Introduction

The draft Energy Bill that Minister Ségolène Royal presented to the French Council of Ministers on 18 June 2014 contains an article that stipulates: "If a basic nuclear facility ceases to operate for a period of over two years, its outage is considered final (…)".[15] If this criterion were to apply today in Japan then all but four nuclear reactors would be considered shut down for good. The implications would be substantial, including the requirement for full-scale new licensing procedures prior to any restart authorization request.

The world's nuclear statistics are seriously distorted by an anomaly whose cause is not technical but political. Three years after the Fukushima events started unfolding on 11 March 2011, all of the government, industry and international institutional organizations—whether the Japanese or any other government, the Japan Atomic Industrial Forum (JAIF), the international industry's representation World Nuclear Association (WNA) or the International Atomic Energy Agency (IAEA)—continue, without exception, to misrepresent the real and very concrete effects of the disaster on the Japanese nuclear program. In every single statistical document on the issue, with the exception of the six units at Fukushima Daiichi, the entire Japanese reactor fleet of 48 units is considered "in operation" or "operational".

The IAEA in its online Power Reactor Information System (PRIS) classifies 48 Japanese reactors as "in operation"—11 percent of what the IAEA considers the world nuclear fleet—despite the fact that none of them have generated power since September 2013, only two produced electricity in 2013 and just ten in 2012. In other words, 38 units, four fifths of Japan's fleet, have not "operated" in at least two and a half years. The *average* outage of these Japanese "operational" units is over three years, as this report documents. In fact, three units at the Kashiwazaki-kariwa site have not generated power for the past *seven* years, since a large earthquake stopped all seven of operator TEPCO's units at that site in July 2007. When the 3/11 events hit Fukushima, TEPCO was still in post-earthquake recovery in Niigata Prefecture on the other side of Honshu Island.

To find a more appropriate way to deal with this situation, the *World Nuclear Industry Status Report 2014* inaugurates a new category called Long-Term Outage (LTO). The definition is simple and purely empirical: A nuclear power reactor is considered to be in LTO, if it has not generated any power in the entire previous calendar year and in the six months of the current calendar year. This classification decision leads to some significant retroactive adjustments in nuclear statistics, as many reactors—mainly in Japan but also one in South Korea and one in India—have generated no power for several years.

Taking into account reactors in LTO, the number of operational reactors in the world drops by 39 (9 percent) from 427 in July 2013 to 388 in July 2014, and brings the world nuclear statistics into closer alignment with reality.

WNISR considers that none of the 10 Fukushima reactors will ever restart and therefore categorizes them as shut down. The two reactors at Ohi in Kansai Prefecture, which produced power in 2013, would be deemed as operational, but all other 42 units are in the LTO category. This edition's Japan Focus contains a thorough analysis of the status of the reactors and their specific situation as to potential restart. The current national government is keen to restart as many reactors as possible, but most of the public and many Prefectural Governors and municipalities (whose consent is required) are not; a recent judicial decision reflects public unease; and such a fundamental conflict, entangled with other political issues, is without clear precedent in recent Japanese history, which therefore offers little guidance.

This edition contains more changes and innovations. Beyond the entirely restructured Economics of Nuclear Power chapter, we have added a section on system issues to the updated Nuclear vs. Renewables chapter. We have also started to rebuild our own database, reactor-by-reactor, and adapted some a-posteriori adjustments to the statistics. The integration of revised data from other international data sources remains a difficult challenge.

Considering the significance of the Japanese nuclear program in this edition, the WNISR team is particularly grateful to Tatsujiro Suzuki, former Vice-Chairman of the Japan Atomic Energy Commission (JAEC), to having kindly contributed the Foreword.

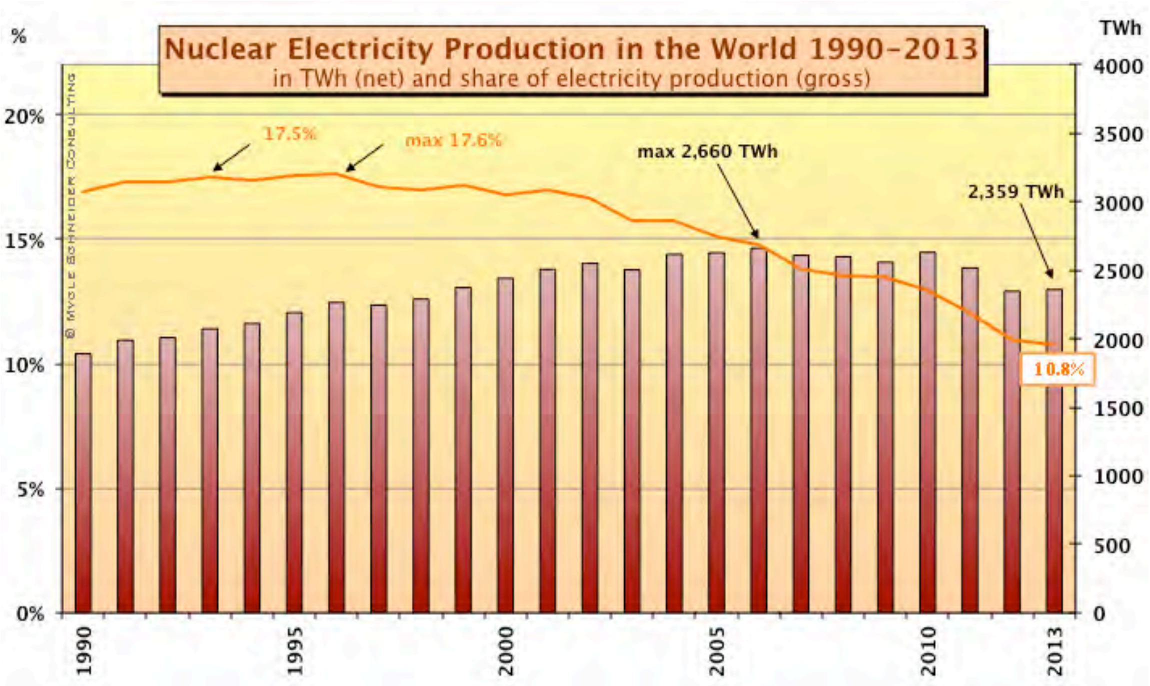
[15] Ministère de l'écologie, du développement durable et de l'énergie, "Projet de loi de programmation pour la transition énergétique", présenté en Conseil des Ministres, 18 June 2014; see *Art.* L. 593-24. The French original reads: "Si une installation nucléaire de base cesse de fonctionner pendant une durée continue supérieure à deux ans, son arrêt est réputé définitif (…)."

General Overview Worldwide

> *Extreme weather events pose a major threat to all power plants but particularly to nuclear plants, where they could disrupt the functioning of critical equipment and processes that are indispensable to safe operation including reactor vessels, cooling equipment, control instruments and back-up generators.*
>
> World Energy Council
> June 2014[16]

As of the middle of 2014, 31 countries were operating nuclear fission reactors for energy purposes. Nuclear power plants generated 2,359 net terawatt-hours (TWh or billion kilowatt-hours) of electricity in 2013[17], a minor increase (+0.5 percent) after two years of significant decline, but still less than in 1999 and 11.3 percent below the historic peak nuclear generation in 2006. (See Figure 1.)

Figure 1: Nuclear Electricity Generation in the World



Source : IAEA-PRIS, BP, MSC, 2014

Nuclear energy's share of global commercial electricity generation also remained almost stable (–0.2 percent) in 2013 compared to the previous year, but declined from a peak of 17.6 percent in 1996 to 10.8 percent (see note[18]).

