Operational Framework" for the contracts-for-difference pricing structure will not be confirmed until the autumn), the Bill may not yet provide nuclear investors with a high-enough degree of certainty. Waiting until sometime in the 2020s before adopting a technology-neutral pricing structure means that renewables will continue to receive preferential treatment for at least another decade.

Construction on a new reactor, Flamanville 3, began in December 2007, but is now delayed till 2016

The failure to deliver a nuclear replacement programme goes back to before this government. In the early 2000s, As PM, Tony Blair was reportedly vetoed by his own cabinet when wanting 10 nuclear power stations. Had he not been thwarted, those power stations would be coming online now when the cost of capital was much lower and the strength of the utilities' balance sheets much greater.

There were also other chances. The introduction of the Renewables Obligation in 2002, which over-rewarded onshore wind, was a missed opportunity to include nuclear power within the obligation. Had a "Low Carbon Obligation" been introduced instead, it could have made a much bigger impact on increasing the quantity of clean and secure electricity supply in the UK.

The government is now stuck between wanting to appear to support new nuclear power but not wishing to upset the powerful green lobby by giving it public subsidy. This is a nigh impossible balancing act.

There are, however, a number of measures that Government could take to minimise the many obstacles for new nuclear investors and that will take a major shift of political position to be more overtly supportive of nuclear power:

- **A long-term government-backed financial indemnity, similar to that with Network Rail, would have a major impact on lowering the cost of capital which today is the most important input cost to nuclear power.**
- **Moving to technology-neutral auctions more quickly within the Electricity Market Reform would reduce any "crowding-out" effect of high levels of renewables subsidies and would better encourage lowest-cost decarbonisation.**
- **Finally, the Government could move fast to endorse an underground storage site for high-level nuclear waste in Cumbria where a recent poll showed that 68% of residents were in favour (for more details, see BBC News, 22 May http://www.bbc.co.uk/news/science-environment-18144720).**

It is vital that nuclear is given the space to develop in Britain, and a fresh effort will be needed to ensure that new atomic power stations do indeed get built in this country. Unlike previous nuclear programmes, the taxpayer will not be hit by a large decommissioning bill 60 years from now, and a more realistic radiation exposure level, as set out in Chapter 3, would bring down the costs and risks of a new nuclear programme.

As Chapter 2 shows, nuclear construction is being carried out at a rapid rate in many parts of the world, and a number of exciting technological developments beckon. Britain should not turn its back on a clean, secure, safe and affordable form of energy.

McMaster University's research nuclear reactor

2. Nuclear 2.0: global construction and technological revolution

By Dan Lewis, Chief Executive of the Economic Policy Centre, Chief Executive of Future Energy Strategies and Energy Policy Adviser to the IoD.

Post-Fukushima, the public and media perception appears set that nuclear power is in the doldrums and on the way out. Perhaps most prominently, The Economist ran a special nuclear report in March, calling it rather melodramatically, "The Dream that failed". A more careful analysis, however, shows that globally, nuclear power is not only growing but is on the verge of a number of innovative technological breakthroughs that, in the decades to come, will quite likely go mainstream.

NUCLEAR POWER POST-FUKUSHIMA

There is no question that Fukushima was a very public disaster for the nuclear industry, although there was no loss of life. It led Japan to shut down all but one of its 54 nuclear stations; a number of European countries to turn away from nuclear, most notably Germany; and other countries, including Brazil,[11] to delay their plans to build new reactors.

Globally, however, nuclear power is still thriving. As of 22 February 2012, almost a year after Fukushima, there were:

TABLE 2.1

Countries that made a major turn away from nuclear power after Fukushima

Japan	Wrote-off Fukushima Daiichi Units 1-4, which are to be decommissioned. All remaining nuclear reactors have been shut down while undergoing two-phase stress tests. Announced a review of the existing plan for nuclear power. The new energy policy will be developed by mid-2012
Germany	Immediately shut reactors operational before 1980 and announced that all other reactors would be closed by 2022
Switzerland	Announced plans to close its five nuclear reactors by 2034
Italy	A referendum in June 2011 imposed a permanent ban on the reintroduction of a nuclear power programme

Sources: *World Nuclear Organisation (http://world-nuclear.org/briefings/policy_responses_fukushima_accident.html); World Energy Council, Nuclear Energy One Year After Fukushima, 2012, Tables 2 and 3*

- 437 reactors operating, with a combined power output of 370GWe;
- 63 reactors, with a combined power output of 60GWe, under construction;
- 161 reactors, with a combined output of 179GWe, planned;
- and 334 reactors proposed, with a combined output of 379GWe.[12]

The number of reactors under construction, planned and proposed is, in fact, very similar to the number in March 2011, before the Fukushima accident:

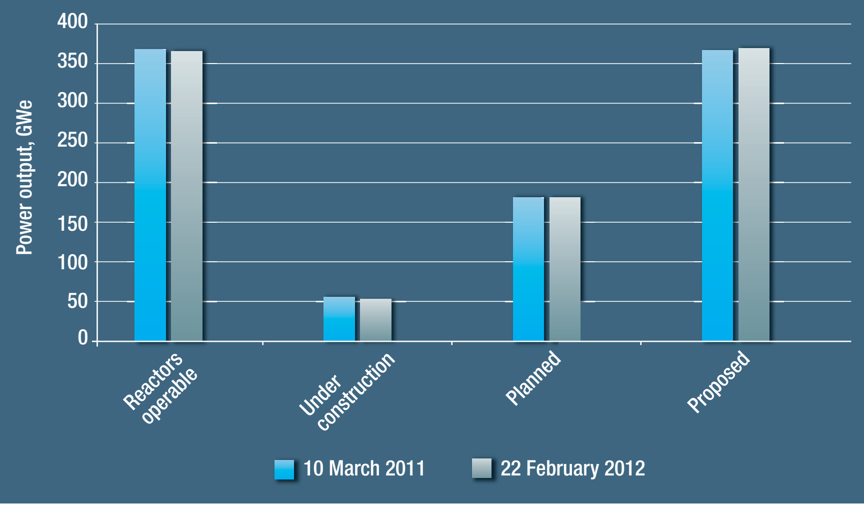
[11] The Wall Street Journal, *UPDATE: Brazil Delays Nuclear Development Plans After Fukushima Disaster* http://online.wsj.com/article/BT-CO-20120208-718332.html

