SENSE about SCIENCE

MAKING SENSE OF

NUCLEAR

What's changed in the debate?

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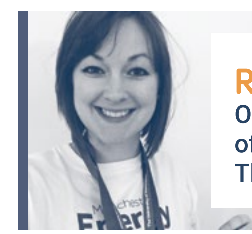

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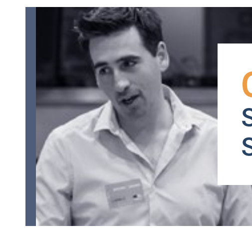

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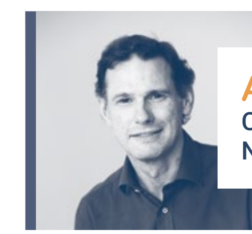

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INTRODUCTION

In recent years some prominent advocates for the environment have become advocates for nuclear power. Film directors, parliamentarians, journalists and environmental campaigners: people who once were opposed to nuclear power have changed their minds.

Some hostile organisations have softened their attitudes and most are debating the evidence on this question. There is now tension in the environmental movement about whether nuclear power should in fact be part of a low-carbon energy future.

A lot of the debate about nuclear power is economic: about whether subsidies for this part of the energy sector would come at the expense of others, whether energy infrastructure should be subsidised at all and whether specific proposals for new nuclear plants make sense. Some people are no doubt concerned by this alone. But nuclear power has a legacy of suspicion attached to it, which in the past gave rise to some claims about safety that have turned out not to be true, but which continue to influence discussions about the options, economic or otherwise. The industry and governments haven't typically in the past been very open on the detail of nuclear installations. That is why we got together with a group of scientific organisations to produce this guide and try to bring discussions up to date.

Some of the people who have revised their opinions about nuclear energy have cited the speed at which climate change is occurring. To reduce greenhouse gas emissions while also creating affordable energy for the world, people are having to reconsider the trade-offs between different methods of energy production — particularly whether no nuclear means more fossil fuels.

There appear to be other reasons too; the world now has better data on the long-term health effects of exposure to radiation, more experience of managing nuclear power, and improved and new technologies to increase safety and efficiency and reduce waste.

Perhaps because of these, the wider debate is shifting. In the UK, public support for nuclear power increased a little, from 26% in 2005 to 32% in 2013, and whereas in earlier decades politicians debated it as a problem, recent debates have focused on it as part of a solution.

This guide is not about promoting nuclear as the route to a low-carbon energy system. It isn't the broad look at energy generation that would help you decide if nuclear power is suitable in any given situation. But none of us wants to make decisions based on outdated information. So it is an exploration of what seems to have changed and to have changed minds.

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REDUCING EMISSIONS WHILE ENERGY DEMAND IS RISING

"As committed environmentalists, our conversion to the cause of nuclear power was painful and disorienting. All of us carried a cost in changing our position, antagonising friends and alienating colleagues. But we believe that shutting down — or failing to replace — our primary source of low carbon energy during a climate emergency is a refined form of madness."

George Monbiot, Mark Lynas, and Chris Goodall[1]

Emission targets

The Paris Agreement on climate change negotiated in December 2015 pledged to keep the increase in global average temperatures "well below 2°C" and to pursue efforts to limit the increase to 1.5°C above pre-industrial levels.[2] While countries involved in the agreement made specific commitments to reduce their emissions,[3] many observers drew attention to the lack of convincing strategies to achieve this, never mind avoid the 3°C or higher increases that some scientists say the world is currently heading for.[4]

> *"I think one unintended outcome of the Paris Agreement was that it made the public think limiting warming to 1.5°C is possible with only marginally stronger policy from government on reducing emissions and this is simply not the case."*
>
> Dr Andrew King, climate extremes research fellow, School of Earth Sciences, University of Melbourne[5]

With the Climate Change Act 2008 the UK had already set itself the legally-binding goal of reducing greenhouse gas emissions to just 20% of 1990 levels by 2050.[6] This target was less ambitious than the Paris Agreement: it was based on limiting temperature rise to around 2°C.[7] To ensure progress towards it the UK sets five-yearly carbon budgets.[8] The first three interim targets to the year 2020 have been met but the UK is not on course to reach its 50% reduction in emissions by 2025.[9] So even the UK, often lauded as a nation doing its part to prevent further climate change, might not manage to stick to the Paris Agreement.

Nuclear power is gaining support in the face of climate change

In 2009, it was concern about making these kinds of emission reductions that led four of the UK's most vocal environmentalists to publicly change their minds about nuclear power. Stephen Tindale, former director of Greenpeace; Lord Chris Smith of Finsbury, then chairman of the Environment Agency; Mark Lynas, science writer; and Chris Goodall, then a Green Party activist, all declared support for nuclear as a necessary means to reduce greenhouse gas emissions.

> *"Being anti-nuclear was an essential part of being an environmentalist for a long time but now that I'm talking to a number of environmentalists about this, it's actually quite widespread this view that nuclear power is not ideal but it's better than climate change."*
>
> Stephen Tindale, director of the Alvin Weinberg Foundation[10]

Public attitudes

Public support for nuclear power has also increased over the same period, from 26% supporting its use in 2005 to 32% in 2013.[11] Interestingly, climate change doesn't seem to lie behind this shift. Support for nuclear power specifically as a way to tackle climate change was somewhat lower in 2013 (47%) than in 2005 (54%). This might reflect a decline in the belief that climate change is happening (from 91% in 2005 to 72% in 2013), or another reason why people favour nuclear power, such as concern about energy supplies.

1 Monbiot, G et al (2015). We are pro-nuclear, but Hinkley C must be scrapped. The Guardian, [online] 18th September. https://www.theguardian.com/environment/2015/sep/18/we-are-pro-nuclear-but-hinkley-c-must-be-scrapped (accessed 22nd February 2017)

2 Carbon Brief (2015). Interactive: The Paris Agreement on climate change. http://www.carbonbrief.org/interactive-the-paris-agreement-on-climate-change (accessed 22nd February 2017)

3 Carbon Brief (2015). Paris 2015: tracking country climate pledges. http://www.carbonbrief.org/paris-2015-tracking-country-climate-pledges (accessed 22nd February 2017)

4 Global Carbon Budget (2015). http://www.globalcarbonproject.org/carbonbudget/15/hl-full.htm#pathways (accessed 22nd February 2017); infographic - http://www.globalcarbonproject.org/carbonbudget/15/files/Infographic_Emissions2015.pdf (accessed 22nd February 2017)

5 Carbon Brief (2016). IPCC special report to scrutinise 'feasibility' of 1.5C. https://www.carbonbrief.org/ipcc-special-report-feasibility-1point5 (accessed 22nd August 2016)

6 Climate Change Act 2008 (c. 27). http://www.legislation.gov.uk/ukpga/2008/27/contents (accessed 2nd March 2017)a

7 Committee on Climate Change (2016). Meeting carbon budgets – 2016 progress report to parliament. https://www.theccc.org.uk/wp-content/uploads/2016/06/2016-CCC-Progress-Report-Executive-Summary.pdf (accessed 22nd February 2017)

8 Committee on Climate Change (no date). Carbon budgets and targets. https://www.theccc.org.uk/tackling-climate-change/reducing-carbon-emissions/carbon-budgets-and-targets/ (accessed 22nd February 2017)

9 Committee on Climate Change (no date). How the UK is progressing. https://www.theccc.org.uk/tackling-climate-change/reducing-carbon-emissions/how-the-uk-is-progressing/ (accessed 22nd February 2017)

10 Connor, S (2009). Nuclear power? Yes please... The Independent, [online] 23rd February. http://www.independent.co.uk/environment/green-living/nuclear-power-yes-please-1629327.html (accessed 22nd February 2017)