---

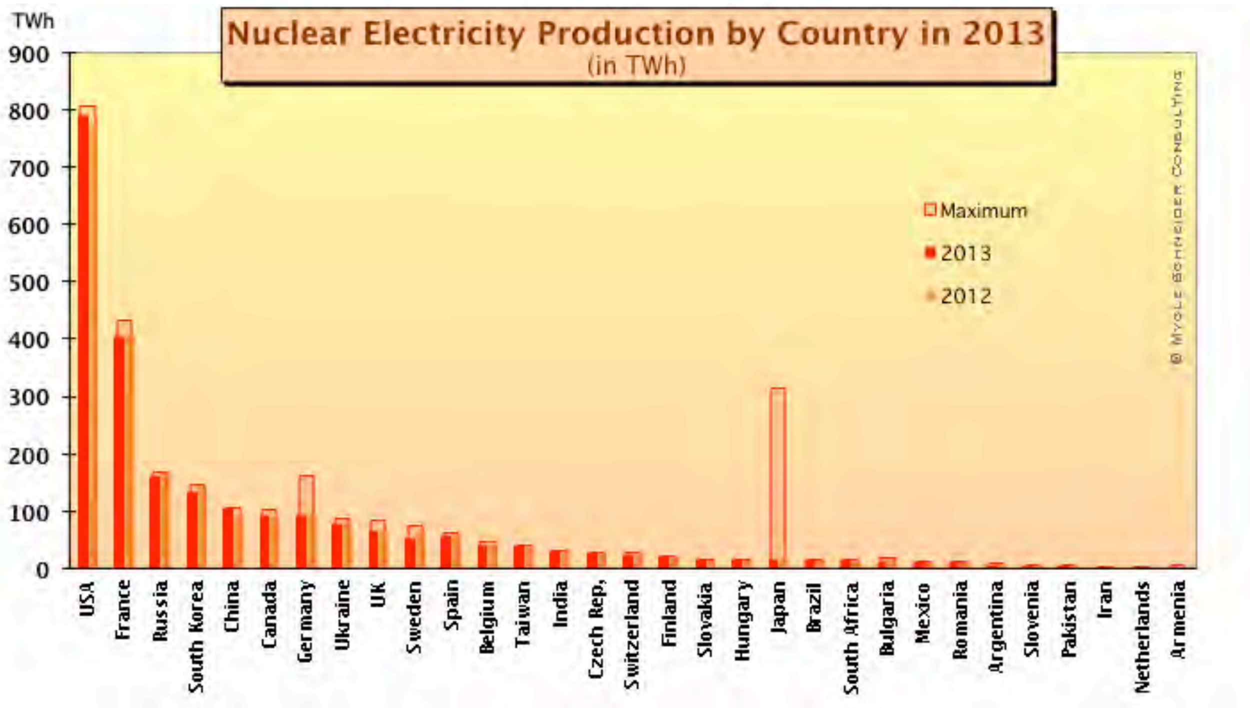
[16] World Energy Council, "Climate Change: Implications for the Energy Sector", University of Cambridge, June 2014, see http://www.worldenergy.org/wp-content/uploads/2014/06/Climate-Change-Implications-for-the-Energy-Sector-Summary-from-IPCC-AR5-2014-Full-report.pdf, accessed 11 July 2014.

[17] If not otherwise noted, all nuclear capacity and electricity generation figures based on International Atomic Energy Agency (IAEA), Power Reactor Information System (PRIS) online database, see www.iaea.org/programmes/a2/index.html. Production figures are net of the plant's own consumption if not otherwise noted.

[18] With the WNISR2014, we have decided to modify the calculation basis for the nuclear share. In previous years, we have used the IAEA's nuclear generation figures and the BP's world electricity generation figures in order to calculate the nuclear share. The main reason for that choice was that we use the IAEA nuclear generation figures throughout the report and intended to provide homogeneous figures. However, the IAEA figures are net of auto-consumption, while the BP figures are gross. Therefore we consider it is more consistent to derive the *share* of nuclear generation (gross) entirely from the BP statistics on gross electricity generation (nuclear vs. total). Unfortunately, there is not a better statistical basis for world net power generation. The WNISR2013 stated: "The maximum contribution of nuclear power to commercial electricity generation worldwide was reached in 1993 with 17 percent (see figure 1). It has dropped to 10.4 percent in 2012, a level last seen in the 1980s." With the same calculation basis, the 2013 figure would drop to 10.2 percent. The differences in the results between both calculation methods remain very limited, below 1 percent.

Nuclear generation declined in 13 countries, while in 16 countries it increased and remained stable in two[19]. Six countries[20] generated their historic maximum in 2013. (See Figure 2.)

Figure 2: Annual Nuclear Power Generation by Country and Historic Maximum



Sources: IAEA-PRIS, MSC, 2014

As in the previous year, the "big five" nuclear generating countries—by rank, the United States, France, Russia, South Korea and China—generated 68 percent of all nuclear electricity in the world. China increased its nuclear power generation for the fifteenth year in a row and overtook Germany as the fifth largest producer in 2013. The three countries that have phased out nuclear power (Italy, Kazakhstan, Lithuania), and Armenia, generated their historic maximum of nuclear electricity in the 1980s. Several other countries' nuclear power generation peaked in the 1990s, among them Belgium, Canada, Japan, and the U.K. A further six countries' nuclear generation peaked between 2001 and 2005: Bulgaria, France, Germany, South Africa, Spain, and Sweden. Besides China, the Czech Republic, Finland (although by a very small margin), India (with a still modest generation of 30 TWh), Iran (its Busheer plant entered commercial operation in the third quarter of 2013) and Mexico (that had undergone major uprating) achieved their greatest nuclear production in 2013.

Even where countries are increasing their nuclear electricity production, this is in most cases not keeping pace with overall increases in electricity demand leading to a reduced and generally declining nuclear share (see Figure 3). Except for Iran, which started up its first nuclear plant only in 2011, only one country in the world, the Czech Republic, had its nuclear share peak in 2013. In fact, all other countries, except for Russia (which peaked in 2012)[21]—reached their maximum share of nuclear power prior to 2010. While two countries peaked in 2008 (China) or 2009 (Romania), the other 26 countries saw their largest nuclear share by 2005. In total, nuclear power played its largest role in ten countries during the 1980s[22], in 12 countries in the 1990s and 13 countries in the 2000s.

Increases in nuclear generation are mostly a result of higher productivity and uprating[23] at existing plants rather than due to new reactors. According to the latest assessment by *Nuclear Engineering International*[24], which assesses about 400 of the world's nuclear reactors, the global annual load

---

However, by 0.1 percent difference, the historical maximum moves from 1993 to 1996. This is likely below the statistical uncertainty.

[19] Less than 1 percent variation from the previous year.

[20] China, Czech Republic, Finland, India, Iran, Mexico.

[21] Data modified retroactively on IAEA-PRIS.

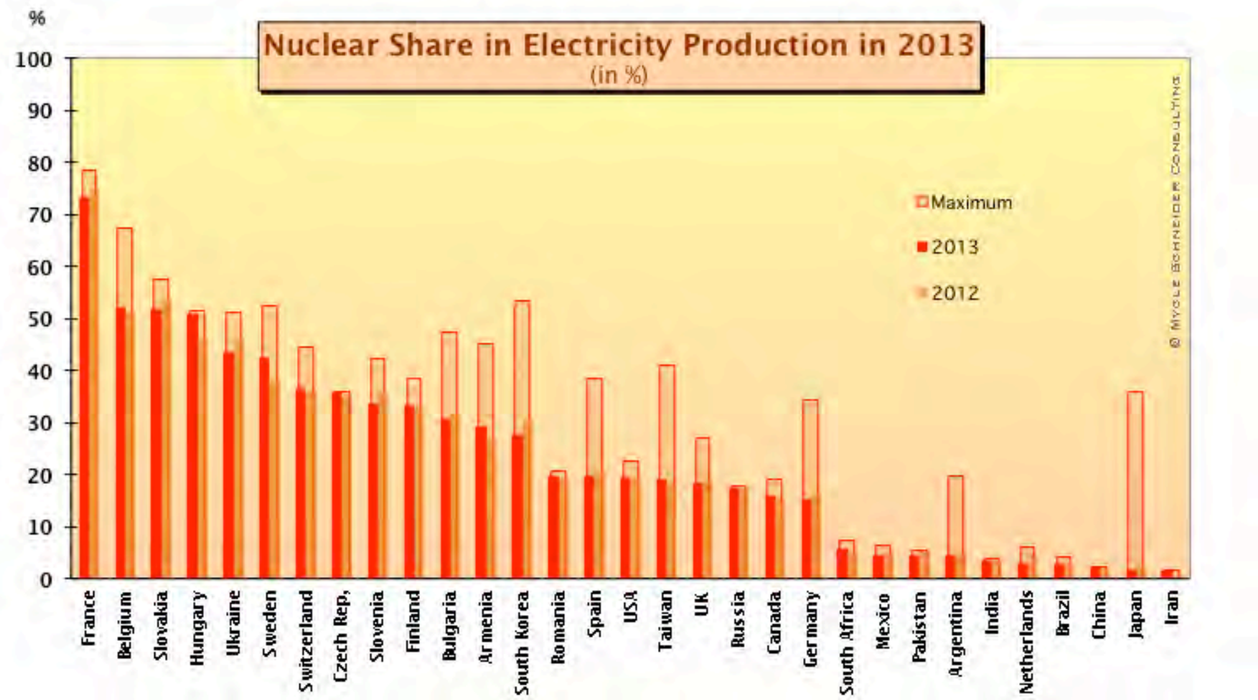
[22] Armenia, Hungary, India, Germany, Italy, Netherlands, South Africa, South Korea, Spain, Taiwan.

[23] Increasing the capacity of nuclear reactors by equipment upgrades e.g. more powerful steam generators or turbines.

[24] Will Dalrymple, Editor of Nuclear Engineering International magazine, personal communication, email 27 June 2014.

factor[25] of nuclear power plants remained stable at 70 percent (+0.2 percent), down from 77 percent in 2011. Excluding Japan, the average load factor decreased slightly (-0.5 percent) to just under 80 percent.

