Toxic assets: nuclear reactors in the 21st century

Financing reactors and the Fukushima nuclear disaster

April 2012

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Greenpeace worked on this report with BankTrack, who organised the background research paper that looked at who financed TEPCO before the Fukushima Daiichi nuclear disaster either through shares, bonds or loans.

Executive Summary

This report looks at the March 2011 Fukushima nuclear disaster from an investors' point of view. It identifies the long-known technological, management, governance and other institutional deficiencies that were instrumental in turning a predicted natural misfortune into a nuclear nightmare. The owner of the Fukushima Daiichi plant, Tokyo Electric Power Company (TEPCO), lost 90% of its market capitalisation, had its bonds rated as junk and is currently in the process of being at least partly nationalised. Investors and financiers of nuclear utilities all over the world saw their investments eroded.

Had analysts and credit-rating agencies looked beyond short-term cash flows and paid attention to the many early warnings, they would have been able to save investors from major losses. These red flags included warnings about:

- Crucial vulnerabilities in the Fukushima reactor design;
- Substantial governance issues and weak management characterised by major frauds and cover-ups;
- Collusion and loose regulatory supervision; and
- Well-understood and ignored earthquake and tsunami warnings.

All of these warnings had been publically highlighted years, often decades, before the nuclear disaster, and should have been taken seriously not only by nuclear authorities but by analysts and investors as well. Still, TEPCO continued to benefit from high credit ratings, supportive analyst recommendations and cheap financing right until the Fukushima nuclear accident. Like Japanese nuclear authorities, financial 'authorities' also missed the many opportunities to force changes on the company. It seems regular dividends were enough to relax the vigilance of analysts who simply ignored major 'fundamental' risks and their fiduciary duty towards their investor clients.

Investors and financiers kept throwing good money after TEPCO. Dozens of banks provided TEPCO with at least €54bn of low-cost capital through bond issues, corporate loans and a share issuance between 2000 and 2011. Bond issues secured most of the funding and Citi, Mizuho, Nomura, Sumitomo Mitsui, Mitsubishi UFJ, BNP Paribas, Deutsche Bank, Merrill Lynch (Bank of America), Daiwa Securities, Morgan Stanley and Goldman Sachs were the largest bond-underwriters.

The potential for similar catastrophic nuclear disasters and disastrous investment decisions is not limited to TEPCO or Japan. Existing and planned new reactors all over the world are inherently at risk from any combination of:

- Similar mistakes in technology design that proved devastating at Fukushima;
- Substantial governance and management issues, and human error;
- The lack of effective independent supervision; and
- The threat of earthquakes, tsunami, floods and other natural disaster risks.

Nuclear power plants are potentially toxic assets for their investors and financiers. Quite uniquely, they can give rise to liabilities that can exceed their owner's equity a hundred-fold or more. The probability of a devastating accident is around one major disaster in a decade based on the five core meltdowns since the 1950s, and this number does not even take into consideration the growing risks of ageing reactors.

Nuclear assets are also dangerous for investors even in the absence of a nuclear disaster. New reactor builds have been a clear investor 'no-go' for at least a decade. Recently, even existing plants have come under increasing pressure from phase-out decisions, early retirements, large-scale regulatory and liability changes, and shrinking taxpayer and government support. The future of nuclear energy will be highly influenced by three tectonic changes:

- Post-Fukushima regulations that will require additional safety investments, shorter lifespans, higher operating and decommissioning costs, and stricter liability systems;
- Renewable energy, with falling costs and more installed capacity than nuclear plants[1], is pushing nuclear out from the merit order and leading to lower plant utilisation; and
- A strong reduction in subsidies, credit guarantees and other state supports to nuclear of earlier generous, but now highly indebted governments.

Contents

1. Introduction

The nuclear disaster of 11 March 2011 at the Fukushima Daiichi plant released an amount of radiation corresponding to 20-40% of the Chernobyl nuclear accident[2] in 1986, contaminated huge areas both on land and at sea[3] and forced the evacuation of at least 100,000 people[4]. Another 50,000 or more people left the area voluntarily from radiation fears. The accident has destroyed large agricultural areas, led to the death of most of the 625,000 farm animals living in the evacuation area[5] and has been a heavy hit on local growers of rice, vegetables and tea, on fisheries, and on producers and processors of milk and meat. It has deleted the region from the list of the most popular tourist destinations in Japan and has destroyed the livelihoods of hundreds of thousands.

We are only starting to grasp the full social, environmental and economic consequences of the failures that led to the disaster. Insured risks are expected to exceed the $71.2bn US dollar losses from Katarina and the next six largest US hurricanes combined. The Japan Centre for Economic Research has put the entire cost of the Fukushima nuclear disaster, including compensation and decommissioning the Daiichi plant's six reactors, at 5.7 to 20 trillion yen ($70-$250bn).[6] Although the government and ultimately taxpayers will probably pay a significant part of this, shareholders and bondholders of TEPCO and other nuclear utilities all over the world have also had to assume massive losses.

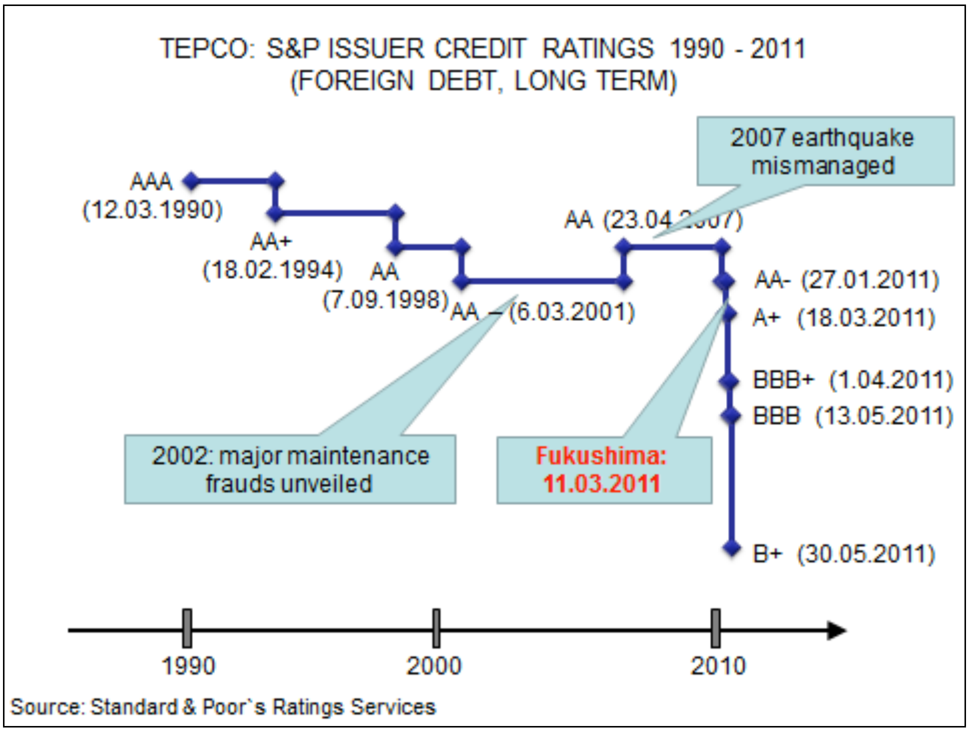
Greenpeace was among those drawing early attention to the risks that ultimately led to the nuclear accident. In addition, Greenpeace has been in the field from the early days after the disaster to support local populations with its independent radiation monitoring information and to understand the causes and consequences of the accident. The Greenpeace International report *Lessons from Fukushima*[7] looked at the problems in the institutional set-ups, regulatory systems, emergency planning and liability schemes, and compiled recommendations to governments, legislators and regulators. In the following pages, we turn to investors to show who financed the Tokyo Electric Power Company (TEPCO), the owner of the Fukushima plant, what early warnings financial analysts and credit rating agencies missed, and how investors can avoid further losses on nuclear energy.

