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Nuclear Energy Option Best, Indian Plants Pretty Safe

- Prime Minister Manmohan Singh

In This Issue

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Editor: B.K. Sinha

EDITORIAL

Dear Reader,

Greetings. The current issue of Asian Nuclear Energy discusses in detail the burning issue of safety, which is at the centre of a global debate in the wake of the March 2011 Fukushima nuclear disaster in Japan. I was in Africa recently, and wondering what makes Asia more vulnerable than other continents. Is it the diversity? Is it the population? Most people in the world live in Asia. I don't know whether Japan is nuclear disaster's favorite child. But then when you are a populous nation such concerns are but obvious. The debate on 'nuclear safety' is doubly relevant to energy-starved India, which has drawn up a massive plan to boost its nuclear energy production. The cover story details Prime Minister Manmohan Singh's reiteration of the Government's stand that the nuclear option is the best for this country and that the safety measures in Indian plants are stringent enough to meet every contingency. The issue presents a study that clearly places nuclear energy as a far cheaper option and lists the measures needed to make it safer. In this context, we also carry a report that places thorium-rich India in an advantageous position with regard to nuclear energy production in the future. There is a report tracing the history of atomic energy, the built-in safety precautions taken at every stage of its development over decades. Most prejudices raised against nuclear energy are based on myths and not facts; the issue presents a list highlighting them. The recent decision of Germany giving up its nuclear energy option, following the Japanese disaster, may not influence other rich nations which have preferred and invested heavily in it. We carry a report. There is an article on how fast-developing countries in Asia are increasingly opting for nuclear energy to sustain their economic growth rate. In the news section, we have reports on experimental reactors being prone to nuclear accidents, 'stress tests being conducted in European plants after the Fukushima disaster, severe accident management plans being put in place at nuclear plants the world over, protecting nuclear plants and materials from terrorist attacks and a comparative study on accidents in nuclear and other energy-related industries. In the final analysis when it comes to safety, it is an ethical dilemma where on one hand we have an energy starving nation and on the other, the concerns of nuclear disaster. India needs a realistic and rational approach.

Wish you happy reading,

Satya Swaroop
Managing Editor


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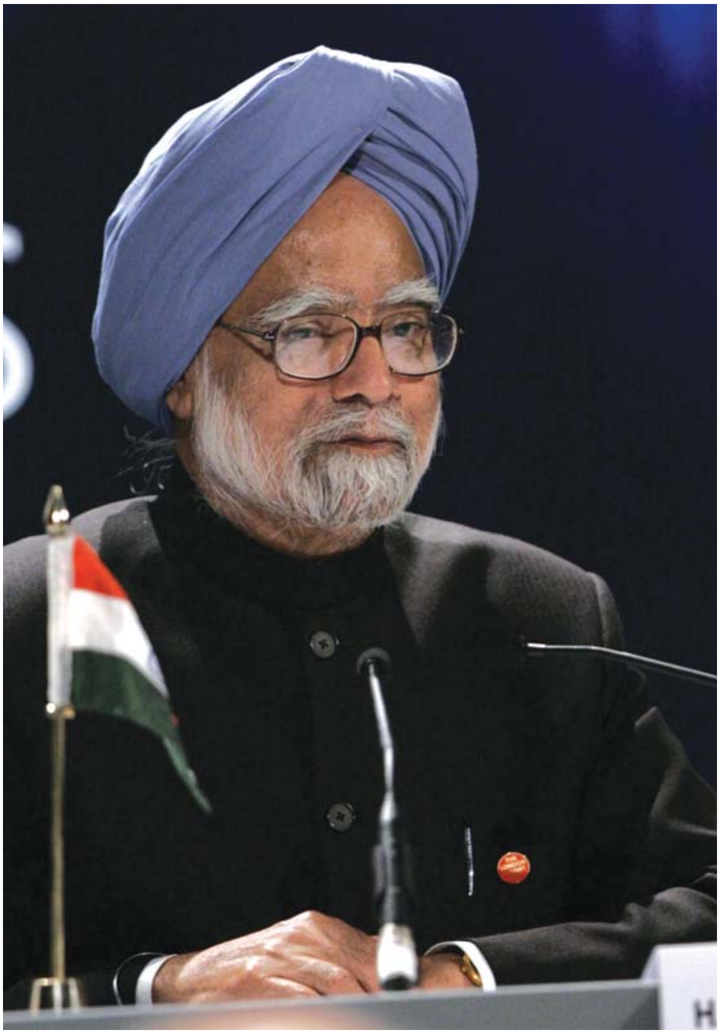
Nuclear Energy Option Best, Indian Plants Pretty Safe

-Prime Minister Manmohan Singh



Power-starved India cannot give up the nuclear energy option, despite vociferous protests against it on the grounds of safety. Prime Minister Manmohan Singh, signatory to the famous Indo-US Civil Nuclear Energy Agreement of 2008, has made it amply clear that this country has little choice than going for the nuclear option.

“It would be harmful for the country to pass an ordinance on denial of nuclear power,” Prime Minister Singh said, replying to a question related to nuclear safety during question hour in Lok Sabha recently.

Singh was replying to a question by Anant Geete (Shiv Sena) on the Prime Minister's views on giving up nuclear power like Japan which has put safety issues ahead of its need for electricity.

"We are not in a situation in which Japan is there... It would be harmful for the country's interest to pass an Ordinance of self-denial that we shall give up the option of having nuclear power as an additional source," he said.

Stating that saying no to nuclear power would be detrimental to the nation's interests, Dr. Singh has reassured lawmakers that the nuclear plants in the country are safe. "We must keep the option of having nuclear power as an additional source of energy open. There would be no compromise on the safety of nuclear power plants," he said.

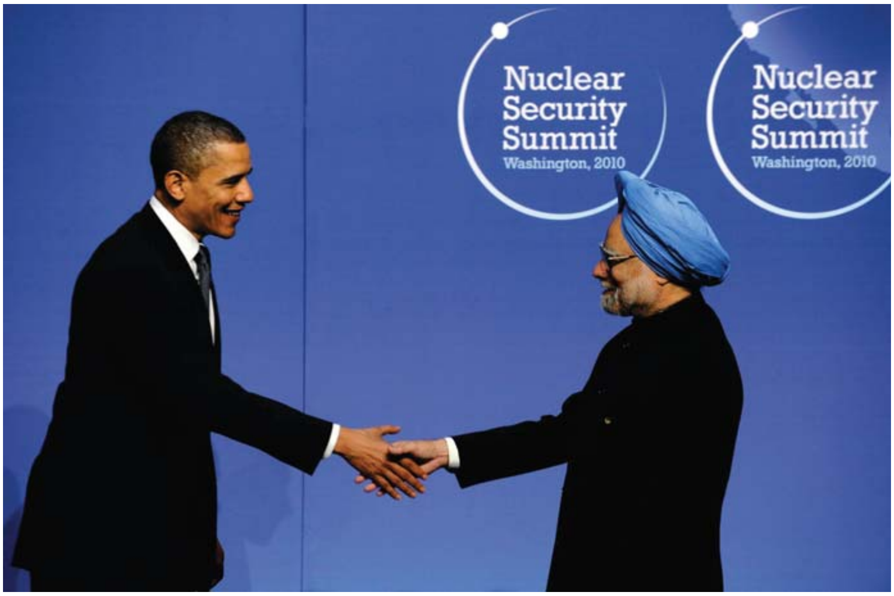
Making a strong pitch for nuclear energy, the Prime Minister Singh said would be "harmful" if the country gave up the option of additional source of electricity. At the same time, the Prime Minister said there would be no compromise on the issue of nuclear safety.

He said that as far as the present policies with regard to nuclear power were concerned, the government was of the view that when it comes to questions of safety, there should be no compromise whatsoever.

"Our safety measures are an open book... So, I think, the policy that we have right now is that we must do everything in our power to ensure foolproof safety of the nuclear plant. That we will never compromise with," Dr. Singh said.

"But, at the same time, I would respectfully submit that it would be harmful for the country's interest to pass an Ordinance of self-denial that we shall give up the option of having nuclear power as an additional source," he said.

The Prime Minister said his that government would never do anything which creates doubts about the safety of nuclear plants. India has 19 functioning nuclear reactors and there has never been any unfortunate incident, Dr. Singh noted.



Some of the risks which the agitators have voiced out-

Risk of Explosion

The foremost risk when anyone talks about Nuclear Energy is the Nuclear explosion at Hiroshima Nagasaki. This is the risk which a common man fears..the risk of explosion. The fall out of an explosion cannot be managed. But talking about nuclear plants. nuclear scientists may argue that in the long history of nuclear plants only 31 people died because of an explosion, and that was at Chernobyl.

"And even after Fukushima, I ordered a complete revisit to all the 19 reactors. Those findings of the NPCIL are on the websites for everybody to see," he said.

On Germany giving up nuclear power, the Prime Minister pointed out that Germany relies on France to meet its power need and France has a large number of nuclear power plants.

At the same time there are diverse views which the agitators at Koodankulam have. Many of them are of the view that all the nuclear plants in India need to be shut down. The point of content for the agitators is that all technologies have inherent risks, where some are manageable and some are not. Nuclear is one, which they feel cannot be managed and hence one should not take them. Whether it was, Three Mile Island disaster in the 1970s, Chernobyl in the 1980s and Fukushima in 2011 after a certain point the countries concerned even with the best of the talent and technology were unable to handle the fallout.

Besides the better known disasters at Kyshtym in the erstwhile USSR, in 1957, Three Mile Island in 1979 and Chernobyl in 1986, there are 76 other accidents. 56 accidents occurred after Chernobyl. Damages were worth $19.1 billion (Rs 101,230 crore) between 1947 and 2008. This translates into one serious nuclear accident every year causing $332 million in damage.

Loss of Lives

Actually speaking, it's difficult to account this. Nuclear accidents may not result in immediate death. But just like the Bhopal gas tragedy where generations are facing the trauma, actual impact would be difficult to calculate. We are not talking about immediate deaths. The unfortunate ones survived and they are dying long, painful, lingering deaths.

So though the immediate impact looks miniscule, its long term impact can be devastating. The suffering is multi-fold. The cost of a disaster other than human pain and suffering is the long term environmental and economic damage. The total cost of the damage will run into hundreds of millions of dollars.

Even now, Ukraine, the country where Chernobyl is located, still allocates 6-7 percent of the government's total spending for disaster rehabilitation.

Radiation Contamination

In Chernobyl, the radiation contamination because of the disaster extends to 200,000 sq km mostly in Russia, Ukraine and Belarus, which is roughly the size of Tamil Nadu. In the case of a disaster at Koodankulam, it will be passed on to the ocean, Sri Lanka and Kerala.

A multi-agency study done by World Health

Organization (WHO) says that there were more than 5,000 cancer related deaths at Chernobyl. In Fukushima, people are facing thyroid problems. The affects of radiation sometimes are difficult to find, on how many are suffering due to illnesses related to radiation in addition to the psychological trauma because of the inability to resume normal lives. Only the wearer knows where the shoe pinches and it is difficult to fathom for others. It is not death alone but the repercussions of radiations that one needs to account for.

The Indian Context

When Homi Bhaba envisioned that nuclear energy is going to be the future way back in 1962, everyone had expected that it will make a significant contribution. But till date it contributes to only 3.0 percent of India's energy needs. Like the basic needs of food, clothing and shelter, and now mobile phone), governments come and go, but the needs for energy are kept live. Over the years, several promises have been made and precious tax savers money has been spent, where after spending more than Rs 5000 crore, the final outcome has been nil electricity.

Fact of the matter is how serious India is about nuclear energy as an option.

With 20 nuclear plants in India, the number of agitations is still minuscule. Nuclear energy has become more fashionable and not been able to make significant contribution, and we have not been able to tap its true potential.

Nuclear Reactors & Safety Factor

- From the outset, there has been a strong awareness of the potential hazard of both nuclear criticality and release of radioactive materials from generating electricity with nuclear power.
- As in other industries, the design and operation of nuclear power plants aims to minimise the likelihood of accidents, and avoid major human consequences when they occur.
- There have been three major reactor accidents in the history of civil nuclear power - Three Mile Island, Chernobyl and Fukushima. One was contained without causing harm to anyone. The next involved an intense fire without provision for containment, and the third severely tested the containment, allowing some release of radioactivity.
- These are the only major accidents to have occurred in over 14,500 cumulative reactor-years of commercial nuclear power operation in 32 countries.
- The risks from western nuclear power plants, in terms of the consequences of an accident or terrorist attack, are minimal compared with other commonly accepted risks. Nuclear power plants are very robust.