Figure 3: Annual Nuclear Share in Electricity Mix by Country and Historic Maximum



Sources: IAEA-PRIS, MSC, 2014

Romania and Finland achieved the highest annual load factors in 2013 with 94.2 and 93.8 percent respectively.[26] The two countries also lead the Top Ten of the lifetime load factors with 90.8 and 87.3 percent. However, Romania and Finland only operate two and four reactors. Amongst the larger nuclear programs, the most remarkable changes in load factor performance are reported from Canada (+7.6 percent), the U.S. (+4.6 percent) on the positive side and from South Korea (-8.6 percent) and Ukraine (-6.3 percent) on the negative side. Canada brought three units (Bruce-1 and -2, Point Lepreau) that had experienced multi-year outages back into commercial operation in 2013. In the U.S., remarkably low outage times helped increase availability, a performance that could be repeated in 2014, as the outage level is below that of 2013 for the first half of the year.[27] South Korea had to deal with the ongoing aftermath of a major scandal of forged quality control documents that kept three reactors down for most of the year (see country profile in Annex 1). The main origin of the decreasing load factor in Ukraine was major upgrading work on South-Ukraine-1 that kept the reactor down for 240 days but led to a proposed lifetime extension of ten years.

Overview of Operation, Power Generation, Age Distribution

Since the first nuclear reactor was connected to the Soviet power grid at Obninsk on 27 June 1954, 60 years ago, there have been two major waves of grid connections (see Figure 4). The first wave peaked in 1974, with 26 reactor startups in that year. The second wave reached a historic maximum in 1984 and 1985, just before the Chernobyl accident, reaching 33 grid connections in each year. By the end of the 1980s, the uninterrupted net increase of operating units had ceased, and in 1990 for the first time the number of reactor shutdowns outweighed the number of startups. The 1991-2000 decade showed far more startups than shutdowns (52/30), while in the decade 2001-2010, as many units

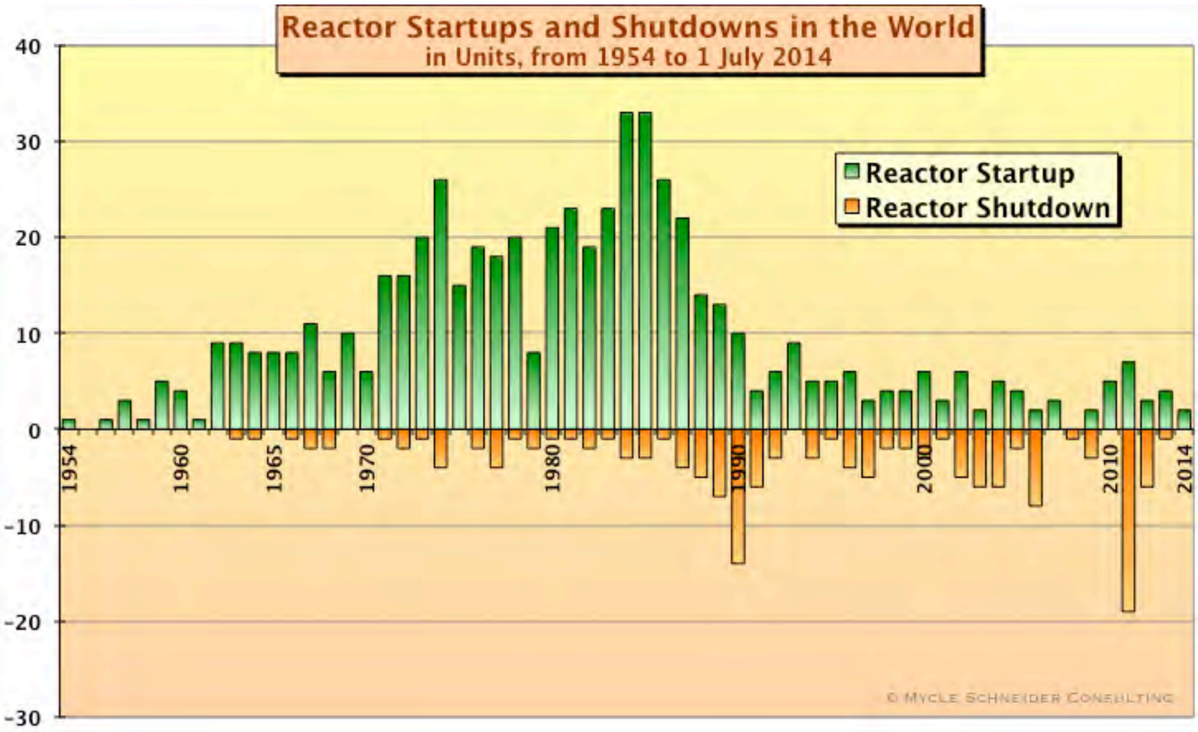
[25] Nuclear Engineering International load factor definition: "Annual load factors are calculated by dividing the gross generation of a reactor in a one-year period by the gross capacity of the reactor (sometimes called output), as originally designed, multiplied by the number of hours in the calendar year. The figures are expressed as percentages. Where a plant is uprated, the revised capacity is used from the date of the uprating."

[26] Unless noted otherwise, all load factor figures are from Nuclear Engineering International, "Load Factors to end December 2013", May 2014 (print version), see also http://www.neimagazine.com/news/newsload-factor-tables-17, accessed 11 July 2014.

[27] U.S.EIA, "Status of U.S. Nuclear Outages", see http://www.eia.gov/beta/outages, accessed 25 June 2014.

started up as were shut down (32/32). In other words, after 2000, it took a whole decade to connect as many units as in a single year in the middle of the 1980s. Between 2011 and the middle of 2014, the startup of 16 reactors did not match the shutdown of 26 units over the same period—partly as a result of events in Fukushima. In 2013, four reactors started up (three in China, one in India) and one was shut down. In the first half of 2014, one reactor started up each in Argentina and in China, while none were shut down. Overall, since 2001, it is in Asia that 39 units (81 percent) out of 48 units were connected to the world's power grids.

Figure 4: Nuclear Power Reactor Grid Connections and Shutdowns, 1954–2014



Source: IAEA-PRIS, MSC, 2014

The International Atomic Energy Agency (IAEA) in its online database Power Reactors Information System (PRIS) still accounts for 48 units in Japan in its total number of 435 reactors "in operation",[28] while no nuclear electricity has been generated in Japan since September 2013 and it is now expected that the first units could restart operations in September 2014 "at the earliest".[29] Only two reactors (Ohi-3 and -4) have operated in 2013 and ten in 2012. The particular situation in Japan needs to be reflected in world nuclear statistics. The attitude taken by the IAEA, the Japanese government, utilities, industry and research bodies to continue considering the entire reactor fleet in the country as "in operation" or "operational" is misleading.

The IAEA actually does have a reactor-status category called "Long-term Shutdown" or LTS.[30] Under the IAEA's definition, a reactor is considered in LTS, if it has been shut down for an "extended period (usually more than one year)" and in early period of shutdown either restart is not being "aggressively pursued" or "no firm restart date or recovery schedule has been established". As we have illustrated in the WNISR 2013, one could argue that all but two Japanese reactors fit the category. And for two days in January 2013, the IAEA moved 47 units to the LTS category on the IAEA-PRIS website, before that action was abruptly reversed and ascribed to clerical error.[31]

The IAEA criteria are vague and hence subject to arbitrary interpretation. What exactly are *extended* periods? What is *aggressively* pursuing? What is a *firm* restart date or recovery schedule? Faced with this dilemma, the WNISR team decided to create a new category with a simple definition, based on empirical fact, without room for speculation: "Long-term Outage" or LTO. Its definition:

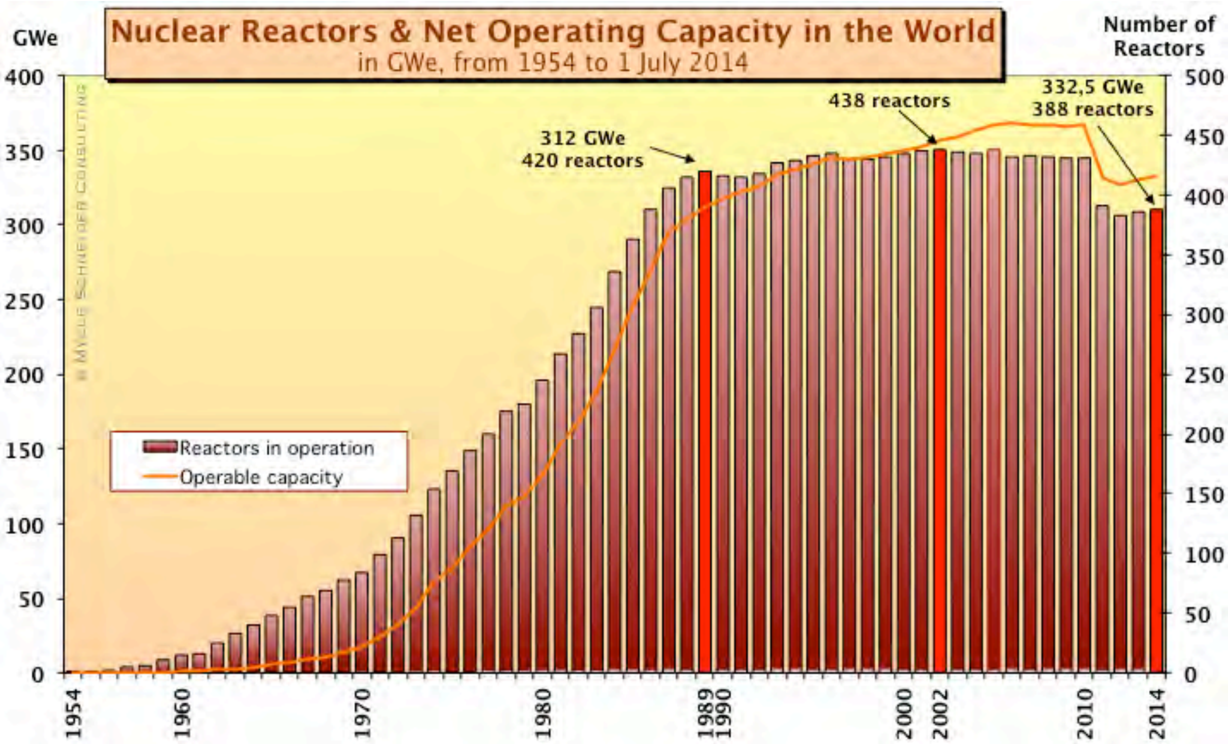
[28] IAEA, "Power Reactor Information System", see http://www.iaea.org/pris/, accessed 27 June 2014.
[29] Asahi Shimbun, "Japan to experience nuclear-free summer", 25 June 2014, see http://ajw.asahi.com/article/0311disaster/fukushima/AJ201406250047, accessed 27 June 2014.
[30] See IAEA Glossary www.iaea.org/pris/Glossary.aspx, accessed 27 June 2014.
[31] See detailed accounts on www.WorldNuclearReport.org.