2. Who financed TEPCO before the Fukushima nuclear disaster?

Before looking at who financed TEPCO's nuclear activities, we look at what advice investors based their decisions on. Interestingly, the bad advice was often followed by the analysts' own banks as well, at least when acting on behalf of their clients.

2.1 Dubious advice from analysts and credit-rating agencies

TEPCO enjoyed high credit ratings and cheap financing right up until the Fukushima accident, despite numerous warnings related to nuclear risks. No single mention of nuclear-specific risks could be found in the large volume of credit analyses issued on the company during the past decade. This shows that the banks' risk-screening systematically ignored the inherent risks of running nuclear power plants, the specific technological risks of TEPCO's plants and the company's serious governance and management problems.



Standard & Poor's Ratings Services (S&P) maintained AA- to AAA (long-term, foreign-currency) issuer credit ratings for two decades before the Fukushima disaster. Even after the disaster, TEPCO was downgraded only in slow and small steps, e.g. only one notch down from AA- to A+ one week after the disaster, and then slowly down to below investment grade 50 days after the disaster. There was no downgrading even after such strong warning signs as the highly publicised management frauds and cover-ups during 2002. On the contrary, Moody's stated in its 2002 September rating that TEPCO's systematic falsification of maintenance records was "unlikely ... to exercise a significant negative and direct impact on TEPCO's credit profile"[8].

Financial analysts maintained a Buy or Overweight recommendation for TEPCO for years, including in the months leading up to the disaster. Barclays Capital's Equity Research Team included TEPCO among its global top picks for 2011 in its December, 2010 report[9]. TEPCO was the only top pick in their selection in the Power & Utilities sector for the whole Asia and Pacific region. Barclays saw +19% base-case potential from the actual share-price of 1,975 yen (target share price of 2,360 yen), the upside case expected +29%. The bank seemed to base its recommendations on TEPCO's dividend policy and expected a share-price of 1,860 yen by December 2011 in the worst-case scenario. One year later TEPCO's actual share price stood at 176 yen.

In its December 2010 Global Utilities Matrix, Morgan Stanley gave an Overweight recommendation[10] and set the target share price at 2,300 yen when the actual share price was 1,983 yen. In August 2010, Goldman Sachs[11] seemed to have underestimated the consequences of the long-term outages at TEPCO's Kashiwazaki-Kariwa plant and maintained its Buy recommendations with a 2,600 yen, 12-month share price recommendation. The actual share price dropped to 435 yen a year later.

2.2 Toxic money: bonds and loans to TEPCO

It was not only the equity research teams who had not seen what was coming to TEPCO, the world's then fourth largest utility, with 192 power stations, 65GW of capacity, 293TWh electricity in sales and 28 million customers. During the 10 years leading up to the Fukushima disaster, TEPCO sold approximately €44bn in bonds to commercial banks, secured €6bn in loans and €4bn in equity[12]. Beyond commercial banks TEPCO`s largest lenders included the Development Bank of Japan and such large insurance companies as Nippon Life and Dai-ichi Life. Based on the share of nuclear power plants within TEPCO's capital expenditures and operating costs, approximately a quarter of was spent on nuclear energy[13].

Of the 10 most important commercial banks involved in TEPCO's numerous bond issues since 2000, Citiunderwrote the largest amount. Mizuho Financial Group, Nomura Group, Sumitomo Mitsui Financial Group and Mitsubishi UFJ Financial Group followed it. The other top TEPCO bond pickers were BNP Paribas, Daiwa Securities Group, Merrill Lynch (part of Bank of America today), Morgan Stanley and Goldman Sachs. UBS and Credit Suisse were also significant.

LARGEST COMMERCIAL BANKS IN TEPCO`S BOND ISSUES 2000 - 2010

Top banks in TEPCO bond issues (2000 – 2010)	Number of bond issues bank participated	Total value under-written (in EUR)
Citi	16 bond issues	5.217 M
Mizuho Financial Group	21 bond issues	4.940 M
Nomura Group	22 bond issues	2.601 M
Sumitomo Mitsui Fin. Group	9 bond issues	2.421 M
Mitsubishi UFJ Fin. Group	21 bond issues	1.381 M
BNP Paribas	14 bond issues	860 M
Daiwa Securities Group	13 bond issues	695 M
Bank of America/Merrill Lynch	14 bond issues	576 M
Morgan Stanley	10 bond issues	502 M
Goldman Sachs	13 bond issues	468 M

Source: Jan Willem van Gelder and Anna van Ojik: Financing of TEPCO, Profundo, July, 2011

TEPCO secured nine bank loans between 2000 and the nuclear disaster[14]. Of the more than 60 banks Profundo researched, Sumitomo Mitsui Financial Group provided the largest amount of TEPCO's loans, BNP Paribas was second, while Mizuho Financial Group, Citi, Mitsubishi UFJ Financial Group, Intesa Sanpaolo, Crédit Agricole and Société Générale were also among the large corporate loan providers.

2.3 TEPCO's key shareholders

TEPCO has a highly fragmented ownership structure[15]. The two largest owners at the time of the disaster were insurance companies: Dai-ichi Life (3.4%) and Nippon Life (3.3%). Other major shareholders include the Tokyo Metropolitan Government, the TEPCO Employees Fund and Japanese and international banks.