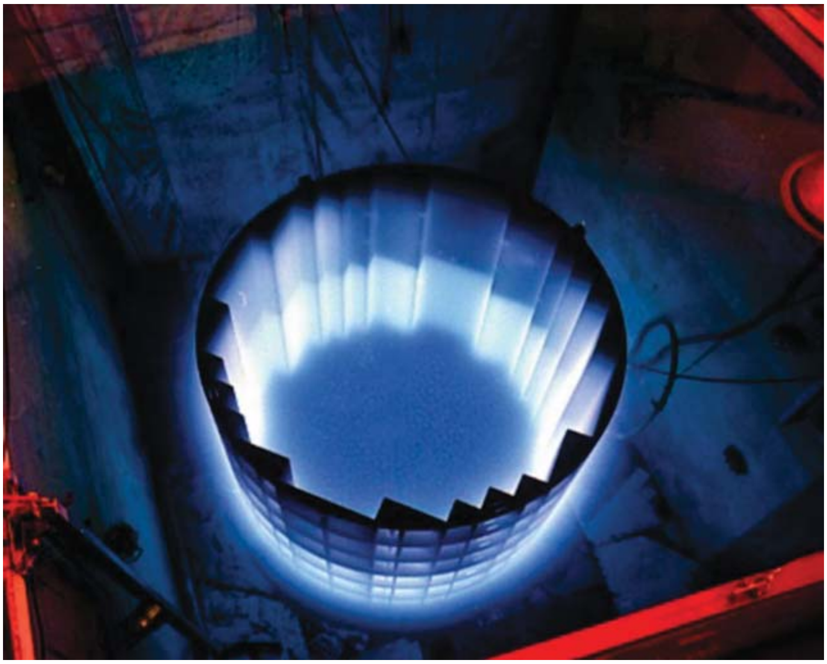
Safety & Security

In relation to nuclear power, safety is closely linked with security and in the nuclear field also with safeguards. **Some distinctions:**

Safety focuses on unintended conditions or events leading to radiological releases from authorised activities. It relates mainly to intrinsic problems or hazards.

Security focuses on the intentional misuse of nuclear or other radioactive materials by non-state elements to cause harm. It relates mainly to external threats to materials or facilities.

Safeguards focus on restraining activities by states that could lead to acquisition of nuclear weapons. It concerns mainly materials and equipment in relation to rogue governments.

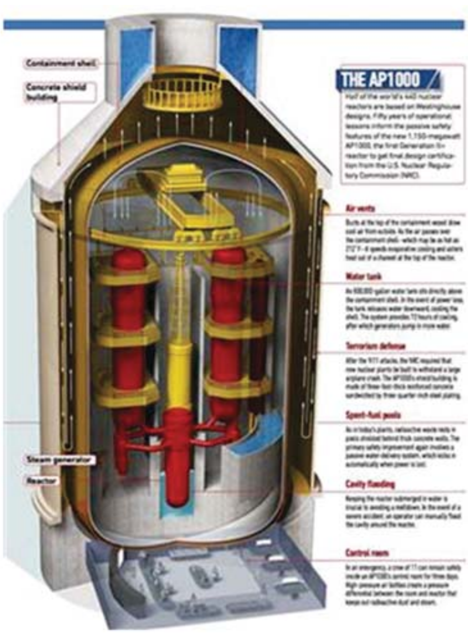


N-Energy Far Cheaper, But How to Make it Safer?

In the aftermath of the Fukushima disaster in March, 2011, the appetite for new nuclear power plants slipped to post-Chernobyl lows. Regulators from Italy to Switzerland to Texas moved to stop pending nuclear-power projects, and the U.S. Nuclear Regulatory Commission (NRC) began to re-evaluate the safety of all domestic plants. Yet nuclear power still provides 20 percent of America's total electric power and 70 percent of its emissions-free energy, in large part because no alternative energy source can match its efficiency.

One nuclear plant with a footprint of one square mile provides the energy equivalent of 20 square miles of solar panels, 1,200 windmills or the entire Hoover Dam. If the country wants to significantly reduce its dependence on carbon-based energy, it will need to build more nuclear power plants. The question is how to do so safely.

In the 30 years since regulators last approved the construction of a new nuclear plant in the U.S., engineers have improved reactor safety considerably. (You can see some of the older, not-so-safe ones in this sweet gallery.)

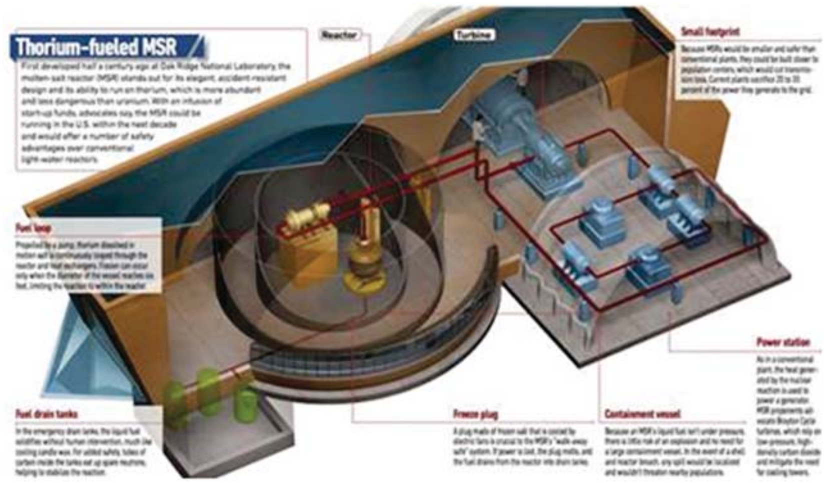


The newest designs, called Generation III+, are just beginning to come online. (Generation I plants were early prototypes; Generation IIs were built from the 1960s to the 1990s and include the facility at Fukushima; and Generation IIIs began operating in the late 1990s, though primarily in Japan, France and Russia.)

Half the world's 440 nuclear reactors are based on Westinghouse designs. Fifty years of operational safety features inform the passive safety features of the new 1,150-megawatt AP1000, the first Generation III+ rector to get final design certification from the NRC.

Unlike their predecessors, most Generation III+ reactors have layers of passive safety elements designed to stave off a meltdown, even in the event of power loss. Construction of the first Generation III+ reactors is well under way in Europe. China is also in the midst of building at least 30 new plants. In the U.S., the Southern Co. recently broke ground on the nation's first Generation III+ reactors at the Vogtle nuclear plant near Augusta, Ga. The first of two reactors is due to come online in 2016.

Like many of the 20 or so pending Generation III+ facilities in the U.S., the Vogtle plant will house Westinghouse AP1000 reactors. A light-water reactor, the AP1000 prompts uranium-235 into a chain reaction that throws off high-energy neutrons. The particles heat water into steam, which then turns a turbine that generates electricity.



The greatest danger in a nuclear plant is a meltdown, in which solid reactor fuel overheats, melts and ruptures its containment shell, releasing radioactive material. Like most reactors, the AP1000 is cooled with electrically powered water pumps and fans, but it also has a passive safety system, which employs natural forces such as gravity, condensation and evaporation to cool a reactor during a power outage.

The U.S. has 104 nuclear reactors operating at 65 sites in 31 states, all of them approved before 1980. A central feature of this system is an 800,000-gallon water tank positioned directly above the containment shell. The reservoir's valves rely on electrical power to remain closed. When power is lost, the valves open and the water flows down toward the containment shell. Vents passively draw air from outside and direct it over the structure, furthering the evaporative cooling.

Depending on the type of emergency, an additional reservoir within the containment shell can be manually released to flood the reactor. As water boils off, it rises and condenses at the top of the containment shell and streams back down to cool the reactor once more. Unlike today's plants, most of which have enough backup power onsite to last just four to eight hours after grid power is lost, the AP1000 can safely operate for at least three days without power or human intervention.

Even with their significant safety improvements, Generation III+ plants can, theoretically, melt down. Some people within the nuclear industry are calling for the implementation of still newer reactor designs, collectively called Generation IV. The thorium-powered molten-salt reactor (MSR) is one such design. In an MSR, liquid thorium would replace the solid uranium fuel used in today's plants, a change that would make meltdowns all but impossible.

MSRs were developed at Tennessee's Oak Ridge National Laboratory in the early 1960s and ran for a total of 22,000 hours between 1965 and 1969. "These weren't theoretical reactors or thought experiments," says engineer John Kutsch, who heads the nonprofit Thorium Energy Alliance. "(Engineers) really built them, and they really ran." Of the handful of Generation IV reactor designs circulating today, only the MSR has been proven outside computer models. "It was not a full system, but it showed you could successfully design and operate a molten-salt reactor," says Oak Ridge physicist Jess Gehin, a senior program manager in the lab's Nuclear Technology Programs office.

Courtesy of PopSci

In a thorium-powered molten-salt reactor (MSR), liquid thorium would replace the solid uranium fuel used in today's plants, a change that would make meltdowns all but impossible. MSRs were developed at Tennessee's Oak Ridge National Laboratory in the early 1960s.

One pound of thorium produces as much power as 300 pounds of uranium — or 3.5 million pounds of coal. The MSR design has two primary safety advantages. Its liquid fuel remains at much lower pressures than the solid fuel in light-water plants. This greatly decreases the likelihood of an accident, such as the hydrogen explosions that occurred at Fukushima. Further, in the event of a power outage, a frozen salt plug within the reactor melts and the liquid fuel passively drains into tanks where it solidifes, stopping the fission reaction. "The molten-salt reactor is walk-away safe," Kutsch says. "If you just abandon it, it has no power, and if the end of the world came like a comet hitting Earth — it would cool down and solidify by itself."

Although an MSR could also run on uranium or plutonium, using the less-radioactive element thorium, with a little plutonium or uranium as a catalyst, has both economic and safety advantages. Thorium is four times as abundant as uranium and is easier to mine, in part because of its lower radioactivity. The domestic supply could serve U.S. electricity needs for centuries. Thorium is also exponentially more efficient than uranium. "In a traditional reactor, you're burning up only a half a percent to maybe 3.0 percent of the uranium," Kutsch says. "In a molten-salt reactor, you're burning 99 percent of the thorium." The result: One pound of thorium yields as much power as 300 pounds of uranium — or 3.5 million pounds of coal.

Because of this efficiency, a thorium MSR would produce far less waste than today's plants. Uranium-based waste will remain hazardous for tens of thousands of years. With thorium, it's more like a few hundred. As well, raw thorium is not fissile in and of itself, so it is not easily weaponized. "It can't be used as a bomb," Kutsch says. "You could have 1,000 pounds in your basement, and nothing would happen."

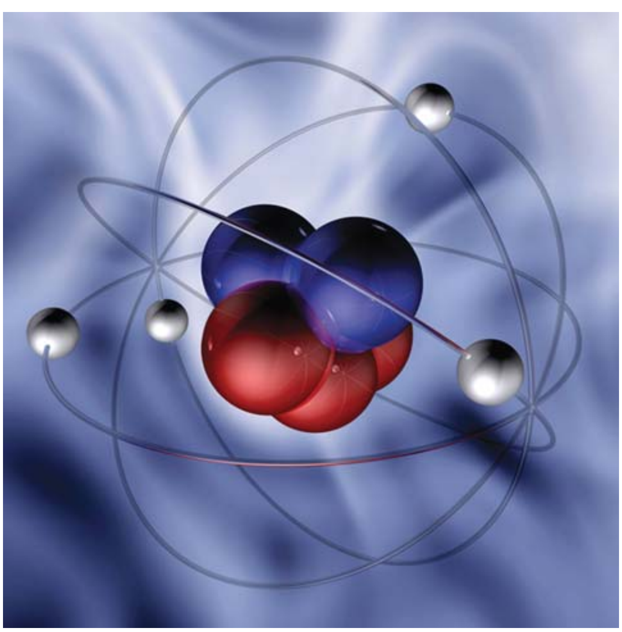
One nuclear plant provides the energy equivalent of 1,200 windmills or 20 square miles of solar panels. Without the need for large cooling towers, MSRs can be much smaller than typical light-water plants, both physically and in power capacity. Today's average nuclear power plant generates about 1,000 megawatts. A thorium-fueled MSR might generate as little as 50 megawatts. Smaller, more numerous plants could save on transmission loss (which can be up to 30 percent on the present grid). The U.S. Army is interested in using MSRs to power individual bases, Kutsch says, and Google, which relies on steady power to keep its servers running, held a conference on thorium reactors last year. "The company would love to have a 70- or 80-megawatt reactor sitting next door to a data center," Kutsch says.