> A nuclear reactor is considered in Long-term Outage or LTO if it has not generated any electricity in the previous calendar year and in the first half of the current calendar year. It is withdrawn from operational status retroactively from the day it has been disconnected from the grid.

Applying this definition to the world nuclear reactor fleet leads to considering 43 Japanese units in LTO, as WNISR considers all ten Fukushima reactors shut down permanently (while TEPCO has written off the six Daiichi units, it keeps the four Daini reactors in the list of operational facilities). Annex 2 provides a detailed overview of the status of the Japanese reactor fleet. In addition, the IAEA classifies as LTS the fast breeder reactor Monju[32], because it was shut down after a sodium fire in 1995 and has never generated power since. But it meets WNISR's new LTO criterion. Besides the Japanese reactors, the Indian reactor Rajasthan-1, off-line since 2004, and the South-Korean unit Wolsong-1, shut down since 2012, fall into the LTO category. The total number of nuclear reactors in LTO are therefore 45; all but one (Monju) are considered by the IAEA as "in operation".

As of 1 July 2014, a total of 388 nuclear reactors are considered operating in 31 countries, down 39 units (-9.1 percent) from the situation one year ago, mainly due to the revised categorization and the situation in Japan. The current world reactor fleet has a total nominal electric net capacity of 333 gigawatts (GW or thousand megawatts), down from 364 GW (-8.5 percent) one year earlier. (See Figure 5.)

Figure 5. World Nuclear Reactor Fleet, 1954–2014



Sources: IAEA-PRIS, MSC, 2014

The total world installed nuclear capacity decreased during six years since the beginning of the commercial application of nuclear fission, five of them during the past seven years—in 2003, 2007–09, and 2011–12. Overall, the net installed capacity has continued to increase far beyond the net increase of numbers of operating reactors. This is a result of the combined effects of larger units replacing smaller ones and, mainly, technical alterations at existing plants, a process known as uprating. In the United States, the Nuclear Regulatory Commission (NRC) has approved 154 uprates since 1977. These included, in 2013 and the first half of 2014, seven minor uprates between 1.6 and 1.7 percent, except for one (Monticello) with 12.9 percent. The cumulative approved uprates in the United States total 7 GW[33] most of which have already been implemented (for a detailed overview see Annex 3). A similar trend of uprates and lifetime extensions of existing reactors can be seen in Europe. The main incentive for lifetime extensions is their considerable economic advantage over new-build. Upgrading but extending

[32] The IAEA also considers the Spanish reactor Garoña in LTS, while WNISR considers it shut down permanently.
[33] Nuclear Regulatory Commission (NRC), "Approved Applications for Power Uprates", updated 21 February 2014, see www.nrc.gov/reactors/operating/licensing/power-uprates/status-power-apps/approved-applications.html, accessed 27 June 2014.

the operating lives of older reactors usually also lower safety margins than replacement with more modern designs.

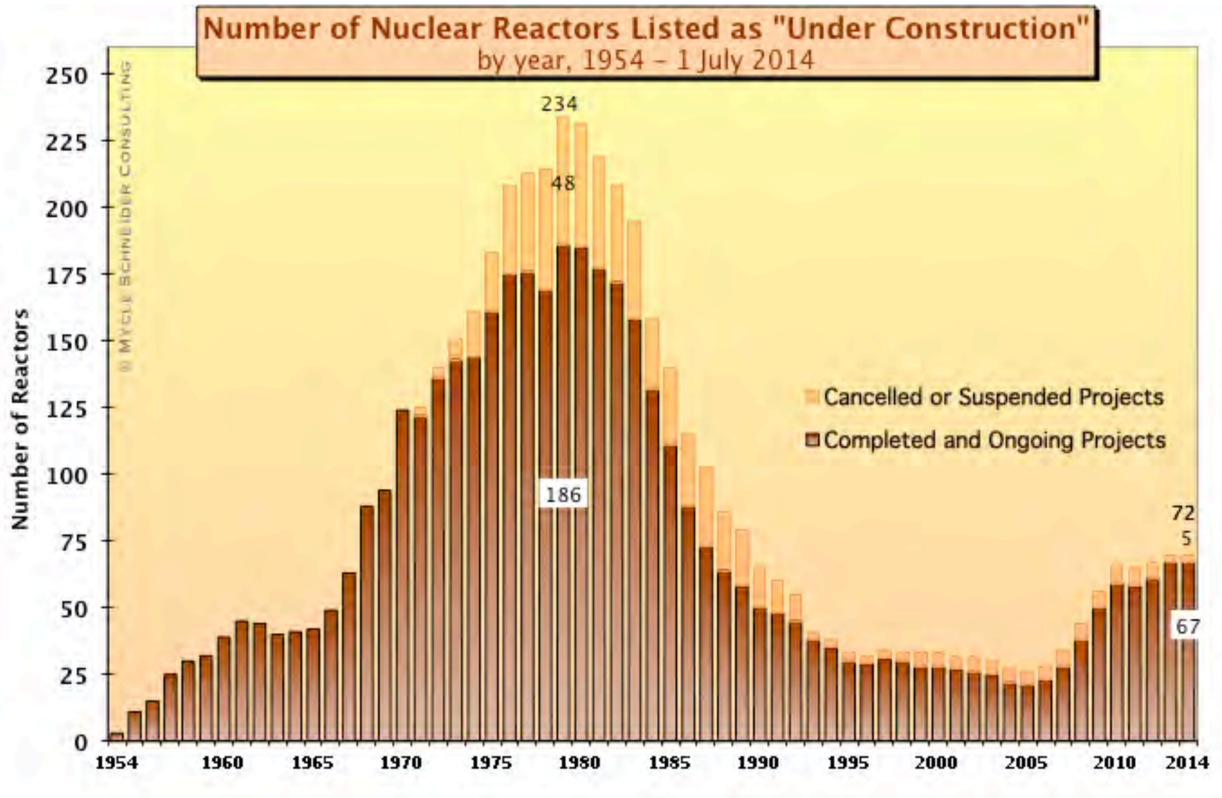
It appears, however, that the incentives and opportunities for power uprates are reducing as in 2012 the number of units with pending applications in the U.S. dropped from 20 in the previous year to 14, declining to eight by the middle of 2014, of which six are "on hold" and the total capacity increase that would occur should they be implemented be limited to 0.8 GW—in other words, insignificant on a U.S. scale.[34]

The use of nuclear energy remains limited to a small number of countries, with only 31 countries, or 16 percent of the 193 members of the United Nations, operating nuclear power plants as of June 2014 (see Figure 2). Close to half of the world's nuclear countries are located in the European Union (EU), and in 2013 they accounted for 36 percent of the world's nuclear production, of which France generated about half (48.7 percent).

Overview of Current New Build

Just as one year ago, currently there are 14 countries building nuclear power plants. Japan halted work at two units following the 3/11 events, Ohma and Shimane-3, which had been under construction since 2007 and 2010 respectively. Officially, construction resumed at Ohma on 1 October 2012 and Shimane-3 has remained "under construction", according to the Japan Atomic Industrial Forum (JAIF)[35] and IAEA statistics. However, in view of the current situation in Japan, it is very unlikely that these plants will be completed (see also Japan Focus) as it will be hard enough for the industry to get its stranded plants restarted.

Figure 6. Number of Nuclear Reactors under Construction



Source: IAEA-PRIS, MSC 2014

As of the middle of July 2014, 67 reactors are considered here as under construction, one more than WNISR reported a year ago; four fifths of all new-build (56) are in Asia and Eastern Europe, of which half (28) are in China alone. Almost two thirds (43) of the units under construction are located in just three countries: China, India and Russia. Ten projects started construction in 2013, in the U.S. (4),

[34] NRC, "Pending Applications for Power Uprates", updated 30 April 2012, see www.nrc.gov/reactors/operating/licensing/power-uprates/status-power-apps/pending-applications.html, accessed 27 June 2014.