Since the disaster, only the TEPCO Employees Fund increased its share significantly. About two thirds of the shareholders from the top 300 have reduced their positions, many selling 100% of their shares and suffering substantial losses. For example, AllianceBernstein (AXA Group) sold close to four million shares last autumn, probably losing billions of yen. In total, TEPCO has lost more than 90% of its market capitalisation, or 3,100bn yen (or $41bn) since the disaster[16].

3. Early warnings - what did analysts and investors miss?

Failures in reactor design, maintenance problems, inappropriate risk analysis, lack of preparedness for natural disasters, and inadequate counter-measures against these risks were largely due to management mistakes, weak governance and lax regulatory oversight. The Great East Japan Earthquake on 11 March 2011 cut the Fukushima Daiichi reactors off from the electricity grid and the tsunami disabled the plant's emergency diesel generators. Once the reactors had no power to run emergency cooling systems, the heat generated by the nuclear fuel started to build up and things spiralled out of control within just a few hours.

Hence, three main reasons for the disaster can be identified: design and technical issues; governance, management and regulatory weaknesses; and vulnerability to earthquakes and tsunamis. The following sections summarise some of the early warnings related to these main reasons. Among others, analysts, rating agencies and investors could have easily picked up on these warnings.

3.1 Warnings about the defective design

The reactor model used at Fukushima Daiichi, the General Electric Mark I boiling-water reactor (BWR), has been criticised for 40 years for exactly the kinds of vulnerabilities that became all too apparent during the disaster. The following are only a few examples of the well-known criticisms.

1972: Dr. Stephen Hanauer, an Atomic Energy Commission safety official, recommended that the pressure suppression system of the Mark 1 be discontinued and any further designs not be accepted for construction permits. Hanauer's supervisor, Joseph Hendrie — later a Chairman of the US Nuclear Regulatory Commission (NRC) — essentially agreed with Hanauer, but denied the recommendation on the grounds that it could end the nuclear power industry in the US[17].

1976: David Bridenbaugh and two of his nuclear engineer colleagues at General Electric publicly resigned their positions citing dangerous shortcomings in the GE design[18]. Thirty-five years before the Fukushima disaster, they acknowledged that the effects of a loss of coolant to the Mark 1 reactor core had not been fully taken into account. The result "could tear the containment apart and create an uncontrolled release".

1986: Harold Denton, who became famous for his role in managing the Three Mile Island nuclear crisis in 1979 and was NRC's top safety official in 1986, told a nuclear industry trade group that: "the Mark I containment, especially being smaller with lower design pressure, in spite of the suppression pool, if you look at the WASH 1400[19] safety study, you'll find something like a 90% probability of that containment failing."[20]

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1996: As a result of these warnings, modifications were made to the design. In 1996, nuclear engineer Paul Gunter[21] summarised the effect of these changes: "Reactor operators now have the option by direct action to expose the public and the environment to unknown amounts of harmful radiation in order to 'save containment'." This is exactly what happened 15 years later in Fukushima.

2005: A Greenpeace International report warned about the large amount of zirconium alloy in the reactor core, the risk of hydrogen explosions and the large amount of penetrations at the bottom, as well as the vulnerability of the containment: "In older BWR designs, such as the … US Mark 1 containment, core melt will almost inevitably lead to a rapid breach of containment, resulting in very high releases of radioactivity ... if an oxyhydrogen explosion also damages crucial components of the reactor's control and protection system and/or the containment envelope, a severe accident with catastrophic radioactive releases (comparable to those at the Chernobyl accident) will develop."[22]

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2010: The irradiated (or 'spent') fuel pools in GE Mark I reactors are above the reactor core and outside the primary containment system. This design was chosen for efficiency, not safety. The fuel rods in the reactor are lifted by crane and simply moved over to the fuel pool. The Union of Concerned Scientists highlighted the issue half a year before the Fukushima disaster, noting that the location of spent fuel pools in BWR Mark 1 and Mark 2 designs could 'couple' reactor and spent fuel accidents[23], much the way the disaster unfolded in Fukushima.

3.2 Governance risks and lax supervision

TEPCO's governance structure should have warned analysts and investors that even minimum internal controls did not work properly at the company. For example, 18 of TEPCO's 20 board directors were TEPCO managers and one of the two 'independents' was also a quasi-insider[24]. TEPCO has never appointed a chair of the board from outside. If the governance structure had not been a strong enough warning for regulators and investors, the series of TECPO's cover-ups and collusions in 2002 should definitely have been sufficient.

In August 2002, a highly publicised scandal emerged regarding the maintenance of TEPCO's reactor fleet. The company failed to report cracks in core shrouds, massive cylinders that contain the reactor fuel elements inside the reactor vessel. Some defects were repaired without authorisation or regulatory oversight, and CCTV recordings were manipulated to remove evidence of unauthorised repairs. TEPCO falsified inspection records and covered up defects in 13 of the company's 17 nuclear reactors.[25] The discovery of the cracks dated as far back as 1993, meaning that the cover-up lasted for almost a decade. Japan's Nuclear and Industrial Safety Agency (NISA), the Japanese nuclear regulator, did not carry out any of its own inspections of the reactor cores; instead it trusted the company with the inspections. As it turns out, employees had been falsifying inspection records since the 1980s. Even after the cover-up was revealed, the regulator waved away concerns about increased accident risk based on calculations supplied by TEPCO. In response to TEPCO's deception, NISA adopted a special 'defect standard' to allow the company's reactors to continue operating.[26]

That was not all for 2002. Later that year, TEPCO was found to have falsified test data on the air-tightness of the reactor containment of Fukushima Daiichi Unit-1. Preliminary tests had shown that the sealing system was inadequate[27]. On 20 September, other cover-ups of damage in the re-circulation pipe system were revealed in TEPCO's eight nuclear reactors, as well as at the Onagawa Unit-1 of the Tohoku Electric Power Company and at the Hamaoka Unit-1 of the Chubu Electric Power Company. In addition, cracks in the core shroud were also found at Onagawa Unit-1, Hamaoka Unit-4, Tsuruga Unit-1 (Japan Atomic Power Co., Ltd), and at Shimane Unit-1[28]. This series of cover-ups showed the scandal was not merely a TEPCO problem but involved most of Japan's electricity utilities. Four years later, in 2006, TEPCO admitted to falsifying records on coolant water temperatures between 1985 and 1988[29].

The underestimation of earthquake risks by TEPCO became apparent in 2007, when a strong earthquake hit TEPCO's Kashiwazaki-Kariwa nuclear plant. Ground acceleration was more than double the value the plant was designed to withstand without damage, and 50% higher than the plant was required to cope with without releasing radioactivity. The earthquake triggered a fire and a spill of radioactive liquid at the plant. TEPCO at first concealed the extent of the damage, such as the leakage of hundreds of gallons of radioactive wastewater[30]. TEPCO wanted to restart the reactor fast, but was not allowed to do so[31]. Luckily, conservative design margins prevented a large-scale accident even if design specifications were inadequate. TEPCO identified 63 separate cases of damage or leaks, including burst pipes, waste spillage and radiation monitor blackouts[32]. The first reactor was only restarted in May 2009, followed by three more units during 2009 and 2010, but three units have not yet been restarted.

