NUCLEAR ENERGY REPORT

The Indian Point Nuclear Power Plant in Buchanan – Courtesy lohud.com

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INTERNATIONAL NUCLEAR SOCIETIES COUNCIL

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EXECUTIVE SUMMARY

HISTORY

Many countries began exploring peaceful applications of nuclear energy in the earnest in the 1950s. The development of nuclear power has proceeded in many parts of the globe since that time.

The prospect of nuclear power in Australia has been a topic of public debate since the 1950s. Australia has never had a nuclear power station.

In 1955, the China National Nuclear Corporation (CNNC) was established. On 15 December 1991, China's first nuclear power reactor, a 288 MWe PWR at the Qinshan Nuclear Power Plant, was connected to the grid

The development of nuclear energy in Japan started with the appropriation of the national nuclear energy budget in 1954. Since then, the development of breeder reactor and fuel cycle technology was carried out as a national project while the US LWR technology was a mainstream of nuclear energy deployment. In response to the energy crisis of the 1970s, the Japanese government promoted the further deployment of nuclear energy utilization as well as new energy resources such as biomass, PV, and others.

South Korea, nuclear activities were initiated when the country became a member of the International Atomic Energy Agency in 1957. The first nuclear reactor to achieve criticality in South Korea was a small research unit in 1962, while the first nuclear power plant started operation in 1977 and commercial service in 1978.

In Taiwan, though active seismic faults run across the island, and anti-nuclear environmentalists argue Taiwan is unsuited for nuclear plants, the island currently has 3 active plants and 6 reactors.

The first period of nuclear development in Europe (1960-1980) resulted from the very fast scientific and technological developments of nuclear for civil purposes following the 1953 Atoms for Peace call of President Eisenhower, the United Nations creation of the International Atomic Energy Agency (IAEA) in 1957, and the establishment of the European Atomic Energy Community (Euratom) also in 1957. The oil crisis of the 1970s boosted the deployment of nuclear power at large industrial scale.

The second period of nuclear development in Europe (1980-2000) saw a gradual decline in the rate of new investment. Some attributed this in part to the energy market liberalization of the 90s, coupled with the Three Mile Island and Chernobyl nuclear accidents.

The 50's are considered the romantic era for nuclear development in Latin America with Argentina, Mexico, and Brazil establishing governmental organizations to explore the development of a nuclear-energy program. The first reactor was built in Argentina in 1974, while Brazil built its first reactor in 1982.

Mexico's interest in nuclear energy was made official in 1956 with the establishment of the National Commission for Nuclear Energy (CNEN). Its first commercial nuclear reactor came into operation in 1989.

Nuclear power in the United States began in the 1940s with the events around the Chicago Pile 1 reactor and the Manhattan Project. The construction of the first commercial nuclear generating station in the United States (the Shippingport Atomic Power Station) started in 1954. The industry saw a rapid rise in new builds, and by the 70s, there were over 100 nuclear reactors.

Canada was involved in nuclear research from the very outset of the science, and following the discovery of fission in 1938, experimental work on graphite-moderated subcritical assemblies was performed at the Canadian National Research Council. However, the roots of Canada's nuclear industry lie in the war effort in World War II. Canada's first reactor, the Zero Energy Experimental Pile (ZEEP) reactor went critical a few days after the end of WWII.

Though the continent of Africa has been part of the nuclear movement since the 1950s with a number of the countries joining and signing various UN initiated treaties such as the nuclear Non-Proliferation (NPT), only one country in Africa (South Africa) currently has commercial nuclear reactors. The reactors began operation in 1984.

Nuclear activities in Russia dates back to 1945. Russia's Obninsk reactor was the first in the world to produce electricity for a grid in 1954, while its first commercial-scale plant started up in 1963

CURRENT STATE OF NUCLEAR

According to IAEA, the nuclear power capacity has shown a gradual growth trend over the past decade, with a global operating nuclear power capacity of 389.5 GW(e) at the end of 2021. This capacity was provided by 437 operational reactors in 32 countries.

Australia has a significant infrastructure to support any future nuclear power program that includes the Australian Safeguards & Non-proliferation Office (ASNO), the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), and a well-developed uranium mining industry. Though certain nuclear Facilities and Nuclear Activities Prohibition Acts are currently in place in Australia, the country's commitment to reducing CO_2 emissions and achieving net zero emissions by 2050 may be the driver for establishing nuclear power in Australia.

While China ranks third in the world both in total nuclear-power capacity installed and electricity generated, it is the second largest nuclear power producer after the United States. As of June

2021, China has a total nuclear power generation capacity of 49.6 GW from 50 reactors, with an additional 17.1 GW under construction.

The Fukushima nuclear accident of 2011 resulted in the shutting down of the reactors by the Japanese government. As of December 2022, of the 33 operational reactors in the country, 17 had complied with the new regulatory requirements, and 10 of them have been restarted. In June 2021, the Mihama Nuclear Power Station Unit 3 restarted, and it is the first in Japan to be approved for operation beyond 40 years.

The implementation of the "Long-term Nuclear Policy Direction for 2030" decided by the Korean Atomic Energy Commission has resulted in Korea's technological independence of nuclear power plant construction and nuclear power export. This has led to the development of the APR-1400 for which, in 2009 the UAE signed an export contract for 4 units.

Nuclear activities in Taiwan have not been very encouraging, especially as a result of political decisions amongst others. Life extension licenses have been submitted and withdrawn; Kuosheng-1 was shut down in July 2021, while Chinshan is planned for decommissioning.

The UK being outside the EU continued its active nuclear programs with the pursuit of the construction of the EPR in Hinckley Point. Dynamic research and innovation programs are also in the work, particularly in the field of SMRs.

The nuclear situation in Continental Europe is complex. The sole right of the Member States to decide on their energy mix is enshrined in the Treaty of the European Union. Thus resulting in the diverse opinions and actions by member states in the area of nuclear power. Germany's post-Fukushima political nuclear phase-out policy has resulted in the country subsidizing at very high cost, the deployment of renewable energy sources, and an increasing recourse to fossil fuels. In 2022, France decided to engage in the construction of six new EPR reactors, with the possibility of more later. The first of these reactors is planned to be commissioned in 2035. Fifty percent of Belgium's electricity comes from its seven nuclear reactors. Currently, there is the political decision to phase out these reactors. However, Russia's invasion of Ukraine has temporarily "halted" the phase-out program. The situation in Spain is not too different. There is plan to shut down all Spanish nuclear reactors by 2035. For Sweden and Finland, there is positive political and public opinion to nuclear. Four reactors in Finland are in lifetime extensions, and one EPR has just been commissioned. These two countries are the most advanced worldwide for the handling of their ultimate nuclear waste. Other countries including the Netherlands, Czech Republic, Slovakia, Hungary, Slovenia, Romania, and Bulgaria are keen to continue to rely on nuclear power for their electricity supply, keeping their plants in long-term operation and building new power plants when the need arises.

Argentina has three nuclear reactors in operation. They generate about 5% of the country's electricity. Brazil has two operating reactors that generate 2.5% of the country's electricity. Brazil is said to have about 5% of the world's uranium reserves. Mexico's only nuclear power plant (Laguna Verde NPP) produces about 4.5% of the country's electricity. A 30-year extension license for Unit 1 of the two reactors was granted by the Mexican Regulatory body in 2020.

In the United States, its 92 nuclear power reactors produce approximately 20 percent of the country's electricity. The majority of those reactors have applied for and received license renewal for operation ranging from 60 – 80 years. Two new reactors are currently under construction in the US. The country's nuclear regulatory body (the NRC) has also issued combined construction and operating licenses for six other light water reactors.

Canada has 19 reactors, all of them of the CANDU design. They generate about 14% of the country's electricity, and up to 60% of the electricity generation in the province of Ontario. As a result of this large nuclear base in Ontario, the province was able to close all coal electricity-generation stations in the Province in 2014. There is active refurbishment program going on for most of the reactors. The 8-unit Bruce Station is meant to operate till 2060 with the refurbishment.

In Africa, though only South Africa currently operating reactors for electricity generation, many African countries remain resolute that nuclear energy could be the answer to their energy woes and to increase their level of energy security. There is significant government support for nuclear energy development especially in countries like Egypt, Ghana, Nigeria, Uganda and Zambia.

In Russia, 38 power units are currently in industrial operation at 11 NPPs. Nuclear electricity generated by Russian nuclear power plants reached 214 billion kWh by the end 2020. Test operations of the floating nuclear thermal and electric power plant (FNPP) "Akademik Lomonosov" are showing stable and accident-free operation at design parameters. Russia has a very robust and active new nuclear construction abroad.

FUTURE STATE OF NUCLEAR

There is substantial interest in expanding the use of nuclear energy in many parts of the world in order to address pressing concerns associated with climate change and energy security.

Australia's draft National Infrastructure Research Roadmap released in 2016 set out priorities for the decade ahead, with research infrastructures such as the OPAL reactor and the Australian Synchrotron in Melbourne being recognized as "a category of research infrastructure that is of such scale that the national interest is best served by landmark facilities," relying on government investment.

China's target of nuclear-generating capacity is 200GWe by the year 2035. In 2020, Bloomberg News reported that China's National People's Congress supported future building of 6 to 8 reactors a year.

Japan has set energy-related targets to be met by 2030 including the reduction of energy demand from 363 million kl crude oil equivalent in 2013 to 280 million kl by enhancing energy efficiency; electricity production 20 ~ 22% nuclear, 36 ~ 38% renewable, 1% hydrogen and ammonia, 20% LNG, and 19% coal. Japan's policy for nuclear energy is to promote the stable use of nuclear energy, promote research and development on the premise of ensuring safety; while its policy of Nuclear R&D is to sustain the development of fast reactors, demonstrate the technology of small modular reactors, establish the elemental technology related to hydrogen production in high-temperature gas reactors, and promote the fusion science and engineering for future nuclear energy.

South Korea's plan for Long-term Electricity Supply and Demand envisages 13 new reactors to be in operation by 2029. The current South Korean government reverted the nuclear exit policy of the previous government and is putting more emphasis on nuclear power to achieve its carbon neutrality goal. It is believed that the share of nuclear power will continue its steady rise in the future.

While the leaders of Taiwan advocate the phasing out of nuclear by 2025, they have expressed concern about feasible options for meeting its energy needs with the nuclear phaseout. The use of fossil fuels will face so much opposition environmentally, while the reliance on renewables could be so expensive as to undermine the Taiwan industry's competitiveness.