11 UK Energy Data Centre (2013). Public attitudes to nuclear power and climate change in Britain two years after the Fukushima accident: summary findings of a survey conducted in March 2013 - working paper. http://www.ukerc.ac.uk/publications/public-attitudes-to-nuclear-power-and-climate-change-in-britain-two-years-after-the-fukushima-accident-summary-findings-of-a-survey-conducted-in-march-2013-working-paper.html#sthash.GH73RjEx.dpuf (accessed 23rd February 2017)

REDUCING EMISSIONS WHILE ENERGY DEMAND IS RISING

World energy consumption and access to energy

The International Energy Agency projects that between 2014 and 2040 world energy demand will have increased by 37%.[12] The majority of this increased demand is from non-OECD (Organisation for Economic Co-operation and Development) countries, primarily China and India. The energy needs of the UK and many other OECD nations are projected to fall slightly due to energy efficiency improvements and energy saving policies; the UK projects a 3% reduction in energy demand by 2035 based on 2015 levels.[13]

So even if you disagreed with the need to reduce emissions, clearly we still need to provide more energy globally. An estimated 1.2 billion people remain without electricity, and 2.7 billion rely on traditional solid biomass such as dung or charcoal for cooking, putting their health at risk.[14] New UN targets aim to achieve universal access to energy by 2030, although this is defined at quite a low level, certainly much lower than is the norm in developed countries.[15]

Decarbonising

The decarbonisation target dates for even the more modest reduction in warming are sufficiently urgent that fossil fuels must be phased out and replaced with low- or zero-carbon alternatives to achieve them. The discussion about how to achieve this — which sources of power should make up the low-carbon "energy mix" — has often been idealistic, hoping for innovations and political commitments that are not yet in sight. This has been frustrating for people who seek urgent practical solutions and in recent years there has been a growth of new groups and organisations that emphasise pragmatic approaches.

> *"The climate problem is mostly an energy problem"*
>
> The late Professor Sir David MacKay, former chief scientific adviser to the UK Department of Energy and Climate Change

There are many different low-carbon possibilities and what is required is a combination. Because, even with big advances in efficiency, no single low-carbon source of energy will be sufficient to meet the world's rising demand for energy yet also significantly reduce emissions.

Determining the most appropriate sources of energy requires trade-offs: between what's practical, what's affordable, what's acceptable, the scale and reliability of the supply and so on. Every method of energy production has strengths and limitations. For instance, weather and geography constrain many of them — particularly renewable energy technologies — in different ways in different parts of the world. Factors like these need to be considered when deciding how best to produce energy in different countries or regions. The potential for change must also be considered: with cost-effective ways of storing energy for example, more use of solar power might become feasible in some of the countries where the sun doesn't always shine, whereas currently it works best for countries with year round sun and short winters.[16]

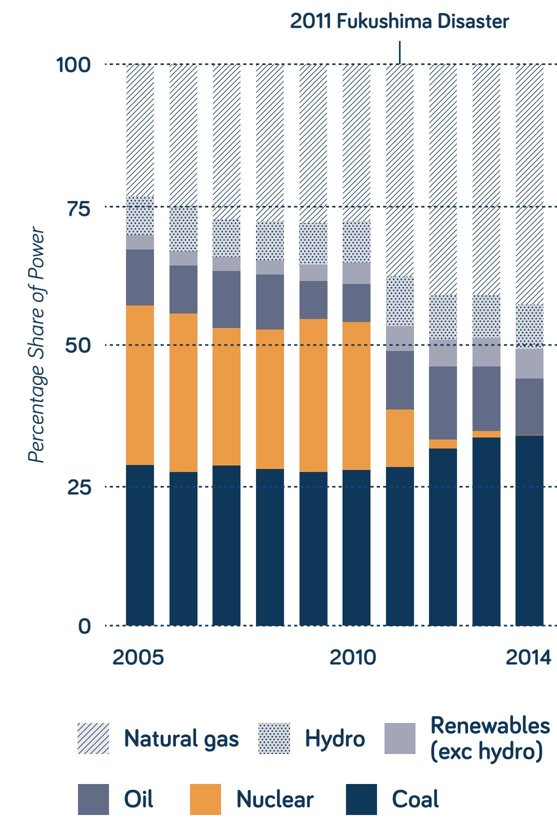
Limiting the options

Along with intensifying interest in using nuclear power to achieve a faster shift away from fossil fuels, in the past six years we have also witnessed the direct effects of withdrawing nuclear from the available options in countries such as Japan and Germany.

Japan

Like the UK, Japan also committed to reducing its greenhouse gas emissions, and by 2010 had stabilised its gas and coal consumption.[17] Then in 2011, the magnitude 9.0 great east Japan earthquake and subsequent tsunami caused major damage to the Fukushima Daiichi nuclear power plant. The plant lost power in the tsunami, leading to equipment failure, which caused the reactor cores to overheat and the nuclear fuel melted. Structural damage to the containment vessels and reactor buildings following hydrogen explosions meant radioactive material was released from the plant.[18] The earthquake and tsunami killed almost 16,000 people,[19] but this vied with Fukushima Daiichi for the attention of the world's press. Although no-one died from radiation released during the nuclear incident, what many people remember is the meltdown at the power plant.

JAPAN'S ENERGY SUPPLY



[12] International Energy Agency (2014). World energy outlook 2014 factsheet. http://www.worldenergyoutlook.org/media/weowebsite/2014/141112_weo_factsheets.pdf (accessed 23rd February 2017)

[13] Department of Energy and Climate Change (2015). Updated energy and emissions projections 2015. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/501292/eepReport2015_160205.pdf (accessed 23rd February 2017)

[14] International Energy Agency (2015). World energy outlook 2015. https://www.iea.org/Textbase/npsum/WEO2015SUM.pdf (accessed 23rd February 2017)

[15] United Nations General Assembly (2015). Transforming our world: the 2030 agenda for sustainable development. https://sustainabledevelopment.un.org/post2015/transformingourworld (accessed 23rd February 2017)

[16] Nelsen, A (2015). Morocco poised to become a solar superpower with launch of desert mega-project. The Guardian, [online] 26th October. https://www.theguardian.com/environment/2015/oct/26/morocco-poised-to-become-a-solar-superpower-with-launch-of-desert-mega-project (accessed 23rd February 2017)

[17] Carbon Brief (2016). Analysis: the legacy of the Fukushima nuclear disaster. https://www.carbonbrief.org/analysis-the-legacy-of-the-fukushima-nuclear-disaster (accessed 23rd February 2017)

[18] International Atomic Energy Agency (2015). The Fukushima Daiichi accident. http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1710-ReportByTheDG-Web.pdf (accessed 23rd February 2017)

[19] According to the National Police Agency of Japan, as of 9th September 2016 the death toll stood at 15,894 people, with a further 2,557 still missing; http://www.npa.go.jp/archive/keibi/biki/higaijokyo_e.pdf (accessed 14th October 2016)

Fearing a public outcry, the Japanese government shut down all nuclear power reactors.[20] For the first time since 1970, Japan was generating none of its electricity using nuclear power — which in 2010 had supplied 26% of the country's power.[21] The resulting shortfall in energy production was necessarily met by increased consumption of gas, oil and coal.

Greenhouse gas emissions soared; Japan's emissions were its highest to date in 2013. Even with a slight reduction in 2014, the latest year for which figures are available, emissions were still higher than 2010 levels.[22] Although the Japanese government has increased incentives for investment in renewables, it has also begun the process of restarting several of its nuclear reactors.