Regulatory records show that prior to the Fukushima disaster, TEPCO was cited for more dangerous operator errors over the previous five years than any other utility[33]. According to assessments carried out after the 2002 scandals, it has become clear that TEPCO's managers tended to put cost savings ahead of safety. Despite the mediocre performance, there was little regulatory action to improve the situation.[34] But banks and rating agencies also treated such scandals as mere political episodes, and increased risks were not considered. TEPCO's own technical assessments were taken at face value.[35]

These major frauds, governance and management mistakes were aggravated by systemic problems in the Japanese nuclear regulatory and public supervisory system. The following quotes from the head of the government's nuclear safety organisation and from the prime minister at the time of the disaster make clear that analysts and credit rating agencies missed not only the above mentioned major frauds and management mistakes at TEPCO, but also the inherent institutional flaws and low safety standards in the country with the world's third largest nuclear power sector. Investor recommendations and rating opinions should have reflected these for all Japanese nuclear utilities and nuclear technology companies.

In a parliamentary investigation in mid-February 2012, Haruki Madarame, the chief of the Cabinet Office's Nuclear Safety Commission, acknowledged and apologised for the flaws in the government's safety regulations and the inappropriate counter-measures after the tsunami. He also described the institutional set-up that left major flaws uncorrected: "While other countries considered [stricter nuclear safety standards], Japan made excuses to avoid them. A system was created in which decision-making was difficult and change was avoided. I think this attitude is at the root of various problems."[36]

The Prime Minister of Japan during the disaster, Naoto Kan, acknowledged in a February 2012 interview how important institutional mistakes were in the disaster: "Before 3/11, we were totally unprepared. Not only in terms of the hardware, but our system and the organisation were not prepared. That was the biggest problem … We should have taken more adequate safety steps, and we failed to do so. It was a big mistake and I must admit that [the accident] was due to human error."[37] He also added: "I came to think that the safest way is to build a society that does not have to depend on nuclear power plants, and that this is possible … Japan can strengthen its energy supply system outside of nuclear and fossil fuel while moving forward with energy conservation ... It is possible for Japan to become the model of a society that does not rely on nuclear power."[38]

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3.3 Earthquake and tsunami warnings

Since 1990, Tohoku Electric Power Co, Tohoku University and the National Institute of Advanced Industrial Science and Technology have researched the traces left by the 10th century Jogan Earthquake[39], which hit the area that is now the Fukushima and Miyagi prefectures[40]. Their studies have shown that the ancient tsunami was on the same scale as the one on 11 March 2011. Before the disaster, scholars had repeatedly warned that a massive tsunami could hit the Tohoku region in the future. However, TEPCO played down and ignored these reports.

On the heels of the 2004 Sumatra earthquake and tsunami (one of the deadliest natural disasters ever recorded), TEPCO launched a study into tsunami risks. The TEPCO team presented its findings in 2007, putting the probability of a tsunami of six metres or more at 10% over a 50-year period, and identified the Fukushima reactors as particular concerns.[41] The company's management ignored the analysis. The Japan Nuclear Energy Safety Organisation (JNES) predicted the possible damage tsunamis could cause to Mark 1 nuclear reactors that are about the same size as the Nos. 2 and 3 reactors at the Fukushima plant. The *Daily Yomiuri* quotes several relevant JNES reports[42]. One report said if a breakwater that extended up to 13 metres above sea level was hit by a 15-metre-high tsunami, all power sources would be knocked out, including outside electricity and emergency power generators. In such a situation, the report said, cooling functions would be lost and the reactor's core would be 100% damaged – a meltdown, in other words. The breakwater at the Fukushima No. 1 plant was 5.5 metres high, the tsunami may have reached 21 metres on 11 March 2011[43]. Another quoted report predicted that if all power sources were lost due to an earthquake, fuel rods would begin melting after only 100 minutes; the reactor containment vessel would be damaged after about seven hours, and a large amount of radioactive material would be released into the air. This is very close to what actually happened at the No. 1 unit of the Fukushima plant[44].

4. Are these risks unique or widespread among nuclear utilities?

The main problems leading up to the nuclear disaster at Fukushima are by far not unique to TEPCO or to the Japanese context. Failures in reactor design and other technical problems, human error, serious governance issues, institutional failures of political influence and industry-led regulation, as well as vulnerability to natural disasters, are widespread and affect the world's existing and planned nuclear plants. The following sections discuss these issues and highlight some signals to analysts and investors to watch out for when considering nuclear investments.

4.1 Widespread old and new design problems

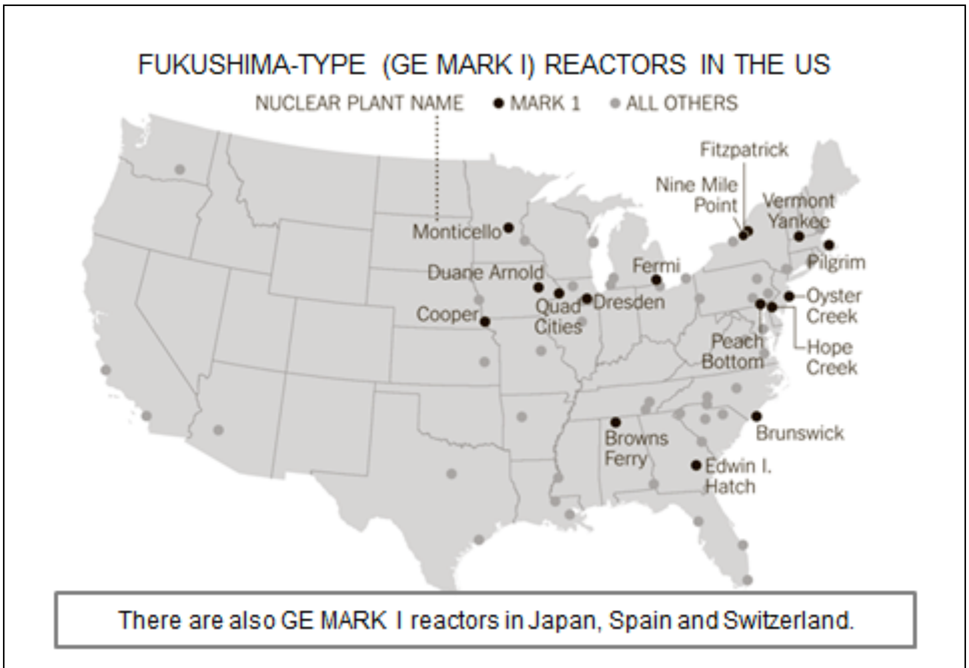
Design and technical problems are not specific to the Fukushima reactors. They are widespread among both old and new reactor designs.