[35] JAIF, "Nuclear Power Plants in Japan", 22 May 2013.

China (3), Belarus (1), South Korea (1) and United Arab Emirates (1). In the first half of 2014, only two projects got underway: a second building site opened up in Belarus and the construction of an experimental 25 MWe reactor (CAREM) was launched in Argentina.

The current number of active building sites is the highest since 1987 and is still relatively small compared to a peak of 234 units in building progress—totaling more than 200 GW—in 1979. However, many of those projects (48) were never finished (see Figure 6.) The year 2004, with 26 units under construction, marked a record low since the beginning of the nuclear age in the 1950s.

Table 1. Nuclear Reactors "Under Construction" (as of 1 July 2014)[36]

Country	Units	MWe (net)	Construction Start	Grid Connection
China	28	27,756	2008-2013	2014-2018
Russia	9	7,273	1983-2019	2014-2019
India	6	3,907	2002-2011	2014-2016
South Korea	5	6,320	2008-2013	2014-2018
USA	5	5,633	1972-2013	2015-2019
Belarus	2	2,218	2013-2014	2019-2020
Pakistan	2	630	2011	2016-2017
Slovakia	2	880	1985	2014-2015
UAE	2	2,690	2012-2013	2017-2018
Ukraine	2	1,900	1986-1987	2015-2016
Argentina	1	25	2014	2018
Brazil	1	1,245	2010	2016
Finland	1	1,600	2005	2016
France	1	1,600	2007	2016
Total	67	63,677	1972-2014	2014-2020

Sources : IAEA-PRIS, MSC, 2014

The total capacity of units now under construction in the world remained stable at about 63.7 GW (+0.2 GW), with an average unit size of 947 MW (see Table 1 and Annex 8 for details). A closer look at currently listed projects illustrates the level of uncertainty and problems associated many of these projects, especially given that most constructors assume a five-year construction period:

- Eight reactors have been listed as "under construction" for more than 20 years. The U.S. Watts Bar-2 project in Tennessee holds the record, as construction started in December 1972, but was subsequently frozen. It failed to meet the latest projected startup date in 2012 and is now scheduled to be connected to the grid in late 2015. Other long-term construction projects include three Russian units, two Mochovce units in Slovakia, and two Khmelnitski units in Ukraine. One Russian unit, the fast breeder reactor BN-800, went critical in June 2014 and is expected to start generating power in mid-2014.
- One reactor, the Indian Kudankulam-2 unit, has been listed as "under-construction" for 12 years. Due to massive opposition, work on two Taiwanese units at Lungmen was stopped in April 2014 after about 15 years of construction.
- At least 49 of the units listed as "under construction" have encountered construction delays, most of them significant (several months to several years). For the first time, major delays have been officially admitted relating to projects in China.[37] Indeed, 21 of the 28 units under construction in China are experiencing delays between several months and over two years.
- All of the 18 remaining units under construction in the world were started within the past three years or have not reached projected start-up dates yet. This makes it difficult to assess whether or not they are on schedule.

The lead time for nuclear plants includes not only construction times but also lengthy licensing procedures in most countries, complex financing negotiations, and site preparation. Past experience shows that simply having an order for a reactor, or even having a nuclear plant at an advanced stage of

[36] For further details see Annex 8.

[37] Shan Sun, "Challenges during construction of new NPPS", IAEA Technical Meeting, 6 February 2014, see www.iaea.org/nuclearenergy/nuclearpower/Downloadable/Meetings/2014/2014-02-04-02-07-TM-INIG/Presentations/37_S7_China_Sun.pdf, accessed 28 June 2014; see also Nuclear Intelligence Weekly (NIW), "China: Sanmen—Two Year Delay Pushes Costs Higher", 14 March 2014.

construction, is no guarantee for grid connection and power production. The French Atomic Energy Commission (CEA) statistics on "cancelled orders" through 2002 indicate 253 cancelled orders in 31 countries, many of them at an advanced construction stage (see also Figure 6). The United States alone accounted for 138 of these cancellations.[38] Many U.S. utilities incurred significant financial harm because of cancelled reactor-building projects.

Operating Age

In the absence of any significant new-build *and* grid connection over many years, the average age (from grid connection) of operating nuclear power plants has been increasing steadily and at mid-2014 stands at 28.5 years.[39] Some nuclear utilities envisage average reactor lifetimes of beyond 40 years and even up to 60 years. In the United States, reactors are initially licensed to operate for 40 years, but nuclear operators can request a license renewal for an additional 20 years from the NRC. As of June 2014, 72 of the 100 operating U.S. units have received an extension, with another 19 applications are under NRC review.[40] However, these applications are currently on hold pending completion of a review of the management of commercial nuclear reactor spent fuel, with no license extension decision to be granted until completion of this process.[41]

However, even license renewal does not guarantee longer operating life and none of the 32 units that have been shut down in the U.S. had reached 40 years on the grid. In other words, at least a quarter of the reactors built in the U.S. never reached their initial design lifetime. On the other hand, of the 100 currently operating plants, 24 units have operated for more than 40 years. In other words, one third of the units with license renewals have already entered the life extension period.

Many other countries, have no specific time limits on operating licenses. In France, where the country's first operating PWR started up in 1977, reactors must undergo in-depth inspection and testing every decade. The French Nuclear Safety Authority (ASN) evaluates each reactor before allowing a unit to operate for more than 30 years. The French utility Électricité de France (EDF) has clearly stated that, for economic reasons, it plans to prioritize lifetime extension beyond 40 years over large-scale new-build. Having assessed EDF's lifetime extension outline, ASN stated:

> ASN requested additional studies and underlined the fact that if operation of the existing reactors were to be extended beyond 40 years, they would be operating alongside other reactors around the world of more recent design and compliant with significantly strengthened safety requirements. Through its requests, ASN thus restated that the reactor operating life extension desired by EDF was in no way a foregone conclusion. Over and above the question of management of aging, it is also dependent on an ambitious safety reassessment aiming to achieve a level as close as possible to that of a new reactor.[42]

In fact, only a few French plants have so far received a permit to extend their operational life from 30 to 40 years, but even then only under the condition of significant upgrading. The draft Energy Bill presented by Minister Ségolène Royal in June 2014 caps the installed nuclear operating capacity at the current level. This would mean that prior to the startup of the EPR under construction in Flamanville, an equivalent nuclear generating capacity has to be shut down. Incidentally, this would be close to the capacity of the country's oldest reactors at Fessenheim that President François Hollande vowed to close down by the end of 2016, the current planned startup date for Flamanville-3. The draft Energy Bill also confirms the target to reduce the nuclear share in power generation from 75 to 50 percent by 2025. If ASN gave the go-ahead for all of the oldest units to operate for 40 years, 22 of the 58 French operating reactors will still reach that age by 2020. In fact, in order to reach the 50-percent goal by 2025 and significantly increase the renewable energy share, at constant power consumption, over 20 units will need to be closed by 2025. According to an independent assessment[43], lifetime extension beyond 40 years will probably be very expensive (between €1 billion and €4 billion (US$1.4–5.5 billion) per reactor, depending on the safety level to be achieved). Because of the different costs

---

[38] CEA, "Elecnuc – Nuclear Power Plants in the World", 2002.

[39] WNISR calculates reactor age from grid connection to final disconnection from the grid. In WNISR statistics, "startup" is synonymous with grid connection and "shutdown" with withdrawal from the grid.

[40] U.S. Nuclear Regulatory Commission (NRC), "Status of License Renewal Applications and Industry Activities", see www.nrc.gov/reactors/operating/licensing/renewal/applications.html, accessed 2 June 2014.