Germany

Following the Fukushima Daiichi incident, Germany also announced that all 17 of its nuclear power plants would be shut down by 2022.[23] Germany has met its shortfall in energy production by increasing the contribution from renewable sources and by continuing to use coal despite a planned phase-out.[24]

As a result, Germany's greenhouse gas emissions have stopped declining (they had been in steady decline from the early 1990s until 2010). Emissions actually increased by 0.7% in 2015 after Germany's largest nuclear power plant, Grafenrheinfeld, went offline.[25] It is possible that factors such as cooler weather might have contributed to this. However it's also clear that removing nuclear power as a low-carbon energy source makes it more difficult to reduce CO_2 emissions, because renewables have to be funded and built to replace both fossil fuels and the prematurely decommissioned nuclear plants at the same time.

20 Batty, D (2012). Japan shuts down last working nuclear reactor. The Guardian, [online] 5th May. https://www.theguardian.com/world/2012/may/05/japan-shuts-down-last-nuclear-reactor (accessed 23rd February 2017)

21 World Development Indicators (energy production from nuclear sources (% of total)), World Bank, http://databank.worldbank.org/data/reports.aspx?source=world-development-indicators (accessed 23rd February 2017)

22 Japan's National Greenhouse Gas Emissions in Fiscal Year 2014, Japanese National Institute for Environmental Studies, http://www.nies.go.jp/whatsnew/jqjm10000007eqzy-att/jqjm10000007erj8.pdf (accessed 2nd March 2017). NB: NIES measures emissions in Japan's fiscal year which runs from 1st April to 31st March; 2014 refers to 1st April 2014 to 31st March 2015

23 Breidthardt, A (2011). German govt wants nuclear exit by 2022 at latest. Reuters, [online] 30th May. http://uk.reuters.com/article/idINIndia-57371820110530 (accessed 23rd February 2017)

24 Rueter, G (2015). How far along is Germany's nuclear phase-out? Deutsche Welle, [online] 29th June. http://www.dw.com/en/how-far-along-is-germanys-nuclear-phase-out/a-18547065 (accessed 23rd February 2017)

25 German Environment Agency and the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (2016). UBA emissions data for 2015 indicate urgent need for consistent implementation of Climate Action Programme 2020. [English language press release, online] 17th March. https://www.umweltbundesamt.de/en/press/pressinformation/uba-emissions-data-for-2015-indicate-urgent-need (accessed 23rd February 2017)

Other responses to Fukushima

China

China also reacted to the incident at Fukushima Daiichi. Its State Council suspended approval of nuclear power projects pending a comprehensive safety review. By October 2012, China decided to continue with its rapid, large scale construction of new nuclear power plants.[26] Nuclear is intended to provide 8-10% of China's electricity by 2030,[27] in contrast to just 3% in 2015.[28] The main reason driving China's shift to nuclear power is a desire to reduce air pollution from burning coal. China burnt 3,957 million tonnes of coal in 2013 and this is projected to increase in the near future.[29]

> *"Without nuclear, the battle against global warming is as good as lost. Even many greens now admit this in private moments."*
>
> Mark Lynas[30]

26 International Atomic Energy Agency (2015). Country nuclear power profiles. http://www-pub.iaea.org/MTCD/Publications/PDF/CNPP2015_CD/countryprofiles/China/China.htm (accessed 23rd February 2017)

27 World Nuclear Association (2017). Nuclear power in China. http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-power.aspx (accessed 23rd February 2017)

28 International Atomic Energy Agency (2017). Nuclear share of electricity generation in 2015. https://www.iaea.org/PRIS/WorldStatistics/NuclearShareofElectricityGeneration.aspx (accessed 23rd February 2017)

29 US Energy Information Administration International Energy Statistics (). International Energy Statistics. http://www.eia.gov/beta/international/data/browser/#?ord=CR&cy=2014&v=H&vo=0&so=0&io=0&start=1980&end=2014&vs=INTL.7-2-CHN-MT.A&c=00000002&pa=000000000000000000000000000000000000000jg0880000000008&f=A&ug=8&ct=0&tl_type=p&tl_id=1-A&s=&pin=p (accessed 27th February 2017)

30 Lynas, M (2012). Without nuclear, the battle against global warming is as good as lost. The Guardian, [online] 14th September. https://www.theguardian.com/environment/2012/sep/14/nuclear-global-warming (accessed 23rd February 2017)

KNOWLEDGE ABOUT LONG TERM HEALTH EFFECTS

Looking back over previous discussions about nuclear power and health, it's clear there were two limitations: a lack of long term data to draw on; and a lack of comparison with other radiation risks, including the radiation from coal-fired power plants, to show the trade offs.

In earlier debates, influenced by the Cold War and fear of the nuclear arms race, there were some quite wild predictions about what would happen in the event of a nuclear power plant accident, and in 1986 many people thought that the accident at the decrepit Chernobyl plant in the former Soviet Union would end up killing millions.[31] Chernobyl certainly destroyed a community, but predictions about an epidemic of cancer from radiation exposure have turned out to be wrong. The data didn't exist then to refute those claims, but it does now. Because of this, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) is able to make a rapid and much more accurate assessment of risk following an incident, as it did in Fukushima.

Health data from Chernobyl and Fukushima

In April 2011, UNSCEAR published an update to its 2000 and 2008 reports, *Exposures and effects of the Chernobyl accident.*[32] The objective of this was "to provide an authoritative and definitive review of the health effects" from the data accumulated over two decades of health monitoring of the regional population.

This showed that the effect of exposures at Chernobyl has been an increase in cases of thyroid cancer reported in children and adolescents in Ukraine, Belarus and the four most affected regions of the Russian Federation. Up until 2005, 6,848 cases were reported in those under the age of 18 at the time of exposure. Only 15 of these proved fatal as thyroid cancer is mostly treatable.[33] Many of the cases of thyroid cancer could have been prevented by treatment with potassium iodide at the time of exposure, or by preventing exposure to radioactive iodine-131 via contaminated cow's milk. There hadn't been prompt provision of such countermeasures at Chernobyl.

In the case of Fukushima, the impacts of radiation exposure on human health were clearer. There were no deaths attributed to it. UNSCEAR concluded in 2013 that, "radiation exposure following the nuclear accident at Fukushima Daiichi did not cause any immediate health effects"[34] — not among members of the general public, or those on site.[35] Their report further concluded that radiation doses received by the public were generally low or very low and that "no discernible increased incidence of radiation-related health effects are expected among exposed members of the public or their descendants." UNSCEAR's findings suggest that an increased rate particularly of thyroid cancer in exposed children could occur, but data available so far suggests that it's just that extra cases have been observed due to active screening programmes, not because radiation has caused more cases.[36,37]

There were also no deaths or immediate health effects caused by radiation exposure among the roughly 25,000 workers who were at the Fukushima Daiichi plant, including plant staff, contractors, emergency personnel and volunteers. UNSCEAR examined data from 12 of the most exposed workers and concluded that they may be at increased risk of thyroid cancer or other thyroid disorders. Around 160 further workers were exposed to estimated radiation doses of more than 100 millisieverts (mSv): among this group an increased risk of cancer would be expected in the future. However, the precise numbers of new cases of diseases vary around predicted levels, and because this group of workers is so small, it would be difficult in future to say for sure whether they had experienced a higher cancer rate.[37]

The radioactive leak from the site led to a precautionary ban on leafy vegetables and milk from animals that had been feeding on local grass. An extensive monitoring system was put in place and an analysis in 2015 found that radioactivity levels fell quickly in most vegetables: just five months after the disaster, only a handful of samples exceeded the limit.[37]

The EU and some other parts of the world refused imports from the region as a precaution but no risk was identified. UNSCEAR also found that the radiation exposure of the Japanese population was low, leading to correspondingly low risks of health effects later in life. A simultaneous World Health Organisation report found the same thing,[38] as did a subsequent extensive report from the IAEA.[39]

31 Balonov, M I (2012). On protecting the inexperienced reader from Chernobyl myths. Journal of Radiological Protection, 8th May (http://iopscience.iop.org/0952-4746/32/2/181) debunks http://www.nyas.org/Publications/Annals/Detail.aspx?cid=f3f3bd16-51ba-4d7b-a086-753f44b3bfc1