Outdated designs

The 'Fukushima reactor design', General Electric's BWR Mark I, is in use in 23 US nuclear reactors, but also in a few plants in Japan and Spain. Switzerland's Mühleberg also has a Mark I reactor, which has primary and secondary containment. Two GE reactors with a similar, earlier design are also in operation in India (Tarapur 1&2).[45] These reactors share with the Fukushima reactors the vulnerable containment-building design and the location of the spent fuel pool above the reactor and outside the containment.

An important lesson from Fukushima is the inherent vulnerability of BWRs to the loss of power supply over long periods even after the reactors are stopped. You do not need a 9.0 earthquake and tsunami for a similar disaster. In 2006, at the Swedish Forsmark nuclear plant (a BWR with a different design) a short circuit caused a near-catastrophic situation by temporarily stopping all cooling systems.[46] In the US, 14 serious 'near-misses' happened in 2010[47] alone.

Some reactor models suffer from additional safety issues. Eleven 'Chernobyl-type' RBMK reactors[48] are in operation in Russia. Twelve VVER440 reactors are also operating within the EU; these plants have no secondary containment, making them more vulnerable to reactor accidents and terrorist attacks.



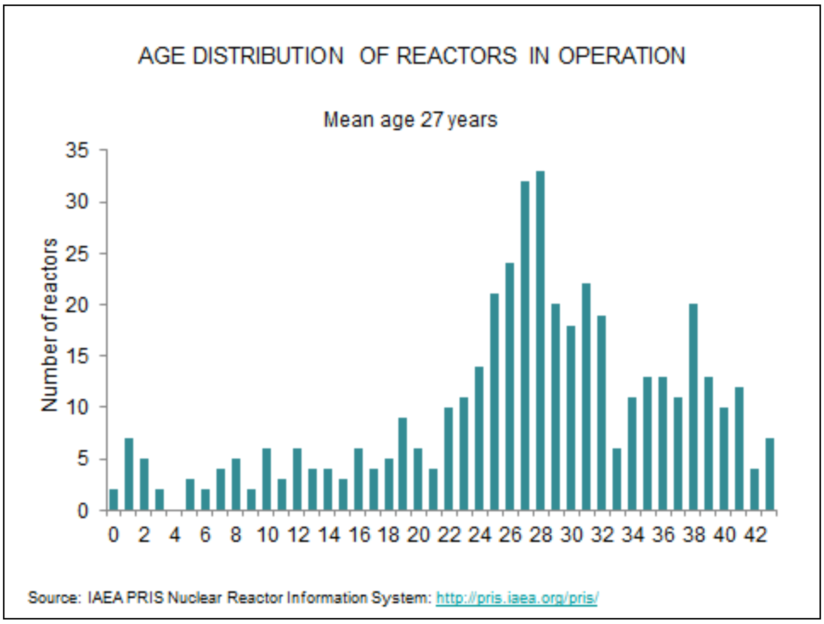
Source: Tom Zeller Jr.: Experts had long criticized potential weakness in design of stricken reactor, The New York Times, 15 March, 2011: http://www.nytimes.com/2011/03/16/world/asia/16contain.html?_r=1

The Canadian reactor design, the CANDU reactor, suffers from a positive void coefficient[49] (a characteristic that proved fatal at Chernobyl) and its uranium-containing pressure tubes can degrade rapidly. Rules in Germany and France would not allow the design of the existing CANDU reactors (operating, for example, in Romania). To avoid disaster, expensive repair programs have had to be undertaken, in some cases after only 20 years of operation.[50] CANDUs are in use in Canada (17), South Korea (4), China (2) India (2 Canadian designs and 13 Indian derivatives), Argentina (1), Romania (2) and Pakistan (1).

These substantial design risks do not seem to have been taken seriously in the financial valuation of the nuclear utilities operating these plants.

Ageing reactors[51]

Of the 436 nuclear reactors currently in operation worldwide, 121 were commissioned before the Three Mile Island accident (1979) and 289 before the Chernobyl accident (1986)[52]. Therefore, 410 nuclear reactors do not incorporate the lessons from these catastrophes. Older reactors (over 30 years) have higher risks not only because of this, but also due to the fatigue that steel and welding seams experience under constant neutron bombardment. The average age of reactors in operation is 27 years, and 160 operating reactors are already older than 30 years.



The impacts of ageing processes are difficult to detect because impacts usually occur on the microscopic level of the inner structure of materials. Impacts frequently become apparent only after a component failure, for example when pipe breakages have occurred. The most notable ageing effect is the embrittlement of a reactor pressure vessel, which increases the risk of the vessel bursting. Failure of the pressure vessel of a Pressurised Water Reactor (PWR) or a Boiling Water Reactor (BWR) constitutes an accident for which there are no safety systems – inevitably leading to a release of radioactive material to the environment.

The high temperature and pressure of cooling water in Pressurised Water Reactors can accelerate the corrosion of components. Also, steam generators frequently have to be replaced. In the early 1990s, cracks began to appear in the vessel heads of some reactors in France. Worldwide investigations were carried out and similar problems were found in reactors in Sweden, Switzerland and the US. The most serious example of cracks in a vessel head discovered to date occurred at the Davis Besse reactor in Ohio, US, where in March 2002 maintenance workers discovered a football-sized hole in the reactor vessel head and even the replacement developed cracks[53]. Significant corrosion problems have also been observed in many Boiling Water Reactors, for example in the early 90s, a vast amount of cracking was detected in a number of German BWRs[54].

Before Fukushima analysts and investors did not take such significant problems seriously. The Davis Besse plant was closed down for two years and its owner, FirstEnergy Corporation, was heavily fined, yet still the operator's share-price was hardly affected. It actually outperformed the Dow Jones Industrial Average in 2002, and the share price more than doubled in the following six years[55].

Problems with new reactor designs

During the past year, financial analysts started to express worries about how new nuclear reactor designs would be affected by the vulnerabilities exposed by the Fukushima accident. For example, HSBC experts said that: "New designs are therefore apparently 'fail safe' compared to the manual intervention required at Fukushima. Nevertheless, the current new generation of nuclear reactors (eg Areva's EPR technology) already have apparent safety concerns, which will only be magnified by Fukushima."[56] According to UBS, the Swiss financial services group, "most designs would have struggled to survive the Japanese tsunami"[57].