Based on the decision of some member states to phase out nuclear energy or to reduce its share in their energy mix, the European Commission predicts a decline in nuclear generation capacity at the EU level up to 2025. The Commission also expects a reversion of this trend by 2030 resulting from new reactors being connected to the grids. Nuclear capacity is expected to be between 95 GWe and 105 GWe by 2050.

To maintain this 95-105 GWe capacity, it is estimated that EUR 45-50 billion will be invested in the long-term operation of existing reactors, while EUR 350 and 450 billion would have to be invested in new plants to replace most of the existing nuclear-power capacity.

More than 500 million diagnostic procedures using x-rays or radioisotopes are carried out in Europe each year, and more than 700 000 European healthcare workers use nuclear and radiation technology on a daily basis. Europe is the second largest consumer of technetium-99m (Tc-99m), the most widely used diagnostic radioisotope. To sustain these demands and to minimize interruptions in radioisotope production, action such as the establishment of the European Observatory on the Supply of Medical Radioisotopes has been taken to coordinate the operation of research reactors in the European Union.

Euratom supports nuclear research and training activities and aims at continuously improving nuclear safety, security, and radiation protection. The Euratom initiative believes that the future of nuclear energy involves the development of fusion, and the initiative is doing this through the International Thermonuclear Experimental Reactor (ITER). The ITER aims to demonstrate the technological and scientific feasibility of fusion energy.

Argentina's multipurpose research reactor, RA-10 will be used for the production of medical radioisotopes, as well as irradiation tests of advanced nuclear fuel and materials, and neutron beam research. Similar to Argentina's RA-10 is the Brazil Multipurpose Reactor (RMB). The expectation is that between them, they will provide the capacity to supply about 40% of global radioisotopes. Brazil's Energy Plan (PNE 2050 is such that in the period 2020-2030, Brazil will consider "existing technologies", while advanced technologies such as Generation IV and SMRs will be considered in the 2040 to 2050 period. Meanwhile, Mexico's 2020 PRODESEN projected 1500 MWe of additional nuclear capacity for the 2025 – 2031 period.

Many US states and the federal government are calling for aggressive reductions in greenhouse gas emissions, and policy actions at the state and federal levels encourage clean energy sources like nuclear power. The US Department of Energy (DOE) is conducting the Advanced Reactor Demonstration Program (ARDP) to support concept development, risk reduction, and deployment of advanced reactors. There is a substantial focus on new designs for the regulatory framework that provides safety and environmental oversight of reactors. There is increased awareness of the critical role nuclear power can play in reducing greenhouse gas emissions and addressing climate change, thus resulting in strong and growing public support for nuclear power in the US.

In Canada, the growing realization that nuclear power will be important and needed in the fight against climate change is expected to effect some change in the public perception of nuclear energy. A number of vendors have recognized the great interest in SMRs in Canada, and have established a presence in the country with the ultimate aim of developing and deploying their designs in Canada. The first SMR new build, a BWRX-300 by GE Hitachi Nuclear Energy, is to be built on OPG's Darlington nuclear site and is to be operational by 2028. There are also designs proposed for micro-SMRs for remote applications. One such micro-SMR is the OPG-initiated Micro Modular Reactor Project (MMRP) which is projected to be in service at the Chalk River site in Ontario by 2026.

Of the nearly 30 so-called newcomer countries that are embarking [on] or considering nuclear power, almost one-third are in Africa. To these countries, nuclear power is a present energy solution, and a future energy alternative. South Africa has affirmed plans to end by 2024, procurement process for a new 2,500 MWe nuclear power plant.

Rosatom has commenced the development of the second generation of FNPP – an optimized floating nuclear power plant (OFNPP), which is planned to be smaller than its predecessor and equipped with two RITM-200M type nuclear reactors of 50 MW each. Belorussia is expected to have an additional 2400 MW of generating capacity by the end of 2022. The strategic framework of future Russian nuclear power development is fast-neutron reactors and standard VVERs with thermal neutrons.

Contents

INTRODUCTION

It is my great pleasure and privilege to introduce the INSC "Nuclear Energy Report", which I expect to enhance a shared understanding of world nuclear energy trends among the member societies of INSC and many others.

Nuclear energy has played a critical role in providing the world with energy that cause no significant harm to the environment. It does not produce carbon dioxide to the air, although it generates a certain amount of radioactive wastes which can be handled with proper technology. While there have been major accidents such as Three Mile Island II, Chernobyl and Fukushima Daiichi, nuclear power is considered to be the least killer energy source among many energy sources. With high energy density, nuclear energy is considered as one of the most economical energy sources. Although some countries are planning to phase out nuclear energy, many countries such as those in Africa, the Middle East and Eastern Europe remain resolute that nuclear energy could be the answer to their energy problems including the need to increase energy security in the midst of energy crises that has been worsened by the war between Russia and Ukraine.

The primary mission of INSC is to foster ongoing cooperation, communication and exchange of information among the world's nuclear societies. This report was prepared for that mission and has been planned for a long time. After years of effort of Dr. Peter Ozemoyah from the Canadian Nuclear Society who volunteered to lead this project with the help of many delegates and guests who wrote and repeatedly reviewed the draft, this report could finally be published. Some parts of the report may need further elaboration and correction, but that will be in the near future.

I am deeply grateful to the many who contributed to making this report complete, especially the members of INSC Executive and some Delegates from various member Societies. These contributors are listed on the next page.

I look forward to constructive comments from many readers from all over the world and, hence, to updating the report accordingly in due time.

December 21, 2022
Poong Hyun Seong
INSC Chair (2021-2022)

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ASIA-PACIFIC REGION

Brief history of nuclear development in the Asia-Pacific Region

The Asia-Pacific Region comprises Australia, China, Japan, South Korea, and Taiwan. A brief history of nuclear development in the Region is highlighted below, by country.

Australia

The prospect of nuclear power in Australia has been a topic of public debate since the 1950s. Australia has never had a nuclear power station. Australia hosts about 30% of the world's uranium deposits and was in 2021 the world's third largest producer of uranium after Kazakhstan and Canada[1]. Historically, Australia's extensive low-cost coal and natural gas reserves have meant there has been little need to introduce nuclear power. However, there is increasing interest in the benefits of nuclear power as a means of reducing carbon emissions and replacing fossil fuel energy generation.

An anti-nuclear movement developed in Australia in the 1970s, initially focusing on prohibiting nuclear weapons testing and limiting the development of uranium mining and export. The movement also challenged the environmental and economic costs of developing nuclear power and the possibility of fissile material being diverted into nuclear weapons production. In the 1990s, legislative prohibitions against nuclear power were passed in the Federal Government and some States. A resurgence of interest in nuclear power as a low-carbon generator of electricity prompted Prime Minister John Howard in 2006 to support an inquiry into the nuclear power option.

Interest in the nuclear power industry at State level led to the South Australian Nuclear Fuel Cycle Royal Commission in 2015 and, more recently, the New South Wales Uranium Mining and Nuclear Facilities (Prohibitions) Repeal Bill 2019 and the Victorian Inquiry into Nuclear Energy Prohibition (2020). Additionally, at the federal level, an Inquiry into the Prerequisites for Nuclear Energy in Australia by the House of Representatives Standing Committee on the Environment and Energy was undertaken 2019. A recommendation of this inquiry was that Australia lifts the moratorium in relation to certain types of nuclear technology, including small modular reactors [2].

There is increased interest in removing the legislative prohibitions against nuclear power, but this is likely to require bilateral support from the Liberal and Labor parliamentary parties.

China

In 1955, the China National Nuclear Corporation (CNNC) was established. On 8 February 1970, China issued its first nuclear-power plan, and the 728 Institute (now called Shanghai Nuclear Engineering Research and Design Institute) was founded [3]. On 15 December 1991, China's first nuclear power reactor, a 288 MWe PWR at the Qinshan Nuclear Power Plant, was connected to the grid [4]. It is of type CNP-300.

Figure 1: Qinshan Nuclear Power Plant(Courtesy CNNC)[i]

The nuclear safety plan of 2013 stated that beyond 2016 only Generation III plants would be started, and until then only a very few Generation II+ plants would be started [5]. In 2014, China still planned to have 58 GW of capacity by 2020 [6]. However, due to reevaluation following the Fukushima Daiichi nuclear disaster in Japan, few plants commenced construction from 2015, and this target was not met[7]. In 2019, China had a new target of 200 GWe of nuclear generating capacity by 2035, which is 7.7% of a predicted total electricity generating capacity of 2600 GWe[8].

Japan

Development of nuclear energy in Japan started with the appropriation of the national nuclear energy budget in 1954. In 1955, the Atomic Energy Basic Act was enacted to promote the peaceful use of nuclear energy. The Japan Atomic Energy Commission (JAEC) was inaugurated in the following year 1956, and the system for promoting nuclear energy development was established. Its Long-Term Plan in 1956 had given directions of Japan’s nuclear energy development and deployment. In fact, it had turned out that development of breeder reactor and fuel cycle technology were given an R&D priority and carried out as national project. In parallel, the US LWR technology was imported during the inception of nuclear energy deployment and it was JPDR (GE, natural circulation BWR, 12.5Mwe) in Tokai, that generated electricity by nuclear, 1963 for the first time in Japan. Since then, the LWR technology became the main stream for the nuclear energy deployment by utilities and reactor vendors in Japan. JAEC had also concluded in its 1966 decision that the development of a high converter, Advanced Thermal Reactor (ATR), the first to fully utilize MOX fuels, was to be pursued.

In 1970s, in response to the energy crisis created by the oil shock, the government established a system to financially support development of the local regions, to improve various infra-structures for the local residents which promised the increased welfare system and ensured healthful and safe living, which as a result made it possible to smoothly build new power plants in the regions. This system promoted the development of nuclear energy utilization as well as the development and introduction of new energy systems.