32 United Nations Scientific Committee on the Effects of Atomic Radiation (2000). Exposures and effects of the Chernobyl accident. http://www.unscear.org/docs/reports/annexj.pdf (accessed 23rd February 2017)

33 United Nations Scientific Committee on the Effects of Atomic Radiation (2011). Sources and effects of ionizing radiation. http://www.unscear.org/docs/reports/2008/11-80076_Report_2008_Annex_D.pdf (accessed 23 February 2017)

34 United Nations Information Service (2013). No immediate health risks from Fukushima nuclear accident says UN expert science panel. [Press release, online] 31st May. http://www.unis.unvienna.org/unis/en/pressrels/2013/unisinf475.html (accessed 28th February 2017)

35 United Nations Scientific Committee on the Effects of Atomic Radiation (2013). Sources, effects and risks of ionizing radiation. UNSCEAR 2013 Report, Volume I, Report to the General Assembly, Scientific Annex A: Levels and effects of radiation exposure due to the nuclear accident after the 2011 great east-Japan earthquake and tsunami. http://www.unscear.org/docs/publications/2013/UNSCEAR_2013_Report_Vol.I.pdf. (accessed 23rd February 2017)

36 Ohira, T et al (2016). Comparison of childhood thyroid cancer prevalence among 3 areas based on external radiation dose after the Fukushima Daiichi nuclear power plant accident. Medicine (Baltimore), 95(35), e4472. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5008539/ (accessed 23rd February 2017)

37 Merz, S et al (2015). Analysis of Japanese radionuclide monitoring data of food before and after the Fukushima nuclear accident. Environmental Science and Technology, 29(5), pp2875-2885. http://pubs.acs.org/doi/abs/10.1021/es5057648 (accessed February 24th 2017)

38 World Health Organisation (2013). Health risk assessment from the nuclear accident after the 2011 Great East Japan earthquake and tsunami, based on preliminary dose estimation. http://www.who.int/ionizing_radiation/pub_meet/fukushima_risk_assessment_2013/en/ (accessed February 24th 2017)

39 International Atomic Energy Agency (2015). The Fukushima Daiichi accident. http://www-pub.iaea.org/MTCD/Publications/PDF/AdditionalVolumes/P1710/Pub1710-TV4-Web.pdf (accessed February 24th 2017)

But... evacuation effects

The supply of long-term data shows there is cause for another kind of concern. Recent studies have found that significant impacts of radiation emergencies can be psychological and earlier over-statement of the risk of low-level exposure is probably itself harmful.[35,40,41,42]

In radiation emergencies, protecting people in the area against immediate physical harm and minimising their further exposure are the priorities. But achieving these has usually involved extensive evacuations of whole populations. This disrupts normal life for many unaffected people, sometimes for a long time, and many thousands of evacuees suffer from post-traumatic stress, depression and stigma — problems exacerbated by overblown estimations of the radiation risk.

> *"The one thing we appear not to have learnt is how to deliver information about radiation risk to an exposed population. There have been considerable psychological consequences, unrelated to the actual radiation risks for human health, from the Chernobyl accident, which have been poorly researched. Radiation risk must be put into context."*
>
> Professor Gerry Thomas, Imperial College London

Working with radiation

The international limit for people working with radiation, whether they work in nuclear power plants or hospitals using radiation for medical procedures, is 20 mSv per year.[43] This dose limit is widely debated. Some believe it is too strict and imposes unreasonable costs on sectors that use radiation such as dentistry. Others believe that it is not strict enough and that there's a theoretical risk for people who are more exposed to other sources of radiation too.

The effects of exposure to radiation from nuclear power have generally not been discussed in the context of exposure from other sources. In the UK people are on average exposed to an annual dose of 2.7 mSv from lots of different sources including the ground under our feet.[44] One transatlantic flight would expose you to around 0.05 mSv while a chest CT scan is around 7 mSv (see Comparing Radiation Dose on p18).

40 Bromet, EJ and Havenaar, JM (2007). Psychological and perceived health effects of the Chernobyl disaster: a 20-year review. Health Physics, 93(5), pp516-521. http://journals.lww.com/health-physics/Abstract/2007/11000/PSYCHOLOGICAL_AND_PERCEIVED_HEALTH_EFFECTS_OF_THE.17.aspx (accessed 26 April 2017)

41 Ohtsuru, A et al (2015). Nuclear disasters and health: lessons learned, challenges, and proposals. The Lancet, 386(9992), pp489-497. https://www.ncbi.nlm.nih.gov/pubmed/26251394 (accessed 26 April 2017)

42 Bromet, EJ (2015). Emotional consequences of nuclear power plant disasters. Health Physics, 106(2), pp206-210. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3898664/ (accessed 24th February 2017)

43 Health and Safety Executive. The Ionising Radiations Regulations 1999 (IRR99). http://www.hse.gov.uk/radiation/ionising/doses/ (accessed 2nd March 2017)

44 Public Health England (no date). Ionizing radiation and you. https://www.phe-protectionservices.org.uk/radiationandyou (accessed 24th February 2017)

KNOWLEDGE ABOUT LONG TERM HEALTH EFFECTS

What we know and don't know

Internationally, there is now a lot more information than in the 1990s about the health effects of different kinds of radiation exposure, not just from nuclear incidents but from medical scans, flying, living near natural radiation and many other sources. Accurate assessment of the type and level of radiation different populations have been exposed to over their lives is extremely complex.[35,45] But it is essential for working out the true effects of exposure to radiation and it's what UNSCEAR was set up to do.

Unfortunately there is still an important gap in our knowledge, which is tricky to overcome. Radiation exposure shows a relationship between the dose one is exposed to and the response (the effect of that exposure); the higher the dose, the more harmful the effect.

The effects of *high* doses of radiation are well understood. But we know less about the effects of low doses. At present, we assume the effects of radiation are on a linear scale according to the size of the dose. This is the Linear No-Threshold (LNT) model and it assumes that any level of radiation exposure carries some increased risk of future cancer. LNT applies an extreme level of caution and it is the model that all current protection guidelines and regulations are based on.

However, there is no convincing evidence that very low levels of radiation, such as our environmental background radiation, are damaging (and there may never be[46]). The model is being called into question,[47,48] and studies commissioned by the French and US Governments concluded that there is no evidence to support the LNT approach.[49,50]

45 United Nations Scientific Committee on the Effects of Atomic Radiation (2008). Sources and effects of ionizing radiation, UNSCEAR 2008 Report to the General Assembly with Scientific Annexes, Volume II, Scientific Annexes C, D & E. http://www.unscear.org/docs/publications/2013/UNSCEAR_2013_Report_Vol.I.pdf (accessed 23rd February 2017)

46 Thomas, G (2015). Distrust of nuclear power is a post-Hiroshima hang-up we can fix. New Scientist, [online] 6th August. https://www.newscientist.com/article/dn28009-distrust-of-nuclear-power-is-a-post-hiroshima-hang-up-we-can-fix/ (accessed 24th February 2017)

47 National Council on Radiation Protection and Measurements (2001). Report no. 136 – Evaluation of the linear-nonthreshold dose-response model for ionizing radiation (2001). http://www.ncrppublications.org/Reports/136. (accessed 24th February 2017)

48 Cohen, BL (2008). The linear no-threshold theory of radiation carcinogenesis should be rejected. Journal of American Physicians and Surgeons, 13(3), pp70-76. http://www.jpands.org/vol13no3/cohen.pdf (accessed 24th February 2017)

49 Tubiana, M and Aurengo, A (2006). Dose–effect relationship and estimation of the carcinogenic effects of low doses of ionising radiation: the Joint Report of the Academie des Sciences (Paris) and of the Academie Nationale de Medecine. International Journal of Low Radiation, 2(3-4), pp135-153. http://www.inderscienceonline.com/doi/abs/10.1504/IJLR.2006.009510 (accessed 24th February 2017)

50 National Council on Radiation Protection and Measurements (1995). Report no. 121 - Principles and application of collective dose to radiation protection (1995). http://www.ncrppublications.org/Reports/121 (accessed 24th February 2017)

People who live in areas with naturally higher levels of radiation from the earth, such as Cornwall in the UK or Ramsar in Iran, don't appear to suffer from higher levels of cancer.[51,52] There is even evidence that very low radiation doses are associated with beneficial effects: a long-term study reported in 2016 found that radiologists who graduated after 1940 showed the same or lower rates of all causes of mortality than their counterparts in psychiatry, who have a similar socio-economic status but no professional use of radiation.[53] This was the largest study of its kind. It is going to be very helpful in understanding long-term effects of low-level exposure because radiologists experience higher doses than other professions exposed to radiation, such as nuclear power workers.