[12] World Energy Council, *Nuclear Energy One Year After Fukushima*, 2012, Table 4 http://www.worldenergy.org/documents/world_energy_perspective__nuclear_energy_one_year_after_fukushima_world_energy_council_march_2012_1.pdf

- As of 10 March 2011, there were 547 reactors under construction, in the pipeline or proposed, with a combined power output of 610GWe. As of 22 February 2012, those figures were 558 reactors with a combined power output of 618GWe.[13]

CHART 2.1

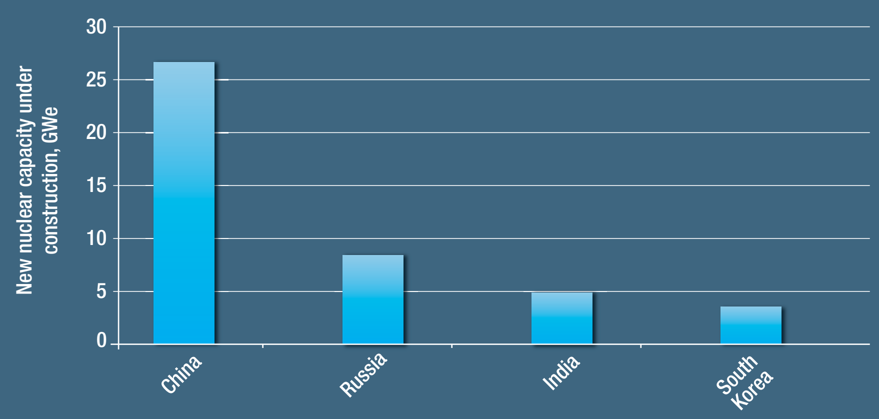
Nuclear development pre- and post-Fukushima



A number of countries, particularly in the emerging world, continue to press ahead with new reactor construction, led, as ever, by China. In a recent announcement, the Chinese government set out plans to accelerate the development of nuclear power, hydroelectric energy and shale gas, putting an end to "blind expansion" in industries such as solar and wind.[14]

CHART 2.2

Countries with the highest levels of nuclear construction, as of 22 February 2012



Source: World Energy Council, *Nuclear Energy One Year After Fukushima,* 2012, Table 4

[13] World Energy Council, *Nuclear Energy One Year After Fukushima,* 2012, Tables 1 and 4
[14] Asia Pulse, *China to drop solar energy to focus on nuclear power*, 12 March 2012 http://www.elp.com/index/from-the-wires/wire_news_display/1621584677.html

The following table presents the overall global picture.

TABLE 2.2

World nuclear power reactors as of 22 February 2012

Country	Reactors operable		Reactors under construction		Reactors planned		Reactors proposed	
	Number	MWe	Number	MWe	Number	MWe	Number	MWe
Argentina	2	935	1	692	2	773	1	740
Armenia	1	375			1	1,060		
Bangladesh					2	2,000		
Belarus					2	2,000	2	2,000
Belgium	7	5,927						
Brazil	2	1,884	1	1,245			4	4,000
Bulgaria	2	1,906	2	1,906	2	1,900		
Canada	18	12,624			3	3,300	3	3,800
Chile							4	4,400
China	16	11,688	26	26,620	51	57,480	120	123,000
Czech Republic	6	3,766			2	2,400	1	1,200
Egypt					1	1,000	1	1,000
Finland	4	2,736	1	1,600			2	3,000
France	58	63,130	1	1,600	1	1,720	1	1,100
Germany	9	12,068						
Hungary	4	1,889					2	2,200
India	20	4,391	7	4,824	17	15,000	40	49,000
Indonesia					2	2,000	4	4,000
Iran	1	915			2	2,000	1	300
Israel							1	1,200
Italy							10	17,000
Japan	50	44,215	2	2,650	10	13,772	5	6,760
Jordan					1	1,000		
Kazakhstan					2	600	2	600
Korea, North							1	950
Korea, South	23	20,671	3	3,640	6	8,400		
Lithuania					1	1,350		
Malaysia							2	2,000
Mexico	2	1,300					2	2,000
Netherlands	1	482					1	1,000
Pakistan	3	725	2	630	1	340	2	2,000
Poland					6	6,000		
Romania	2	1,300			2	1,310	1	655
Russia	33	23,643	10	8,203	14	16,000	30	28,000
Saudi Arabia							16	20,000
Slovakia	4	1,816	2	782			1	1,200
Slovenia	1	658					1	1,000
South Africa	2	1,830					6	9,600
Spain	8	7,567						
Sweden	10	9,320						
Switzerland	5	3,263					3	4,000
Taiwan (China)	6	5,081	2	2,600	1	1,350		
Thailand							5	5,000
Turkey					4	4,800	4	5,600
Ukraine	15	13,107	2	1,900	2	1,900	11	12,000
UAE					4	5,600	10	14,400
UK	18	9,920			4	6,680	9	12,000
USA	104	101,240	1	1,165	11	13,260	19	25,500
Vietnam					4	4,000	6	6,700
WORLD	437	370,402	63	60,057	161	178,995	334	378,905

Note:
Operating = Connected to the grid;
Under construction = First concrete for reactor poured, or major refurbishment under way;
Planned = Approvals, funding or major commitment in place, mostly expected in operation within 8-10 years;
Proposed = Specific programme or site proposals, expected operation mostly within 15 years.

THE NUCLEAR TECHNOLOGY REVOLUTION

"Globally, nuclear construction is still alive and well."

In Britain new nuclear looks to be in a degree of trouble, but in the grand scheme of things, nuclear construction is still alive and well. And in the future, nuclear power may look radically different.

In the popular imagination, nuclear is all about big designs, huge companies and gigawatt quantities of power. But below the radar, a major amount of innovation is taking place that could turn all of that upside down. So just what will this impending new dawn of nuclear power look like?

The next few years: new suppliers going global
The increasing globalisation of the industry is opening up new suppliers of nuclear technology to what was historically a nationally or regionally closed shop. For example, the Department for Energy and Climate Change was recently somewhat taken aback when Russia's state-owned Rosatom said that it was ready to take the place of RWE and E.ON and construct nuclear plants in Britain.