Japan, as a country lacking in natural resources, keeps a sustainable strategy and promote the nuclear fuel cycle from the viewpoint of effective use of natural resources. Construction of the Rokkasho Reprocessing Plant started in 1993 to reprocess spent fuels generated in nuclear power plants and is still an on-going effort. In 2000, the Law Concerning the Final Disposal of Designated Radioactive Waste was enacted in order to carry out the disposal of high-level radioactive waste in a planned and reliable manner. The breeder reactor development had been promoted since mid-60's in association with the fuel cycle system including design, construction and operation of Experimental sodium-cooled Fast Reactor JOYO (first criticality 1977, uprated power 140MWth with Mark-III core in 2003) in O-arai, Ibaraki prefecture, and Proto-type Liquid Metal-cooled Fast Breeder Reactor (LMFBR) Monju, with first criticality in 1994 on Shiraki site, Fukui prefecture. As of now, the Monju is taken out of commission as will be explained later.

In the policy statement for the nuclear energy which was approved by the Cabinet in October 2005, it was stated that nuclear power would be responsible for more than 30 to 40% of the total electric power generation in Japan after 2030. However, after the accident at TEPCO's Fukushima Daiichi Nuclear Power Station or the Fukushima Daiichi accident that was caused by the gigantic tsunami in the Great East Japan Earthquake in March 2011, the national energy and environmental strategy was reviewed on zero-basis. At present (2022), to maintain the stability of energy supply and demand, the policy for nuclear power is to strive to recover the trust of the public and to continuously utilize the necessary scale on the major premise of ensuring safety.

In terms of ensuring nuclear safety, Nuclear Safety Commission was established in 1978 within the cabinet of Japan. Its main roles were to plan, deliberate on and determine matters related to nuclear safety administration, e.g., reviewing safety inspections conducted by regulatory agencies including the Nuclear and Industrial Safety Agency (NISA) that was established in 2001 as oversight branch of the Agency for Natural Resources and Energy under the Ministry of Economy, Trade and Industry (METI). Based on the lessons learned from the Fukushima Daiichi accident, all these regulatory agencies were merged to the Nuclear Regulation Authority (NRA) that was established in September 2012 responsible for the nuclear safety regulations from a totally independent and neutral standpoint based on the expert knowledge.

In nuclear R&Ds, so-called all-Japan system involved universities, reactor vendors and national institutes including Japan Atomic Energy Research Institute (JAERI, established 1955, later JAEA since 2005) and Power Reactor and Nuclear Fuel Development Corporation (PNC, 1967-1998, later JNC then JAEA since 2005). JAERI in Tokai area had introduced research reactor JRR-1 that started operation in 1957, followed by several research reactors on the site, and was in principle responsible for R&Ds related to LWR safety and regulation. Whereas PNC, now JAEA, had been responsible for LMFBR and Fuel cycle related R&Ds, e.g., design and safety research, construction, operations, …, etc. ATR Fugen was constructed in Tsuruga, Fukui prefecture and operated by PNC. It was connected to the grid from 1978 to 2003. Then, the ATR project was terminated in 2005 and replaced by the MOX fueled LWRs.

The nuclear waste reprocessing plant in PNC's (later JAEA's) Tokai Works which had operated since 1977, with 1,140 tons of spent nuclear fuel reprocessed so far, is going to be decommissioned due to the massive estimated cost to meet the new regulatory standards of NRA after the 2011 Fukushima Daiichi accident.

As the first commercial nuclear power plant, a Magnox type of gas cooled reactor or GCR was introduced from the United Kingdom and started commercial operation in 1966. After that, light water reactors were adopted for commercial electric power generation.

Both first BWR and PWR plants started commercial operation in 1970. By 2010, 32 BWRs and 24 PWRs had been constructed and altogether a total of 54 units under operation. As of June 2022, there were 33 operational reactors. Nuclear power provided 11% of primary energy supply in 2010, but was reduced to only 3% in 2019. ([9],[10],[11],[12],[13],[14],[15],[16],[17])

Figure 2: Tōkai Nuclear Power Plant   By ENERGY.GOV - HD.15.058, Public Domain

South Korea

Nuclear activities were initiated when South Korea became a member of the International Atomic Energy Agency in 1957. In 1958 the Atomic Energy Law was passed and in 1959 the Office of Atomic Energy was established by the government.

Figure 3: Kori NPP (Taken from ANS publication “South Korea Reverses Course[ii]

The first nuclear reactor to achieve criticality in South Korea was a small research unit in 1962.Ten years later, construction of the first nuclear power plant began – Kori 1, a Westinghouse unit built on a turnkey contract. It started up in 1977 and achieved commercial operation in 1978.

After this, there was a burst of activity, with eight reactors under construction in the early 1980s.South Korean energy policy has long been driven by considerations of energy security and the need to minimize dependence on imported fuels. Whilst energy policy continues to have nuclear power as a major element of electricity production in the near term, the incumbent government has introduced a phase-out policy over a period of about 40 years. After drawing on Westinghouse and Framatome technology for its first eight PWR units, and Combustion Engineering (which became part of Westinghouse) for two more, the Korean Standard Nuclear Power Plant (KSNP) became a recognized design and evolved a little to KSNP+. In 2005 the KSNP/KSNP+ was rebranded as OPR-1000 (Optimized Power Reactor) apparently for Asian markets. Ten operating units are now designated OPR-1000. Based on OPR-1000 design,APR1400 was developed and all the key technologies have been completely localized. The design of APR-1400 was certified in the US, and four units were exported to the United Arab Emirates and started commercial operation successfully.

South Korean energy policy continues to recognize nuclear power as a major element of electricity production, and the nuclear power is expected to play a major role for reaching carbon neutrality in the future. Even though there once was a short period of time which the Korean government pursued a nuclear phase-out policy, but the South Korean people quickly realized the importance of nuclear power and reverted the policy democratically.

Taiwan

Nuclear power in Taiwan accounts for 5,028 MWe of capacity by means of 3 active plants and 6 reactors. This makes up around 8.1% of its national energy consumption, and 19% of its electricity generation as of 2015 [18]. The technology chosen for the reactors has been General Electric BWR technology for 2 plants and Westinghouse PWR technology for the Maanshan Nuclear Power Plant.

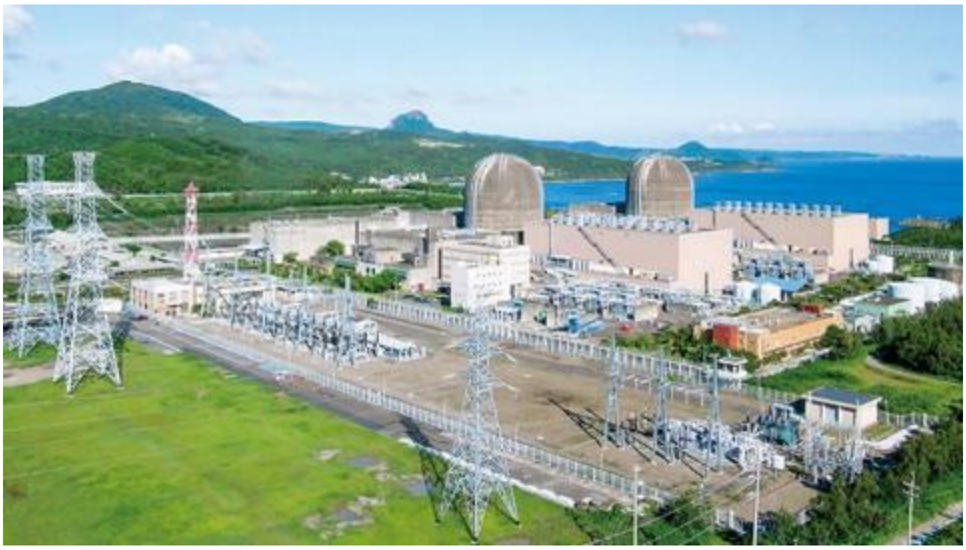


Figure 4: The Maanshan plant in southern Taiwan (Courtesy WNN)[iii]

Construction of the Lungmen Nuclear Power Plant using the ABWR design has encountered public opposition and a host of delays, and in April 2014 the government decided to suspend construction[19]. Active seismic faults run across the island, and anti-nuclear environmentalists argue Taiwan is unsuited for nuclear plants [20]. A 2011 report by the environmental advocacy group, the Natural Resources Defense Council, evaluated the seismic hazard to reactors worldwide, as determined by the Global Seismic Hazard Assessment Program data, placed all of Taiwan's reactors within the highest risk group of 12 reactors within very high seismic hazard areas, along with some of Japan's reactors[21]. The 2016 election was won by a government with stated policies that included phasing out nuclear power generation[22]. A referendum in 2018 voted to retain nuclear power[23], however in January 2019 the government stated that there would be no life-extensions for existing plants or restarts to building nuclear power plants [24].

Benefits of nuclear to the Asia-Pacific Region since inception

Australia

Australia has the world's largest Economic Demonstrated Resources (EDR) of uranium - 1,147 thousand tonnes of uranium as at 31 December 2019 - and is the world's third largest producer of uranium [25]. In 2019, Australia's uranium production was from three operating uranium mines: Olympic Dam and Four Mile in South Australia, and Ranger in the Northern Territory. Australian uranium production fell by about 30 per cent due to the cessation of mining at the Ranger mine. All of Australia's domestic production is exported. Environmental aspects of uranium exports are notable: Shipping 7000 tonnes of U_3O_8 as in 2018 is the energy equivalent of shipping 140 million tonnes of thermal coal. Australia's present thermal coal exports are about 200 million tonnes, requiring about 1,500 voyages of bulk carriers through environmentally sensitive regions such as the Great Barrier Reef. Export coal also has an environmental impact through the provision of harbours and railways.

China

While coal is the main energy source, most reserves are in the north or northwest and present an enormous logistical problem – nearly half the country's rail capacity is used in transporting coal. Because of the heavy reliance on old coal-fired plants, electricity generation accounts for much of the country's air pollution, which is a strong reason to increase nuclear share. The State Council published the Energy Development Strategy Action Plan, 2014-2020, in November 2014. The plan aimed to cut China's reliance on coal and promote the use of clean energy, confirming the 2012 target of 58 GWe nuclear in 2020, with 30 GWe more under construction. The plan called for the "timely launch" of new nuclear power projects on the east coast and for feasibility studies for the construction of inland plants. It said that efforts should be focused on promoting the use of large Pressurized Water Reactors (including the AP1000 and CAP1400 designs), high temperature gas-cooled reactors (HTRs) and fast reactors. It also said that research should be conducted to "improve the nuclear fuel-cycle system", including reprocessing of used fuel. In the 13th Five-Year Plan from 2016, six to eight nuclear reactors were to be approved each year. Non-fossil primary energy provision should reach 15% by 2020 and 20% by 2030 (from 9.8% in 2013). Annual average new nuclear capacity 2005 to 2020 is 3.4 GWe/yr, from 2020 to 2030 it is 9.0 GWe/yr.