The LNT idea might seem to be a sensible protective assumption to hang on to even if the evidence says otherwise, but as always there are trade-offs. One reason why nuclear power plants are so expensive is because of the extreme engineering implications of reducing radioactive releases down to miniscule amounts to satisfy current radiological protection. We now know that coal-fired power plants emit higher levels of radiation than nuclear power plants: the average dose for living within 80km of a coal fired power plant 0.003 mSv per year — the dose from a nuclear power plant is 0.0009 mSv per year.[54] When coal is burned, the naturally occurring radioactive materials within it are concentrated into the fly and bottom ash that is left over. The fly ash from a coal-fired power plant carries 100 times more radiation into the environment than a nuclear power plant.[55]

More importantly, LNT has caused people to be exposed to the harm of evacuations when they weren't at risk of being harmed by radiation, so the desire to come up with an alternative to LNT, particularly after Fukushima, appears to be growing.

51 Etherington, DJ et al (1996). An ecological study of cancer incidence and radon levels in South West England. European Journal of Cancer, 32A(7), pp1189-1197. https://www.ncbi.nlm.nih.gov/pubmed/8758252 (accessed 24th February 2017)

52 Ghiassi-nejad, M et al (2002). Very high background radiation areas of Ramsar, Iran: preliminary biological studies. Health Physics, 82(1), pp87-93. http://journals.lww.com/health-physics/Abstract/2002/01000/Very_High_Background_Radiation_Areas_of_Ramsar,.11.aspx (accessed 24th February 2017)

53 Berrington de González, A et al (2016). Long-term mortality in 43 763 U.S. radiologists compared with 64 990 U.S. Psychiatrists. Radiology, 281(3), pp847-858. http://dx.doi.org/10.1148/radiol.2016152472 (can't access) (accessed 26 April 2017)

54 Want to estimate your annual radiation dose? https://scilearn.sydney.edu.au/fychemistry/calculators/radiation_dose.shtml (accessed 26 April 2017)

55 McBride, JP et al (1978). Radiological impact of airborne effluents of coal and nuclear plants. Science, 202(4372), pp1045-1050. http://science.sciencemag.org/content/202/4372/1045 (accessed 27th February 2017)

Dose Comparison Chart References

1 http://health.phys.iit.edu/extended_archive/9503/msg00074.html (accessed 26 April 2017)

2 TURNER RC, RADLEY JM, MAYNEORD WV. The naturally occurring alpha-ray activity of foods. Health Phys. 1958 Dec;1(3):268-75.

G. Hiromoto, J. Oliveira, J.S. Carvalho, R. Vicente, S.A. Bellintani; Collective Dose and Risk Assessment from Brazil Nut Consumption. Radiat Prot Dosimetry 1996; 67 (3): 229-230. doi: 10.1093/oxfordjournals.rpd.a031822

3 https://www.radiologyinfo.org/en/info.cfm?pg=safety-xray (accessed 26 April 2017)

4 https://hps.org/publicinformation/ate/faqs/commercialflights.html (accessed 26 April 2017)

https://www.ncbi.nlm.nih.gov/pubmed/11045535 (accessed 26 April 2017)

5 https://www.oecd-nea.org/rp/docs/2010/crpph-isoe2010-5.pdf (accessed 26 April 2017)

6 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/340209/HpaRpd001.pdf (accessed 26 April 2017)

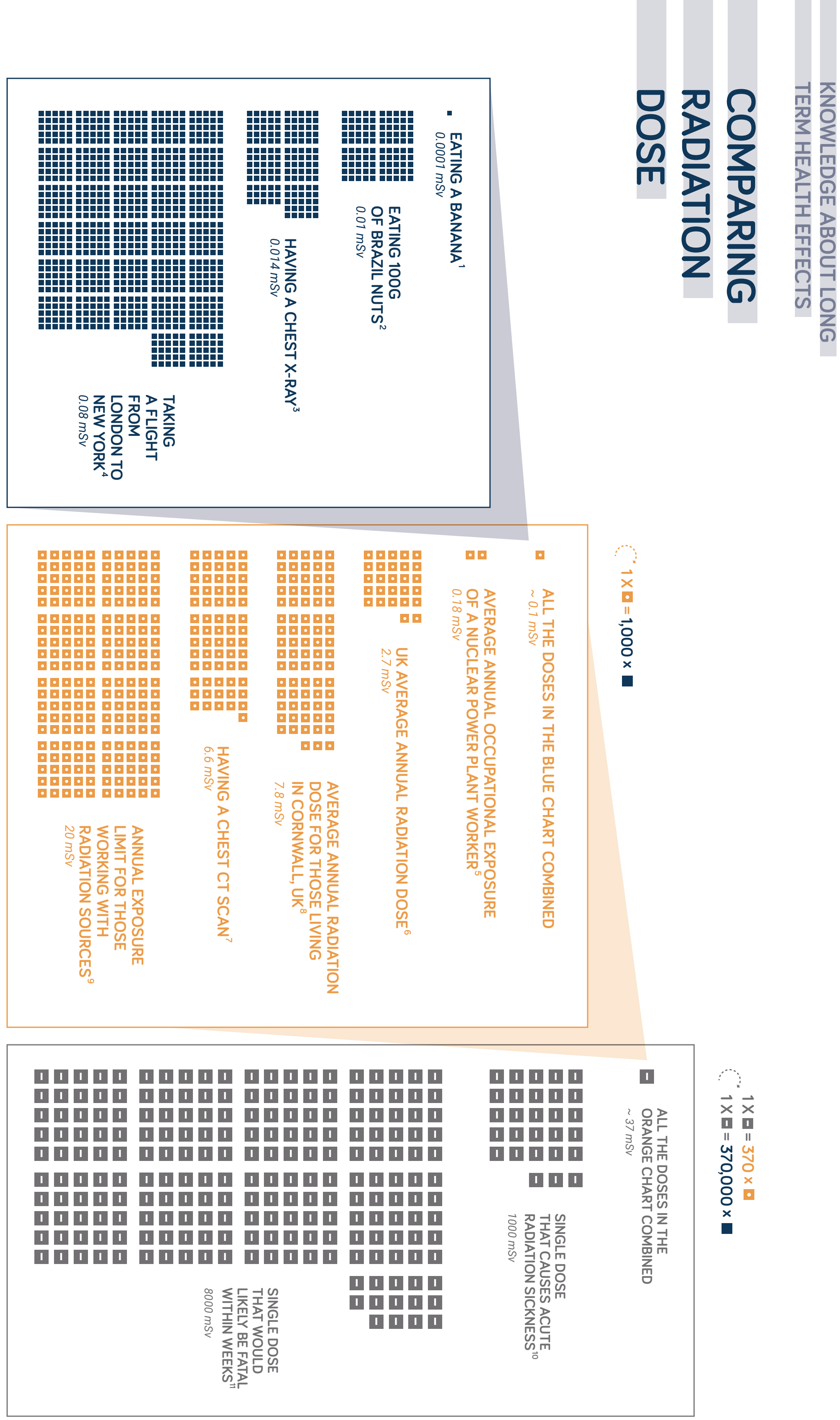
7 http://www.radiologyinfo.org/en/info.cfm?pg=safety-xray (accessed 26 April 2017)

8 https://www.radiologyinfo.org/ (accessed 26 April 2017)

9 http://www.legislation.gov.uk/uksi/1999/3232/contents/made (accessed 26 April 2017)

10 http://www.world-nuclear.org/focus/radiation/what-are-health-risks-from-ionising-radiation.aspx (accessed 26 April 2017)

11 https://www.radiologyinfo.org/ (accessed 26 April 2017)



MORE EXPERIENCE OF MANAGING NUCLEAR POWER PROGRAMMES

Historically, two other big concerns about nuclear power have been 1) how to dispose of the waste, and 2) the belief that more nuclear facilities would lead to more nuclear weapons programmes or new targets for terrorists.