The rest of this section focuses on examples of the Generation III+ European Pressurised Reactor (EPR) model in a Fukushima-like situation, but similar conclusions can be drawn about other widespread new models as well. The EPR's architects failed to design against a sustained loss of power to the cooling systems. In addition to the primary emergency diesel generators, the EPR has two secondary diesel generators, but they are insufficient to power many of the systems needed to keep the reactor under control. The entire design is built on the assumption that either grid power or primary diesel generators can be restored within 24 hours.[58] The blackout in Fukushima lasted for 11 days.

Box 1: What would happen to an EPR design in a situation similar to the one causing the Fukushima disaster?

If faced with a situation similar to Fukushima, the operators of an EPR would have:

- no ability to cool water in reactor below 100°C and achieve stable shutdown;
- no power to pump water into reactor, this would be critical if the primary cooling system starts leaking or the water level drops because of lack of cooling;
- no operable boron injection system (boron is needed to keep the nuclear chain reaction from restarting); and
- no hydrogen recombiners or igniters in fuel building to prevent explosions.

Even if designers had thought of everything to prepare their reactors for Fukushima-like situations, the long and complex construction process can contribute to new problems, and new reactor designs are proving much harder and more expensive to build than was anticipated. Arthur D Little, the leading international management consultancy, has identified several recurring issues during construction based on detailed assessments of past and new nuclear ventures and in-depth discussions with experts within the nuclear supply chain[59]. Many of these issues signal governance and management problems analysts and investors should be aware of. These include:

- "start of construction before design completion";
- "insufficient incorporation of regulatory requirements into design, and lack of reliability of licensing process";
- "insufficient schedule integration and communication between suppliers and owner";
- "lack of strategic and operational planning by the owner";
- "insufficient control and progression of the new build project"; and
- "hesitant implementation of counter-measures for identified risks and constraints".

For example, widespread problems have been documented in the construction of both of the first EPR plants being built, Olkiluoto 3 in Finland and Flamanville 3 in France. Areva-led consortiums are constructing both of these plants[60]. These shortcomings[61,62,63] include: concrete quality; substandard quality of welding work; and skipping mandatory quality controls and tests. In both Olkiluoto and Flamanville, the testimony of workers of deliberate cover-ups of structural defects has been recorded[64]. Their testimony shows that subcontractors were given orders to cover defective structures in concrete or to accept quality control reports that show non-conformance with quality standards. A leaked inspection report exposes similar oversights by the same companies at the Taishan nuclear construction site in China.[65]

The nuclear safety, technical and construction issues with new plants still seem to be underestimated by analysts and credit rating agencies, even in cases where they have substantially negative cash flow implications. In the case of the two new EPR plants in Europe, analysts seem more worried about Areva than the utilities and other investors owning these new plants. For example, Fitch Ratings sees no problem for TVO (the operator of Olkiluoto 3) in its reports[66] despite the five-year delay in construction and the massive cost overruns: the plant will cost at least €6.6bn instead of the originally planned €3bn[67]. This may change: TVO has a turnkey contract with Areva, but Areva has already taken TVO and other investors to court with a claim for €1.9bn.

4.2 Failing governance structures and weak regulators

Most countries operating or building nuclear plants lack a truly independent, properly resourced nuclear regulator. Even though the international Convention on Nuclear Safety requires that national nuclear regulators be separate from bodies tasked with the promotion of nuclear power, there is no effective international mechanism for even monitoring compliance, let alone enforcing the rules. This is evidenced by the fact that the international community was unable to identify and rein in the collusion between the Japanese nuclear industry and its regulator. Outside of Japan, Brazil, India and South Africa came under the spotlight at the 2008 Convention on Nuclear Safety review conference because their regulatory bodies were considered too close to organisations that promote nuclear energy[68].

Recent European developments show how frequently the 'revolving doors' operate between so-called 'independent' regulators and regulated companies. In Finland, Jukka Laaksonen, the Director General of the country's regulator (STUK) was negotiating for a position at Rosatom,[69] the state Atomic Energy Corporation in Russia, while still overseeing Rosatom's Finnish activities. Under the 'regulatory eye' of STUK, Rosatom built the Loviisa nuclear power plant in Finland, has supplied it with fuel since the reactor started up, and has also been involved in tenders for new builds. In Belgium, the Head of the Belgian regulator (FANC[70]) is – for the second time – the former general site manager of the Doel nuclear power station, located about 30km from Antwerp, Belgium.[71] In Hungary, the nuclear regulator (OAH), which actively promotes nuclear energy[72], has three positions in the industry's lobby organisation, Hungarian Nuclear Society.

In South Africa, the National Nuclear Regulator (NNR) has also been part of the revolving door syndrome[73] by appointing as its CEO an official of the Pebble Bed Modular Reactor Company[74]. In its own Annual Reports,[75] the NNR has reported difficulty attracting and retaining appropriately skilled and experienced personnel to carry out its mandate, and is so underfunded that it relies on licensing fees from the nuclear industry to make up its income. As a result, the NNR can never be fully independent as it favours the expansion of nuclear facilities in order to grow its own capacity, rather than being neutral on expansion.[76]

A June 2011 Associated Press report, based on a year-long investigation, revealed numerous examples of collusion between the 'independent' regulators and nuclear operators in the US[77]: "Federal regulators have been working closely with the US nuclear power industry to keep the nation's ageing reactors operating within safety standards by repeatedly weakening those standards, or simply failing to enforce them. Time after time, officials at the US Nuclear Regulatory Commission (NRC) have decided that original regulations were too strict, arguing that safety margins could be eased without peril, according to records and interviews. Examples abound. When valves leaked, more leakage was allowed – up to 20 times the original limit. When rampant cracking caused radioactive leaks from steam generator tubing, an easier test of the tubes was devised, so plants could meet standards. Failed cables, busted seals, broken nozzles, clogged screens, cracked concrete, dented containers, corroded metals and rusty underground pipes — all of these and thousands of other problems linked to ageing were uncovered. All of them could escalate dangers in the event of an accident. Yet despite the many problems linked to ageing, not a single official body in government or industry has studied the overall frequency and potential impact on safety of such breakdowns in recent years, even as the NRC has extended the licences of dozens of reactors."

A report[78] published by Congressman E J Markey found that a range of US reactor operators have an alarming track record in ensuring proper operation of their emergency diesels: "There have been recurrent and prolonged malfunctions of emergency diesel generators at nuclear power plants in the US. In the past eight years there have been at least 69 reports of emergency diesel generator inoperability at 33 nuclear power plants ...There never have been any requirements in the US for spent fuel pools to include technologies to prevent the same kind of hydrogen explosions that reportedly occurred at spent nuclear fuel pools in Fukushima. Alarmingly, NRC's regulations do not require emergency diesel generators to be operational at times when there is no fuel in the reactor core, even though this could leave spent nuclear fuel pools without any backup cooling systems in the event of a loss of external electricity to the power plant."