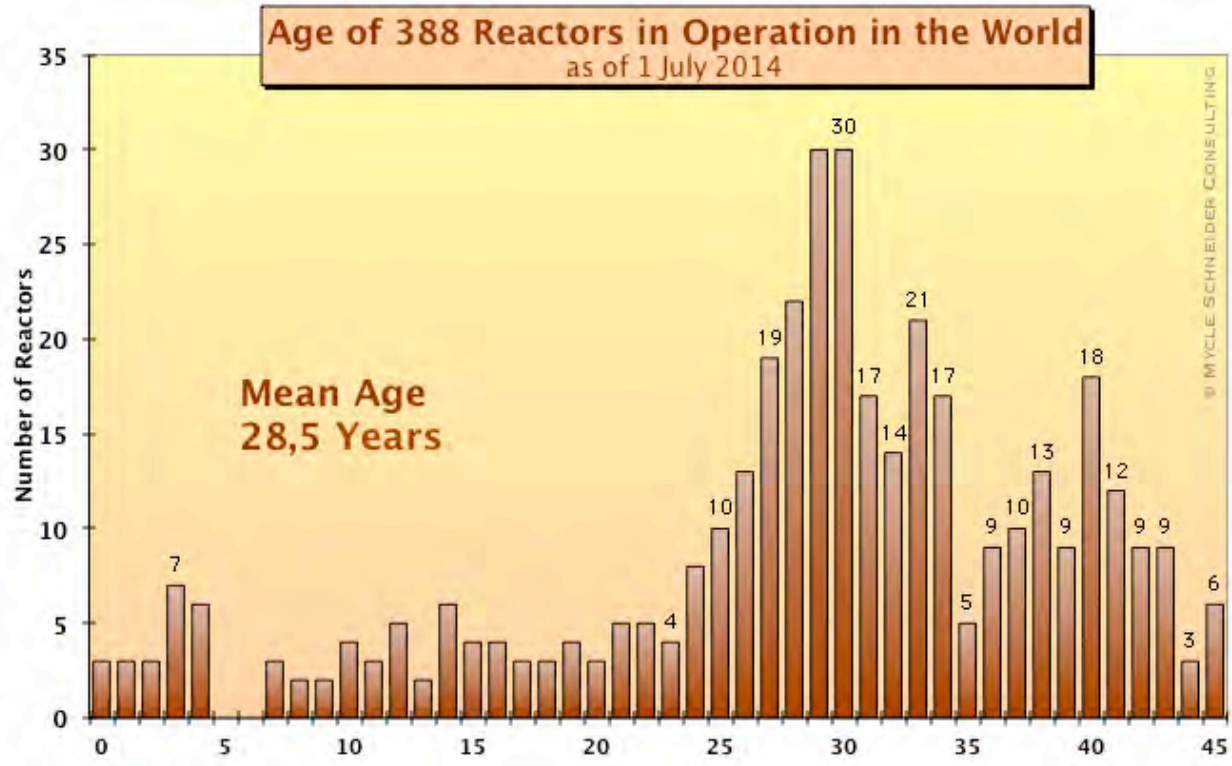
[41] U.S.NRC, "Waste Confidence", updated 29 May 2014, see http://www.nrc.gov/waste/spent-fuel-storage/wcd.html, accessed 10 July 2014.

[42] ASN, "ASN report abstracts—on the state of nuclear safety and radiation protection in France in 2013", 2014.

[43] Yves Marignac, "L'échéance des 40 ans pour le parc nucléaire français : Processus de décision, options de renforcement et coûts associés à une éventuelle prolongation d'exploitation au-delà de 40 ans des réacteurs d'EDF", WISE-Paris, commissioned by Greenpeace France, February 2014, 169 p., see http://www.greenpeace.org/france/PageFiles/266521/greenpeace-rapport-echeance-40-ans.pdf, accessed 7 June 2014.

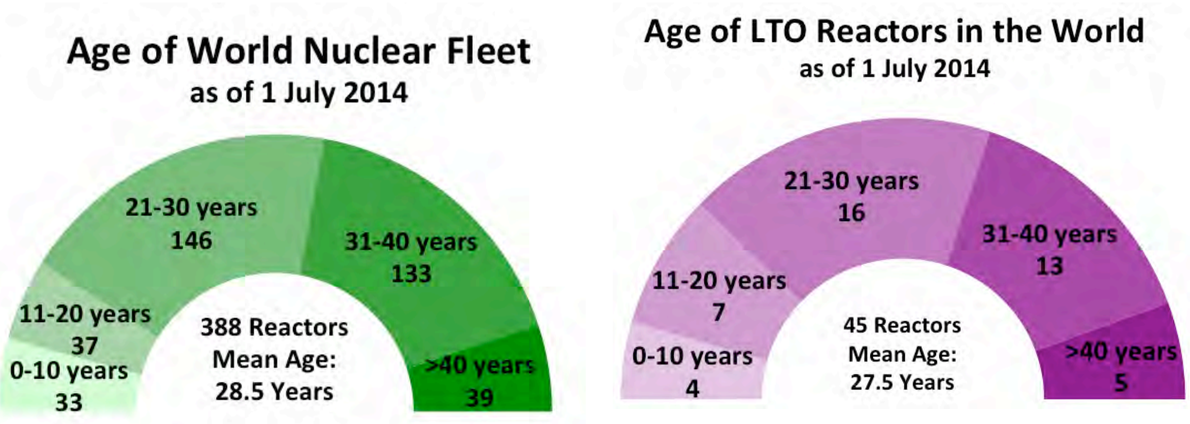
associated with lifetime extensions at different reactors and other considerations (geographical distribution, overall target to reduce the nuclear share, etc.) EDF will likely attempt to extend lifetimes of some units while others might be closed prior to reaching the 40-year age limit. (See also the section on Lifetime Extension in the Economics chapter).

Figure 7a. Age Distribution of Operating Nuclear Reactors



Sources: IAEA-PRIS, MSC, 2014

Figures 7b: Age Distribution of 388 Operating and 45 LTO Reactors in the World (by Decade)

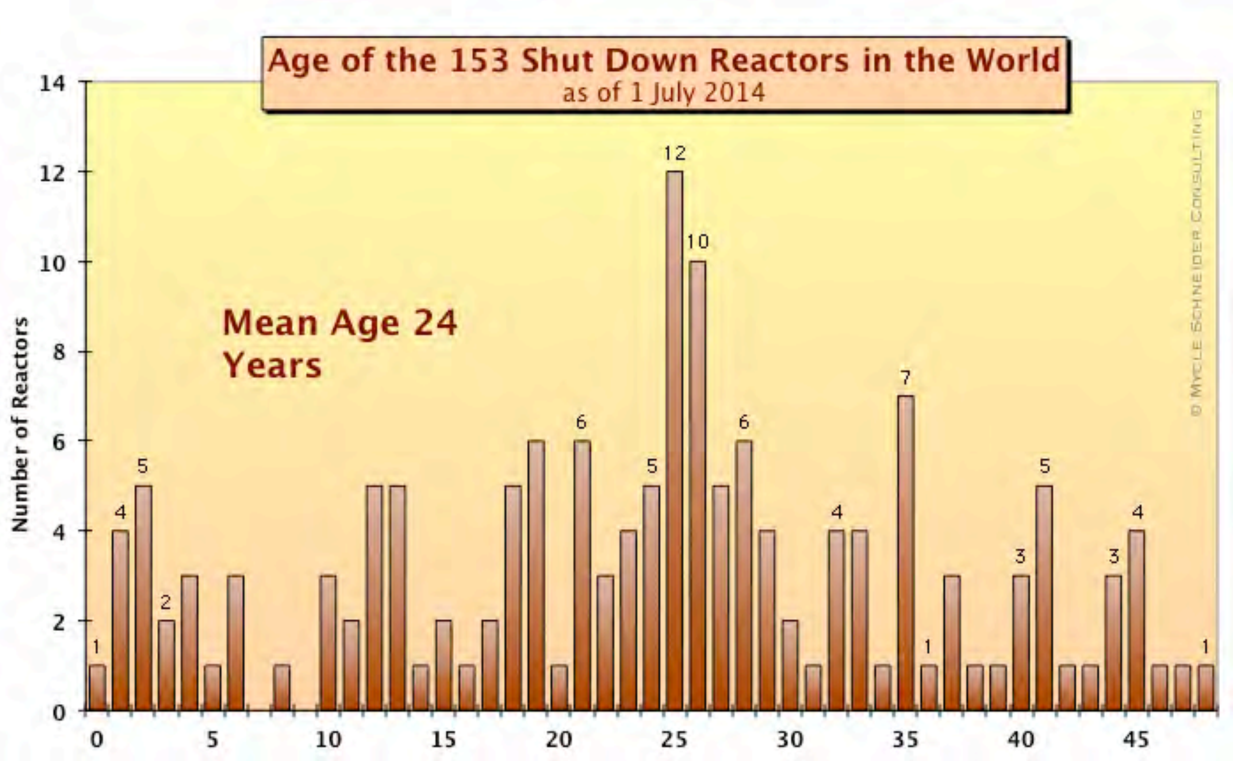


Sources: IAEA-PRIS, MSC, 2014

In assessing the likelihood of reactors being able to operate for up to 60 years, it is useful to compare the age distribution of reactors that are currently operating with those that have already shut down (see Figures 7 and 8). As of mid-2014, 39 of the world's operating reactors have exceeded the 40-year mark (eight more than one year ago).[44] As the age pyramid illustrates, that number could rapidly increase over the next few years. A total of 172 units have already reached age 30 or more. In fact, none of the 120 reactors started up in the past 25 years (since 1989) has been permanently shut down yet.