Rosatom have allegedly already hired KPMG to examine possible nuclear site purchases while UK-based PR firms are said to be vying for a contract to promote their international image. Rosatom certainly have wide experience with 26 plants in operation – amounting to some 20 gigawatts of nuclear power – and impending projects in Bulgaria, India and China.

And on a recent trip to Japan, David Cameron signed an agreement to open Britain's nuclear market to "Japanese companies' technical expertise in new plant design and construction" which perhaps shows that he has a lot more faith in their abilities than Japanese public opinion.

Meanwhile, across the channel, a big wake-up call to France's nuclear industry was when it was outbid – undercut by 30% – by the Korea Electric Power Corp (KEPCO) for a $20 billion contract to build four plants totalling 5.6GWe in the United Arab Emirates in 2009. KEPCO claims that it won because it could demonstrate the highest capacity factor, lowest construction cost and the shortest construction amongst the bidders.[15] And several years on, these are currently on track to be delivered on time and to budget.

TABLE 2.3

Planned UAE nuclear power reactors

	Type	MWe gross	Start up
Braka 1	APR 1400	1,400	2017
Braka 2	APR 1400	1,400	2018
Braka 3	APR 1400	1,400	2019
Braka 4	APR 1400	1,400	2020
	Total	**5,600 MWe**	

It's also inevitable that soon we are going to see a more concerted effort by China to export its own nuclear technology. China has already sent abroad outdated designs to Pakistan, and the next step is to roll out a third generation CP 1000 pressurized water reactor for export – as developed by the China National Nuclear Corporation (CNNC), China Guangdong Nuclear Power Group and the State Nuclear Power Technology Corporation (SNPTC).

[15] See http://www.world-nuclear.org/info/UAE_nuclear_power_inf123.html

The next decade: the arrival of Small Modular Reactors (SMRs)

For all that, third generation reactors producing 1GW or more of power are still a big outlay for any nation or company. In these financially straitened times, tying up £6 billion over 30 years to make a return on a 1.65GW Areva EPR is not an easy risk to shoulder without a strong balance sheet. And across the world, many utilities – not just those in Britain – are emphatically not in a robust position, having run up considerable debt over the last decade. Big industrial projects all too often don't turn out right and investors have noticed and started to close their chequebooks.

Financial reticence, combined with CO_2 and air pollution reduction targets, has led to a revival of interest and funding for small nuclear power reactors, ranging in size from 25 to 300MWe, and medium-sized reactors, from 300 to 700MWe. These are deemed to have a future in the marketplace, not just because they will cost less, but because much of the world still does not have or need a big integrated multi-gigawatt-capable national grid that can accommodate large power plants.

In a little noticed announcement earlier this year, President Obama's administration made available $450 million to support first-of-a-kind engineering, design certification and licensing for up to two SMR designs over the next five years.

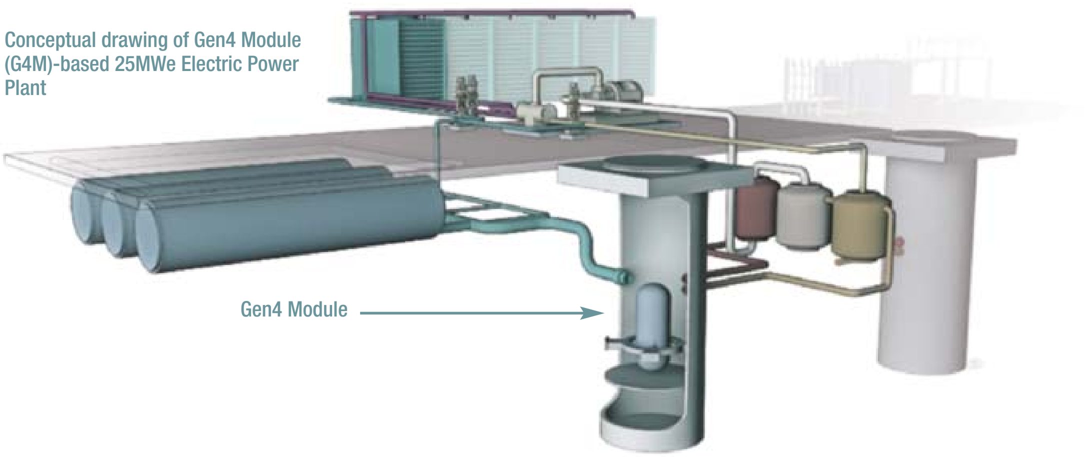
It should be pointed out that SMRs are not actually a new idea. According to the World Nuclear Organisation, there are quite a few that have been operating for decades – in submarines, ice breakers and US and French aircraft carriers, and also at a civilian level. For example, since 1976, the Bilbino co-generation plant in Siberia has had four 62MWe reactors working side by side, mostly for steam for district heating and 11MWe each of electricity.

But it is what is likely to come to fruition over the next 10-15 years that merits our attention.

The smallest reactor on the verge of a commercial breakthrough is made by Gen4 Energy (formerly known as Hyperion Power Generation) – a venture capital funded company. The Gen4 Module would provide 25MWe of continuous power for 10 years until the sealed unit would have to be removed and replaced in its underground containment vault. No on-site refuelling would be required. Crucially, it would compete not with the wholesale electricity market price – in fact it would bypass the grid – but with off-grid or distribution network competitors that often run on much more expensive and less predictable diesel generators, which cost perhaps $0.30 a kilowatt hour.

As these Gen4 modules would be standardised units, there could be a continuous manufacturing line, delivery by truck and vastly reduced on site construction complexity and time to completion. These are all good features but perhaps the most eye-catching is the projected cost per unit – just $50 million or $2,000 per kilowatt. This is at least half that of a conventional nuclear power station.

Conceptual drawing of Gen4 Module (G4M)-based 25MWe Electric Power Plant



The first unit will be constructed at US Department of Energy Laboratory at Savannah River and be operational in 2020. Were these capital costs to be maintained and in the unlikely scenario that no other costs incurred, this translates into a highly competitive cost per kilowatt hour of just over $0.02.[16] The final price is likely to be higher than that, but even if it were twice or three times higher, the technology would still be very competitive on most wholesale electricity markets.