Japan

Japan has a very low primary energy self-sufficiency rate and relies on imports for most of its energy resources. As a result, energy supply is susceptible to changes in the international situation and is fundamentally vulnerabilities.

Nuclear fuel has an overwhelmingly large energy density per unit mass and can provide electricity for several years with the amount stored in the country. For this reason, nuclear power is regarded as a semi-domestic energy source. Nuclear power generation also is characterized by excellent stable supply and economic efficiency and does not emit greenhouse gases during the plant operation. Therefore, in Japan, the nuclear power is regarded as an important base-load power source that contributes to the stability of the energy supply-demand structure.

Japan's energy demand increased during the period of high economic growth that began in the late 1950s. In terms of energy supply, the fuel transition from coal to oil progressed, and the energy self-sufficiency rate drastically decreased due to the massive import of oil. In 1960, 58.1% of the primary energy was supplied by domestic natural resources such as coal and hydropower but by 1970 it decreased to 15.3%. After that, the energy self-sufficiency rate increased to about 20% by 2010 due to the introduction of nuclear power generation. However, since 2011, when the Fukushima Daiichi accident occurred, the energy self-sufficiency rate has declined due to the decrease in nuclear power generation, and it reached as low as 11.2% in 2020.([9],[10],[11],[12],[13],[14],[15],[16],[17])

South Korea

Korea is an isolated system country in which it is impossible to export or import electricity. 42.5% of energy is used to generate electricity every year. About 20% of the final energy consumed is electricity, of which nuclear energy accounts for about 30%. In other words, nuclear power supplies roughly 12% of the energy used in the country. Nuclear power is a technology and capital-intensive power source, and fuel costs account for only 5-7% of power generation costs. The supply of low-enriched uranium, a fuel for nuclear power plants, is guaranteed under the Korea-US Atomic Energy Agreement. In addition, nuclear fuel is small in volume, making it easy to store in a small space. At the time of the second oil crisis in 1979, most of the electricity was dependent on oil in South Korea, so electricity rates more than tripled for over a year. Therefore, nuclear energy plays a role in maintaining energy security in the state of absolute poverty in energy resources. In some countries, the economic feasibility of nuclear power has been lost or the cost of post-treatment of nuclear power plants is uncertain, so the economic feasibility is being reconsidered but this is not true in South Korea. The cost reflects the post-treatment cost of nuclear power plants above the international level. For a long time, the unit price of nuclear power plants has been maintained at 40 won per kWh being the lowest of all available energy sources in South Korea, contributing to maintaining the international competitiveness of the domestic industry. Since 1982, consumer prices have risen by about 270%, but electricity rates have risen by about 50% thanks to nuclear power. The nuclear power plant industry also creates jobs and has a ripple effect in the fields of engineering, construction, operation, maintenance, and R&D. Since a nuclear power plant takes about 10 years to build and operates for more than 40+ years, it has a greater impact on related industries compared to other industries in terms of scale and duration. A good example is the UAE nuclear power plant export and operation rights order. According to the order for operation rights, stable job creation abroad and sales of 54 trillion won are expected over the next 60 years.

Taiwan

Taiwanese plants' performance has improved considerably. Their availability rose from 70% in the 1970s to 90% in the 1990s [8]. Safety indices also improved as the number of scrams decreased (30 a year in 1984 to 2 or 3 a year now) and radioactive emissions decreased. Funds are collected as part of nuclear electricity sales to pay for management of the spent fuel and for decommissioning. This NT$196+ billion (in 2009) fund is expected to cover all future liabilities and it was. Generating capacity in 2017 was 49.7 GWe. Electricity consumption grew by 60% between 1997 and 2007. Since then, consumption growth has been more modest, increasing from 230 TWh in 2007 to 260 TWh in 2017. Nuclear power has been a significant part of the electricity supply for the past two decades in Taiwan, providing around 14% of electricity generation in 2015 although this declined to 8% in 2017 due to the temporary shutdown of some reactors.

Taiwan imports about 98% of its energy, which is vital to the rapidly industrializing economy. The government has set ambitious plans for 20% of the island's electricity to be generated from renewable sources by 2025, with coal (30%) and natural gas (50%) providing the balance. There has been a concerted program to develop renewable capacity since the Renewable Energy Development Act of 2009. The Ministry of Economic Affairs (MOEA) plans 20 GWe solar capacity and 7.7 GWe wind capacity by 2025.

Problems associated with nuclear in the Asia-Pacific Region, and steps taken to resolve these problems

Australia

One of the arguments often made by opponents of nuclear power in Australia is the problem of the management of long-lived and toxic nuclear wastes, including, but not limited to spent nuclear fuel. After processes lasting many years, a site has been selected for a national radioactive waste management facility for Australia's low and intermediate level radioactive wastes, which are held in temporary storage at various locations around the country. On 29 April 2015 Josh Frydenberg MP, the Minister for Resources, Energy and Northern Australia, announced the shortlisting of a site near Barndioota in South Australia's Flinders Ranges and two sites near Kimba in South Australia. On 29 November 2021, the Minister for Resources and Water, the Hon Keith Pitt MP, declared part of the land at Napandee near Kimba as the site for the National Radioactive Waste Management Facility (NRWMF). An Australian Radioactive Waste Agency (ARWA) was established in July 2020 to manage Australia's radioactive waste.

China

Most nuclear power plants in China are located on the coast and generally use seawater for cooling a direct once-through cycle. The New York Times has reported that China is placing many of its nuclear plants near large cities, and there is a concern that tens of millions of people could be exposed to radiation in the event of an accident [26]. China's neighboring Daya Bay and Lingao nuclear plants have around 28 million people within a 75-kilometre radius that covers Hong Kong [27]. China is experiencing civil protest over its ambitious plans to build more nuclear power plants following the Fukushima nuclear disaster. There has been "inter-provincial squabble" over a nuclear power plant being built near the southern bank of the Yangtze River. The plant in the center of the controversy is located in Pengze county in Jiangxi and across the river the government of Wangjiang county in Anhui wants the project shelved[28]. More than 1,000 people protested in Jiangmen City Hall in July 2013 to demand authorities abandon a planned uranium-processing facility that was designed as a major supplier to nuclear power stations. The Heshan Nuclear Power Industry Park was to be equipped with facilities for uranium conversion and enrichment as well as the manufacturing of fuel pellets, rods, and finished assemblies. Protesters feared the plant would adversely affect their health and the health of future generations. As the weekend protest continued, Chinese officials announced the state-run project's cancellation [29]. By 2014, concerns about public opposition caused Chinese regulators to develop public and media support programs, and developers to begin outreach programs including site tours and visitor centers[30]. In 2020, Bloomberg News reported that public opposition had stopped nuclear power construction on inland river sites and caused the cancellation of a nuclear fuel plant in Guangdong in 2013[31].

Japan

Japan without natural resources has a basic policy of promoting the nuclear fuel cycle from the viewpoint of effective utilization of uranium resources, and reduction of the volume and toxicity of high-level radioactive waste. With the technology transfer from the JAEA's Tokai nuclear waste reprocessing plant operations, it is required to promote the completion and operation of the Rokkasho Reprocessing Plant of JNFL (Japan Nuclear Fuel Limited) in cooperation with the public and private sectors. At present, the construction is still on-going efforts. It is suggested to promote the construction and utilization of intermediate storage facilities to expand the storage capacity of spent fuel and, without ATR Fugen and FBR Monju, to promote the use of plutonium at light water reactors (use of MOX fuel). It is also essential to promote the investigation for the selection of final disposal site for high-level radioactive waste.

The Monju (714MWth, 280Mwe rated) was expected to be one of the critical components in Japan's nuclear fuel cycle strategy to close. With its design completed 1977, license application in 1980, construction permit obtained in 1983, construction completed in 1991, the Monju attained first criticality attained on April 5, 1994 and the first electricity output (5%) August 1995. It went into a power increase test to 40% electricity output when the sodium leak incident took place on December 8, 1995. The incident itself was not technically serious in the non-radioactive secondary system, caused by thermo-couple sheath failure leaving a concern about the quality control/assurance routines of PNC management. After long lasted nation-wide debates, and coinciding with the timing while in sought of shrinking Japan's reliance on nuclear energy as a consequence of the Fukushima Daiichi NPS accident, the government decided to decommission the Monju plant which had operated for only 250 days since its first criticality in 1994.

As such, the Fukushima Daiichi accident seriously impacted the nuclear industry, and especially damaged the public confidence in the safety of nuclear power in Japan. It is necessary to resolve public concerns about the use of nuclear power. In the questionnaire survey conducted in November 2011, immediately after the accident, 38% of the respondents answered affirmatively to the need for nuclear power generation, down from 77% in the previous year. 10 years later, in October 2021, 7.5% of the respondents wanted the immediate shutdown of all the nuclear power plants, and 53% wanted a phased withdrawal from nuclear power generation.

In the summer 2022, reflecting the unstable global energy situation, the government of Japan has started considering development and construction of the next generation innovative reactors incorporating new safety mechanisms, as well as maximizing the use of existing nuclear power plants by restarting idled nuclear reactors and extending their life. In response to the government policy statement, according to Nikkei opinion poll (Aug. 1, 2022) on nuclear power plants operation in the winter to come, 70% of respondents said they favored nuclear power plants to operate, surpassing 22% of the respondents who said no nuclear power plants should operate. Another Nikkei poll (Sep. 19, 2022) on construction of new plants, 53% of the respondents were in favor and 38% not in favor.

The Fourth Basic Energy Plan approved by the Cabinet in April 2014, which was first published after the Fukushima Daiichi accident, stated that nuclear power plants should be restarted as an important baseload power source, while at the same time, reducing dependence as much as possible. In the "Long-term Energy Supply and Demand Outlook" formulated in July 2015, the ratio of nuclear power in the energy mix in 2030 was set at 20% to 22%, and this target has been maintained up to today.

The final report by the government's investigation and verification of the Fukushima Daiichi accident was compiled and published in July 2012. In December 2011, the road map for decommissioning of the TEPCO Fukushima Daiichi nuclear power plant unit 1 ~ 4 was formulated.