There is not a great deal that is new in what we know about either of these issues — the properties of radioactive material, relevant to them both, have been well understood for a long time. They're also often secondary to health and climate change in people's thinking about nuclear. However, they're included here because they're talked about a lot and because there does seem to be some new information to consider about managing radioactive materials.

Radioactive waste

The nuclear power industry — which includes nuclear fuel manufacturing, nuclear power plants, reprocessing of spent nuclear fuel, and research and development programmes — is the source of most (94%) of the UK's radioactive waste.[56] The rest of the radioactive waste comes from medical treatment, sterilisation of food and medical equipment, research, and defence.[57]

However, the vast majority of the radioactive waste that the UK currently has to deal with is **legacy waste**, from past nuclear power programmes and the 1950s weapons programme. Much of this came from a period when waste disposal and nuclear power plant decommissioning were afterthoughts.

One consequence of that lack of thought, was that in the early years materials of different levels of radioactivity were mixed together (eg vials of highly radioactive materials were not properly separated from the gloves and lab coats worn in a research facility or from lumps of concrete from old nuclear facility buildings). At the last inventory in 2013, the UK had about 4.3 million cubic metres of this radioactive waste (all kinds from all sources).[55]

By contrast, based on current plans for the existing nuclear power industry, and use of radioactive materials for defence, medical and industrial purposes, the UK's Nuclear Decommissioning Agency estimates that a further 160,000 cubic metres of waste would be produced over the next *100 years*.[56]

[56] Department of Energy and Climate Change (2014). Radioactive wastes in the UK: a summary of the 2013 inventory. http://ukinventory.nda.gov.uk/wp-content/uploads/sites/2/2014/02/14D039-NDASTSTY140006-UKRWI-2013-High-Level-Summary.pdf (accessed 2nd March 2017)

[57] UK Radioactive Waste Inventory (no date). How is radioactive waste produced? See 'Radioactive waste from other sectors' - https://ukinventory.nda.gov.uk/about-radioactive-waste/how-is-radioactive-waste-produced/ (accessed 2nd March 2017)

Of course, they can't really say exactly how much waste will be generated without knowing how many and which type of nuclear reactors might exist in the future. The nuclear industry claims that third generation nuclear reactors being built today produce far less waste than their predecessors[58] but maybe the government won't commission those. Whatever happens, decommissioning plants and managing the waste are now planned in at development stage, so there isn't the poorly thought out stockpiling that created much of the legacy waste.

Dealing with the legacy waste

In the UK, waste is categorised by how much radioactivity it contains and its associated heat production. Of current UK radioactive waste, about 94% is low or very low level, about 6% is intermediate, and less than 0.1% is high level waste. Although high level waste makes up only a tiny proportion of the volume, it contains about 95% of all the radioactivity; conversely, the much larger volume of low and very low level waste accounts for less than 0.01% of the total radioactivity.[56]

Nuclear waste is dangerous because it contains radioactive isotopes, whose radioactivity declines over time. This is measured in terms of a 'half-life', the time taken for the radioactivity of a substance to fall to half its original value. The half-lives of different isotopes vary hugely: from fractions of a second up to millions or even billions of years. A long half-life is not necessarily an indication of potential to cause harm.

What type of waste is it?

Low level waste includes materials such as scrap metal, paper and plastics, and items such as laboratory coats and gloves that have been used in all kinds of nuclear facilities.[56]

Intermediate level waste is mainly metal items such as nuclear fuel casing and reactor components and graphite from reactor cores. High level waste includes reprocessed spent nuclear fuel.

58 World Nuclear Association (no date). Our mission. http://www.world-nuclear.org/our-association/who-we-are/mission.aspx (accessed 27th February 2017)

How is radioactive waste dealt with?

Low level waste can be disposed of by controlled burial. Very low level waste (a subset) can be safely disposed of with normal municipal, commercial or industrial waste or sent to landfill.[56]

Most intermediate level waste is encapsulated in cement in large stainless steel containers or concrete boxes. Materials may be compacted to reduce their size first, or treated to reduce their water content. Some intermediate level waste is stored directly in thick-walled cast iron containers, which reduce the need for further shielding in storage facilities.[56]

High level waste can produce a lot of heat as a result of its radioactivity. Initially these waste products are in a nitric acid solution, and then they are vitrified (turned into glass) for stable long-term geological disposal.[56,59] After 40-50 years the radioactivity of spent fuel falls to one thousandth its level at removal from a nuclear power plant.[60] After 1000 years, the radioactivity of the waste is about the same as that of uranium ore. This means waste storage engineers need to plan to secure high level waste for about 1000 years.[61]

59 World Nuclear Association (2016). Treatment and conditioning of nuclear wastes. http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-wastes/treatment-and-conditioning-of-nuclear-wastes.aspx (accessed 27th February 2017)

60 World Nuclear Association (2016). Radioactive waste management. http://world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-wastes/radioactive-waste-management.aspx#.UlWjHBBRh24 (accessed 27th February 2017)

61 MacKay, DJC (2008). Sustainable energy – without the hot air. Chapter 24, page 170 https://www.withouthotair.com/c24/page_170.shtml (accessed 27th February 2017)

Geological disposal

One way of managing radioactive waste is to bury it deep underground, known as geological disposal. It is a simple engineering premise: radiation is easy to stop, all you need is something thick and dense.

Geological repositories are excavated deep (typically below 300 metres or 1000 feet), in stable rock formations so that the waste won't be exposed to groundwater movement or compromised as a result of earthquakes. These facilities are designed to provide long-term isolation without the need for future maintenance.

Finland is to become the first country in the world to use a long-term underground storage facility. Known as Onkalo, it is being built on an island off Finland's southwest coast. Finnish authorities expect to start storing high level waste there in 2023; canisters containing waste will be packed in with clay, until the facility is sealed in around 2120. This should isolate the waste for several hundred thousand years, long past the point of it being dangerous.[62]

Re-using 'waste'

People often use the term "nuclear waste" to describe all by-products of nuclear power generation, however some of these products can be reused. Spent nuclear fuel can be reprocessed to recover uranium and plutonium, which can be used to make new fuel.[63]

Mixed oxide (MOX) fuel can be made from plutonium recovered from used reactor fuel, mixed with depleted uranium,[64] which also makes it even harder to adapt for nuclear weapons.[65] An alternative, regenerated mixture (REMIX), fuel is being tested, in which recycled uranium and plutonium which haven't been separated are topped up with fresh enriched uranium for further use.[64]

Such attempts to close the nuclear fuel cycle could both reduce future waste and provide a way to deal with some of the existing waste using some of the technologies described in section 4.