Elsewhere around the world – in Russia, China, India, South Korea, France and even Argentina – there is a quite staggering range of research and development focused on small nuclear reactors.

One proposed design is called FlexBlue, developed by France's DCNS and Areva who build nuclear submarines and nuclear reactors respectively. They propose a small power plant in the range of 50 to 250MWe which would be placed on the seabed by ship a few kilometres out at sea, 60-100 metres below the surface and connected via subsea power cables to coastal towns and cities.

DCNS estimate a potential market size of up to 200 of these units over the next 20 years, particularly for countries that are new to nuclear power and that do not have large grids or power requirements.

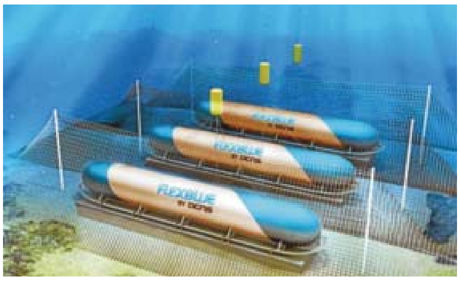
The appeal of SMRs is clear and it is not just about cost. To quote a report by the World Nuclear Association:[17]

"Generally, modern small reactors for power generation are expected to have greater simplicity of design, economy of mass production, and reduced siting costs. Most are also designed for a high level of passive or inherent safety in the event of malfunction. A 2010 report by a special committee convened by the American Nuclear Society showed that many safety provisions necessary, or at least prudent, in large reactors are not necessary in the small designs forthcoming."

2028 onwards: thorium-based reactors

Further out on the horizon is another possibility that could be even more disruptive – nuclear power from thorium. Thorium, named after the Norse God Thor, is a slightly radioactive metal four times as abundant as uranium and with a number of major advantages over its rival:

- Meltdown is impossible. This is because using a proposed "sub-critical" design known as an Accelerator Driven System, which requires no uranium or plutonium to start it off, a thorium reactor would have an off switch. This switch would be in the shape of a particle accelerator that fires protons on command – when turned off it would stop the fission process and any potential chain reaction.
- Weapons-grade fissile material cannot be made from it. When uranium is mined it contains only 0.7% of the 235 uranium isotope that is fissile. In order for it to be used in reactors, it needs to be concentrated or "enriched" to 3-5%. If it is concentrated to 85% or more and in a quantity of more than 10 kg, it can be used to make a nuclear weapon and beyond 20% – the limit demanded



Artist's impression of FlexBlue en route and modules aligned side by side on the sea floor

[16] $50 million divided by 87,600 hours (10 years), divided by 25 (assuming unlikely maximum 100% load factor) equals $22.83 per megawatt hour, or $0.02 per kilowatt hour.

of Iran – an effective dirty bomb. Thorium, however, has no isotopic content.

- Thorium reactors could be used to burn up existing nuclear waste and nuclear stockpiles. The radioactive actinides like plutonium that are produced as waste from conventional nuclear power plants can be used as a fuel in a thorium reactor.
- The waste is radioactive for only 500 years rather than 10,000. This matters because trying to create a safe storage depot for waste for 500 years is much easier than for 10,000 years – three times the age of the Pyramids.
- For the same power output, it only needs one eighth of the input by weight compared to uranium. A typical 1,000MW reactor requires, over 12 months, 550,000 pounds of uranium before enrichment. However a 1,000MW thorium reactor would only require 69,000 pounds of thorium which would need no further enrichment.
- In volume terms, it produces a fraction of the waste. According to Energy From Thorium, a typical 1,000MW uranium-fuelled light-water reactor would over the course of 12 months produce 39 metric tons of spent fuel – consisting of unburned uranium, transuranics and fission products. A thorium reactor would produce just 0.8 metric tons.[18]

"Nuclear technology is not going away; it is advancing at a disruptive pace."

The irony is that but for the need for a nuclear weapons and reactor programme, civilian nuclear power probably would have gone down the thorium route. Indeed, in the 1950s and 1960s, Alvin Weinberg built a working Molten Salt Reactor that used thorium at the US Oak Ridge National Laboratory.

So that begs the question, if thorium is such a great idea, why aren't there thorium reactors the world over?

It's at this point where thorium advocates tend to quieten down. On grounds of technological readiness, the case against thorium is – for now – actually quite solid. Perhaps some of the optimism for thorium is not dissimilar to the problem-free claims made for wind power a decade ago.

In August 2010, the UK's National Nuclear Laboratory produced a report that poured quite a lot of cold water over some of the pro-thorium ardour. The report argued that *"it is likely to take 10 to 15 years of concerted R&D effort and investment before the Thorium fuel cycle could be established in current reactors and much longer for any future reactor systems"*.[19]

Then there is the fact that supplies of uranium are still some way from running out. It's no accident that the most advanced work on thorium has been done in India which was not permitted to import nuclear fuel from the West (it came from Russia) but had substantial reserves of thorium. At current rates of consumption and known available resources, uranium supplies could be exhausted in 100-200 years. So the price of uranium or yellowcake (U308) is currently quite low and stable at $51 per pound.[20] The UK has no naturally occurring uranium or thorium (although rumours abound that the Falklands does), so there's no obvious energy security benefit of replacing one imported fuel with another.

But that would be meaningless were an economic way to be found of extracting the 4.5 billion tons of uranium from the world's ocean – around 60,000 years supply. That could be multiplied again if working fast-breeder reactors were developed that require only 1% of the uranium required by Light Water Reactors.

Still, the fact remains that public opinion would be far more likely to embrace thorium rather than uranium-based nuclear power, should the not insurmountable technical problems be overcome in the next 15 years.