As for the nuclear safety regulations, the Nuclear Reactor Regulation Act was revised in June 2012 as an effort to restore trust in the nuclear regulatory administration. This includes strengthening the measures against severe accidents and introducing the backfit system that requires existing nuclear facilities to comply with new regulatory requirements incorporating the latest technical knowledge. The Nuclear Regulation Authority (NRA) was established in September 2012, and new regulatory requirements based on the Nuclear Reactor Regulation Act were enforced in July 2013. ([9],[10],[11],[12],[13],[14],[15],[16],[17])

South Korea

Since the launch of the 7th Basic Plan, a new government was elected in May 2017. This government has introduced a policy to phase out nuclear power over a period of 40 years. Those outlined in May 2020 include increasing the share of energy from renewables to 40% of electricity generation by 2034, keeping the share of generation from natural gas at about 31-32%, reducing coal's share from 27% to 15%, and reducing the share of nuclear from 19% to 10%. The plan suggests that by 2034, South Korea will have 17 operable units. The provisional plan assumes that power demand will grow at an average of 1% a year to 2034. In July 2017 an open letter to the president signed by 27 international scientists and conservationists – including climate scientist James Hansen – called for him to reconsider his policy. It said: "If South Korea withdraws from nuclear, the world risks losing a valuable supplier of cheap and abundant energy needed to lift humankind out of poverty and solve the climate crisis". Publication of the letter came as a group of several hundred South Korean university professors and scholars also called on the president to drop his nuclear phase-out plans. Some 410 professors – including those from Seoul National University and the Korea Advanced Institute of Science and Technology – called for the government to "immediately halt the push to extinguish the nuclear energy industry that provides cheap electricity to the general public" and called for the phase-out plan to be carried out only after extensive deliberation, not only by government officials but also by industry experts.However, the new government starting from 2022 has reverted the nuclear phase-out policy and intends to rely more on nuclear power to reach carbon neutrality. The license renewal of long operating nuclear power plants will be allowed again and the new construction project will initiate to revitalize the nuclear industry. The rejection of the previous nuclear phase-out policy is a result of strong support of the South Korean people which changed dramatically in the previous government.

Taiwan

The Democratic Progressive Party elected in January 2016 has a policy of phasing out nuclear power by 2025. The MOEA in April 2015 said the closure of the three operating nuclear power plants by 2025 could result in lower economic growth rates and higher levels of pollution. The shutdown of the plants could lead to an increase of more than 10% in electricity prices and a 0.5% decline in Taiwan's GDP, while carbon dioxide emissions could rise by as much as 15%. Nevertheless, in September 2016 the government confirmed that it would not extend the operating licences of the Chinshan and Kuosheng units. After running for several months with very low reserve margin, which fell below 2% a week earlier, a problem at a large gas-fired power plant plunged half of Taiwan into darkness for about five hours on 15 August 2017. The World Nuclear Association said: “The Taiwanese government has allowed ideology to undermine public wellbeing by keeping nuclear capacity offline at a time when the country is struggling with power shortages”. The World Nuclear Association also reminded the government: “Blackouts clearly pose far greater safety risks to the people of Taiwan than the responsible use of nuclear energy. A modern society depends upon a reliable supply of electricity.” It added: “It’s clear that nuclear energy has the best safety record of any major form of electricity generation”. In November 2018 a referendum question on nuclear power in Taiwan showed 59% support for maintaining the island’s significant dependence on nuclear power, with nearly ten million votes cast.

Advances in nuclear since inception in the Asia-Pacific Region

Australia

The High Flux Australian Reactor (HIFAR) operated at Lucas Heights near Sydney from 1958 to 2007. It was used for materials research, to produce radioactive materials for medicine and industry and to irradiate silicon for the high-performance computer industry. It was a 10 MW unit which had the highest level of availability of any research reactor in the world. It was at the heart of almost all the research activities of the Australian Nuclear Science and Technology Organization (ANSTO) and supported those of several other organizations on the same site. In 2006 HIFAR was replaced by a new research reactor, known as OPAL (Open Pool Australian Light-water reactor), a modern 20 MW neutron source. It often achieves over 300 operational days per year, in the top league of the world's 240 research reactors. OPAL uses low-enriched fuel and for Mo-99 production it irradiates low-enriched targets which are then processed to recover the Mo-99. In December 2016 the draft National Infrastructure Research Roadmap was released, setting out priorities for the decade ahead. Research infrastructure such as the OPAL reactor and the Australian Synchrotron in Melbourne are recognized in the document as "a category of research infrastructure that is of such scale that the national interest is best served by landmark facilities," which rely on government investment.

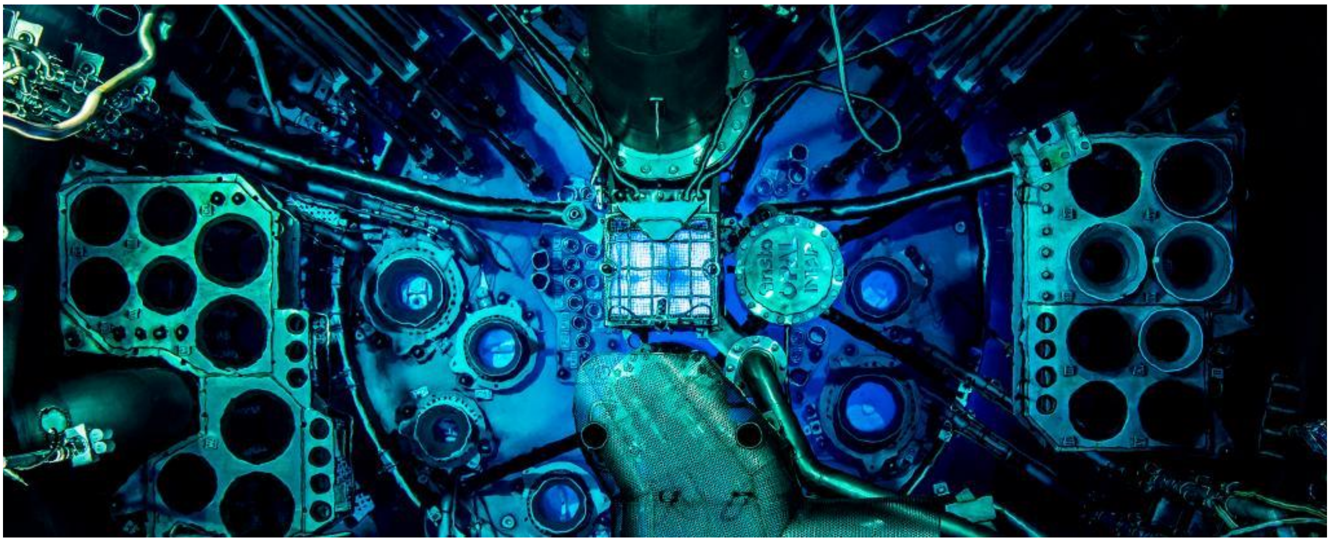


Figure 5: The OPAL Research Reactor (Courtesy ANSTO)[32]

China

China has set the following points as key elements of its nuclear energy policy. PWRs will be the mainstream but not the sole reactor type. Nuclear fuel assemblies are fabricated and supplied indigenously. Domestic manufacturing of plant and equipment will be maximized, with self-reliance in design and project management. International cooperation is nevertheless encouraged. The technology base for future reactors remains officially undefined, though two designs are currently predominant in construction plans: CAP1000 and Hualong One, after plans for more CPR-1000 units were scaled back post-Fukushima. Beyond them, high-temperature gas-cooled reactors and fast reactors appear to be the main priorities. A major struggle between the established China National Nuclear Corporation (CNNC) pushing for indigenous technology and the small but well-connected State Nuclear Power Technology Corp (SNPTC) favoring imported technology was won by SNPTC about 2004. In particular, SNPTC proposed use of indigenized 1000+ MWe plants with advanced third-generation technology, arising from Westinghouse AP1000 designs at Sanmen and Haiyang. In 2014 SNPTC signed a further agreement with Westinghouse to deepen cooperation in relation to AP1000 and CAP1400 technology globally and “establish a mutually beneficial and complementary partnership”.

Japan

In Japan, 57 nuclear power reactors (24 PWRs, 32 BWRs, 1 GCR), plus Joyo and Monju and ATR Fugen, have been constructed. At the end of 2010, before the Fukushima Daiichi accident, 54 reactors were under operation and 3 reactors (2 BWRs and 1 GCR) were closed. In July 2013, the NRA established and enforced new regulatory requirements that stipulate the strengthening of severe accident countermeasures and the introduction of backfit system as already explained in the previous section. Including the 4 reactors at the Fukushima Daiichi site, the utilities decided to close a total of 21 reactors from the viewpoint of economic efficiency in compliance with the new regulatory requirements. Currently, 33 reactors are operational, and 3 more are under construction and planned. As of June 2022, 10 PWRs have been restarted. The restart of nuclear power plants consists of safety assessment by the Nuclear Regulation Authority and explanations by operator to local government where nuclear power plants are located.

In July 2017, the Atomic Energy Commission's "Basic Policy for Nuclear Energy" was approved by the Cabinet. It suggests a long-term direction for nuclear policy. The Important initiatives and directions for future use of nuclear energy are (1) Continuous improvement of safety: zero-risk doesn't exist, (2) Nuclear energy use in addressing the global warming, nation's livelihoods and economic issues, (3) Nuclear energy in the global context, (4) Peaceful use of nuclear energy: enhancing non-proliferation and security regime, (5) Rebuilding public trust as a prerequisites of nuclear energy use, (6) Coping with Decommissioning and radioactive waste, (7) Expanded use of radiation and radioisotopes, and (8) Solid foundation for nuclear energy use. ([9],[10],[11],[12],[13],[14],[15],[16],[17])

South Korea

Nuclear power is a major power source in South Korea, providing 29% of the country's electricity.[33] The total electrical generation capacity of the nuclear power plants of South Korea is 20.5 GWe from 23 reactors, equivalent to 22% of South Korea's total electrical generation capacity.[33] In 2012 South Korea had plans for significant expansion of its nuclear power industry, and to increase nuclear's share of generation to 60% by 2035.[34] Eleven more reactors were scheduled to come online in the period 2012 to 2021, adding 13.8 GWe in total.[35]However, in 2013 the government submitted a reduced draft plan to parliament for nuclear output of up to 29% of generation capacity by 2035, following several scandals related to falsification of safety documentation.[33] This plan still involved increasing 2035 nuclear capacity by 7 GWe, to 43 GWe[36]. However, responding to widespread public concerns after the Fukushima Daiichi nuclear disaster in Japan, the high earthquake risk in South Korea, and the nuclear scandals, the new government of President Moon Jae-in elected in 2017 decided to gradually phase out nuclear power. The three reactors currently under construction will be completed, but the government decided these will be the last built, and as the existing plants close at a 40 years end-of-life they will be replaced with other modes of generation. ([37],[38]) In 2020 it was planned that the number of nuclear reactors would be reduced to 17 by 2034, after a peak of 26 in 2024 [39].This policy has now been reversed in the new government starting from 2022 and the license renewal will commence with the end-of-life nuclear power plants to rely more on nuclear power. Moreover, the new government led by Yoon, Suk-yeol, plans to export more than 10 nuclear power plants abroad and strong governmental support to meet this goal is expected.