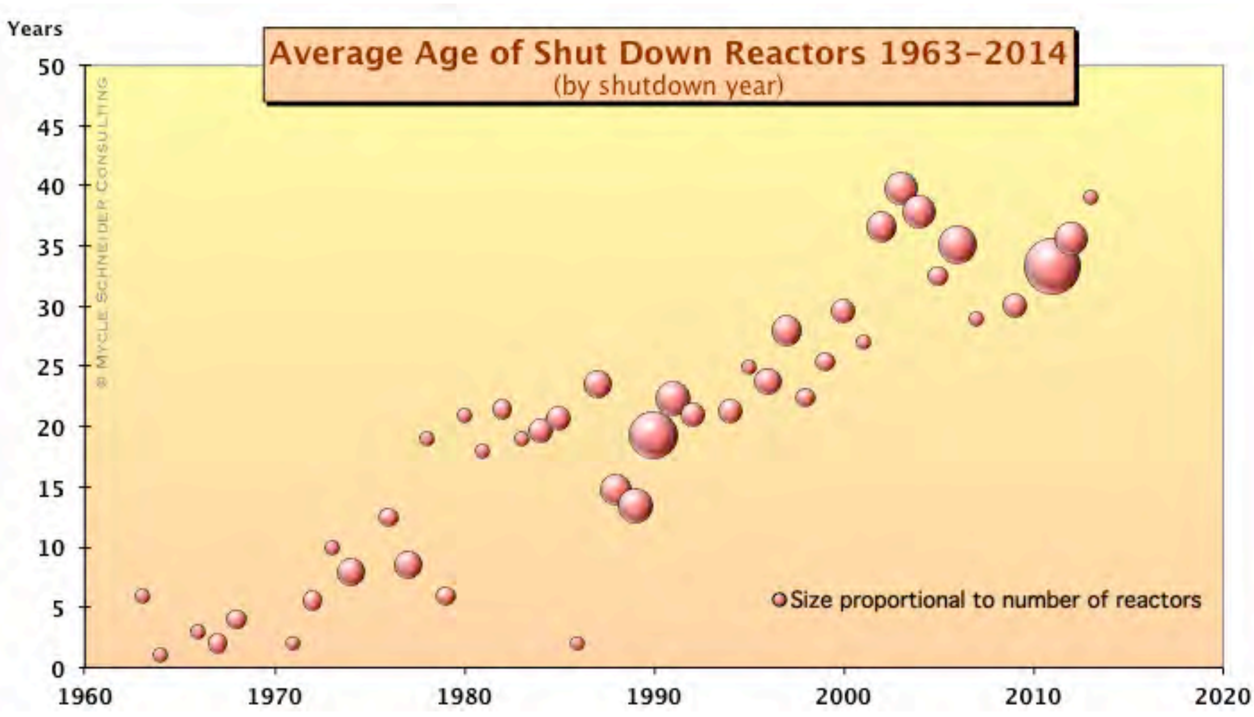
[44] WNISR considers the age starting with grid connection, and figures are rounded by half-years.

Figure 8a. Age Distribution of 153 Shut Down Nuclear Reactors



Sources: IAEA-PRIS, MSC, 2013

Figure 8b. Average Age Profile of Shut Down Nuclear Reactors



Sources: IAEA-PRIS, MSC, 2014

The age structure of the 153 units already shut down confirms the picture. In total, 45 of these units operated for 30 years or more and of those, 20 reactors operated for 40 years or more (see Figure 8a). The majority of these were Magnox reactors located in the U.K. As they were designed to produce weapons-grade plutonium, these were all small reactors (50–490 MW) that had operated with very low burn-up fuel and very low power density (watts of heat per liter of core volume).

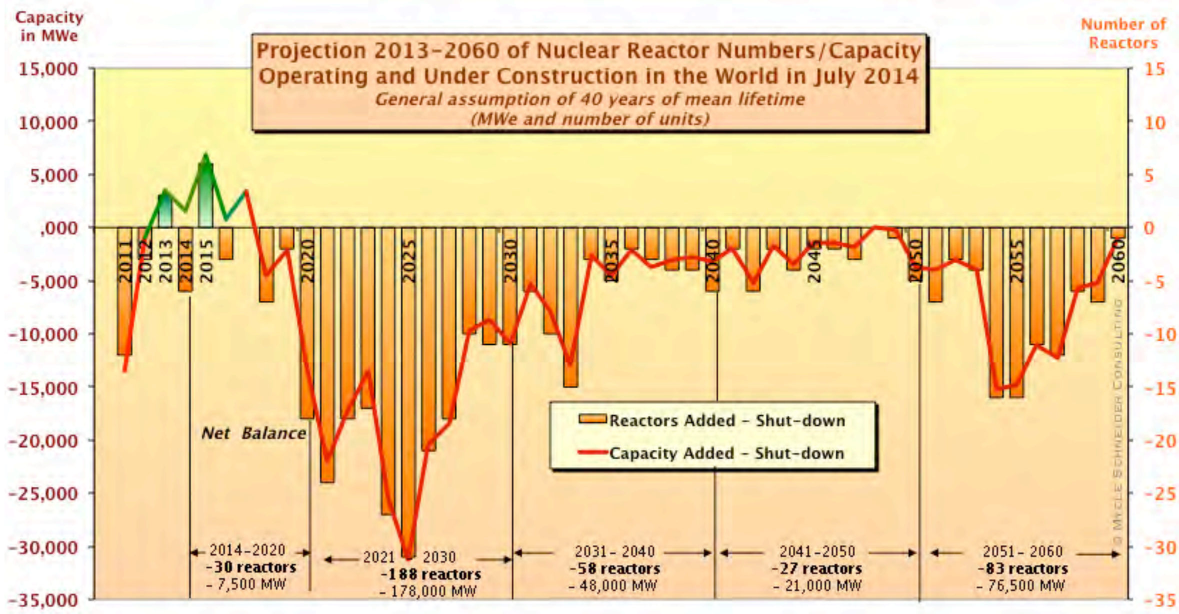
Therefore there are significant differences from the large 900 MW or 1,300 MW commercial reactors whose high burn-up fuel and high power density generate significantly more stress on materials and equipment. Many units of the first generation have operated for only a few years. Considering that the average age of the 153 units that have already shut down is about 24 years, plans to extend the operational lifetime of large numbers of units to 40 years and beyond seems rather optimistic. The operating time prior to shutdown has clearly increased continuously, as illustrated in Figure 8b. But while the average age at shutdown got close to, it never passed the 40-year line. In 2003, six units averaged 39.8 years, and one reactor closed in 2013 (Kewaunee in the U.S.) operated for 39 years.

As a result of the Fukushima nuclear disaster, questions have been raised about the wisdom of operating older reactors. The Fukushima-I units (1 to 4) were connected to the grid between 1971 and 1974. The license for unit 1 was extended for another 10 years in February 2011. Four days after the accidents in Japan, the German government ordered the shutdown of seven reactors that had started up before 1981. These reactors, together with another unit that was closed at the time, never restarted. The sole selection criterion was operational age. Other countries did not adopt the same approach, but it is clear that the 3/11 events had an impact on previously assumed extended lifetimes in other countries as well, including in Belgium, Switzerland, and Taiwan.

Other countries continue to implement or prepare for lifetime extensions. We have therefore created two lifetime projections. In a first scenario (40-Year Lifetime Projection, see Figure 9), we have assumed a general lifetime of 40 years for worldwide operating reactors (not including reactors in LTO, as they are not considered operating), with a few adjustments, while we take into account already-authorized lifetime extensions in a second scenario (PLEX Projection, see Figure 10).

The lifetime projections allow for an evaluation of the number of plants that would have to come on line over the next decades to offset closures and simply maintain the same number of operating plants. Even with 67 units under construction—as of 1 July 2014, all of which are considered online by 2020—installed nuclear capacity would drop by 7.5 GW. In total 30 additional reactors would have to be finished and started up prior to 2020 in order to maintain the status quo of the number of operating units. This corresponds to about five grid connections per year, with an additional 188 units (178 GW) over the following 10-year period—one every 19 days. This compares to 37 grid connections over the past 10-year period with an average construction time of ten years.

Figure 9. The 40-Year Lifetime Projection (not including LTOs)