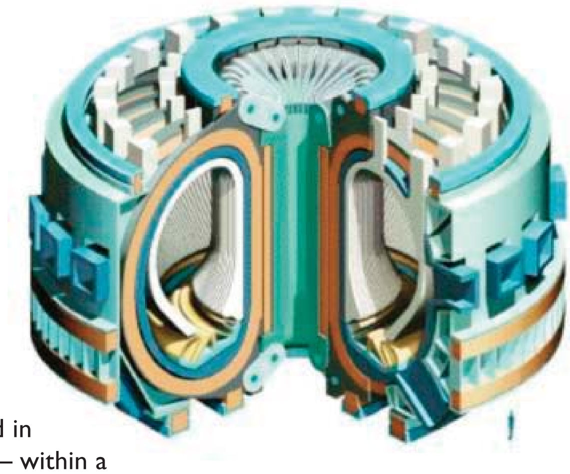
[17] See http://www.world-nuclear.org/info/inf33.html
[18] See http://energyfromthorium.com/2007/01/09/uranium-vs-thorium-mining-processing-waste-generation/

2033 onwards: nuclear fusion reactors

Further beyond the horizon – beyond a potential wide-scale deployment of thorium reactors – would be the arrival of gigawatt-capable nuclear fusion reactors. Fusion is the reverse of conventional nuclear power (fission) because power is generated by the fusing of two light nuclei rather than the splitting of the atom.

Currently there are two methods of achieving fusion that are being developed:

- The first uses a magnetic field shaped like a torus – known as a tokamak – to confine and stabilise the plasma equilibrium. This is known as magnetic confinement fusion and is the chosen method of the ITER (International Thermonuclear Experimental Reactor) being built in Cadarache in France. Due to be completed in 2019, the plant will require 50MW of input energy and output 500MW of energy for up to 1,000 seconds. Should the project prove successful, the plan is then to roll out a follow-on prototype commercial design called DEMO which would produce 25 times as much power as input and 2,000 MW on a continual basis. Should this run to plan, it would be working by 2033.



Schematic of ITER

- The second method is to use lasers to superheat and compress a small amount of fuel until fusion takes place. This is the approach taken by the United States in the National Ignition Facility, located in California. It uses 192 individual lasers – the world's largest array – within a very short period of time to bombard a cylinder – a "hohlraum" that contains a capsule of fuel – to re-emit the energy as X-rays. It is hoped that this could be working as a fusion power station by 2020, well ahead of ITER.

Jaded energy experts often say that fusion has always been the future for a long time. Whilst this is true, much progress has been made in plasma containment and the ability to create extreme heat – approaching that of the temperature at the centre of the sun at 27 million degrees fahrenheit – which is essential to creating a self-sustaining fusion reaction. That's why the future for fusion is now starting to look closer.

Fusion after all, is the holy grail of energy – producing abundant and 100% clean power, which would permanently lay to rest all worries about decarbonisation, fuel poverty and energy security.

CONCLUSION

Nuclear in all its forms does have a great future. Today though, the primary obstacles to a nuclear renaissance in Britain are not technological but financial:

- The weak balance sheets of the utilities, partly as a result of too many acquisitions and the chasing of renewable subsidies;
- Uncertainty over long-term government support;
- The observation of chronic cost and time overruns that have plagued Olkiluoto in Finland and Flamanville 3 in France;
- The cost of capital that investors and markets use to factor all of these in.

Permanence however is the illusion of every age.

[19] National Nuclear Laboratory, *The Thorium Fuel Cycle – An independent assessment,* August 2010 http://ripassetseu.s3.amazonaws.com/www.nnl.co.uk/_files/documents/aug_11/NNL__1314092891_Thorium_Cycle_Position_Paper.pdf

[20] See http://www.uxc.com/review/uxc_Prices.aspx

Building long-lasting nuclear infrastructure requires patience and a strategic long-view, as well as money. But nuclear technology is not going away; it is advancing at a disruptive pace. Nuclear power is still an egg and maybe a golden one, well worth having in the basket.

The National Ignition Laser Bay

A Linear Accelerator

3. Why radiation from civil nuclear plants should not be treated as exceptionally dangerous

By Wade Allison, Emeritus Professor of Physics and Fellow of Keble College, University of Oxford.

Although civil nuclear technology has no equivalent of the initial blast and fire of an exploding nuclear weapon, both raise questions in the public mind about the after-effects of nuclear radiation, questions that have led to widespread opposition to peaceful and beneficial uses of nuclear technology. Today's scientific data and understanding, and also the beneficial experience of radiation used for personal clinical health, are available to show that this fear is not justified.[21]

NUCLEAR ACCIDENTS

Nuclear technology is impressively powerful. For each kilogram of fuel, nuclear fission gives about a million times more energy than chemical fire or high explosive. But this fission process requires free neutrons that only exist within a working reactor. Otherwise there is only radioactive decay, and this radioactivity cannot spread by contagion like fire or disease.

In a serious civil nuclear accident, the heat released by this decay can destroy a reactor. There are, however, almost no related deaths – none at Windscale (1957) or Three Mile Island (1979) and less than 50 at Chernobyl (1986). An extraordinary safety record, thanks not to luck but to biology.

THE AFTER-EFFECTS OF RADIATION – HIROSHIMA, NAGASAKI AND FUKUSHIMA

In 1945 about 150,000 people were killed or missing as a result of the nuclear bombs dropped on Hiroshima and Nagasaki. In 2011 about 19,000 were lost in the Tsunami that triggered the destruction of several reactors at Fukushima Dai-ichi.

With the recent availability of the published health records of 86,000 survivors of Hiroshima and Nagasaki for the period 1950-2000 it has been possible to measure the after-effects of acute radiation, including cancer, by comparing with data from other Japanese cities of that period. These make possible reasoned estimates of the number of deaths from radiation in the next 50 years for the workers and population near Fukushima.

[21] For extended discussions of the issues raised in this paper, see *Radiation and Reason: the Impact of Science on a Culture of Fear (2009)* and *Public Trust in Nuclear Energy* (2012), www.world-nuclear.org/publications/personalperspectives.html. These may also be found at www.radiationandreason.com.