Taiwan

Taiwanese law requires that applications for decommissioning must be filed by the licensee three years prior to the scheduled final shutdown of a reactor and that it must be approved by authorities before decommissioning can commence. In January 2016 Taipower published a decommissioning plan for Chinshan. Decommissioning is to be over 25 years, in four stages: shutdown and defuelling to end of 2026, dismantling to 2038, testing to 2041, and site restoration to 2044. The used-fuel pool will be removed over 2027-31. In October 2018, both Chinshan units were permanently shut down.

There have been six research reactors in operation on Taiwan, most very small and now shut down and being decommissioned. Only THOR, a 2-MW Triga unit, at National Tsing Hua University is operating. TRR, a 40-MW heavy-water reactor, was shut down in 1987 and was to be redesigned as a light-water reactor but is dismantled. Currently there are four nuclear research centers in Taiwan, ranging up to 2.8 MW. [41] According to Dr. Cheng Chio-Zong, [42] Taiwan has to step up its pace in fusion power research if it wishes to develop more sources of "clean" energy.

Current and Future state of Nuclear in the Asia-Pacific Region:

Australia - Current state of nuclear in Australia

Australia has a significant infrastructure to support any future nuclear power program. As well as the Australian Nuclear Science & Technology Organization (ANSTO), which owns and runs the modern 20 MWt OPAL research reactor, there is a world-ranking safeguards set-up – the Australian Safeguards & Non-proliferation Office (ASNO), a nuclear safety regulator - the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) and a well-developed uranium mining industry. The main driver for nuclear power is Australia's commitment to reduce CO2 emissions and achieve net zero emissions by 2050. There are several legal hurdles impeding consideration of nuclear power in Australia. NSW has a Uranium Mining and Nuclear Facilities (Prohibition) Act 1986, and Victoria has a Nuclear Activities (Prohibitions) Act 1983. Federally, the Environment Protection and Biodiversity Conservation Act 1999 and Australian Radiation Protection and Nuclear Safety Act 1988 will need to be amended to remove prohibitions against effective regulation of nuclear power. In November 2018 the International Atomic Energy Agency (IAEA) completed a 12-day integrated regulatory review service mission focused on ARPANSA to assess the regulatory framework for nuclear and radiation safety in Australia.

China - current state of nuclear in China

China is one of the world's largest producers of nuclear power. The country ranks third in the world both in total nuclear-power capacity installed and electricity generated, accounting for around one tenth of global nuclear power generated. Nuclear power contributed 4.9% of the total Chinese electricity production in 2019, with 348.1 TWh[8]. As of June 2021, China has a total nuclear power generation capacity of 49.6 GW from 50 reactors, with an additional 17.1 GW under construction [43]. Nuclear power has been looked into as an alternative to coal due to increasing concerns about air quality, climate change and fossil fuel shortages ([44][45]). In 2009, China's National Development and Reform Commission indicated the intention to raise the percentage of China's electricity produced by nuclear power to 6% by 2020 [46]. China aims to maximize self-reliance on nuclear reactor technology manufacturing and design, although international cooperation and technology transfer are also encouraged. Advanced pressurized water reactors such as the Hualong One are the mainstream technology in the near future, and the Hualong One is also planned to be exported. By mid-century fast-neutron reactors are seen as the main technology ([47],[48]), with a planned 1400 GW capacity by 2100([49],[50],[51]).

Japan - current state of nuclear in Japan

The Sixth Strategic Energy Plan, approved by the Cabinet in October 2021, adopted the policy of "Put safety first, respect the judgment of the Nuclear Regulation Authority, and promote the restart of nuclear power plants". Of the 33 operational reactors, as of June 2022, 17 had complied with the new regulatory requirements and approved to restart, of which 10 PWRs have been restarted. Most recently, The Kansai Electric Power Co., Inc. Mihama Power Station Unit 3 became the first in Japan to be approved for operation beyond 40 years and restarted in June 2021.

In the nuclear fuel cycle field, Japan is working to deal with the approximately 19,000 tons of spent fuel in the country. Japan Nuclear Fuel or JNFL's Rokkasho Reprocessing Plant received permission from the Nuclear Regulation Authority (NRA) for the modification of safety measures in July 2020 and planned to be completed in fiscal 2022 with safety as the top priority. The company's MOX fuel fabrication plant also received permission for the modification of safety measures in December 2020 and is working toward completion in fiscal 2024. Proper management and use of plutonium are essential for the completion of the Rokkasho Reprocessing Plant. In February 2021, the Federation of Electric Power Companies (FEPC) of Japan announced a new plutonium utilization plan.

Since autumn 2020, efforts have been made to expand the storage capacity of spent fuel interim storage. The onsite dry interim storage at the Ikata and Genkai Nuclear Power Station and the Recyclable Fuel Storage Center received regulatory clearances from the NRA.

With regard to the final disposal of high-level radioactive waste, the government is taking the lead in promoting dialogue activities with The Nuclear Waste Management Organization of Japan (NUMO) which is engaged in the mission of implementing safe geological disposal of radioactive waste. The number of groups interested in geological disposal projects is gradually increasing nationwide. In November 2020, literature survey of the geographical features was initiated in 2 regions of Hokkaido.

Measures for the decommissioning, contaminated water, and treated water at the Fukushima Daiichi Nuclear Power Station, where core meltdown took place, are being implemented based on the Mid-and-Long-Term Roadmap which was revised in December 2019. Under the principle of "balancing regional reconstruction and decommissioning," the government is taking the lead in steadily promoting the measures.

Cooling water of the fuel debris and groundwater that entered the reactor building on the accident site of Fukushima Dai-ichi Nuclear Power Station have been purified by the Advanced Liquid Processing System (ALPS) and stored on the site. In April 2021, the government announced its policy to discharge ALPS-treated water into the ocean on the condition that the public health and environmental protection are ensured and that the government takes thorough measures against rumors. The planned total amount of tritium discharge is below about 22 trillion Bq per year, much less than the actual discharge of about 100 trillion Bq from nuclear power plants in Japan or neighboring countries in compliance with the laws and regulations of respective countries. The IAEA also published the first report on its review results of Japan’s policy of the discharge of ALPS-treated water in February 2022. The report concludes that radiation effects on humans have been confirmed to be significantly lower than levels set by Japanese regulators. The IAEA review mission on this issue will continue. ([9],[10],[11],[12],[13],[14],[15],[16],[17])

South Korea -current state of nuclear in South Korea

In 1994, the Atomic Energy Commission decided on the “Long-term Nuclear Policy Direction for 2030”, and started the long journey toward technological independence of nuclear power plant construction and nuclear power export. The design technology of the nuclear steam supply system was transferred from the United States, and nuclear technology independence and localization were achieved. The 1,000-MW Korean Standard Nuclear Power Plant OPR1000 (Optimized Pressurized Water Reactor, later improved to APR-1000) was developed, and Hanul Units 3 and 4 were built for the first time in 1998 and 1999, respectively. In the 2000s, the nuclear power plant design code, the reactor coolant pump, and the nuclear power plant control and instrumentation technology development, which are core technologies that are not self-reliant, were started, and complete independence of all technologies was completed in 2012. From the design of nuclear power plants to equipment supply, construction, commissioning and operation, it achieved independence in all nuclear industry technologies. Based on this, the APR-1400 (Advanced Power Reactor-1400 MW) with an electrical output of 1400MW, which greatly improved safety and economy, was developed. The APR-1400 is the Shin-Kori Units 3 and 4 and the 4 nuclear power plants that the UAE signed an export contract with in 2009. Also, in the research reactor sector, the JRTR research reactor was exported to Jordan in 2009 and completed in 2016. In the small modular reactor sector, in 2015, a contract was signed with Saudi Arabia to export SMART reactor design technology (power capacity of 100MW), a multi-purpose small reactor designed by a Korean industry consortium.

Taiwan -current state of nuclear in Taiwan

In 2019 it was announced that the Chinshan plant would commence decommissioning, and in July 2021 Kuosheng 1 was shut down. All remaining reactors are operated by the utility Taipower, under the MOEA, and were initially expected to have 40-year operating lifetimes. Five of the six units had undergone minor upgrades by the end of 2008, resulting in a net increase of 44 MWe. In 2009 Taipower said that it planned to replace the steam generators of the two Maanshan PWR reactors by about 2020 if it could obtain operating licence extensions from the Atomic Energy Council (AEC). This and other work would have yielded uprates of some 440 MWe across the six reactors. In 2007 the AEC said that the Chinshan BWR plant had undergone a safety evaluation and was safe to run for a further 20 years following the planned licence expiry in 2017. The AEC had approved this lifetime extension, though in November 2011 a new national energy policy disallowed it and affirmed simply a 40-year operating lifetime. Taipower had expected to seek 20-year licence renewals for all six reactors. In December 2013 Taipower submitted a new application for lifetime extension of Chinshan, and the AEC safety evaluation report was expected late in 2016. However, due to the new energy policy of the ruling Democratic Progressive Party, Taipower withdrew the application in July 2016, and AEC ceased its evaluation accordingly. In July 2019 the AEC approved decommissioning plans for both Chinshan units over a 25-year period. Nuclear output on Taiwan can be a very cost competitive option. MOEA figures quoted in 2014 showed electricity from nuclear plants at NT$ 0.72 per kWh, compared with that from LNG being NT$ 3.8/kWh, wind NT$ 2.6/kWh and solar NT$ 6 to 9/kWh.