62 Gibney, E (2015). Why Finland now leads the world in nuclear waste storage. Nature, [online] 2nd December. http://www.nature.com/news/why-finland-now-leads-the-world-in-nuclear-waste-storage-1.18903 (accessed 27th February 2017)

63 UK Radioactive Waste Inventory (no date). What is radioactive waste? https://ukinventory.nda.gov.uk/about-radioactive-waste/what-is-radioactive-waste/ (accessed 27th February 2017)

64 World Nuclear Association (2016). Mixed oxide (MOX) fuel. http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/fuel-recycling/mixed-oxide-fuel-mox.aspx (accessed 27th February 2017)

65 United States Nuclear Regulatory Commission (2017). Frequently asked questions about mixed oxide fuel. http://www.nrc.gov/materials/fuel-cycle-fac/mox/faq.html#1 (accessed 27th February 2017)

Nuclear Weapons

Developing the capacity to generate nuclear power is seen by some as creating the basic ingredients for nuclear weapons. There are some links between the two capabilities — defence programmes and energy programmes – in large countries, but the material used to provide power is not suitable for weapons. Specific types of fissile uranium and plutonium (radionuclides uranium-235 and plutonium-239) are needed and must be concentrated to very high levels (enriched) to create nuclear bombs.

The uranium used for nuclear fuel is enriched so that it contains up to 5% uranium-235.

The uranium used in nuclear bombs needs to be enriched to around 90% uranium-235.[66]

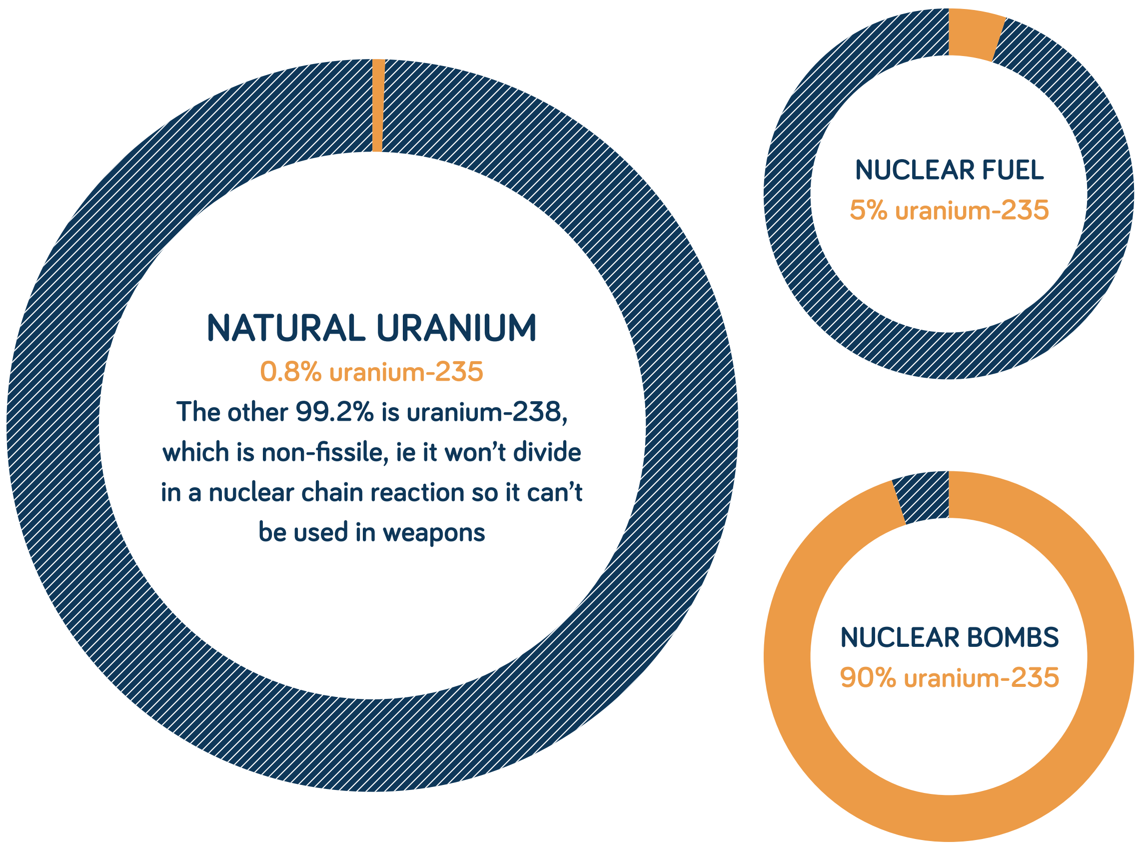
Reactor-grade plutonium is a waste product created over years of burning up uranium-238, which can then be used in plutonium reactors to create further energy. It contains some of the isotope plutonium-240, which has captured an extra neutron.

Weapons-grade plutonium must contain very little plutonium-240, so it has to be made more quickly in a reactor under special conditions.

Enrichment is costly and difficult, and requires highly specialised facilities. There are international non-proliferation agreements — such as the landmark Treaty on the Non-Proliferation of Nuclear Weapons which came into force in 1970 and will continue indefinitely — and UN monitoring of nuclear weapons, so secrecy would be costly and hard to manage too. Some governments could attempt it (though if they would flout proliferation agreements, presumably any restrictions on nuclear power programmes wouldn't stop them.) It is unlikely that anyone else could attempt, undetected, to enrich uranium or create weapons-grade plutonium. But the rules governing nuclear materials, and the search for new types of system, assume that all of these things are a possibility and that the risk should be further reduced where possible.

66 World Nuclear Association (2017). Military warheads as a source of nuclear fuel. http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/uranium-resources/military-warheads-as-a-source-of-nuclear-fuel.aspx (accessed 27th February 2017)

DIFFERENT KINDS OF URANIUM



CHANGING TECHNOLOGIES

Improvements in technology also seem to have influenced some environmentalists' views about nuclear power. New reactors are more efficient (they produce more energy for less waste) and safer.

Old reactor safety

Over the past 40 years the two most serious nuclear power incidents were Chernobyl, and Fukushima. It would have been better to have had none, but they have provided hard data on what happens in extreme situations, which has led to improvements.

The nuclear reactors in the UK, the US, Japan and many other countries are now aging. Even compared to those, though, Fukushima Daiichi power plant was old: the first of its six reactors was switched on in 1971. All of them were boiling water reactors, which safety inspectors had raised concerns about as early as 1972.[67] However, the Japanese government accepted Fukushima Daiichi being upgraded to continue running. These upgrades were found to have contributed to its failure after the 2011 earthquake and tsunami.[68]

Japan is in an extremely active seismic zone, so the Fukushima Daiichi nuclear plant was designed to withstand a 5.7 metre tsunami. The tsunami that hit it was 15 metres high. When the earthquake started, the reactors had successfully shut down automatically, but the tsunami then flooded the back-up diesel generators and batteries, which were needed to keep the reactors cool in order to prevent a meltdown. The placement of the generators in basements and low lying areas was part of what has been described as a "cascade of engineering and regulatory failures".[69]

This was a case study in how to make a nuclear plant dangerous. But it led environmental advocate and journalist, and long-time opponent of nuclear power, George Monbiot, to a different conclusion: "A crappy old plant with inadequate safety features was hit by a monster earthquake and a vast tsunami. The electricity supply failed, knocking out the cooling system. The reactors began to explode and melt down. The disaster exposed a familiar legacy of poor design and corner-cutting.[67] Yet, as far as we know, no one has yet received a lethal dose of radiation… Atomic energy has just been subjected to one of the harshest of possible tests, and the impact on people and the planet has been small. The crisis at Fukushima has converted me to the cause of nuclear power."[70]

67 Goldenberg, S (2011). Japan's nuclear crisis: regulators warned of reactor risks. The Guardian, [online] 14th March. https://www.theguardian.com/environment/2011/mar/14/nuclearpower-energy (accessed 27th February 2017)

68 HM Chief Inspector of Nuclear Installations (2011). Japanese earthquake and tsunami: implications for the UK nuclear industry. http://www.onr.org.uk/fukushima/final-report.htm (accessed 27th February 2017)

69 Synolakis, C and Kânoğlu, U (2015). The Fukushima accident was preventable. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 373(2053):20140379. http://rsta.royalsocietypublishing.org/content/373/2053/20140379 (can't access) (accessed 26 April 2017)

70 Monbiot, G (2011). Going critical. [Blog, online] 21st March. http://www.monbiot.com/2011/03/21/going-critical/ (accessed 27th February 2017)

So what is new?