TABLE 3.1

Cancer death rates for survivors of Hiroshima and Nagasaki, 1950-2000

Dose range (milli-sievert)	Number of people, 1950	Cancer deaths (excluding leukaemia)		Leukaemia deaths	
		Total rate	Rate from radiation	Total rate	Rate from radiation
Less than 100	68,467	11.2%	0.09%	0.2%	0.01%
100 to 200	5,949	12.3%	0.7%	0.2%	-0.01%
200 to 1,000	9,806	13.2%	1.9%	0.6%	0.3%
More than 1,000	2,389	18.4%	8.1%	2.7%	2.4%
All	86,611	11.7%	0.6%	0.3%	0.1%

Source: Table based on published data from Preston, Dale L. et al (2004) *Effect of Recent Changes in Atomic Bomb Survivor Dosimetry on Cancer Mortality Risk Estimates,* Tables 3 & 7, Radiation Research, 162: 377–389 http://www.bioone.org/doi/abs/10.1667/RR3232

Table 3.1 shows the percentage of deaths from solid cancer and leukaemia in the period 1950 to 2000 including the extra attributable to radiation. Successive rows show the rates in bands of increasing radiation dose, with the total for all doses shown on the bottom line:

- With an average acute dose of 160 milli-sievert (mSv) the overall increased death rate due to radiation was 0.7% in 50 years – about the same as the chance of dying in a road traffic accident.[22]
- For every cancer death from radiation there were, on average, 16 other cancer deaths that would have happened anyway.
- For those receiving a dose less than 100mSv, the cancer death rate from radiation was negligible – too small to detect reliably, even in this large population.

At Fukushima 30 workers received acute doses greater than 100mSv, up to a maximum of 250mSv.[23] The findings in Table 3.1 reveal that the chance that any one of those workers will die of cancer from radiation in the next 50 years is less than 1 in 100 – so probably none of the 30 will actually do so. 220 members of the public from the most contaminated areas were found to have less than 1mSv of contamination[24] and so none are at risk of cancer.

Cancer, however, is not people's only health concern. They also worry about genetic mutations that might be handed down to future generations. In fact, no evidence for these in humans, even at Hiroshima and Nagasaki, has been reported by the BEIR Committee of the National Academy of Sciences.[25] In 2007 the International Commission for Radiological Protection (ICRP) concluded that this risk had been significantly overestimated in the past and that it should be taken to be 20-40 times lower than for cancer.[26]

In summary, it is very unlikely that there will be any loss of life from radiation at Fukushima, even in the next 50 years.[27]

[22] This varies with country and date, currently 0.7% (US) and 0.3% (UK). Office for Nuclear Regulation, *Japanese earthquake and tsunami: Implications for the UK nuclear industry,* September 2011 http://www.hse.gov.uk/nuclear/fukushima/final-report.pdf Table B2

[23] Office for Nuclear Regulation, *Japanese earthquake and tsunami: Implications for the UK nuclear industry,* September 2011 http://www.hse.gov.uk/nuclear/fukushima/final-report.pdf para 524

[24] American Nuclear Society, *Fukushima Daiichi: ANS Committee Report,* March 2012 http://www.hps.org/documents/ANSFukushimaReport.pdf p.16

[25] BEIR Committee of the National Academy of Sciences, Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2, 2006 http://books.nap.edu/catalog.php?record_id=11340

[26] International Commission for Radiological Protection (2007) *Report 103: 2007 Recommendations* http://www.icrp.org para 71, Table 1

[27] http://www.bbc.co.uk/news/world-12860842

BENEFICIAL RADIATION – MEDICAL USE

> *"It is very unlikely that there will be any loss of life from radiation at Fukushima, even in the next 50 years."*

The harmful effects of radiation are less than commonly supposed.[28] But radiation also has a number of beneficial uses, not least in clinical medicine.

People are often exposed to radiation, perhaps without appreciating it. Radiation is used in many types of medical scan, not only to picture a patient's internal anatomy, but also to observe its working. These involve moderate doses, sometimes given externally and sometimes internally. The various types of radiation used are similar – even identical – to those to be found at sites of reactor accidents. Imaging doses may be 5 to 10mSv, about the same as anyone receives from the natural environment in the course of two or three years, depending on where they live.

Much higher doses of radiation and radioactivity, however, can kill biological cells. For example, most of the firefighters at Chernobyl who received an acute dose of more than 4,000mSv died within a few weeks of Acute Radiation Syndrome – which is due to cells dying.

Cell death from radiation is used beneficially in the treatment of cancer. High doses are delivered during a course of radiotherapy by aiming beams of radiation to kill the tumour cells. Such a course may last 4-6 weeks with a daily dose of 2,000mSv given each time to the tumour. Unfortunately it is not possible to restrict the radiation to the tumour alone and neighbouring tissue and organs may get as much as 1,000mSv each day – and these can indeed survive the radiotherapy course. Over a month the tumour gets more than 40,000mSv and the peripheral healthy tissue as much as 20,000mSv – that is five times the fatal dose experienced by some Chernobyl workers.

Each day the cells of the tumour are marginally overwhelmed by the radiation damage, while the cells of the neighbouring healthy tissue – receiving about half the dose – just manage to repair or replace themselves in time for the next dose on the following day. This separation of the dose into daily treatments is called fractionation.[29] At the end of a successful treatment the cancerous cells are dead and the healthy tissue is recovering.

Everyone knows a friend or relative who has had such treatment and lived to thank the medical profession for it – but the effect of radiation on the human body is similar, whether in a clinic or in the environment.

Much has been discovered in biology in recent decades, particularly about what happens when radiation is absorbed by living cells. Doubtless more will be discovered in the future, but enough is already known to explain why life is so extraordinarily resilient.

Damage to cells and their DNA is repaired or replaced by a number of overlapping mechanisms, developed naturally through evolution. Some of these act within minutes of cells detecting radiation damage, while others act in days or weeks, as illustrated by the example of radiotherapy. This means that repair is more effective for a dose spread over a period (as in the radioactivity at Fukushima) than for the same dose delivered all at once (as in the flash of radiation at Hiroshima and Nagasaki). Experiments with mice and rats, and also with cells in test tubes, confirm that life is extremely well protected from radiation at low and moderate dose rates.