Australia - Future state of nuclear in Australia

In December 2016 the draft National Infrastructure Research Roadmap was released, setting out priorities for the decade ahead. Research infrastructure such as the OPAL reactor and the Australian Synchrotron in Melbourne are recognized in the document as "a category of research infrastructure that is of such scale that the national interest is best served by landmark facilities," which rely on government investment. In September 2012, ANSTO announced a $168 million expansion of its Sydney facilities, principally for molybdenum-99 (Mo-99) production, the source of technetium-99 which is widely used in nuclear medicine for diagnosis. The new plant became operational in 2018 and more fully utilizes the OPAL reactor's capacity. The investment also covers building an industrial-scale plant for Synroc waste form to immobilize the intermediate-level wastes from Mo-99 production. ANSTO hopes that the Synroc technology “will become the benchmark for waste treatment in the production of Mo-99 radiopharmaceuticals."

China -Future state of nuclear in China

As of 2020, China had 45GW of operational nuclear power, with 11GW under construction. Bloomberg News reported that the 2020 National People's Congress supported future building of 6 to 8 reactors a year, which Bloomberg considered likely to be dominated by the domestic Hualong One design[31]. In 2019, China had a new target of 200 GWe of nuclear generating capacity by 2035, which is 7.7% out of predicted total electricity generating capacity of 2600 GWe[8]. In January 2011, the Chinese Academy of Sciences began the TMSR research and development project to create reactors which, among other advances, will be air-cooled. A small prototype reactor of this type, the TMSR-LF1, is planned [52]. The LF1 will be sited in Gansu province[53], in an industrial park in Minqin County [54]. In February 2019, China's State Power Investment Corporation (SPIC) signed a cooperation agreement with the Baishan municipal government in Jilin province for the Baishan Nuclear Energy Heating Demonstration Project, which would use a China National Nuclear Corporation DHR-400 (District Heating Reactor 400 MWt) ([55],[56]).

Japan -Future state of nuclear in Japan

In October 2020, Prime Minister declared that Japan aims to reduce its greenhouse gas emissions by 46% in fiscal year 2030 from its fiscal year 2013 levels, setting an ambitious target which is aligned with the long-term goal of net-zero by 2050. Furthermore, he stressed that Japan will continue strenuous efforts in its challenge to meet the lofty goal of cutting its emission by 50%. Based on this declaration, the Cabinet approved the Sixth Strategic Energy Plan in October 2021. Plans for 2050 call for all options to be pursued in the energy sector, which accounts for more than 80% of greenhouse gas emissions. In the field of nuclear power, it is stated that the necessary scale of nuclear power generation will be continuously utilized on the major premise of securing public trust and ensuring safety.

The basic policy for 2030 is based on safety as a major premise, placing priority on the stable energy supply, and promoting low-cost energy supply and environmental friendliness. The specific target for 2030 is to reduce energy demand from 363 million kl in 2013 to 2.8 million kl by thorough energy saving. The electricity production will be 20 ~ 22% nuclear, 36 ~ 38% renewable, 1% hydrogen and ammonia, 20% LNG, and 19% coal. Reduce CO2 emissions from energy sources by 45% from 2013 levels by 2030. The energy self-sufficiency rate will be improved from 12.1% in 2019 to about 30%. The basic policy for nuclear energy is to promote the stable use of nuclear energy, build a relationship of trust with local governments, and promote research and development on the premise of ensuring safety. The policy of Nuclear R&D up to 2030 is to steadily promote the development of fast reactors through international cooperation, to demonstrate the technology of small modular reactors through international cooperation, and to establish the elemental technology related to hydrogen production in high temperature gas reactors, while utilizing the ingenuity and knowledge of the private sector. It also intends to work on fusion research and development through international cooperation such as the ITER program. ([9],[10],[11],[12],[13],[14],[15],[16],[17])

South Korea -Future state of nuclear in South Korea

The government's 7th Basic Plan for Long-term Electricity Supply and Demand (2015-2029) was released by the Ministry of Trade, Industry and Energy (MOTIE) in July 2015. The plan envisages 13 new reactors to be in operation by 2029, with Kori 1 closed by then. This is five more than outlined in the 6th Basic Plan in 2013. Electricity demand is expected to increase by 2.2% annually to 2029, reaching 657 TWh/yr and with peak demand of 112 GWe, but this outlook is dependent on aggressive conservation measures. Nuclear capacity would increase to 38.3 GWe, 28.2% of the total, up from 21.7 GWe in 2015, but less than the 42.7 GWe target for 2035 outlined in the January 2014 2nd Korea Energy Master Plan. In the newly elected government in 2022, the role of nuclear power is more emphasized for achieving carbon neutrality and the share of nuclear power is expected to steadily rise in the future. South Korea is seeking to export its nuclear technology, with a goal of exporting 10 nuclear reactors by 2027. The currently operating nuclear power plants in South Korea will be seeking license renewal in the following decades to extend the operation while new construction projects will continue to expand the role of nuclear energy in the country.

Taiwan -Future state of nuclear in Taiwan

Former president Lee Teng-hui in 2013 stated that Taiwan could not afford to abandon nuclear power in the near future and should enhance its nuclear energy program by developing advanced nuclear technologies, such as nuclear fusion[41] . Lee Teng-hui also stated that wind and solar sources of energy both have limitations and could not fill the void left by nuclear power [41]. In 2013, Don Shapiro, Senior Director of the American Chamber of Commerce in Taipei, noted that risks regarding nuclear safety and security will need to be weighed against the risk of serious power shortages and substantially higher electricity costs if Taiwan abandons the nuclear option. He further observed that nuclear power currently accounts for about 17 percent of the electricity generated in Taiwan, and President Ma Ying-jeou has already stated that the existing three nuclear plants will be decommissioned when their authorized 40-year lifespans expire between 2018 and 2025. Without a new nuclear plant or extension of the old ones, Shapiro questioned whether Taiwan has feasible options for meeting its energy needs, since in Shapiro's opinion, renewable sources such as solar and wind energy are not sufficient to take up that slack, coal-fired plants face opposition on environmental grounds, and heavy reliance on liquefied natural gas – which is highly expensive to transport and store – could be so expensive as to undermine Taiwan industry's competitiveness [19]. President Tsai Ing-wen said in January 2015 that her party aimed to phase out nuclear power in Taiwan by 2025.

The Role of nuclear in the future in the Asia-Pacific Region based on policy statements by government and stakeholders

Australia

Australia is a preferred uranium supplier to the world, especially East Asian markets where demand is growing most rapidly. An agreement with the United Arab Emirates (UAE) came into force in 2014, and another with India came into force in November 2015, at which time administrative arrangements for each were also finalized and they became operational. In 2016 a bilateral agreement was signed with Ukraine. This made the total 25 treaties covering 43 countries plus Taiwan.

China

China has a determined policy of exporting nuclear technology, based on development of the CAP1400 reactor, and subsequently the Hualong One reactor, with Chinese intellectual property rights and backed by full fuel cycle capability. The 'go global' policy is being pursued at a high level politically, utilising China's economic and diplomatic influence. In January 2015 the cabinet announced new incentives and financing for industry exports, particularly nuclear power and railways, on the back of $103 billion outbound trade and investment in 2014. In May 2017 the Belt & Road Initiative (BRI) was formally launched, with much fanfare, to boost global connectivity and trade and inviting countries to become partners in the BRI. Projects in Pakistan, Indonesia, eastern Europe and northern Africa were mentioned along with Chinese funding of $75 billion from banks, $20 billion through a new Silk Road Fund, and $12 billion as aid. CNNC and SPIC/SNPTC are focused on the export potential of the CAP1400, and SNPTC aims at “exploration of the global market” from 2013, particularly in South America and Asia. The Hualong One reactor is also intended for export, with CGN focusing on Europe and CNNC elsewhere, particularly Pakistan and South America. CNNC is keen to export the Hualong One reactor more widely, and says it is open to EPC (engineering, procurement, construction), BOT (build, operate, transfer) and BOO (build, own, operate) project models. It sees potential for selling up to 30 Hualong One reactors abroad through the BRI.

Japan

The IEA expects the global nuclear capacity to double up to 800 GW by 2050 with the expansion of global warming countermeasures. In particular, in the Asia-Pacific region, a large portion of the coal-fired power generation is expected to be replaced by nuclear power, and the amount of nuclear power generation is expected to increase threefold due to strong demand for electricity and global pressure for decarbonization.

In these circumstances Japan published an interim report on its Green Growth Strategy in May 2022. It is a strategy to ensure the stable and affordable energy supply in the future based on the Strategic Energy Plan and other factors, and to promote energy transformation on the demand side, such as industry, leading to further economic growth.

Regarding the nuclear power sector, it is reported that the government will accelerate research and development of innovative reactor technologies through public-private partnerships, and strengthen the technology and human resources of the nuclear industry and research institutes in pursuit of global standards through strategic partnerships with the United States, Britain, France, and other countries. More specifically, it is reported that the government will promotes research and development to improve the safety of light water reactors, continuing promotion of fast reactor development and demonstration of small modular reactor technology through domestic efforts as well as international cooperation, establishment of elemental technology related to hydrogen production in high temperature gas reactors, technological development and demonstration of the fusion technology through international cooperation such as the ITER program, and human resource development.

In addition, it is proposed that JAEA, which has accumulated a wealth of nuclear technology, and the Japanese industries with high-quality manufacturing capabilities should participate in the international development projects such as those initiated in the United States, France, the United Kingdom, and other countries in cooperation with each other, and that through these projects, Japan would be in the position to gain the global standards of innovative reactors, e.g., liquid metal-cooled fast reactors, small modular reactors and high-temperature gas reactors. It is considered important for Japanese suppliers to effectively participate in international projects for innovative reactors. It is proposed that a strategic team should be formed at a national level to enable this participation and that the government should support the creation of business opportunities for Japanese suppliers through the acquisition of certification for international code and standards and business matching with overseas companies.([9],[10],[11],[12],[13],[14],[15],[16],[17])

South Korea

The main roles of nuclear R&D of South Korea are to ensure that the national energy supply is secure, and to build the country's nuclear technology base to support nuclear exports. The Korea Atomic Energy Research Institute (KAERI) is the main body responsible for R&D. Particular goals established in 1997 include reactor design and nuclear fuel, nuclear safety, radioactive waste management, radiation and radioisotopes application, and basic technology research. Nuclear power research in South Korea is also very active with projects involving a variety of advanced reactors, including a small modular reactor, a liquid-metal fast/nuclear transmutation reactor, and a high-temperature hydrogen generation design. Moreover, the Korean research institutions are now also focused on the molten salt reactor development as well. Fuel production and waste handling technologies have also been developed locally. South Korea is also a member of the ITER nuclear fusion research project. Recently, the Korean government plans to spend R&D funding of $300 Million for developing the innovative SMR (iSMR), which can replace old and small coal power plants around the world. The project is targeted to obtain standard design certificate until 2028, so that it can contribute to carbon-neutrality around the world in 2030s.

