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Reactors, residents and risk

A world population analysis reveals the locations that could put the most people in danger should a nuclear accident occur.

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Map showing the population size living within 75 kilometres of each of the world’s nuclear power plants. Population increases with circle size and with colour, from green (< 0.5 million) to red (> 20 million). You need to download the Google Earth plug-in to view this graphic. For a larger version, click here.

In the aftermath of the Fukushima nuclear accident, people everywhere are asking: could a similar disaster strike closer to home?

For much of the world’s population, distance offers no comfort. An analysis carried out by Nature and Columbia University, New York, shows that two-thirds of the world’s 211 power plants have more people living within a 30-kilometre radius than the 172,000 people living within 30 kilometres of the Fukushima Daiichi plant, who have been forced or advised to leave. Some 21 plants have populations larger than 1 million within that radius, and six have populations larger than 3 million.

Population size was just one of the factors that Nature set out to explore in a bid to map reactor hazards around the world. Nuclear experts say that an objective ‘danger’ ranking is almost impossible because each reactor has its own unique risk profile, and some risks are simply unknowable. Reactor safety depends above all on a ‘culture of security’, including the quality of maintenance and training, the competence of the operator and the workforce, and the rigour of regulatory oversight, says Mycle Schneider, an independent nuclear consultant based in Paris. This means that a better-designed, newer reactor is not always a safer one. “What is more dangerous, a drunk driver in a brand new Ferrari or a sober Formula 1 pilot in a 30-year-old 2CV?” Schneider says. But experts do agree on a few critical risk factors, and on measures that could limit them.

Population

Population density is one critical lens through which other risks have to be assessed, says Laurent Stricker, a nuclear engineer who is chairman of the World Association of Nuclear Operators (WANO), created as an international forum on nuclear safety in the aftermath of the 1986 Chernobyl accident.
"We need to look at the safety of reactors taking into account where they are," he says (see Nature 472, 274; 2011).

To carry out the population analysis, Nature teamed up with the NASA Socioeconomic Data and Applications Center based at Columbia University (see 'How population sizes were estimated' for an explanation of how the analysis was carried out). The KANUPP plant in Karachi, Pakistan, has the most people — 8.2 million — living within 30 kilometres, although it has just one relatively small reactor with an output of 125 megawatts (see 'Nuclear neighbours'). Next in the league, however, are much larger plants — Taiwan's 1,933-megawatt Kuosheng plant with 5.5 million people within a 30-kilometre radius and the 1,208-megawatt Chin Shan plant with 4.7 million; both zones include the capital city of Taipei. The findings of Nature's population analysis are "scary", says Ed Lyman, a nuclear expert with the Union of Concerned Scientists in Washington DC.

If the radius is broadened to 75 kilometres, the picture looks even more disconcerting. China’s neighbouring Guangdong and Lingao plants top that league, each with around 28 million people within a 75-kilometre radius that covers Hong Kong, followed by the Indian Point plant near New York, with 17.3 million, and the Narora plant in Uttar Pradesh, India with 16 million. One hundred and fifty-two nuclear power plants have more than 1 million people living within 75 kilometres; and all but five plants have more than 1 million people within 150 kilometres. Fortunately, prevailing winds have so far blown most of Fukushima Daichi’s radioactivity out to sea, as some 7.7 million people, including some in the greater Tokyo area, live within 150 kilometres of that site (see 'Where the worst could happen').

External threats

As Fukushima showed, external threats — such as earthquakes, tsunamis, fires, flooding, tornadoes or even terrorist attacks — are some of the greatest risk factors for a serious nuclear accident. Conventionally, nuclear plant operators have considered some accident sequences so unlikely that they have not built in complete safeguards — such accidents are called ‘beyond design basis’ events. Yet forecasting the location of the next earthquake or the size of the next tsunami is an imperfect art.

This means that nuclear plants situated outside known geological danger zones could pose greater accident threats in the event of an earthquake than those inside, as the former could have weaker protection built in. The Fukushima Daichi plant, for example, was located in an area designated, on Japan’s seismic risk map, as having a relatively low chance of a large earthquake and tsunami; when the 2011 tsunami arrived, it was in excess of anything its engineers had planned for.

The possibility of beyond design basis accidents is a major thrust of the many safety reviews being conducted post-Fukushima. The International Atomic Energy Agency (IAEA) is already paying attention to external threats — creating an internal International Seismic Safety Centre in 2008, for example, after an earthquake hit the Kashiwazaki-Kariwa plant on the west coast of Japan in 2007, prompting an automatic shutdown and a minor release of radioactivity (see Nature 448, 392–393; 2007).