In fact, evolution has devolved responsibility for this biological action down to cells, singly and collectively, and so the over-anxious human brain should not worry so much. Over-reaction to radiation may be seen as a concern in its own right, and in the event of a radiation incident, real or false alarm, it is the behaviour of the "worried well" that is the greatest threat to public order, not the radiation itself.[30]

[28] http://www.radiationandreason.com
[29] The Royal College of Radiologists, *Radiotherapy Dose-Fractionation,* June 2006 http://rcr.ac.uk/docs/oncology/pdf/Dose-Fractionation_Final.pdf
[30] Stone, Fred P. (2007), The *"Worried Well" Response to CBRN Events: Analysis and Solutions,* USAF Counterproliferation Center, Counterproliferation Paper No. 40 http://www.fas.org/irp/threat/cbw/worried.pdf

BENEFICIAL RADIATION – SUNLIGHT AND SPAS

So there is no need for people to run away from radiation.[31] The way that we behave in sunlight provides a sensible pattern to follow. The ultra-violet radiation from the Sun is closely related to X-rays and other nuclear radiation, and with similar effects on life:

- **At small dose rates it is harmless – in fact it is beneficial, creating the important Vitamin D.**
- **At higher dose rates it causes sunburn within hours and this can be serious although seldom fatal.**
- **Such sunburn when repeated may result in skin cancer years later, and this may be fatal if not treated promptly.**

One way to escape such threats would be to avoid exposure to sunlight altogether. After all, the Sun is a very large nuclear reactor whose radiation hits us directly and is poorly filtered by our atmosphere – so people might think it unacceptably dangerous. Imagine an advertisement for an expensive holiday offering accommodation buried deep underground with a guarantee of two weeks with no sunlight! Fortunately, such holidays do not sell. We do not worry about small doses and have learnt to enjoy sunny holidays, using barrier creams and avoiding prolonged exposure in the strongest sun.

Then there are people who prefer to take their holidays at spas and enjoy hot baths in radioactive waters. Whether as a placebo taken in luxurious surroundings or as a direct biological benefit, such treatment usually lets tourists return home feeling happy and relaxed. There is no evidence that their health is damaged in any way, indeed they may even live longer.

Generally, it is well established in the scientific literature that those whose employment regularly exposes them to mild doses of ionising radiation have a mortality from all forms of cancer before age 85 that is 15-20% lower than other equivalent workers – this is called the *Healthy Worker Effect*.[32]

"World Health Organisation, UN and International Atomic Energy Authority reports confirm that the most serious effects at Chernobyl have been caused not by the radiation but by the fear of it."

FOOD AND EVACUATION – CHERNOBYL AND FUKUSHIMA

The accident at Chernobyl was more than 25 years ago and what happened, who suffered and how, has been extensively reported in publications by the World Health Organisation, the United Nations and the International Atomic Energy Authority. The known loss of life as a result of radiation exposure includes the 28 firefighters who died of Acute Radiation Syndrome and 15 children who died from thyroid cancer. There is no firm evidence for any other loss of life due to radiation, either individually identified or statistically shown.

The international reports confirm that the most serious effects at Chernobyl have been caused not by the radiation but by the fear of it. The hurried evacuation of 116,000 local inhabitants caused social and economic stress that resulted in depression, suicides, alcoholism, family breakup and broken livelihoods. People who are told that they have received a radiation dose and must abandon their homes, jobs and way of life, naturally develop an attitude of hopelessness and a victim culture. Even those far away can be affected in this way. For instance, studies have shown an increase of about 2,500 abortions in Greece associated with an irrational fear of radiation from Chernobyl.[33]

Further social and economic damage resulted from restrictions on the sale of food. For example, in June 1986 in Norway the maximum activity permitted for food stuffs was set at 600 becquerel per kilo (Bq/kg). The economic effect on the reindeer industry was so severe that in November 1986 this was relaxed to 6,000Bq/kg.

[31] http://www.bbc.co.uk/news/world-12860842
[32] Muirhead, C R et al (2009), *Mortality and cancer incidence following occupational radiation exposure: third analysis of the National Registry for Radiation Workers,* British Journal of Cancer, 100, 206–212 http://www.nature.com/bjc/journal/v100/n1/full/6604825a.html
[33] Trichopoulos et al (2007), *The victims of Chernobyl in Greece: induced abortions after the accident* http://www.bmj.com/content/295/6606/1100.extract

Sweden experienced a similar story. In April 2002 the Swedish Radiation Protection Authority published an apology in the daily press, admitting that the intervention level had been set too low and that 78% of all reindeer meat had been destroyed at great expense to the taxpayer and adversity to the industry.

But it seems that these lessons were not learnt in Japan. In July 2011 the "Measures.... to Ensure Safety of Beef" issued by the Japanese Government set a maximum of 500Bq/kg, stating that the consumption of 1 kg would give a dose of 0.008mSv.[34] This means that you would have to eat 1,000kg of meat in four months to get the same dose as that received within a couple of hours during a regular scan. This shows that the regulation is quite inappropriate, and it has been causing great hardship and alarm among the people for no good reason.

The evacuation criteria and public exposure limit at Fukushima were based on 20mSv per year. There has been public pressure to lower the figure to 1mSv per year. (Such a limit can only be interpreted as additional to natural levels which themselves average 2.4mSv per year and show large variations with soil type, altitude and latitude.) Even 20mSv per year as a chronic dose is 10,000 times lower than the monthly dose to some healthy organs accepted by radiotherapy patients in Japan (as elsewhere) – and standards of medical care in Japan are of the highest.

The evacuation and clean-up regime imposed at Fukushima has had serious socio-economic consequences for the whole region and has been a tragic mistake. To this should be added the major economic and environmental cost of failing to restart the existing nuclear power plants and the related import of fossil fuel.

A NEW RADIATION SAFETY LEVEL

The efficacy of radiotherapy shows strong evidence that if a dose is spread in time, repairs can be effected, not perfectly perhaps, but sufficiently to make nonsense of any safety assessment based simply on a measurement of dose accumulated over a long time. The actual repair times vary from minutes up to days and weeks, and some allowance should be made for repairs that are never effected. This suggests a safety regime that places limits on the size of:

- any single acute exposure;
- the exposure accumulated in any month;
- a life-long accumulated dose (to cover the damage that never gets repaired).

What the value of these limits should be is a matter for discussion based on scientific data, conservatively interpreted. As data improves these limits should be relaxed, science permitting.

When a new technology is introduced, risks are poorly understood, monitoring and control are weak and it is reasonable to take a precautionary view of safety. So it was, for instance, when "locomotives" first appeared on public highways, propelled initially by steam and later by internal combustion engines. Under the influence of popular pressure (in the UK), safety laws restricting speeds to 2 or 4 miles per hour were enacted in the "Red Flag" Act of 1865. Fortunately for modern civilisation, in 1896 these traffic restrictions were relaxed by factors of 20 or more. Initially the public thought such traffic unacceptable (and liable to frighten the horses), but progressively the technology improved and accident rates fell. Mankind learnt to accept the risks and reap the benefits.