Similar issues also exist in several European countries. For example, Greenpeace Czech Republic has documented a case in which the Czech nuclear regulator has been engaged for more than 15 years in a cover-up of faulty welding work in a crucial part of the Temelin nuclear plant[79]. In India, a former chairman of the nuclear regulator has highlighted the effects of the lack of regulatory independence: "This dependency is deliberately exploited by the [Department of Energy] to influence, directly and indirectly, the [nuclear regulator's] safety evaluations and decisions. The interference has manifested itself in the AERB toning down the seriousness of safety concerns, agreeing to the postponement of essential repairs to suit the DAE's time schedules, and allowing continued operation of installations when public safety considerations would warrant their immediate shutdown and repair."[80]

4.3 Reactors in seismic and other natural disaster risk areas

A total of 107 nuclear reactors are operating or are under construction on moderate to high seismic activity areas as designated by a Global Seismic Hazard Program study published in 1999 by the US Geological Survey (USGS) and the Swiss Seismological Service. The most affected countries are Japan, China mainland and Taiwan, France and the US. Thirty-seven of these operating or under-construction reactors are on 'high' seismicity areas. An additional 15 units are planned on moderate, elevated or high seismic activity areas in Armenia, Bulgaria, Canada, China, Iran, Japan and Romania.[81] The following table shows the number of nuclear reactors by reactor status in high, elevated and moderate seismic risk areas. As an additional risk factor to be considered, around a third of these 148 reactors are within one kilometre of the closest coast.

NUCLEAR REACTORS IN SEISMIC RISK AREAS

Reactor status	High seismic risk	Elevated seismic risk	Moderate seismic risk	Total
Operating	34	27	31	92
Planned	1	6	8	15
Shut down	6	3	17	26
Under construction	3	3	9	15
Total	44	39	65	148

Source: Wall Street Journal March 19, 2011: Scores of Reactors in Quake Zones. http://on.wsj.com/e4OSRA

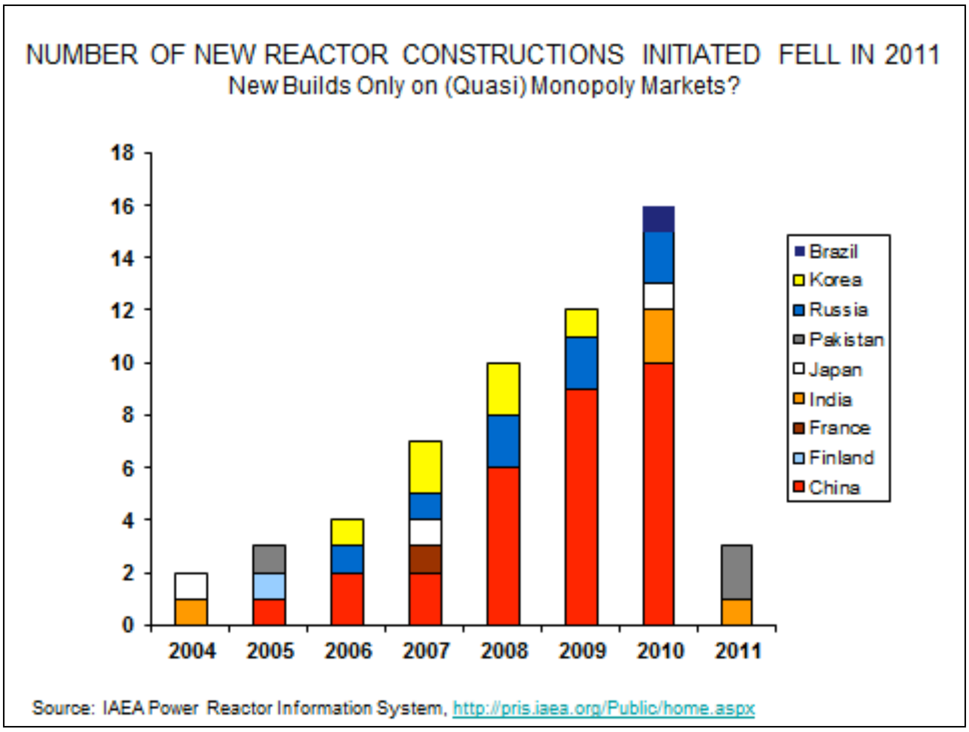
According to the US Nuclear Regulatory Commission, 67 reactors out of the 104 in the US face a 1-in-100,000 years or higher risk of an earthquake causing core damage, with Indian Point, 38 miles north of New York City, topping the list at a 1-in-10,000 years probability.[82] Most of these 67 reactors are not even found in moderate-to-high seismic zones as identified by the USGS — showing that reactors located on areas with 'low' seismic activity can also face a material earthquake risk.[83]

5. Impacts on nuclear investments

5.1 New builds

In 2011, construction was only initiated on three new reactors, while 16 new reactors were started in 2010. Nuclear power plants also increasingly symbolised monopolies and taxpayer-financed subsidies. During the decade before Fukushima, nearly all new builds were initiated in countries with monopolistic market structures; the only exception being Finland, but even there the Olkiluoto-3 plant was practically taken out of the market with a long-term power purchase agreement (PPA) and government loan guarantees. This increased dependence on taxpayer financing is also becoming less and less sustainable with the European sovereign debt crisis and the increasing indebtedness of governments all around the world.

The capital costs of new nuclear power plants were prohibitive for utilities in competitive electricity markets because of the usual cost overruns and very long building periods for many years before Fukushima. After Fukushima, capital costs are expected to increase further, and construction periods could become even longer. Financing costs may also increase as shown by Fitch Ratings' recent downgrading of Santee Cooper[84] from AA to AA-[85], partly because of its planned new reactor.