Even with military and corporate support, the transition to a new type of nuclear power generation is likely to be slow, at least in the U.S. Light-water reactors are already established, and no regulations exist to govern other reactor designs. Outside the U.S., the transition could come more quickly. In January the Chinese government launched a thorium reactor program. "The Chinese Academy of Sciences has approved development of an MSR with relatively near-term deployment — maybe 10 years," says Gehin, who thinks the Chinese decision may increase work on the technology worldwide. Even after Fukushima, "there's still interest in advanced nuclear," he says. "I don't see that changing. ▪

Advantage India!

Thorium-Powered N-Plants Emerge as Safer, Future Option

Use of relatively low-carbon, low-radioactivity thorium instead of uranium may be the breakthrough in energy generation has announced plans for a prototype nuclear power plant that uses an innovative "safer" fuel.



Officials are currently selecting a site for the reactor, which would be the first of its kind, using thorium for the bulk of its fuel instead of uranium – the fuel for conventional reactors. They plan to have the plant up and running by the end of the decade.

The development of workable and large-scale thorium reactors has for decades been a dream for nuclear engineers, while for environmentalists it has become a major hope as an alternative to fossil fuels. Proponents say the fuel has considerable advantages over uranium. Thorium is more abundant and exploiting it does not involve release of large quantities of carbon dioxide, making it less dangerous for the climate than fossil fuels like coal and oil.

In a rare interview, Ratan Kumar Sinha, the director of the Bhabha Atomic Research Centre (BARC) in Mumbai, told the Guardian newspaper of London that his team is finalising the site for construction of the new large-scale experimental reactor, while at the same time conducting "confirmatory tests" on the design.

"The basic physics and engineering of the thorium-fuelled Advanced Heavy Water Reactor (AHWR) are in place, and the design is ready," said Sinha. Once the six-month search for a site is completed – probably next to an existing nuclear power plant – it will take another 18 months to obtain regulatory and environmental impact clearances before building work on the site can begin.

"Construction of the AHWR will begin after that, and it would take another six years for the reactor to become operational," Sinha added, meaning that if all goes to plan, the reactor could be operational by the end of the decade. The reactor is designed to generate 300MW of electricity – about a quarter of the output of a typical new nuclear plant in the west.

Sinha added that India was in talks with other countries over the export of conventional nuclear plants. He said India was looking for buyers for its 220MW and 540MW Pressurised Heavy Water Reactors (PHWRs). Kazakhastan and the Gulf states are known to have expressed an interest, while one source said that negotiations are most advanced with Vietnam, although Sinha refused to confirm this.

“Many countries with small power grids of up to 5,000 MW are looking for 300MW reactors," he said. "Our reactors are smaller, cheaper, and very price competitive.”

Producing a workable thorium reactor would be a massive breakthrough in energy generation. Using thorium – a naturally occurring moderately radioactive element named after Thorium Norse, god of thunder – as a source of atomic power is not new technology. Promising early research was carried out in the US in the 1950s and 60s and then abandoned in favour of using uranium.

The pro-thorium lobby maintains this was at least partly because national nuclear power programmes in the US and elsewhere were developed with a military purpose in mind: namely access to a source of plutonium for nuclear weapons. Unlike uranium, thorium-fuelled reactors do not result in a proliferation of weapons-grade plutonium. Also, under certain circumstances, the waste from thorium reactors is less dangerous and remains radioactive for hundreds rather than thousands of years.

That is a considerable plus for governments now worried about how to deal with nuclear waste and concerned about the possibility of rogue governments or terrorists getting their hands on plutonium. Also, with the world's supply of uranium rapidly depleting, attention has refocused on thorium, which is three to four times more abundant and 200 times more energy dense..

“Given India's abundant supply of thorium it makes sense for her to develop thorium reactors," said Labour

peer Baroness Worthington who is patron of the Weinberg Foundation, which promotes thorium-fuelled nuclear power. She added: "However, many of the advantages of thorium fuel are best realised with totally new reactor designs such as the molten salt reactor developed Alvin Weinberg in the 60s. I hope India will also commit to exploring this option.”

India has the world's largest thorium deposits and with a world hungry for low-carbon energy, it has its eyes on a potentially lucrative export market for the technology. For more than three decades, India's nuclear research programme had been subject to international sanctions since its controversial 1974 nuclear tests. But after losing its pariah status three years ago as a result of the Indo-US nuclear deal, India is keen to export indigenous nuclear technology developed in research centres such as the BARC.

There are still restrictions though. One problem is the "trigger fuel" the reactor needs to initiate operation. In the original design, this is a small quantity of plutonium. Instead the new reactor's trigger will be low-enriched uranium (LEU) – which India is permitted to import under the 2008 Indo-US deal.

“The AHWR will eventually have design flexibility, using as fuel either plutonium-thorium or LEU-thorium combinations," said Sinha. "The LEU-thorium version will make the AHWR very much marketable abroad, as it would generate very little plutonium, making it suitable for countries with high proliferation resistance.”

The LEU-thorium design is currently at pilot stage. For the first time last year, the BARC tested the thorium-plutonium combination at its critical facility in Mumbai, but is still some way from doing the same for the thorium-LEU combination.

High Quality R&D, Designs Ensure Built-in Safety

The Story of Powering the Atom for Energy

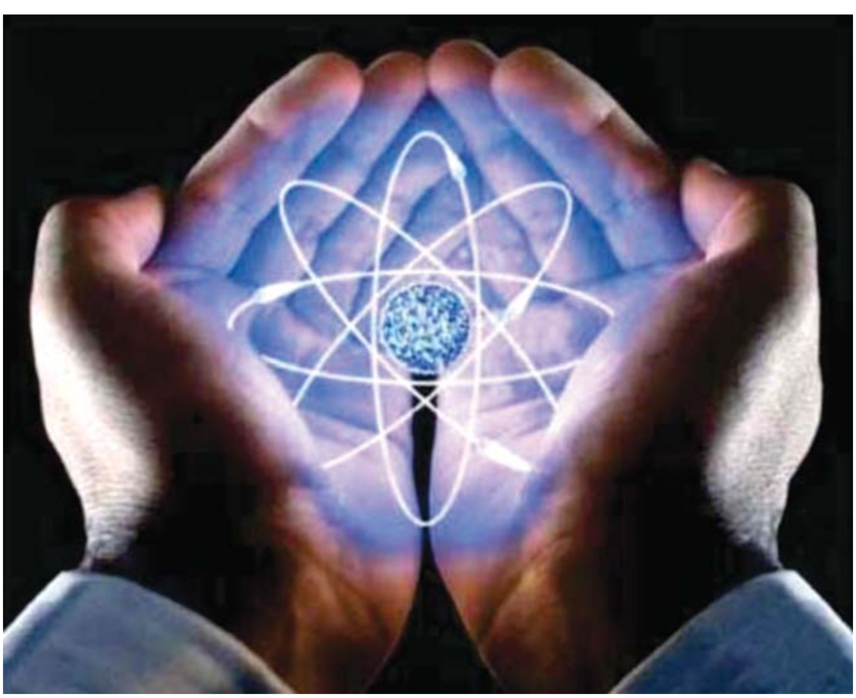
In the 1950s attention turned to harnessing the power of the atom in a controlled way, as demonstrated at Chicago in 1942 and subsequently for military research, and applying the steady heat yield to generate electricity. This naturally gave rise to concerns about accidents and their possible effects. However, with nuclear power safety depends on much the same factors as in any comparable industry: intelligent planning, proper design with conservative margins and back-up systems, high-quality components and a well-developed safety culture in operations.

A particular nuclear scenario was loss of cooling which resulted in melting of the nuclear reactor core, and this motivated studies on both the physical and chemical possibilities as well as the biological effects of any dispersed radioactivity. Those responsible for nuclear power technology in the West devoted extraordinary effort to ensuring that a meltdown of the reactor core would not take place, since it was assumed that a meltdown of the core would create a major public hazard, and if uncontained, a tragic accident with likely multiple fatalities.

In avoiding such accidents the industry has been very successful. In over 14,500 cumulative reactor-years of commercial operation in 32 countries, there have been only three major accidents to nuclear power plants - Three Mile Island, Chernobyl, and Fukushima - the second being of little relevance to reactor design outside the old Soviet bloc.

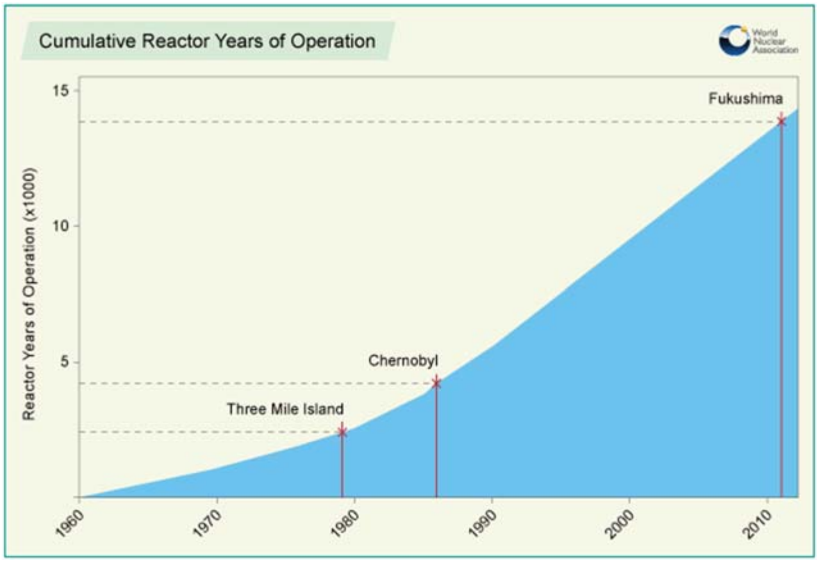
It was not until the late 1970s that detailed analyses and large-scale testing, followed by the 1979 meltdown of the Three Mile Island reactor, began to make clear that even the worst possible accident in a conventional western nuclear power plant or its fuel would not be likely to cause dramatic public harm. The industry still works hard to minimize the probability of a meltdown accident, but it is now clear that no-one need fear a potential public health catastrophe simply because a fuel meltdown happens. Fukushima has made that clear, with a triple meltdown causing no fatalities or serious radiation doses to anyone, while over two hundred people continued working on the site to mitigate the accident's effects.

The decades-long test and analysis program showed that less radioactivity escapes from molten fuel than initially assumed, and that most of this radioactive material is not readily mobilized beyond the immediate internal structure. Thus, even if the containment structure that surrounds all modern nuclear plants were ruptured, as it has been with at least one of the Fukushima reactors, it is still very effective in preventing escape of most radioactivity.



It is the laws of physics and the properties of materials that mitigate disaster, as much as the required actions by safety equipment or personnel. In fact, licensing approval for new plants now requires that the effects of any core-melt accident must be confined to the plant itself, without the need to evacuate nearby residents.

The three significant accidents in the 50-year history of civil nuclear power generation are:



- **Three Mile Island (USA 1979)** where the reactor was severely damaged but radiation was contained and there were no adverse health or environmental consequences

- **Chernobyl (Ukraine 1986)** where the destruction of the reactor by steam explosion and fire killed 31 people and had significant health and environmental consequences. The death toll has since increased to about five.

- **Fukushima (Japan 2011)** where three old reactors (together with a fourth) were written off and the effects of loss of cooling due to a huge tsunami were inadequately contained.

A table showing all reactor accidents, and a table listing some energy-related accidents with multiple fatalities are appended.

These three significant accidents occurred during more than 14,500 reactor-years of civil operation. Of all the accidents and incidents, only the Chernobyl and Fukushima accidents resulted in radiation doses to the public greater than those resulting from the exposure to natural sources. The Fukushima accident resulted in some radiation exposure of workers at the plant, but not such as to threaten their health, unlike Chernobyl. Other incidents (and one 'accident') have been completely confined to the plant.

Apart from Chernobyl, no nuclear workers or members of the public have ever died as a result of exposure to radiation due to a commercial nuclear reactor incident. Most of the serious radiological injuries and deaths that occur each year (2-4 deaths and many more exposures above regulatory limits) are the result of large uncontrolled radiation sources, such as abandoned medical or industrial equipment. (There have also been a number of accidents in experimental reactors and in one military plutonium-producing pile - at Windscale, UK, in 1957, but none of these resulted in loss of life outside the actual plant, or long-term environmental contamination.) See also Table 2 in Appendix.

It should be emphasised that a commercial-type power reactor simply cannot under any circumstances explode like a nuclear bomb - the fuel is not enriched beyond about 5.0 percent.

The International Atomic Energy Agency (IAEA) was set up by the United Nations in 1957. One of its functions was to act as an auditor of world nuclear safety, and this role was increased greatly following the Chernobyl accident. It prescribes safety procedures and the reporting of even minor incidents. Its role has been strengthened since 1996. Every country which operates nuclear power plants has a nuclear safety inspectorate and all of them work closely with the IAEA.