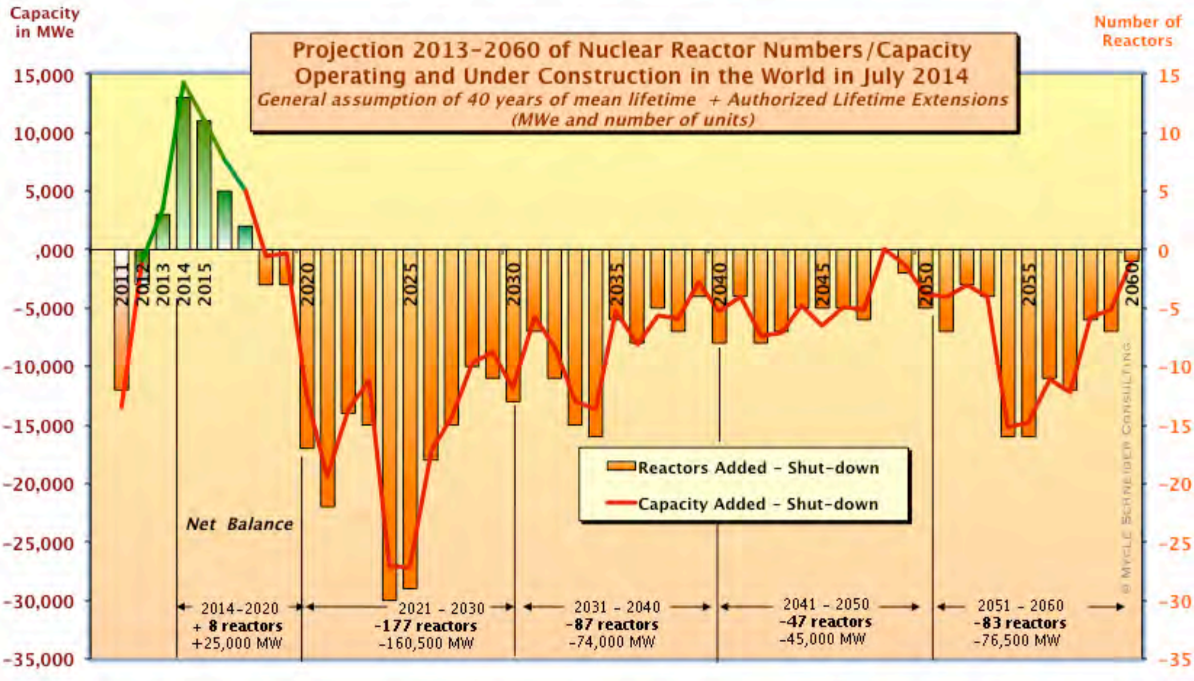


Sources: IAEA-PRIS, WNA, various sources compiled by MSC 2014

The achievement of the 2020 target will mainly depend on the number of Japanese reactors currently in LTO possibly coming back on line and the development pattern of the Chinese construction program. Any major achievements outside these two countries in the given timeframe are highly unlikely given the existing difficult financial situation of the world’s main reactor builders and utilities, the general economic environment and generally hostile public opinion—aside from any other specific post-Fukushima effects.

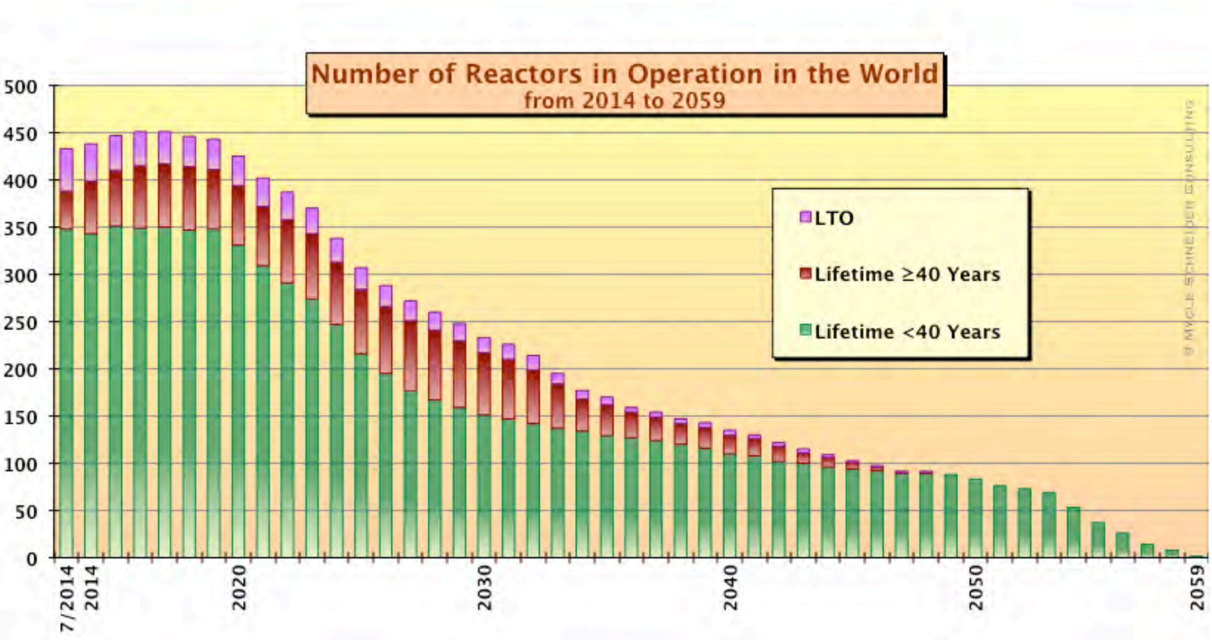
As a result, the number of reactors in operation will stagnate at best but will more likely decline over the coming years unless lifetime extensions beyond 40 years becomes widespread. The scenario of such generalized lifetime extensions is however even less likely after Fukushima, as many questions regarding safety need to be much more carefully addressed. Also, soaring maintenance and upgrading costs, as well as decreasing system costs of nuclear power's main competitors lead to an economic environment that already led to premature plant closures, notably in the U.S. and Germany.

Figure 10. The PLEX Projection



Sources: IAEA-PRIS, WNA, various sources compiled by MSC 2014

Figure 11. Forty-Year Lifetime Projection versus PLEX Projection *(in numbers of reactors)*



Sources: IAEA-PRIS, US-NRC, MSC 2013

Developments in Asia, and particularly in China, do not fundamentally change the global picture. Reported figures for China's 2020 target for installed nuclear capacity have fluctuated between 40 GW and 120 GW in the past. The freeze of construction initiation for almost two years has reduced Chinese ambitions. In addition, the average construction time for the 13 units in China was 5.9 years. At present, 28 units with about 28 GW are under construction and scheduled to be connected before 2020, which will bring the total to 45 GW. The prospects for significantly exceeding the original 2008 target of 40 GW for 2020 is unlikely (see China Focus). There are also indications that new reactors will be allowed only in coastal, not inland, sites, restricting the number of suitable sites available.

We have also modeled a scenario in which all currently licensed lifetime extensions and license renewals (mainly in the United States) are maintained and all construction sites are completed. For all other units we have maintained a 40-year lifetime projection, unless a firm earlier or later shutdown date has been announced. The net number of operating reactors would increase by 8 units and installed capacity by 25 GW in 2020. The overall pattern of the decline would hardly be altered, it would merely be delayed by some years. (See Figures 10 and 11).

Potential Newcomer Countries

A number of countries are actively developing and even constructing nuclear power plants for the first time. Many of these countries have long-held plans to develop nuclear energy, for decades in some countries. According to the World Nuclear Association (WNA), there are eight countries that are either actually building power plants for the first time (Belarus and United Arab Emirates [UAE]), have signed contracts (Lithuania and Turkey) or have committed plans for new-build (Bangladesh, Jordan, Poland, and Vietnam). This list of projects reflects important changes over the last few years with many countries experiencing a rolling-back from previously ambitious plans. This is in marked contrast to an analysis from the IAEA in 2012 that stated it expected Bangladesh, Belarus, Turkey, UAE, and Vietnam, and to start building their first nuclear power plants in 2012 and that Jordan and Saudi Arabia could follow in 2013.[45]

In all cases for these first time nuclear countries, even in the relatively rich Middle East, finance remains a if not the decisive one, in determining the choice of technology. However, what is striking is the extent to which in recent years the Russian industry has expanded its export policy through financial backing, with proposed projects in countries that are building reactors for the first time (Belarus, Turkey and possibly Bangladesh), as well as new proposals with financing in active countries like Finland and Hungary that already have nuclear power plants. The current situation in Ukraine raises questions over both the political support for such projects, especially in Europe, and with the threat of widening economic sanctions against Russia, the ability to fund all of the projects.

Other increasingly active players in the export market are Japanese companies, such as Toshiba and Hitachi. The lack of new-build opportunities domestically means that export markets have become essential to maintain their production capabilities, again with technology sales accompanied by a financial package. Like Russia, this effort encompasses proposals in countries that currently don't have programs (e.g. Lithuania and Turkey) as well as projects under development in more developed nuclear countries such as Bulgaria and the UK. The revised Japanese New Growth Strategy includes an explicit statement that the Government will actively support the export of nuclear power.[46]

The following section provides a country-by-country overview of potential newcomer countries.

Construction started in November 2013 at **Belarus's** first nuclear power plant at the Ostrovets power plant, also called Belarusian-1. According to World Nuclear News (WNN), construction of a second 1200 MWe AES-2006 reactor started in June 2014.[47] In November 2011, the two governments agreed that Russia would lend up to US$10 billion for 25 years to finance 90 percent of the contract between Atomstroyexport and the Belarus Directorate for Nuclear Power Plant Construction. In February 2012,

[45] Lucas W Hixson, "IAEA – Vietnam and 4 other countries to incorporate nuclear energy after Fukushima", Enformable.com, 24 February 2012, see http://enformable.com/2012/02/iaea-vietnam-and-4-other-countries-to-incorporate-nuclear-energy-after-fukushima/, accessed 5 May 2014.

[46] Satoru Koyama, "The Role of Export Credits in NPP Financing", Nippon Export and Investment Insurance, September 2013, see http://www.oecd-nea.org/ndd/workshops/wpne/presentations/docs/3_1_KOYAMA_2013_09_19_OECD_Seminer.pdf, accessed 14 July 2014.

[47] WNN (World Nuclear News), "First concrete for second Belarus unit", 3 June 2014, see http://www.world-nuclear-news.org/NN-First-concrete-for-second-Belarus-unit-0306144.html, accessed 14 July 2014.