Design and age

Some reactors and plants are inherently more dangerous than others. One factor is sheer size. A larger plant can generate more fallout, and when simultaneous crises develop at multiple reactors — as happened at four of Fukushima’s six reactors — operators can be overwhelmed. The Kashiwazaki-Kariwa plant has seven reactors, making it the world’s biggest in terms of electrical output at 7,965 megawatts. Other such mega-sites, besides Fukushima itself, include Qinshan on China’s northeast coast, Yeonggwang and Ulchin in South Korea, the Leningrad plant in Russia, Bruce on the shores of Lake Huron in Ontario, Canada, and Gravelines and Paluel, both on the northern coast of France.
“One hundred and fifty-two nuclear power plants have more than 1 million people living within 75 kilometres.”

Older reactors are not necessarily more dangerous than newer ones. The 1978 Three Mile Island accident in the United States occurred in a reactor that had started operation only three months earlier, and the accident at Chernobyl (now in Ukraine) occurred after only two years of operation. A serious loss of coolant occurred at the French Civaux-1 reactor in 1998, less than five months after start-up. That’s not surprising, says Lyman, as reactors follow a well-known trajectory in reliability engineering called the ‘bathtub curve’. Complex new machines and installations often have features that haven’t been fully tested, or are new to operators, so bugs and mistakes can occur at the start. After the bugs get worked out, reactors enter a relatively lower-risk stable phase, but risk later increases with age-related deterioration. "Institutional loss of memory" is another problem that increases with reactor age, says Jan Beránek, head of nuclear campaigns at Greenpeace International, headquartered in Amsterdam, the Netherlands. "Many engineers who are familiar with the design and were involved in the planning and building of those reactors are retired, and part of their very specific expertise is getting lost."

As the 1986 Chernobyl accident showed, the design itself can pose risks. The Chernobyl reactor core contained flammable graphite, and the fire that burned for weeks after the accident spewed radioactivity high into the atmosphere. The reactor design also contained an inherent instability such that the chain reactions accelerated as the core lost water — an impossible event with most other reactor designs. Several Chernobyl-design reactors are still in operation in Russia, in particular at the plant near St Petersburg, close to large population centres. These reactors have, however, been radically overhauled to address these and other safety issues with the design.

But Lyman cautions against placing too much stock in one reactor design being safer than another. Modern pressurized water reactors would face much the same difficulties as Fukushima if their cooling systems were disabled, he says.

Culture

However safe a plant is designed to be, it is operated by error-prone humans. Operators must guard against complacency, says Stricker. "One flaw that I worry about is that of overconfidence." Experts say that the largest single internal factor determining the safety of a plant is the culture of security among regulators, operators and the workforce — and creating such a culture is not easy. "It is expensive. And it involves an attention to detail and a willingness to accept and learn from intrusive peer review by others," wrote Richard Meserve, president of the Carnegie Institution for Science in Washington DC, in 2010 as chair of the IAEA’s International Nuclear Safety Advisory Group.

Meserve was referring in particular to what many experts see as potentially the fastest-growing risk in the nuclear industry : that many countries with little or no past experience are embarking on nuclear power or are already building large numbers of reactors. Meserve points, for example, to plans to introduce nuclear power in Belarus, Chile, Egypt, Indonesia, Jordan, Lithuania, Malaysia and Morocco, among others. Experts worry about lack of regulatory oversight and corruption in some regions. Stricker says that peer review of plants before they start up will be of particular importance in inexperienced countries, and that WANO intends to increase such reviews.

Tom Cochran, a nuclear expert at the Natural Resources Defense Council in Washington DC, is sceptical that the many post-Fukushima safety reviews already under way in the United States, the European Union and elsewhere will result in significant changes in risk assessment of nuclear reactors. "They will make recommendations and adjustments, but I don’t think you can ask regulators to review whether they have made mistakes in the past ; I don’t think they will do enough." Cochran
wants independent commissions to be established, similar to the Kemeny Commission set up to draw lessons from the Three Mile Island accident.

And with risk assessment so difficult, experts say that one of those lessons is that operators must simply prepare better for a serious nuclear emergency. "One change that WANO could, and in my opinion must, make," says Stricker, "is to be in a position to verify that every nuclear operator company from the smallest to the largest has plans to cope with unforeseen accidents."