While nuclear power plants are designed to be safe in their operation and safe in the event of any malfunction or accident, no industrial activity can be represented as entirely risk-free. Incidents and accidents may happen, and as in other industries, will lead to progressive improvement in safety.

Achieving safety: the record so far

Operational safety is a prime concern for those working in nuclear plants. Radiation doses are controlled by the use of remote handling equipment for many operations in the core of the reactor. Other controls include physical shielding and limiting the time workers spend in areas with significant radiation levels. These are supported by continuous monitoring of individual doses and of the work environment to ensure very low radiation exposure compared with other industries.

Concerning possible accidents, up to the early 1970s, some extreme assumptions were made about the possible chain of consequences. These gave rise to a genre of dramatic fiction (eg The China Syndrome) in the public domain and also some solid conservative engineering including containment structures (at least in Western reactor designs) in the industry itself. Licensing regulations were framed accordingly.

One mandated safety indicator is the calculated probable frequency of degraded core or core melt accidents. The US Nuclear Regulatory Commission (NRC) specifies that reactor designs must meet a 1 in 10,000 year core damage frequency, but modern designs exceed this. US utility requirements are 1 in 100,000 years, the best currently operating plants are about 1 in 1 million and those likely to be built in the next decade are almost 1 in 10 million. While this calculated core damage frequency has been one of the main metrics to assess reactor safety, European safety authorities prefer a deterministic approach, focusing on actual provision of back-up hardware, though they also undertake probabilistic safety analysis for core damage frequency.

Even months after the Three Mile Island (TMI) accident in 1979 it was assumed that there had been no core melt because there were no indications of severe radioactive release even inside the containment. It turned out that in fact about half the core had melted. Until 2011 this remained the only core melt in a reactor conforming to NRC safety criteria, and the effects were contained as designed, without radiological harm to anyone.* Greifswald 5 in East Germany had a partial core melt in November 1989, due to malfunctioning valves (root cause: shoddy manufacture) and was never restarted. At Fukushima in 2011 (a different reactor design with penetrations in the bottom of the pressure vessel) the three reactor cores evidently largely melted in the first two or three days, but this was not confirmed for about 10 weeks. It is still not certain how much of the core material was not contained by the pressure vessels and ended up in the bottom of the drywell containments, though certainly there was considerable release of radionuclides to the atmosphere early on, and later to cooling water**.

*About this time there was alarmist talk of the so-called "China Syndrome", a scenario where the core of such a reactor would melt, and due to continual heat generation, melt its way through the reactor pressure vessel and concrete foundations to keep going, perhaps until it reached China on the other side of the globe! The TMI accident proved the extent of truth in the proposition, and the molten core material got exactly 15 mm of the way to China as it froze on the bottom of the reactor pressure vessel. At Fukushima, cooling was maintained just long enough apparently to avoid testing the containment in this way.

** Ignoring isotopic differences, there are about one hundred different fission products in fuel which has been undergoing fission. A few of these are gases at normal temperatures, more are volatile at higher temperatures, and both will be released from the fuel if the cladding is damaged. The latter include iodine (easily volatalised, at 184°C) and caesium (671°C), which were the main radionuclides released at Fukushima, first into the reactor pressure vessel and then into the containment which in unit 2 apparently ruptured early on day 5. In addition, as cooling water was flushed through the hot core, soluble fission products such as caesium dissolved in it, which created the need for a large water treatment plant to remove them.

However, apart from these accidents and the Chernobyl disaster there have been about 10 core melt accidents - mostly in military or experimental reactors - Appendix 2 lists most of them. None resulted in any hazard outside the plant from the core melting, though in one case there was significant radiation release due to burning fuel in hot graphite (similar to Chernobyl but smaller scale). The Fukushima accident should also be considered in that context, since the fuel was badly damaged and there were significant off-site radiation releases.

Regulatory requirements today for new plants are that the effects of any core-melt accident must be confined to the plant itself, without the need to evacuate nearby residents.

The main safety concern has always been the possibility of an uncontrolled release of radioactive material, leading to contamination and consequent radiation exposure off-site. Earlier assumptions were that this would be likely in the event of a major loss of cooling accident (LOCA) which resulted in a core melt. The TMI experience suggested otherwise, but at Fukushima this is exactly what happened. In the light of better understanding of the physics and chemistry of material in a reactor core under extreme conditions it became evident that even a severe core melt coupled with breach of containment would be unlikely to create a major radiological disaster from many Western reactor designs, but the Fukushima accident showed that this did not apply to all. Studies of the post-accident situation at Three Mile Island (where there was no breach of containment) supported the suggestion, and analysis of Fukushima is pending.

Certainly the matter was severely tested with three reactors of the Fukushima Daiichi nuclear power plant in Japan in March 2011. Cooling was lost after a shutdown, and it proved impossible to restore it sufficiently to prevent severe damage to the fuel. The reactors, dating from 1971-75, were written off. A fourth is also written off due to damage from a hydrogen explosion.

An OECD/NEA report in 2010 pointed out that the theoretically-calculated frequency for a large release of radioactivity from a severe nuclear power plant accident has reduced by a factor of 1600 between the early Generation I reactors as originally built and the Generation III/III+ plants being built today. Earlier designs, however, have been progressively upgraded through their operating lives.

It has long been asserted that nuclear reactor accidents are the epitome of low-probability but high-consequence risks. Understandably, with this in mind, some people were disinclined to accept the risk, however low the probability. However, the physics and chemistry of a reactor core, coupled with but not wholly depending on the engineering, mean that the consequences of an accident are likely in fact be much less severe than those from other industrial and energy sources. Experience, including Fukushima, bears this out.

At Chernobyl the kind of reactor and its burning contents which dispersed radionuclides far and wide tragically meant that the results were severe. This once and for all vindicated the desirability of designing with inherent safety supplemented by robust secondary safety provisions and avoiding that kind of reactor design. However, the problem here was not burning graphite as popularly quoted. The graphite was certainly incandescent as a result of fuel decay heat - sometimes over 1000°C - and some of it oxidised to carbon monoxide which burned along with the fuel cladding.

Electricity Generation

The use of nuclear energy for electricity generation can be considered extremely safe. Every year several thousand people die in coal mines to provide this widely used fuel for electricity. There are also significant health and environmental effects arising from fossil fuel use. To date, even the Fukushima accident has caused no deaths, and the IAEA reported on 1 June 2011: "to date, no health effects have been reported in any person as a result of radiation exposure."

In passing, it is relevant to note that the safety record of the US nuclear navy from 1955 on is excellent, this being attributed to a high level of standardisation in over one hundred naval power plants and in their maintenance, and the high quality of the Navy's training program. Until the 1980s, the Soviet naval record stood in marked contrast.

Achieving optimum nuclear safety

To achieve optimum safety, nuclear plants in the western world operate using a '**defence-in-depth' approach**, with multiple safety systems supplementing the natural features of the reactor core. Key aspects of the approach are:

- high-quality design & construction,
- equipment which prevents operational disturbances or human failures and errors developing into problems,
- comprehensive monitoring and regular testing to detect equipment or operator failures,
- redundant and diverse systems to control damage to the fuel and prevent significant radioactive releases,
- provision to confine the effects of severe fuel damage (or any other problem) to the plant itself.

These can be summed up as: Prevention, Monitoring, and Action (to mitigate consequences of failures).

The safety provisions include a series of physical barriers between the radioactive reactor core and the environment, the provision of multiple safety systems, each with backup and designed to accommodate human error. Safety systems account for about one quarter of the capital cost of such reactors. As well as the physical aspects of safety, there are institutional aspects which are no less important - see following section on International Collaboration.

The barriers in a typical plant are: the fuel is in the form of solid ceramic (UO2) pellets, and radioactive fission products remain largely bound inside these pellets as the fuel is burned. The pellets are packed inside sealed zirconium alloy tubes to form fuel rods. These are confined inside a large steel pressure vessel with walls up to 30 cm thick - the associated primary water cooling pipework is also substantial. All this, in turn, is enclosed inside a robust reinforced concrete containment structure with walls at least one metre thick. This amounts to three significant barriers around the fuel, which itself is stable up to very high temperatures.

These barriers are monitored continually. The fuel cladding is monitored by measuring the amount of radioactivity in the cooling water. The high pressure cooling system is monitored by the leak rate of water, and the containment structure by periodically measuring the leak rate of air at about five times atmospheric pressure.

Looked at functionally, the three basic safety functions in a nuclear reactor are:

- to control reactivity,
- to cool the fuel and
- to contain radioactive substances.

The main safety features of most reactors are inherent - negative temperature coefficient and negative void coefficient. The first means that beyond an optimal level, as the temperature increases the efficiency of the reaction decreases (this in fact is used to control power levels in some new designs). The second means that if any steam has formed in the cooling water there is a decrease in moderating effect so that fewer neutrons are able to cause fission and the reaction slows down automatically.

In the 1950s and '60s some experimental reactors in the Idaho desert were deliberately tested to destruction to verify that large reactivity excursions were self-limiting and would automatically shut down the fission reaction. These tests verified that this was the case.

Beyond the control rods which are inserted to absorb neutrons and regulate the fission process, the main engineered safety provisions are the back-up emergency core cooling system (ECCS) to remove excess heat (though it is more to prevent damage to the plant than for public safety) and the containment.

Traditional reactor safety systems are 'active' in the sense that they involve electrical or mechanical operation on command. Some engineered systems operate passively, eg pressure relief valves. Both require parallel redundant systems. Inherent or full passive safety design depends only on physical phenomena such as convection, gravity or resistance to high temperatures, not on functioning of engineered components. All reactors have some elements of inherent safety as mentioned above, but in some recent designs the passive or inherent features substitute for active systems in cooling etc. Such a design would have averted the Fukushima accident, where loss of electrical power resulted is loss of cooling function.

The basis of design assumes a threat where due to accident or malign intent (eg terrorism) there is core melting and a breach of containment. This double possibility has been well studied and provides the basis of exclusion zones and contingency plans. Apparently during the Cold War neither Russia nor the USA targeted the other's nuclear power plants because the likely damage would be modest.

Nuclear power plants are designed with sensors to shut them down automatically in an earthquake, and this is a vital consideration in many parts of the world.

The Three Mile Island accident in 1979 demonstrated the importance of the inherent safety features. Despite the fact that about half of the reactor core melted, radionuclides released from the melted fuel mostly plated out on the inside of the plant or dissolved in condensing steam. The containment building which housed the reactor further prevented any significant release of radioactivity. The accident was attributed to mechanical failure and operator confusion. The reactor's other protection systems also functioned as designed. The emergency core cooling system would have prevented any damage to the reactor but for the intervention of the operators.

Investigations following the accident led to a new focus on the human factors in nuclear safety. No major design changes were called for in western reactors, but controls and instrumentation were improved significantly and operator training was overhauled.

A 2007 US Department of Energy (DOE) Human Performance Handbook notes that "The aviation industry, medicine, the commercial nuclear power industry, the US Navy, DOE and its contractors, and other high-risk, technologically complex industries have adopted human performance principles, concepts, and practices to consciously reduce human error and bolster defences in order to reduce accidents and mishaps." "About 80 percent of all events are attributed to human error. In some industries, this number is closer to 90 percent. Roughly 20 percent of occurrences involve equipment failures. When the 80 percent human error is broken down further, it reveals that the majority of errors associated with events stem from latent organizational weaknesses (perpetrated by humans in the past that lie dormant in the system), whereas about 30 percent are caused by the individual worker touching the equipment and systems in the facility. Clearly, focusing efforts on reducing human error will reduce the likelihood of occurrences and events." Following the Fukushima accident the focus has been on the organisational weaknesses which increase the likelihood of human error.

By way of contrast to western safety engineering, the Chernobyl reactor did not have a containment structure like those used in the West or in post-1980 Soviet designs. The main positive outcome of this accident for the industry was the formation of the World Association of Nuclear Operators (WANO), building on the US precedent.

At Fukushima Daiichi in March 2011 the three operating reactors shut down automatically, and were being cooled as designed by the normal residual heat removal system using power from the back-up generators, until the tsunami swamped them an hour later. The emergency core cooling systems then failed. Days later, a separate problem emerged as spent fuel ponds lost water. Detailed analysis of the accident continues, but the main results include more attention being given to siting criteria and the design of back-up power and cooling, as well as provision for venting the containment of that kind of reactor and other emergency management procedures.

Nuclear plants have Severe Accident Mitigation Guidelines (SAMG, or in Japan: SAG), and most of these, including all those in the US, address what should be done for accidents beyond design basis, and where several systems may be disabled.