George Monbiot is right, that plant was very old; and developments since 1971 are too many to cover. Because we're talking here about what's likely to interest people who are considering evidence and opinions about using nuclear power today or in the future, the most relevant developments are probably the shift to passive safety and the range of new reactors.

Passive safety

The biggest risk to nuclear power plants is the failure of the coolant system. Both Chernobyl and Fukushima Daiichi involved 'loss of coolant accidents'.

The coolant system removes heat from the reactor core where fission is taking place. If it fails — for instance, with a loss of external power — the core can overheat and suffer damage, such as burst pipes, fires and ultimately melting of the fuel. As a further backup, if the coolant fails, reactors have systems to slow down the fission reaction. This reduces the build-up of heat and the chances of the core overheating.[71]

The design of reactors had already changed a lot from those at Chernobyl and Fukushima Daiichi, but there are now newer types of coolant and back-up systems. Some of these are or will be used in reactors in the UK, France, Finland, the US and China. They include:

Making use of gravity

In the event of a critical power failure it is necessary to stop the nuclear fission reaction within the reactor core. This is achieved by dropping control rods into the core. Traditional reactor safety systems are active: someone has to press a button, or an automated system, reliant on an electrical supply, has to kick in. Most modern reactors have moved to passive safety systems. One example of this is how the control rods are positioned above the core and held in place using electromagnets. When there is a loss of power the control rods fall automatically due to gravity.

71 World Nuclear Association (2016). Safety of nuclear power reactors. http://www.world-nuclear.org/information-library/safety-and-security/safety-of-plants/safety-of-nuclear-power-reactors.aspx (accessed 27th February 2017)

Liquid metal

Traditionally water is used to stop reactor cores overheating. However this water has to be pumped continuously and kept at a high pressure to prevent it from turning into steam. Alternatives to water have now been trialled as coolants with various advantages and disadvantages. In some designs the reactor core is submerged in a pool of liquid sodium, which acts as the coolant and transfers heat to boil water by means of heat exchange. Liquid sodium has a much higher boiling point than water, so there's no need for high pressure to stop it vaporising — a significant safety advantage. Sodium is also much better at conducting heat, making sodium-cooled reactors likely to be passively safe because their heat will dissipate normally even in the event of an accident. However, no system is failsafe — sodium is highly reactive in air and water, so it has to be robustly contained. Sodium cooled reactors are currently only experimental.

New types of reactor

Small modular reactors (SMRs)

Typically a third of the size of a current nuclear power plant, these may offer more affordable and accessible nuclear energy. SMRs have smaller up-front costs, take less time to build, and could be modular — part-assembled efficiently in factories rather than bespoke on-site like larger reactors. A feasibility study for the UK government in 2014 found that current designs could generate electricity by 2025.[72] The UK government said in 2015 that it will invest £250m in research to identify "the best value small modular reactor designs for the UK"[73] and to set out what contribution SMRs could make to low-carbon energy sources.

Thorium

Another alternative to conventional nuclear energy sources may eventually be thorium. Thorium is more abundant in nature than uranium, produces less waste, and is regarded as inherently safer in some ways as well as more proliferation-resistant. Some commentators have suggested that the current programme of nuclear power plants should be scrapped and replaced with a development programme for thorium reactors, which could power humanity for thousands of years on known resources.[74] However, thorium reactors are still only in the developmental stage. The UK experience is largely with uranium, and it would take a full research and development programme to work through the technically and commercial challenges of thorium reactors so they won't address emissions and energy needs in the short term.

72 National Nuclear Laboratory (2014). Small modular reactors (SMR) feasibility study. http://www.nnl.co.uk/media/1627/smr-feasibility-study-december-2014.pdf (accessed 27th February 2017)

73 HM Government (2015). Spending review and autumn statement. https://www.gov.uk/government/topical-events/autumn-statement-and-spending-review-2015 (accessed February 27th 2017)

74 Evans-Pritchard, A (2016). Britain should leap-frog Hinkley and lead 21st Century nuclear revolution. The Telegraph, [online] 17th August

Fusion

Nuclear fusion, as opposed to fission, may possibly one day provide energy. The model for it is the sun, which is a fusion reactor. There is a joke among physicists that nuclear fusion is only 20 (or 30, or 40, depending who you ask) years away, and always will be. A fusion reactor would have to confine a plasma of reacting light elements at a temperature of millions of degrees Celsius. It is included here because it's regularly written about in the news and it is the subject of a major European research initiative.

The Joint European Torus (JET) is a facility to study fusion in conditions like those for a power plant. It achieved a controlled release of fusion power in 1991. The International Thermonuclear Experimental Reactor (ITER) is now building on that, trying to find a way to produce more energy than that required to start the fusion process. However, as the late Professor Sir David MacKay, former chief scientific adviser to the UK Department of Energy and Climate Change, argued, in the context of urgent decarbonisation,

> *"Fusion power is speculative and experimental. I think it is reckless to assume that the fusion problem will be cracked."*[75]

Closing the nuclear fuel cycle

In future, integral fast reactors (IFRs) may provide a solution to both waste management and energy production. IFRs can recycle nuclear waste by fissioning some of the very heavy radioactive elements that would otherwise be discarded. They can also produce more fuel than they consume by transmuting non-fissile uranium-238, which makes up 95% of uranium in reactor fuel, into plutonium that can then be used to produce power. In conventional reactors all the potential energy in 'depleted uranium' and U-238 remaining in spent fuel is thrown away. In a closed fuel cycle there would be no need to mine any new uranium for long periods of time — one recent estimate suggests that IFRs could provide enough electricity to power the UK for 500 years using only the UK's existing legacy waste.[76]

[75] MacKay, DJC (2008). Sustainable energy – without the hot air. Chapter 24, page 172 https://www.withouthotair.com/c24/page_172.shtml (accessed 27th February 2017)

[76] Clarke, D (2012). New generation of nuclear reactors could consume radioactive waste as fuel. The Guardian, [online] 2nd February

FINAL THOUGHTS

There has been a steady flow of private and public investment in nuclear research and development, as nations look for ways to meet energy needs and reduce CO_2 emissions. So there is a lot of new nuclear technology now being tested and developed around the world. Meanwhile, there is more and more data from the operation of the growing number of nuclear power plants internationally.

This information should be transparent and available to inform discussions about alternatives to oil, gas and coal. There is not one singular nuclear option, but several technologies and there are going to be even more over the next ten years. The nuclear industry and government nuclear programmes have in the past been quite secretive and closed. And while that seems to have improved, the commissioning and commercial bidding involved in big energy infrastructure doesn't help to get an honest picture of the relative merits of the different options, as governments and companies lock into their preferred solution and present information to suit it. We all — researchers, environmental groups, science bodies — have to press for a frank and up-to-date picture of how reactors and safety systems compare and their changing costs and benefits. We need that — whether we're open-minded opponents, reluctant accepters or strong advocates of using nuclear power.

MORE INFORMATION

If you've got questions about nuclear energy, or indeed any type of energy generation you can get the answers from independent researchers. The Energy Panel does just that, a one stop shop for the answers to your questions. If we want a frank discussion based on the science we need to cut through the rhetoric and make sure we're listening to what the evidence tells us.

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