There is no reason to handle the safety of ionising radiation any differently in principle. It should be a matter of balancing risks against benefits in the light of experience, but

[34] Government of Japan, *Measures against Beef which Exceeds the Provisional Regulation Values of Radioactive Cesium by the Government to Ensure Safety of Beef*, July 2011 http://www.kantei.go.jp/foreign/kan/topics/201107/measures_beef.pdf

unfortunately that is not what has happened. In 1951 the safety level was set at 3mSv per week (12mSv per month). Although the civil nuclear radiation safety record has remained exceptionally good, since 1951 the maximum dose recommended for the general public has been reduced by a factor of 150 in pursuit of levels that are As Low As Reasonably Achievable (ALARA).

Over the years a powerful "safety" industry has been erected on this basis, and the implementation of its strictures has made applications of radiation and nuclear technology extremely expensive – all on account of fear, not on any scientifically demonstrable risk.

Chart 3.1 shows a schematic diagram in which monthly doses are depicted as simple proportionate areas, as follows:

a) shows a dose fatal to a tumour – more than 40,000mSv a month;

b) shows a radiotherapy dose from which healthy tissue usually recovers – more than 20,000mSv a month;

c) shows a dose rate of 100mSv a month;

d) shows the dose that would be received if living 24/7 in the hall where the waste is stored at Sellafield or Sizewell B – 0.7mSv a month (1 micro-sievert an hour);

e) shows a dose in the environment, recommended as marginally safe as an additional dose over background for the general public by the ICRP – the ALARA level[35] – 0.08mSv a month (1mSv a year). The natural background radiation is around 2.5 times higher.

CHART 3.1

The ALARA level is unreasonably strict. In my book *Radiation and Reason; the Impact of Science on a Culture of Fear*, I have suggested a maximum dose rate of 100mSv per month as a safety level that is As High As Relatively Safe (AHARS). This is shown in the diagram as the rectangle (c). This AHARS level is a conservative factor of 200 below the level tolerated by a radiotherapy patient (b), but 1,000 times more relaxed than the

[35] International Commission for Radiological Protection (2007) *Report 103: 2007 Recommendations* http://www.icrp.org

ALARA level (e) recommended for public safety by ICRP:

- A maximum *single acute* dose of 100mSv seems quite firm.
- A limit for *chronic or protracted doses* of 100mSv in any month would be conservative – a radiotherapy patient receives 200 times that, although not to the whole body. New work from MIT reports that laboratory mice, in receipt of the equivalent of 105mSv of radiation spread over a five week period, show no genetic damage to their DNA (and therefore no cancer at a later date). This is a direct contradiction to the assumption used by the ICRP and supports this AHARS estimate in principle.[36]
- In addition, a *whole-of-life* limit of about 5,000mSv is suggested. This is a fraction of a single radiotherapy course and much smaller than the few sources of life-long chronic doses that have been shown to increase the risk of cancer. These include the radiation experienced years ago by the painters of luminous dials.

In the future, as more is known and accepted, especially on adaptive mechanisms or hormesis, these limits might be relaxed further.

"peaceful nuclear technology should be welcomed as a sure, safe and emission-free answer to baseload energy supply."

WHY IT MATTERS

The world is searching for safe, low-cost alternatives to fossil fuels, and has a major challenge on its hands to maintain socio-economic stability and ensure supplies of food and fresh water. Peaceful nuclear technology should be welcomed as a sure, safe and emission-free answer to baseload energy supply, and also food preservation and fresh water by desalination. Unwarranted safety restrictions linked to ALARA need to be scaled back. These have been responsible for vast increases in cost and the apparent scale of the problems of waste and decommissioning.

New realistic safety regulations should bring large cost savings to any nuclear programme. While no corners should be cut in respect of the control of reactor stability and its heat output, with fresh justifiable safety standards many costs of nuclear power could be reduced dramatically and safely – and that does not depend on which flavour of future nuclear technology is chosen. Matters of nuclear waste, reprocessing and decommissioning should take their place alongside other environmental problems requiring responsible and transparent solutions such as the disposal of hazardous chemical and biological waste. They should not be major problems.

The principal barrier is public acceptance. A substantial public educational exercise is needed to overcome widespread fears. Regulations need to be explained, rather than, as was common practice in the past, simply dictated. The subject is not difficult. If a proportion of citizens understand and feel some ownership of the basic ideas, others in the population will follow. Young people, and older ones too, should study and enter the skilled workforce. If this seems too big a task, reflect that the nuclear skills base was built from zero in four years after 1940.

For those ready to change their ideas, the economic opportunities are ripe for picking and made easier by the number of nations that have backed out of the nuclear field. Generally, it would be unfortunate for the prosperity of first world democracies, if they remained victims of scientifically out-dated fears and left the gate of prosperity wide open to other nations to treat radiation more realistically.

The recommendations from ICRP should be completely redrawn to encourage all nations forward into a new beneficial nuclear age, one that is also backed by public trust. Some may find this view idealistic, but they should reflect that the man in the street will turn eventually when the alternative hits him in the pocket. The world is in trouble. We need to take reasoned radical steps now to maintain political stability and broad prosperity.

[36] Olipitz et al, *Integrated Molecular Analysis Indicates Undetectable DNA Damage in Mice after Continuous Irradiation at ~400-fold Natural Background Radiation*, Environmental Health Perspectives, April 2012 http://web.mit.edu/newsoffice/2012/prolonged-radiation-exposure-0515.html

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The UK's infrastructure was once the best in the world. Great innovators like Brunel and Stephenson were pioneers of the railway, which revolutionised the way people and goods moved around the country.

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The UK still benefits from its infrastructure inheritance, and parts of our network function relatively well. But we have lost our lead, as we try to squeeze too many onto too little. Our roads are congested, many of our trains are standing room only, and planes are forced to circle in stacks before getting a landing slot at our main airport. High taxes on driving and flying, and big rail fare increases, have made getting around more expensive.

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