In 2007 the US NRC launched a research program to assess the possible consequences of a serious reactor accident. Its draft report was released nearly a year after the Fukushima accident had partly confirmed its findings. The State-of-the-Art Reactor Consequences Analysis (SOARCA) showed that a severe accident at a US nuclear power plant (PWR or BWR) would not be likely to cause any immediate deaths, and the risks of fatal cancers would be vastly less than the general risks of cancer. SOARCA's main conclusions fall into three areas: how a reactor accident progresses; how existing systems and emergency measures can affect an accident's outcome; and how an accident would affect the public's health. The principal conclusion is that existing resources and procedures can stop an accident, slow it down or reduce its impact before it can affect the public, but even if accidents proceed without such mitigation they take much longer to happen and release much less radioactive material than earlier analyses suggested. ■

Nuclear Energy - Myths & Facts

Safety is a touchy issue for any country and most countries would look at public safety and worker safety as priority with regard to nuclear energy.

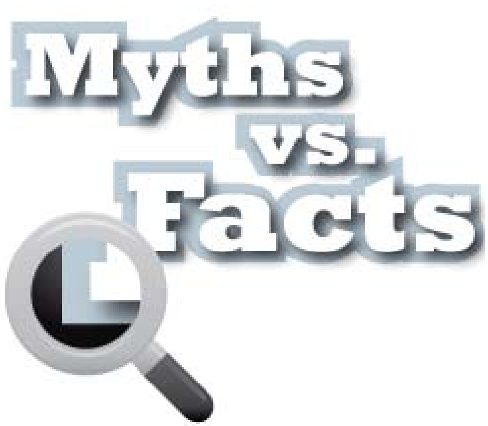
Myth: Nuclear energy is dangerous

Fact: After more than a half-century of commercial nuclear energy production in the United States, including more than 3,500 reactor years of operation, there have been no radiation-related health effects linked to their operation. Studies by the National Cancer Institute, The United Nations Scientific Committee of the Effects of Atomic Radiation, the National Research Council's BEIR VII study group and the National Council on Radiation Protection and Measurements all show that US nuclear power plants effectively protect the public's health and safety. Nuclear plants also are safe for workers. According to the US Bureau of Labor Statistics, it is safer to work at a nuclear plant than at a fast food restaurant or a grocery store or in real estate.

Myth: Nuclear energy plant can explode

Fact: By design, it is physically impossible for any commercial nuclear energy plant to run out of control and explode like the Chernobyl RBMK reactor design did. Unlike the Chernobyl reactor, all US reactors are designed to be self-limiting. During power operations, when the temperature within the reactor reaches a predetermined level, the fission process is naturally suppressed so the power level cannot spike under any circumstances.

Moreover, it is physically impossible for a US commercial reactor to explode like a nuclear weapon. The concentration of uranium-235 within the reactor fuel is far too low to be explosive and all US commercial reactors are self-limiting. During power operations, when the temperature within the reactor reaches a predetermined level, the fission process is naturally suppressed so the power level cannot spike under any circumstances. No one could intentionally or unintentionally alter a commercial nuclear reactor, its controls or its fuel to make it explode like a nuclear bomb.



Myth: The threat of a nuclear meltdown is high.

Fact: The probability of fuel melting, or core damage, in a commercial nuclear reactor is very low. Because of the lessons learned and additional precautions taken after the accident at the Three-Mile Island Nuclear Station 33 years ago, risk assessments performed for the US Nuclear Regulatory Commission determined that an accident that could cause core damage in the current U.S. fleet of 104 reactors could occur approximately once in 1,000 years. The risk of core damage for an individual plant is approximately once in 100,000 years. For a new nuclear reactor, the risk of core damage is less likely—once in a million years—because of enhanced safety features. Core damage does not mean radioactivity would be released from a plant, nor does it mean that anyone would be harmed. Every nuclear plant has an extremely strong containment building that encloses the reactor and multiple safety features designed to mitigate the consequences of a core damage event. Half of the fuel in the Three Mile Island reactor melted and the rest was severely damaged, but no one in or outside the plant was harmed. The potential for a nuclear plant to have a core damage accident resulting in significant release of radiation is low - once in 10,000 years for the operating plant fleet.

Myth: Nuclear power plants are likely targets for terrorism.

Fact: With protective measures similar to high-security military installations, US nuclear plants are among the most highly protected facilities in the nation's industrial infrastructure. It is because of their fortifications and multiple layers of security that nuclear plants present a strong deterrent to potential threats.

Myth: A nuclear power plant cannot withstand a terrorist attack.

Fact: With protective measures similar to high-security military installations, US nuclear plants are among the most highly protected facilities in the nation's industrial infrastructure. Nuclear power plants are protected 24/7 by professional security personnel armed with automatic weapons prepared to repel ground and airborne terrorist attacks. It is because of their fortifications and multiple layers of security that nuclear plants are far less likely to be targets of terrorism than the thousands of far more vulnerable potential targets across the nation. Anti-terrorism measures are regularly tested and closely coordinated with local, state and federal authorities.

Myth: A nuclear power plant cannot withstand the impact of a jetliner.

Fact: Following the terrorist attacks of 11 September 2001, sophisticated computer modeling by some of the world's leading structural engineers showed that nuclear power facilities that contain radioactive material can withstand a jetliner impact without releasing radiation. Likewise, all new nuclear power plants are required to withstand the direct impact of a fully fuelled commercial jetliner.

Myth: Nuclear plants are vulnerable to cyber-attacks.

Fact: There has never been a successful cyber attack at any US nuclear plant. Unlike industries for which two-way data flow is critical (e.g. banking), nuclear power plants do not require incoming data flow. None of a plant's safety and control systems are connected to the Internet. Any additional computers utilized in a nuclear plants are strictly controlled with their content, use and possession monitored by security personnel. Nuclear plants are protected from grid instability and are able to safely shut down in a variety of ways without computer controls under any condition including a total loss of off-site power.

Myth: Nuclear energy leads to the proliferation of nuclear weapons.

Fact: The technology to make highly concentrated uranium and plutonium for nuclear weapons is completely independent of nuclear power plant technology. It is impossible to make a nuclear weapon with the low-enriched uranium contained in commercial nuclear reactor fuel. If every commercial nuclear energy plant and all the supporting technology around the world were dismantled and none were ever built again, the proliferation of nuclear weapons would still be a threat.

Note: Nuclear energy plants reduce the threat of nuclear weapons by using warhead material as fuel and rendering it useless for weaponry. To date, the US-Russia Megatons to Megawatts program has consumed more than 400 metric tons, more than the equivalent of 17,000 nuclear warheads. Strict protocols administered by the International Atomic Energy Agency (IAEA) are used to control fuel enrichment, fabrication and reprocessing facilities. The international community, through the United Nations Security Council, can take action against nations that are not complying with safeguards commitments to the IAEA.

Myth: Terrorists can use commercial reactor fuel to make nuclear weapons.

Fact: It is impossible to make a nuclear weapon with the low-enriched uranium contained in commercial nuclear reactor fuel. Only through extremely complex and expensive reprocessing could the plutonium in used nuclear fuel be isolated for use in a nuclear weapon. This requires a very large industrial complex that would take years and hundreds of millions of dollars to construct—far beyond the capability of any terrorist organization.

Myth: Reprocessing used nuclear fuel will lead to proliferation of nuclear weapons.

Fact: Reprocessing of used nuclear fuel can be designed to prevent the isolation of plutonium therefore posing no threat of proliferation. It is impossible to make a nuclear weapon with the low-enriched uranium contained in commercial nuclear reactor fuel.

Myth: Transporting radioactive materials exposes the public to unacceptable risk.

Fact: Since the 1960s, there have been more than 3,000 shipments of used nuclear fuel and high-level radioactive waste on U.S. roads, highways and railways totalling more than 1.7 million miles. There have been nine accidents, four on highways and five on railways. Because the shipping containers are so strong, there were no injuries, leaks, exposures or environmental damage. The typical high-integrity fuel shipping container can withstand a direct hit by a high-speed locomotive, an 80-mile-an-hour crash into an immovable concrete barrier, immersion in a 1,475-

degree Fahrenheit fire, a direct hit by a projectile 30 times more powerful than an anti-tank weapon, immersion in 600 feet of water, and more.

Myth: The Nuclear Regulatory Commission is too “cozy” with the nuclear industry.

Fact: The commercial nuclear industry is arguably the most strictly regulated industry in the US. The Nuclear Regulatory Commission is an independent, safety-focused, transparent regulatory agency that inspects and monitors all U.S. nuclear power plants. The NRC's five commissioners are appointed by the US President and confirmed by the US Senate. The majority of the agency's funding is drawn from nuclear energy industry user fees as mandated and administered by Congress. The NRC can impose warnings, fines and special inspections; order plants to shutdown; and modify, suspend or revoke a plant's operating license. Each year, the NRC utilizes an average of 3,800 person-hours of inspection effort for each reactor, including at least two full-time resident inspectors with unlimited access to their assigned facility. Specialist teams also conduct inspections throughout the year. If a plant's performance declines, additional inspections are utilized. All NRC inspection reports, hearing information, performance ratings, enforcement orders and license information for every nuclear facility are posted on its website and open to the public. The NRC has strict ethics rules to prevent conflicts of interest between its personnel and members of the nuclear industry and can impose corrective and/or punitive actions if they occur.

Myth: Nuclear plant license renewal is a “rubber stamp” by the NRC.

Fact: The Nuclear Regulatory Commission's license renewal processtakes an average of two years to complete and costs the owners of the facility between $10 million and $20 million. The application for license renewal (ranging from several thousand to tens of thousands of pages of required information for one reactor) involves at least 60,000 person-hours of preparation by the company that owns the facility. The public is encouraged to participate in the process through public meetings and public comment periods on rules, renewal guidance and other documents. In addition, parties and members of the public have an opportunity to request a formal adjudicatory hearing if they believe they would be adversely affected by the renewal. The NRC must determine that a plant can continue to operate safely throughout the extended period of operation to issue the license renewal. A license renewal does not guarantee that a nuclear plant can operate for the extended 20-year period. The plant must continue to meet regulatory safety standards, or the NRC can order it to shut down and can modify or revoke the unit's license.

Note: The original 40-year term for nuclear power plant licenses was not based on an expected operating life span, but was selected by Congress for the Atomic Energy Act of 1954 because this was the typical amortization period for an electric power plant at that time.

Myth: An inadvertent criticality (sustained chain reaction) occurred in a damaged Fukushima Daiichi reactor.

Fact: There is no evidence a criticality occurred in any of the damaged Fukushima Daiichi reactors since the accident in March 2011. A criticality is a sustained chain reaction of fission within the nuclear fuel that generates large amounts of heat and radiation. Spontaneous fission of uranium atoms occurs naturally within the fuel of all reactors and produces small amounts of heat and radiation. Conditions within the damaged reactors at Fukushima do not support criticality. The control rods that absorb neutrons necessary to support a chain reaction are commingled with the fuel thereby minimizing the possibility of a criticality. Operators also can mix boron, a highly effective neutron absorber, in cooling water circulated through the damaged reactors.

Myth: Nations operate and maintain their nuclear energy facilities the same.

Fact: There are distinct differences between nations' nuclear energy industries. For example.the US has a single, independent federal regulator, the US Nuclear Regulatory Commission, while Japan has four regulating bodies with overlapping responsibilities. The US nuclear energy sector implemented an industrywide safety culture program to assess and improve organizational prioritization of safety issues, and all US nuclear energy companies fund an industry watchdog organization, the Institute of Nuclear Power Operations, to maximized safety performance and achieve operational excellence above and beyond NRC requirements. The Japanese nuclear industry has no similar entities. There also are significant differences in plant maintenance, emergency preparedness, reactor operator training and licensing, and plant command and control protocols. ■

Rich Nations May Not Give Up N-Energy, Unlike Germany

Imagine a scenario where developed nations like Germany decide to do away with the nuclear power. The German Government's plans to do away with the use of nuclear energy got a boost when the country's power grid operators announced plans to make major investments to expand the grid. When a country like Germany decides to take such a step, it definitely has a financial impact. It will cost Germany about 20 billion euros ($25 billion) till 2022. The main idea would be to modernize the existing grid and construct high voltage power lines. It's going to be a herculean task for Germany.

Three other high-voltage grid operators, Amprion, 50Hertz and TransnetBW are also involved in the project. The lack of capacity of the grid is seen as one of the major problems Germany will have to overcome if it is to successfully make the transition."Without the expansion of the electricity network, progress on renewable energy won't produce results," the head of Germany's Federal Network Agency, JochenHomann, told a recent news conference, which was also attended by German Chancellor Angela Merkel, Environment Minister Peter Altmaier and Finance Minister Philipp Rösler.