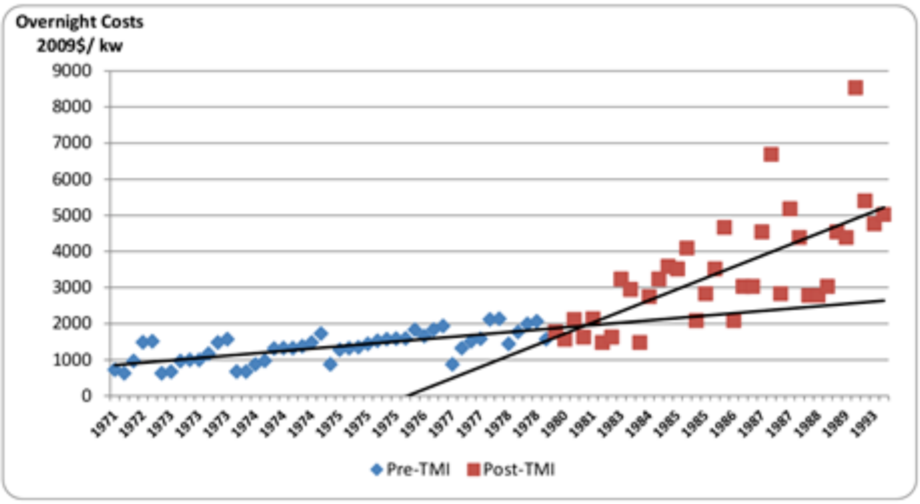
Investors are starting to understand that nuclear technology companies, nuclear plant operators and regulators have systematically downplayed risks. The most widely used industry risk models for reactor accidents are PSAs (probabilistic safety assessments[86]), which typically show the probability of core damage in the range of 1:10,000 to 1:100,000[87,88]. Actual event frequency shows much higher probabilities. Since the beginnings of commercial nuclear plants, five meltdowns have happened (one reactor at Three Mile Island, one in Chernobyl and three reactors at the Fukushima Daiichi plant). Independent nuclear expert Dr Gordon Thompson has estimated that, based upon these five meltdowns, the probability of significant accidents is in fact one core-melt for every 2,900 years of reactor operation.[89] On average, there has been a core meltdown once every 10 years since the beginning of nuclear power generation, assuming an average of 300 operating reactors.

5.2 Existing plants

The Fukushima disaster seems to have speeded up the decade-long slow decline in the number of operating nuclear reactors following the 2002 peak. Germany and Switzerland have decided to phase out their nuclear plants; Belgium confirmed its 2003 nuclear phase-out law at the end of 2011, and Italy confirmed its non-nuclear stance by a 94% majority in a referendum. The probability of early plant closures and shortened lifespans has increased substantially in Japan (where all of the country's 54 reactors are currently offline) and in other countries. In addition, unprecedented discussions about the future of nuclear power have begun in France, where the leader of the opposition party has announced that he would reduce the share of nuclear in the electricity supply if he wins the national election in May 2012.

Nuclear plant economics have deteriorated since both the Three Mile Island and Chernobyl disasters. As the following analysis shows, after the 1979 partial meltdown at Three Mile Island US nuclear plant costs increased substantially overnight and ultimately led to an effective stop to new plant construction.

THE THREE MILE ISLAND ACCIDENT HAS HAD A LARGE IMPACT ON THE COSTS OF THE U.S. NUCLEAR PLANTS



Source: Mark Cooper, Vermont Law School: Nuclear safety and nuclear economics; December 2011

We may expect an even larger impact on economics in this decade. A significant difference from the situation after Three Mile Island in 1979 and Chernobyl in 1986 is that currently nuclear power plants are facing increasing pressure from renewable energy plants that are pushing down the utilisation rates of both nuclear and non-nuclear baseload power plants. Also, governments in key nuclear markets are highly indebted and are not in a position to maintain and justify the high level of direct and indirect subsidies for the nuclear sector of before.

The ongoing discussions between French electricity producer EDF (the largest nuclear electric utility in the world), ASN (the French nuclear regulator) and the Cour des comptes (the French Audit Office) give a flavour of the level of additional costs nuclear operators may expect:

- EDF estimates that new safety improvements ASN requires at French reactors[90] would cost €10bn, or €170m per operating block[91]. ASN has already said that the number is closer to €15bn[92].
- EDF estimates the total costs for life extensions of its reactors at between €680m and €860m per reactor[93], or up to €50bn in total. EDF has 22 reactors reaching their 40th year before 2020.
- The Cour des comptes[94] estimates that decommissioning of the 58 French nuclear power plants will cost €18bn (€320m/power plant) and asks EDF to review its calculation methods. Interestingly, EDF expects that the immediate closure of the Fessenheim plant would cost 5.7 times more per MW (€3bn up to 2040[95]). EDF also has had some sobering experience with dismantling the 70MW Brennilis reactor, where decommissioning costs have been 20 times more than expected.[96]

The Cour des comptes also believes[97] that the amounts dedicated for spent fuel and waste management will be higher than expected, and will reach €28bn – if a solution is found at all. The profitability of existing plants is also expected to deteriorate due to increasing maintenance costs, higher training needs for personnel, higher insurance costs, stronger emergency planning/preparedness regimes and stricter liability schemes, to name but a few factors.

Some of these new realities are starting to be reflected in the share price of major nuclear utilities. The share price of Japanese utilities followed TEPCO down, with 30-40% share price reductions during 2011[98]. France's Areva[99] has lost 44% and EDF[100] 42%, while the Swiss BKW[101] lost 52%. The more diversified RWE[102] and E.ON[103,104] have had to face 39% and 27% share price drops respectively so far. All this is happening during a period when all major market indices have risen.

6. Top three takeaways for financial analysts and investors

Nuclear power plants are potentially toxic assets for any investor. Quite uniquely, they can give rise to liabilities that exceed their equity by more than a hundred-fold. TEPCO, the fourth largest utility in the world before March 2011, has already lost 90% of its market capitalisation[105], was downgraded to junk and would have gone bankrupt without government help. And the full scale of the financial consequences for TEPCO is not even known. The total consequences will be hundreds of billions of dollars (eg compensation, legal charges, clean-up costs, higher fuel costs, burdens of pre-scheduled close-downs and decommissioning). TEPCO is on the edge of formal nationalisation and is being forced to sell some of its thermal power plants[106] probably at depressed prices.

Understanding risks and early warnings related to nuclear utilities becomes even more important. Beyond understanding the consequences of the collapsing illusion of 'nuclear safety', analysts and investors should also closely monitor the specific technological, governance, disaster and other vulnerabilities of individual nuclear operators. Changes in the nuclear sector have become much faster in 2012, and make frequent nuclear utility cover-ups and lack of independent regulatory oversight even more detrimental to investors. Analysts and investors may diversify information sources further and urge governments to ensure the independence of regulators and higher transparency of relevant risk information.

The economics of nuclear energy is worsening fast. The already weak economics of nuclear power will further decline due to:

- Stricter safety, emergency, liability, decommissioning and regulatory requirements, and higher related costs;
- Phase-out decisions, earlier shutdowns and more difficult life-expansions;
- Strong competition from renewable energy, the fall of the 'baseload' concept and lower nuclear utilisation rates; and
- Declining subsidies and other support from indebted governments.

New-build costs are already prohibitive; now even the profitability of such earlier cash-cows as fully depreciated, extended-lifespan plants is coming under pressure. Substantial impacts are also expected on nuclear technology companies. In the coming decades back-end and decommissioning seems to offer better options than earlier parts of the nuclear value chain.

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