This is going to be a big step in ending the nuclear energy regime. Germany in fact is planning to switch off all the nine nuclear plants by 2022. The country's eight oldest plants were also shut down, following the 11 March 2011 nuclear disaster at Fukushima in Japan.

At the same time we have United States promoting nuclear energy, in fact it was Prime Minister Manmohan Singh of India, who actually believed in the positive impact Nuclear energy for India and went ahead to sign a nuclear treaty with US amidst severe opposition from political parties. The other rationale that experts give is that Germany can do away with Nuclear power by sourcing power from France.

The biggest impact of nuclear discontinuation would be in the OECD countries – that is, the "developed" countries, since these countries disproportionately are the users of nuclear energy.

Figure 1. OECD Electricity Generation, based on BP and EIA data.

Figure 1 indicates that nuclear accounts for about 22 percent of electric generation in OECD countries. "Renewables" is the sum of all types of electricity generation (other than hydroelectric) that are referred to as renewables–including burning wood for electricity generation, wind, solar photo voltaic (PV), geothermal, and biogas. Renewable amounts are from EIA data; the other amounts are from BP data.

The Former Soviet Union (FSU) would also be affected if nuclear electricity were discontinued, although to a lesser extent than OECD.

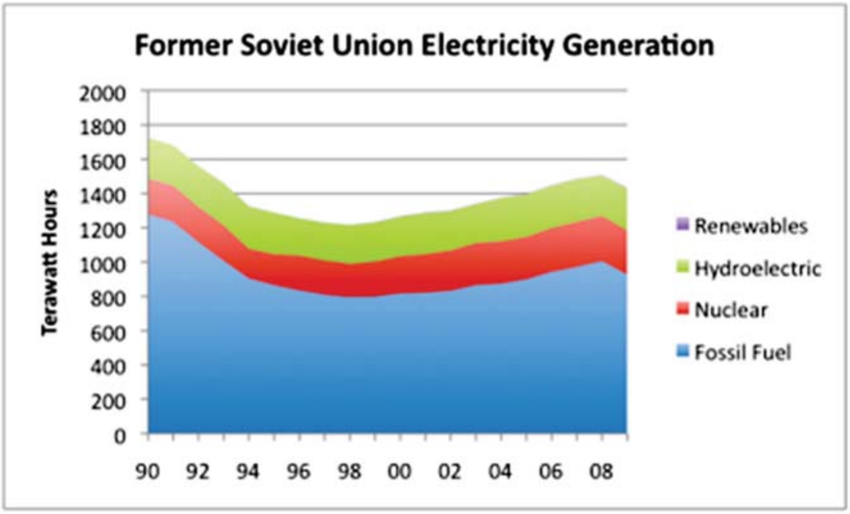


Figure 2. Former Soviet Union electricity generation, based on BP and EIA data.

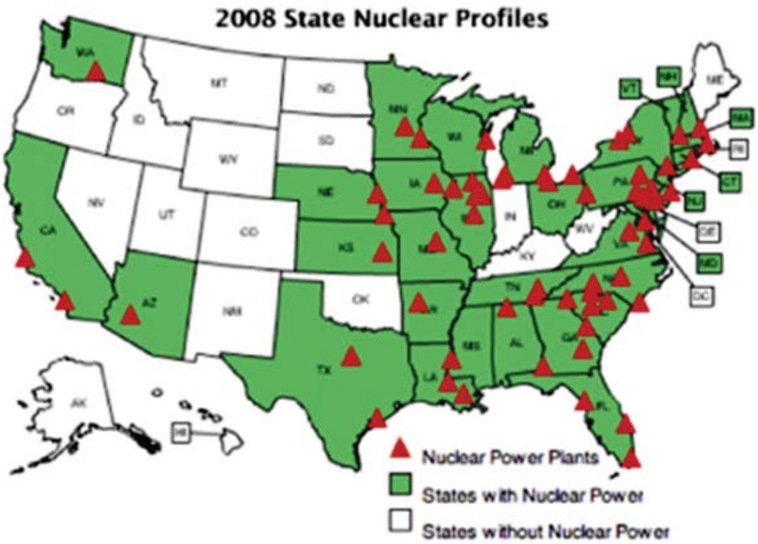
Figure 2 indicates that the FSU gets about 18 percent of its electricity from nuclear, and this percentage has been rising. Since the Russia (and some of the other FSU countries) are big exporters of natural gas, if this area were to lose its nuclear, it would probably substitute natural gas, while reducing exports to other countries–especially Europe

What are called the "developing countries" (calculated as the World – OECD – FSU), have very rapidly growing energy use, but historically, very little nuclear use-a little over 2.0 percent. They would be least affected, as long as they could continue to expand their fossil fuel use (mostly coal) and their hydroelectric.

These are big ifs, of course, as the world is running into limits with both fossil fuels and hydroelectric. Some of these countries (including China and India) are planning big increases in nuclear production in the future.

Figure 3. Developing countries electrical generation, based on BP and EIA data.

2. Within the OECD, vulnerability to a loss of nuclear power varies significantly.



A number of OECD countries have no nuclear electricity generating capacity. These would include Australia, Austria, Denmark, Greece, Ireland, Italy, New Zealand, Norway, Poland, Portugal, and Turkey.

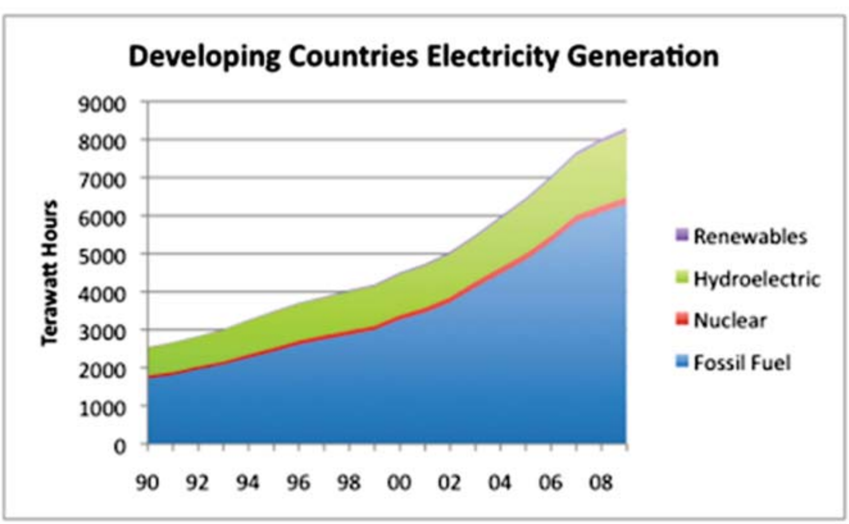
At the other end of the range, some OECD countries have a very high percentage of electrical generation from nuclear. These include France (76 percent), Belgium/Luxembourg (56 percent), Hungary (43 percent), Switzerland (40 percent), Sweden (39 percent), Czech Republic 34 (percent), Finland (33 percent), South Korea (32 percent), Japan (25), Germany (23 percent) United States (20 percent) United Kingdom (19 percent) Spain (18 percent) and Canada (14 percent). These amounts are based on BP statistical data for the year 2009.

Within the United States, there is also variability in the proportion of electrical power from nuclear, with the largest concentration of nuclear power being on the East Coast and in the Midwest.

Figure 4. Map created by EIA showing nuclear electrical generating sites by state.

The two facilities in California are built on the coast, near the earthquake "ring of fire". Diablo Canyon near San Luis Obispo is reported to be built to withstand an earthquake force of 7.5; San Onofre near San Clemente in San Diego County is built to withstand an earthquake force of 7.0. Both of these are far lower levels than the recent earthquake in Japan, which is now rated as a 9.0. California has limited power availability currently (it imports more power than any other state), so would likely have difficulty replacing lost nuclear power.

It might also be noted that Europe, right now, is at risk from declining North Sea natural gas. Replacing this with imports from elsewhere may be difficult, in and of itself. If declining nuclear production is added to the list of problems for these countries, there could be major difficulty. ■



Growth-Hungry Asian Giants Opt for N-Energy over Other Forms

When night falls in a small village in Bihar, a faint light emits from inside hundreds of huts propped on stilts above the river's surface. Though there is no electricity here, people watch television using power from a rechargeable car battery.

There are plans for electricity soon enough. Faced with rising fossil fuel prices and concerns about global warming, governments across this region have ramped up efforts to figure out how to meet the gap in the supply and demand of the region's energy needs. India is perhaps the only country which has special ministry on nuclear energy.

Nuclear power has long been considered a promising solution here. Although the global nuclear energy industry suffered a dark period after the catastrophes at Chernobyl in Ukraine and Three Mile Island in the U.S., it has staged a comeback even as environmental concerns mount. As of 2010, some 65 countries without nuclear plants are either considering or actively planning for nuclear power, according to a report by the International Atomic Energy Agency (IAEA). Two-thirds of nuclear plants under construction are in Asia, with China and India leading the push.

Enter Japan's nuclear crisis. Suddenly, the growth prospects for nuclear energy in Asia have been top-sided. Recently, China announced it would halt all new nuclear plant approvals -- about 40 percent of the planned projects in the world.

The question for industry watchers is whether the Japan crisis will prove a turning point or a speed bump. The implications, both for the industry and for energy security and economic development, could be widely felt across Asia.

Fuelling economic growth

Today, nuclear energy accounts for 16 percent of energy produced globally, and the OECD expects that number to rise to 22 percent by 2050. The majority of production remains concentrated in a few countries -- France, the U.S. and Japan account for 57 percent of the world's nuclear energy generating capacity -- but this picture is rapidly shifting. Nuclear power is no magic bullet for the clean energy needs of the world, but nuclear power in Asia is fundamental to the region's growth, perhaps more so than in any other region.

Unlike in Europe, where a relatively disparate population could effectively use solar, hydro, or geothermal energy as alternatives to nuclear power,

Asia is a developing market with dense population centers that require compact energy sources to support billions of people. Vietnam alone has 87 million people -- more populous than Germany, the European Union's largest country -- and many of them are struggling to rise to middle class status.

"My feeling is that governments in this region don't see an alternative to nuclear power to keep economic growth going," says Dr. T.S. GopiRethinaraj of the Lee Kuan Yew School of Public Policy in Singapore.

China, whose electricity consumption levels rising by 12 percent per year, currently has 13 nuclear reactors in operation and dozens more in the pipeline. It is the most ambitious country in the world when it comes to going nuclear. It is unclear how long Beijing's halt of new nuclear projects will last -- the government says it must first refine its safety rules and check all existing reactors for potential hazards.

China's suspension is the most dramatic move thus far in Asia, although all governments with nuclear reactors in operation are announcing safety checks to ease public anxiety. Countries like South Korea and India, which have developed robust nuclear programs to fend off hostile neighbors, each harness 20 reactors to provide electricity for their expanding populations.

According to the World Nuclear Association, South Korea meets 35 percent of its energy needs with nuclear power, and aims to increase that amount to 59 percent by 2030. India is not nearly as dependent on nuclear energy, but both countries have so many deals in the pipeline that each would stand to lose a fair amount of money if plans stalled. India in particular, which just signed multi-billion dollar agreements with the US, has little choice but to continue.

Unrest in Southeast Asia

The story takes a different slant in Southeast Asia, where nuclear programs are just taking hold. Vietnam is farthest along, having signed definitive agreements with Japan and Russia earlier this year to build two reactors by 2025. The Vietnamese government claims it will stay the course. Indonesia, Malaysia, and Thailand have recently decided to build out nuclear programs.

Japan's nuclear crisis has duly prompted discontent. Protests erupted in Northern Thailand recently and some members of the government called for Thailand's nuclear plans to be abandoned. New debate seized Malaysia as well, and the former Prime Minister is rallying support for a non-nuclear energy policy.

Perhaps most squarely in the crosshairs, now, is Indonesia. The Indonesian government has earmarked $8 billion for two nuclear reactors and the country has been training dozens of scientists since the 1980s in anticipation of its nuclear ambitions. Blackouts in Jakarta, the country's capital, are increasingly common. Coal and oil are running out. But Indonesia sits on the dangerous "Ring of Fire," making it home to more earthquakes than any other country in the world.

Simon Tay, the chairman of the Singapore Institute of International Affairs, recently wrote a Jakarta Post op-ed pleading for regional cooperation in setting nuclear safety standards. "The Japanese situation is a sharp reminder to be humble in the face of the risks and to bring a pause to breakneck ambitions," wrote Tay. "Countries that are vulnerable to earthquakes -- especially Indonesia, but also some provinces in China -- would be well served to re-look at safety issues."

It is clearly too early to know exactly how Japan's crisis will affect the nuclear industry. Policymakers in Asia are already drawing lessons from the crisis, saying that the biggest takeaway is that there will be a push to build future nuclear plants away from large populations and fault lines. All countries claim to have superior designs to Japan's 40-year-old reactor, with a more foolproof cooling system and power generators that aren't at sea level. Testing for earthquakes of this magnitude and beyond will now be included in safety checks.

The latest renaissance in public interest for nuclear was fuelled by climate concerns -- concerns that have not gone away. Coal and renewables cannot fully meet Asia's rising energy demand. Politics remains a veritable obstacle right now for the global nuclear industry, particularly in the US and Europe. But Asian governments -- specifically those that tolerate less public debate than in the West -- can be counted on to move ahead as planned. ■

Experimental N-Reactors More Accident-Prone

There have been a number of accidents in experimental reactors and in one military plutonium-producing reactor, including a number of core melts, but none of these has resulted in loss of life outside the actual plant, or long-term environmental contamination. The list of 10 probably corresponds to incidents rating 4 or higher on today's International Nuclear Event Scale. All except Browns Ferry and Vandellos involved damage to or malfunction of the reactor core. At Browns Ferry a fire damaged control cables and resulted in an 18-month shutdown for repairs; at Vandellos a turbine fire made the 17-year old plant uneconomic to repair.

Mention should be made of the accident to the US Fermi-1 prototype fast breeder reactor near Detroit in 1966. Due to a blockage in coolant flow, some of the fuel melted. However no radiation was released off-site and no-one was injured. The reactor was repaired and restarted but closed down in 1972.

The well-publicized criticality accident at Tokai Mura, Japan, in 1999 was at a fuel preparation plant for experimental reactors, and killed two workers from radiation exposure. Many other such criticality accidents have occurred, some fatal, and practically all in military facilities prior to 1980.

In an uncontained reactor accident such as at Windscale (a military facility) in 1957 and at Chernobyl in 1986, (and to some extent: Fukushima in 2011,) the principal health hazard is from the spread of radioactive materials, notably volatile fission products such as iodine-131 and caesium-137. These are biologically active, so that if consumed in food, they tend to stay in organs of the body. I-131 has a half-life of eight days, so is a hazard for around the first month, (and apparently gave rise to the thyroid cancers after the Chernobyl accident). Caesium-137 has a half-life of 30 years, and is therefore potentially a long-term contaminant of pastures and crops. In addition to these, there is caesium-134 which has a half-life of about two years. While measures can be taken to limit human uptake of I-131, (evacuation of area for several weeks, iodide tablets), high levels of radioactive caesium can preclude food production from affected land for a long time. Other radioactive materials in a reactor core have been shown to be less of a problem because they are either not volatile (strontium, transuranic elements) or not biologically active (tellurium-132, xenon-133).

Accidents in any field of technology provide valuable knowledge enabling incremental improvement in safety beyond the original engineering. Cars and airliners are the most obvious examples of this, but the chemical and oil industries can provide even stronger evidence. Civil nuclear power has greatly improved its safety in both engineering and operation over its 55 years of experience with very few accidents and major incidents to spur that improvement. The Fukushima Daiichi accident is the first since Three Mile Island in 1979 which will have significant implications, at least for older plants.

Scrams, Seismic shutdowns - A scram is a sudden reactor shutdown. When a reactor is scrammed, automatically due to seismic activity, or due to some malfunction, or manually for whatever reason, the fission reaction generating the main heat stops. However, considerable heat continues to be generated by the radioactive decay of the fission products in the fuel. Initially, for a few minutes, this is great - about 7.0 percent of the pre-scram level. But it drops to about 1.0 percent of the normal heat output after two hours, to 0.5 percent after one day, and 0.2 percent after a week. Even then it must still be cooled, but simply being immersed in a lot of water does most of the job after some time. When the water temperature is below 100°C at atmospheric pressure the reactor is said to be in "cold shutdown". ■

'Stress Tests' in European Plants after Fukushima Disaster

Assessment of the aspects of nuclear plant safety highlighted by the Fukushima accident is being applied to the 143 nuclear reactors in the EU's 27 member states, as well as those in any neighbouring states that have decided to take part. These comprehensive and transparent risk and safety assessments, the so-called "stress tests", involved targeted reassessment of each power reactor's safety margins in the light of extreme natural events, such as earthquakes and flooding as natural events, as well as on loss of safety functions and severe accident management following any initiating event.

The Western European Nuclear Regulators' Association (WENRA) proposed these in response to a call from the European Council in March 2011, and developed specifications. WENRA is a network of Chief Regulators of EU countries with nuclear power plants and Switzerland, and has membership from 17 countries. It then negotiated the scope of the tests with the European Nuclear Safety Regulators Group (ENSREG), an independent, authoritative expert body created in 2007 by the European Commission comprising senior officials from the national nuclear safety, radioactive waste safety or radiation protection regulatory authorities from all 27 EU member states, and representatives of the European Commission.

The reassessment of safety margins is based on the existing safety studies and engineering judgment to evaluate the behaviour of a nuclear power plant when facing a set of challenging situations. For a given plant, the reassessment reports on the most probable behaviour of the plant for each of the situations considered.

The results of the reassessment were peer-reviewed and shared among regulators. They may indicate a need for additional technical or organisational safety provisions. WENRA noted that it remains a national responsibility to take any appropriate measures resulting from the reassessment.

The scope of the assessment takes into account the issues that have been directly highlighted by the events in Fukushima and the possibility for combination of initiating events. Two 'initiating events' are covered in the scope: earthquake and flooding. The consequences of these - loss of electrical power and station blackout, loss of ultimate heat sink and the combination of both - are analysed, with the conclusions being applicable to other general emergency situations. In accident scenarios, regulators consider power plants' means to protect against and manage loss of core cooling as well as cooling of used fuel in storage. They also study means to protect against and manage loss of containment integrity and core melting, including consequential effects such as hydrogen accumulation.

Nuclear plant operators start by documenting each power plant site. This analysis of 'extreme scenarios' follows what ENSREG called a progressive approach "in which protective measures are sequentially assumed to be defeated" from starting conditions which "represent the most unfavourable operational states." The operators have to explain their means to maintain "the three fundamental safety functions (control of reactivity, fuel cooling confinement of radioactivity)" and support functions for these, "taking into account the probable damage done by the initiating event."

The documents have to cover provisions in the plant design basis for these events and the strength of the plant beyond its design basis. This means the "design margins, diversity, redundancy, structural protection and physical separation of the safety relevant systems, structures and components and the effectiveness of the defence-in-depth concept." This has to put focus on 'cliff-edge' effects, e.g. when back-up batteries are exhausted and station blackout is inevitable. For severe accident management scenarios they must identify the time before fuel damage is unavoidable and the time before water begins boiling in used fuel ponds and before fuel damage occurs. Measures to prevent hydrogen explosions and fires are to be part of this.

Since the licensee has the prime responsibility for safety, it is up to the licensees to perform the reassessments, and the regulatory bodies then independently review them. The exercise covers 147 nuclear plants in 15 EU countries - including Lithuania with only decommissioned plants - plus 15 reactors in Ukraine and five in Switzerland.

Operators reported to their regulators who then reported progress to the European Commission by the end of 2011. Information was shared among regulators throughout this process before the 17 final reports went to peer-review by teams comprising 80 experts appointed by ENSREG and the European Commission.

The final documents will be published in line with national law and international obligations, provided this does not jeopardise security - an area where each country may behave differently. The process was to be finished in April 2012, but has been extended to June to allow more plant visits and to add more information on the potential effect of aircraft impacts. Drawing on the peer reviews, in April the EC and ENSREG cited four main areas for improving EU nuclear plant safety:

• guidance from WENRA for assessing natural hazards and margins beyond design basis;

• giving more importance to periodic safety reviews and evaluation of natural hazards;

• urgent measures to protect containment integrity; and

• measures to prevent and mitigate accidents resulting from extreme natural hazards.

In June 2011 the governments of seven non-EU countries agreed to conduct nuclear reactor stress tests using the EU model. Armenia, Belarus, Croatia, Russia, Switzerland, Turkey and Ukraine signed a declaration that they would conduct stress tests and agreed to peer reviews of the tests by outside experts. Russia had already undertaken extensive checks. (Croatia is co-owner in the Krsko PWR in Slovenia, and Belarus and Turkey plan to build nuclear plants but have none now.)

In the USA the Nuclear Regulatory Commission (NRC) in March 2012 made orders for immediate post-Fukushima safety enhancements, likely to cost about $100 million across the whole US fleet. The first order requires the addition of equipment at all plants to help respond to the loss of all electrical power and the loss of the ultimate heat sink for cooling, as well as maintaining containment integrity. Another requires improved water level and temperature instrumentation on used fuel ponds. The third order applies only to the 33 BWRs with early containment designs, and will require 'reliable hardened containment vents' which work under any circumstances. The measures are supported by the industry association, which has also proposed setting up about six regional emergency response centres under NRC oversight with additional portable equipment. ■

Severe Accident Management (SAM) Norms Put in Place

In addition to engineering and procedures which reduce the risk and severity of accidents, all plants have guidelines for Severe Accident Management or Mitigation (SAM). These conspicuously came into play after the Fukushima accident, where staff had immense challenges in the absence of power and with disabled cooling systems following damage done by the tsunami. The experience following that accident is being applied not only in design but also in such guidelines, and peer reviews on nuclear plants will focus more on these than previously.

In mid 2011 the IAEA Incident and Emergency Centre launched a new secure web-based communications platform to unify and simplify information exchange during nuclear or radiological emergencies. The Unified System for Information Exchange on Incidents and Emergencies (USIE) has been under development since 2009 but was actually launched during the emergency response to the accident at Fukushima.

Earthquakes & Volcanoes

The International Atomic Energy Agency (IAEA) has a Safety Guide on Seismic Risks for Nuclear Power Plants, and the matter is dealt with in the WNA paper on Earthquakes and Nuclear Power Plants.

Volcanic hazards are minimal for practically all nuclear plants, but the IAEA has developed a new Safety Guide on the matter. The Bataan plant in the Philippines which has never operated, and the Armenian plant at Metsamor are two known to be in proximity to potential volcanic activity.

Flooding - storms, tides & tsunamis

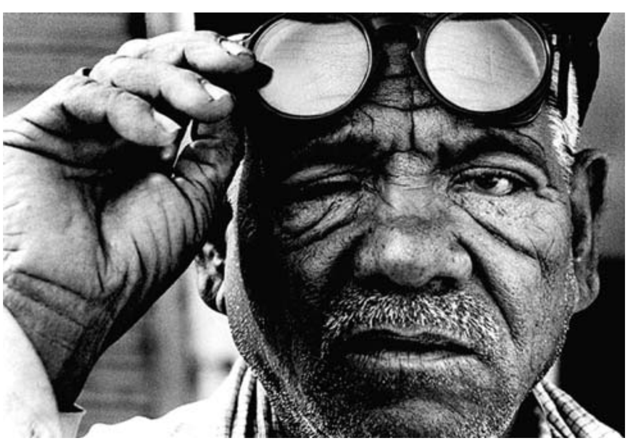
Nuclear plants are usually built close to water bodies, for the sake of cooling. The site licence takes account of worst case flooding scenarios as well as other possible natural disasters and, more recently, the possible effects of climate change. As a result, all the buildings with safety-related equipment are situated on high enough platforms so that they stand above submerged areas in case of flooding events. As an example, French Safety Rules criteria for river sites define the safe level as above a flood level likely to be reached with one chance in one thousand years, plus 15 percent, and similar regarding tides for coastal sites.

Occasionally in the past some buildings have been sited too low, so that they are vulnerable to flood or tidal and storm surge, so engineered countermeasures have been built. EDF's Blayais nuclear plant in western France uses seawater for cooling and the plant itself is protected from storm surge by dykes. However, in 1999 a 2.5 m storm surge in the estuary overtopped the dykes - which were already identified as a weak point and scheduled for a later upgrade - and flooded one pumping station. For security reasons it was decided to shut down the three reactors then under power (the fourth was already stopped in the course of normal maintenance). This incident was rated 2 on the INES scale.

Indian Experience

In 1994 the Kakrapar nuclear power plant near the west coast of India was flooded due to heavy rains together with failure of weir control for an adjoining water pond, inundating turbine building basement equipment. The back-up diesel generators on site enabled core cooling using fire water, a backup to process water, since the offsite power supply failed. Following this, multiple flood barriers were provided at all entry points, inlet openings below design flood level were sealed and emergency operating procedures were updated. In December 2004 the Madras NPP and Kalpakkam PFBR site on the east coast of India was flooded by a tsunami surge from Sumatra. Construction of the Kalpakkam plant was just beginning, but the Madras plant shut down safely and maintained cooling. However, recommendations including early warning system for tsunami and provision of additional cooling water sources for longer duration cooling were implemented.

In March 2011 the Fukushima Daiichi nuclear plant was affected seriously by a huge tsunami induced by the Great East Japan Earthquake. Three of the six reactors were operating at the time, and had shut down automatically due to the earthquake. The back-up diesel generators for those three units were then swamped by the tsunami. This cut power supply and led to weeks of drama and loss of the reactors. The design basis tsunami height was 5.7 m for Daiichi (and 5.2 m for adjacent Daini, which was actually set a bit higher above sea level). Tsunami heights coming ashore were about 14 metres for both plants. Unit 3 of Daini was undamaged and continued to cold shutdown status, but the other units suffered flooding to pump rooms where equipment transfers heat from the reactor circuit to the sea - the ultimate heat sink.



The maximum amplitude of this tsunami was 23 metres at point of origin, about 160 km from Fukushima. In the last century there had been eight tsunamis in the Japan region with maximum amplitudes above 10 metres (some much more), these having arisen from earthquakes of magnitude 7.7 to 8.4, on average one every 12 years. Those in 1983 and in 1993 were the most recent affecting Japan, with maximum heights 14.5 metres and 31 metres respectively, both induced by magnitude 7.7 earthquakes. This 2011 earthquake was magnitude 9.

For low-lying sites, civil engineering and other measures are normally taken to make nuclear plants resistant to flooding. Lessons from Blayais have fed into regulatory criteria since 2000, and those from Fukushima will certainly do so. Sea walls are being built or increased at Hamaoka, Shimane, Mihama, Ohi, Takahama, Onagawa, and Higashidori plants. However, few parts of the world have the same tsunami potential as Japan, and for the Atlantic and Mediterranean coasts of Europe the maximum amplitude is much less than Japan.

Presence of Hydrogen

In any light-water nuclear power reactor, hydrogen is formed by radiolytic decomposition of water. This needs to be dealt with to avoid the potential for explosion with oxygen present, and many reactors have been retrofitted with passive autocatalytic hydrogen recombiners in their containment, replacing external recombiners that needed to be connected and powered, isolated behind radiological barriers. Also in some kinds of reactors, particularly early boiling water types, the containment is rendered inert by injection of nitrogen. It was reported that WANO may require all operators to have hydrogen recombiners in PWRs. As of early 2012, a few in Spain and Japan did not have them.

In an accident situation such as at Fukushima where the fuel became very hot, a lot of hydrogen is formed by the oxidation of zirconium fuel cladding in steam at about 1300°C. This is beyond the capability of the normal hydrogen recombiners to deal with, and operators must rely on venting to atmosphere or inerting the containment with nitrogen. ■

Protecting N-Plants from Terrorist Aircraft & Bombing Attacks

Since the World Trade Centre attacks in New York in 2001 there has been concern about the consequences of a large aircraft being used to attack a nuclear facility with the purpose of releasing radioactive materials. Various studies have looked at similar attacks on nuclear power plants. They show that nuclear reactors would be more resistant to such attacks than virtually any other civil installations – a thorough study was undertaken by the US Electric Power Research Institute (EPRI) using specialist consultants and paid for by the US Department of Energy. It concludes that US reactor structures "are robust and (would) protect the fuel from impacts of large commercial aircraft".

The analyses used a fully-fuelled Boeing 767-400 of over 200 tonnes as the basis, at 560 km/h - the maximum speed for precision flying near the ground. The wingspan is greater than the diameter of reactor containment buildings and the 4.3 tonne engines are 15 metres apart. Hence analyses focused on single engine direct impact on the centreline - since this would be the most penetrating missile - and on the impact of the entire aircraft if the fuselage hit the centreline (in which case the engines would ricochet off the sides). In each case no part of the aircraft or its fuel would penetrate the containment. Other studies have confirmed these findings.

Penetrating (even relatively weak) reinforced concrete requires multiple hits by high speed artillery shells or specially-designed "bunker busting" ordnance - both of which are well beyond what terrorists are likely to deploy. Thin-walled, slow-moving, hollow aluminum aircraft, hitting containment-grade heavily-reinforced concrete disintegrate, with negligible penetration. But further realistic assessments from decades of analyses, lab work and testing, find that the consequence of even the worst realistic scenarios - core melting and containment failure - can cause few if any deaths to the public, regardless of the scenario that led to the core melt and containment failure. This conclusion was documented in a 1981 EPRI study, reported and widely circulated in many languages, by Levenson and Rahn in Nuclear Technology.

In 1988 Sandia National Laboratories in USA demonstrated the unequal distribution of energy absorption that occurs when an aircraft impacts a massive, hardened target. The test involved a rocket-propelled F4 Phantom jet (about 27 tonnes, with both engines close together in the fuselage) hitting a 3.7m thick slab of concrete at 765 km/h. This was to see whether a proposed Japanese nuclear power plant could withstand the impact of a heavy aircraft. It showed how most of the collision energy goes into the destruction of the aircraft itself - about 96 percent of the aircraft's kinetic energy went into the its destruction and some penetration of the concrete, while the remaining 4.0 percent was dissipated in accelerating the 700-tonne slab. The maximum penetration of the concrete in this experiment was 60 mm, but comparison with fixed reactor containment needs to take account of the 4.0 percent of energy transmitted to the slab.

The study of a 1970s US power plant in a highly-populated area is assessing the possible effects of a successful terrorist attack which causes both meltdown of the core and a large breach in the containment structure - both extremely unlikely. It shows that a large fraction of the most hazardous radioactive isotopes, like those of iodine and tellurium, would never leave the site.

Much of the radioactive material would stick to surfaces inside the containment or becomes soluble salts that remain in the damaged containment building. Some radioactive material would nonetheless enter the environment some hours after the attack in this extreme scenario and affect areas up to several kilometres away. The extent and timing of this means that with walking-pace evacuation inside this radius it would not be a major health risk. However it could leave areas contaminated and hence displace people in the same way as a natural disaster, giving rise to economic rather than health consequences.

Looking at spent fuel storage pools, similar analyses showed no breach. Dry storage and transport casks retained their integrity. "There would be no release of radionuclides to the environment".

Similarly, the massive structures mean that any terrorist attack even inside a plant (which are well defended) and causing loss of cooling, core melting and breach of containment would not result in any significant radioactive releases.

However, while the main structures are robust, the 2001 attacks did lead to increased security requirements and plants were required by NRC to install barriers, bulletproof security stations and other physical modifications which in the US are estimated by the industry association to have cost some $2 billion across the country.

Switzerland's Nuclear Safety Inspectorate studied a similar scenario and reported in 2003 that the danger of any radiation release from such a crash would be low for the older plants and extremely low for the newer ones.

The conservative design criteria which caused most power reactors to be shrouded by massive containment structures with biological shield has provided peace of mind in a suicide terrorist context. Ironically and as noted earlier, with better understanding of what happens in a core melt accident inside, they are now seen to be not nearly as necessary in that accident mitigation role as was originally assumed. ■

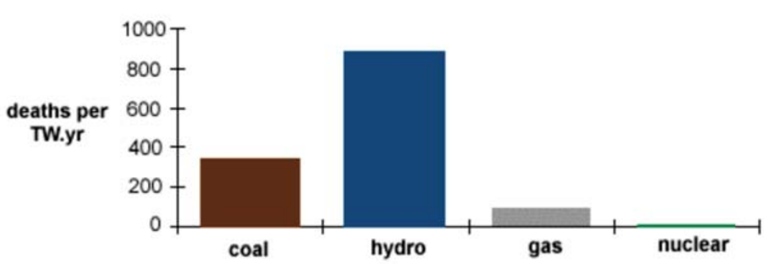
Nuclear Vs Other Energy Related Options – A Study

Many occupational accident statistics have been generated over the last 40 years of nuclear reactor operations in the US and UK. These can be compared with those from coal-fired power generation. All show that nuclear is a distinctly safer way to produce electricity.

Deaths from energy-related accidents per unit of electricity

Coal-fired power generation has chronic, rather than acute, safety implications for public health. It also has profound safety implications for the mining of coal, with thousands of workers killed each year in coal mines.

Hydro power generation has a record of few but very major events causing thousands of deaths. In 1975 when the Banqiao, Shimantan & other dams collapsed in Henan, China, at least 30,000 people were killed immediately and some 230,000 overall, with 18 GWe lost. In 1979 and 1980 in India some 3,500 were killed by two hydro-electric dam failures, and in 2009 in Russia 75 were killed by a hydro-power plant turbine disintegration.



Source: Paul ScherrerInstitut 1998, considering 1943 accidents with more than 5 fatalities. One TW.yr is the amount of electricity used by the world in about five months.

Three simple sets of figures are quoted in the Tables below. A major reason for coal's unfavourable showing is the huge amount which must be mined and transported to supply even a single large power station. Mining and multiple handling of so much material of any kind involves hazards, and these are reflected in the statistics.

Summary of severe* accidents in energy chains for electricity 1969-2000

	OECD		Non-OECD	
Energy chain	**Fatalities**	**Fatalities/TWy**	**Fatalities**	**Fatalities/TWy**
Coal	2259	157	18,000	597
Natural gas	1043	85	1000	111
Hydro	14	3	30,000	10,285
Nuclear	0	0	31	48

*Data from Paul ScherrerInstitut, in OECD 2010. * severe = more than 5 fatalities*

Comparison of accident statistics in primary energy production (Electricity generation accounts for about 40% of total primary energy)

Fuel	Immediate fatalities 1970-92	Who?	Normalised to deaths per TWy* electricity
Coal	6400	workers	342
Natural gas	1200	workers & public	85
Hydro	4000	public	883
Nuclear	31	workers	8

** Basis: per million MWe operating for one year, not including plant construction, based on historic data which is unlikely to represent current safety levels in any industries concerned. Sources: Sources: Ball, Roberts & Simpson, 1994; of the Hirschberg et al, Paul ScherrerInstitut 1996, in: IAEA 1997; Paul ScherrerInstitut, 2001.*

Measuring & Reporting Nuclear-Accidents

The International Nuclear Event Scale (INES) was developed by the International Atomic Energy Agency (IAEA) and OECD in 1990 to communicate and standardise the reporting of nuclear incidents or accidents to the public. The scale runs from a zero event with no safety significance to 7 for a "major accident" such as Chernobyl. Three Mile Island rated 5, as an "accident with off-site risks" though no harm to anyone, and a level 4 "accident mainly in installation" occurred in France in 1980, with little drama. Another accident rated at level 4 occurred in a fuel processing plant in Japan in September 1999. Other accidents have been in military plants.

The International Nuclear Event Scale
For prompt communication of safety significance

Level, Descriptor	Off-Site Impact, release of radioactive materials	On-Site Impact	Defence-in-Depth Degradation	Examples
7 **Major Accident**	Major Release: Widespread health and environmental effects			Chernobyl, Ukraine, 1986 (fuel meltdown and fire); Fukushima Daiichi 1 3, 2011 (fuel damage, radiation release and evacuation)
6 **Serious Accident**	Significant Release: Full implementation of local emergency plans			Mayak at Ozersk, Russia, 1957 (reprocessing plant criticality)
5 **Accident with Off - Site Consequences**	Limited Release: Partial implementation of local emergency plans, or	Severe damage to reactor core or to radiological barriers		Three Mile Island, USA, 1979 (fuel melting); Windscale, UK, 1957 (military)
4 **Accident Mainly in Installation, with local consequences. either of:**	Minor Release: Public exposure of the order of prescribed limits, or	Significant damage to reactor core or to radiological barriers; worker fatality		Saint-Laurent A1, France, 1969 (fuel rupture) & A2 1980 (graphite overheating); Tokai -mura, Japan, 1999 (criticality in fuel plant for an experimental reactor).
3 **Serious Incident any of:**	Very Small Release: Public exposure at a fraction of prescribed limits, or	Major contamination; Acute health effects to a worker, or	Near Accident: Loss of Defence in Depth provisions - no safety layers remaining	Fukushima Daiichi 4, 2011 (fuel pond overheating); Fukushima Daini 1, 2, 4, 2011 (interruption to cooling); Vandellos, Spain, 1989 (turbine fire); Davis-Besse, USA, 2002 (severe corrosion); Paks, Hungary 2003 (fuel damage)
2 **Incident**	nil	Significant spread of contamination; Overexposure of worker, or	Incidents with significant failures in safety provisions	
1 **Anomaly**	nil	nil	Anomaly beyond authorised operating regime	
0 **Deviation**	nil	nil	No safety significance	
Below Scale	nil	nil	No safety relevance	

Source: International Atomic Energy Agency (IAEA)


A nuclear future is nothing without a track record.