Taiwan

All nuclear facilities on Taiwan are subject to a non-governmental safeguards agreement with the International Atomic Energy Agency, and all fall under full safeguards. Taiwan signed the Nuclear Non-Proliferation Treaty (NPT) in 1968 and ratified it but after 1971 the People's Republic of China replaced Taiwan in the NPT and the IAEA. In terms of such treaties and organizations, and for those countries which adhere to a one-China Policy, Taiwan does not exist as an independent state. The USA recognizes Taiwan as an independent state and has state-to-state relations with it. Taiwan has a unique status. Nuclear safeguards are applied in Taiwan under a trilateral agreement between Taiwan, the USA and the IAEA. Thus, the IAEA applies safeguards in Taiwan to all nuclear material and nuclear facilities as if it were an NPT non-nuclear-weapon-state Party; it conducts regular inspections including Additional Protocol verification activities.

Conclusion

Australia's uranium has been mined since 1954, and two mines are currently operating. More are planned. Australia's known uranium resources are the world's largest – about one-third of the world total. In 2019 Australia produced 7798 tonnes of U_3O_8 (6612 tU). It is the world's third-ranking producer, behind Kazakhstan and Canada. All production is exported. Uranium comprises about one-quarter of energy exports. Australia uses no nuclear power, but with high reliance on coal any likely carbon constraints on electricity generation will make it a strong possibility. In May 2016 the South Australian government held a royal commission on the nuclear fuel cycle. Its main recommendation was for an international high-level nuclear waste repository, though this was not accepted. In 2019, a Federal Inquiry recommended that

Australia lift the current moratorium for certain types of nuclear technology, including small modular reactors.

The impetus for nuclear power in China is increasingly due to air pollution from coal-fired plants. China's policy is to have a closed nuclear fuel cycle. China has become largely self-sufficient in reactor design and construction, as well as other aspects of the fuel cycle, but is making full use of western technology while adapting and improving it. Relative to the rest of the world, a major strength is the nuclear supply chain. China's policy is to 'go global' with exporting nuclear technology including heavy components in the supply chain

Japan depends on imports for about 90% of its primary energy needs. For this reason, nuclear power plays an important strategic role in national energy security. Since the first commercial reactor started operation in Japan in 1966, nuclear power generation has been positioned as an important base-load power source that contributes to the long-term stability of the energy supply-demand structure. However, nuclear power generation accounted for about 25% of Japan's total power generation in 2010 but fell to 6% in 2019 due to the Fukushima Daiichi accident.

Under these circumstances, the energy strategy announced in October 2021 aims at achieving Net Zero by 2050 and increasing the share of the nuclear power generation to 20 ~ 22% by 2030. Currently, there are 33 operational reactors, of which 10 have been restarted, and the rest are undergoing inspections and/or relevant improvements for restart.

In addition, efforts are being made for the establishment of nuclear fuel cycles and the final disposal of high-level radioactive materials. The decommissioning of the Fukushima Daiichi NPS is being steadily promoted in line with the Roadmap.

In the future, Japan will accelerate research and development of innovative nuclear reactor technology through the public-private partnership and strengthen the technology and human resources of the nuclear industry and research institutes.

24 reactors provide about one-third of South Korea's electricity from plants with a total capacity of 23 GWe. South Korea is among the world's most prominent nuclear energy countries, and exports its technology widely. It is currently involved in the building of the UAE's first nuclear power plant, under a $20 billion contract. Nuclear energy is a strategic priority for South Korea, and it will be for the future, even though there was a short period of time which the Korean government planned for nuclear phase-out policy. South Korean people now realize the nuclear power is essential energy source in order to grow sustainably while meeting the carbon neutrality goal at the same time.

Taiwan has three operable nuclear power reactors, which account for about 10% of the island's electricity generation. Two advanced reactors were under construction, but this project was cancelled. Existing nuclear power is considerably cheaper than the alternatives. The Democratic Progressive Party elected in January 2016 has a policy of phasing out nuclear power by 2025. A November 2018 referendum showed 59% support for continued use of nuclear power.

EUROPEAN REGION

Brief history of nuclear development in Europe

The first period of nuclear development in Europe *(1950-1980: from science to industrial deployment)* has been the result of the very fast scientific and technological developments for civil purposes following the 1953 Atoms for Peace call of President Eisenhower, and the creation, under the auspices of the United Nations, of the IAEA in 1957. France and the UK had been close to military nuclear developments during the second world war, which allowed them to be the first in row in Europe to build their indigenous research programs, facilities and prototypes.

The European reconstruction after the war was requiring massive access to energy. The European Atomic Energy Community (Euratom) Treaty, one of the founding pillars of the European Communities (now the European Union) promoting the development of nuclear energy, was signed in 1957, laying the ground for nuclear cooperation among the six founding Member States. The Treaty covered a broad range of issues: common nuclear research and information sharing, radiation-protection standards, investments and joint undertakings, fuel supply, safeguards, international relations. The Treaty is a model still in force today in the 27 Member States of the Union, complemented by secondary legislation.

The 60shave seen the launch of the national industrial nuclear programs, most countries willing to proceed with their own reactor types and resources, in some cases constrained by their limited access to sensitive fuel-cycle technologies. It was the case particularly in France and the UK developing their domestic graphite-gas-cooled reactor lines (in France: Uranium Naturel Graphite Gaz - UNGG, and also the heavy water gas cooled HWGCR Brennilis), and in UK: MAGNOX, and, also the heavy water light water cooled SGHWR Winfrith).


Figure 6: The UK's iconic SGHWR (left) and the France's Experimental HWGCR (Right)

A specific mention can be made for Belgium, which hosted the very first PWR reactor in Europe, the 10 MWe BR3 based on the Shippingport design, built with the support of the US as a return for the uranium ore delivered in support to the Manhattan project (more mention is made of the Manhattan project under “Canada”). Some prototypes and demonstrators have been built as cooperative Joint Undertakings under the Euratom Treaty (e.g., the THTR 300 - a Thorium Helium-cooled reactor in Hamm-Uentrop, Germany) or under the Organisation for the European Economic Cooperation, which later became the OECD Nuclear Energy Agency (e.g., the Dragon Project in the UK – a High Temperature Graphite-Helium-cooled prototype reactor). One can also mention the other large joint undertaking under the OECD: Eurochemic in Belgium, an industrial pilot plant for spent-fuel reprocessing, which operated from 1966 until 1974, demonstrating technologies which would then be further industrially deployed in France (La Hague) and the UK (Sellafield). One can say, in a nutshell, that during this decade “all” reactor technologies were tested in principle, in one way or another, at demonstrator or prototype scale.

During the 1970s, nuclear power was deployed at a large industrial scale, boosted by the oil crisis of 1973. This was mainly the case in Europe, much dependent on the import of oil from the Middle East. Interesting to note that France also decided at that time to switch from the national UNGG technology to the US imported Pressurized Water Reactor (PWR) technology, further adapted into a national product, to allow a faster and cheaper deployment at large scale. In all countries that decided to go for peaceful applications of nuclear fission, political support and public-sector investments were necessary to enable the launch of the deployment of the nuclear fleets, as well as the development of the fuel-cycle and supply-chain industry. In most if not all cases, this was done via state-owned organizations or companies, or at least operating under state control. One has to mention that large demonstrators of sodium-cooled fast-neutron reactors were also built during this period: e.g., Phenix/Superphenix reactors in France, PFR Dounray in the UK, SNR300 Kalkar in Germany as a German/Dutch/Belgian project (completed but never started). On the side of the fuel cycle, MOX fuel fabrication plants were built and fuel tested in reactors, in particular in Belgium (Mol) and France (Cadarache) – opening the path for the later Melox plant in France. A large-scale MOX plant in Hanau Germany was completed in the 1990s, but never started.

Then came 1979 and the Three Miles Island (TMI) Accident. While there were no radiological consequences for the environment, it was a major shock in Europe. Core melt had occurred in a power plant, having economic consequences, increasing the fears of the populations, and strengthening the anti-nuclear green movement.

The second period *(1980-2000: the time of uncertainties in a transition towards a market driven electricity system)* has first seen a continuation of a high construction rate during the first decade, mainly implementing investment decisions taken before 1980. But decisions to build more plants have been drastically reduced. This reduction in the rate of new investment decisions was in part most probably a consequence of the TMI accident and its impact on the policy makers and public opinion.

This trend was reinforced during the second decade. The beginning of the 90ths saw a major change, which had much more impact than initially expected, on the future of nuclear new build. The vision of the “end of history” and the credo in the free market as the best way to serve humanity, much promoted in the western world (US and EU) by the Reagan-Thatcher policies, led to the process of liberalization of the electricity sector, considering electricity as a commodity as any other commodity in a market driven economy.

At the end of the millennium, the European Union had a fleet of 140 reactors in operation, delivering one third of its electricity needs.

One has to mention the 1986 Chernobyl accident, the worst in the history of nuclear power. The causes have been analyzed in depth. Even if the Soviet System and design weaknesses of RBMKs were at the origin, the lessons were learned everywhere. Nevertheless, for the public opinion, it was the demonstration that a nuclear accident may lead to significant consequences to people, including deaths and illnesses. In some countries, such as Italy, nuclear programs were terminated for good. In Germany, the Russian VVER type reactors in Greifswald were stopped at the time of reunification. It also had a longer-term impact at the time of the enlargement of the European Union to Central and Eastern European Countries, with the requirement, besides the closing of two RBMKs in Lithuania, to close six first-generation VVERs in Bulgaria and Slovakia.

Figure 7: Two VVER-440 units in Loviisa, Finland (Courtesy of Wikipedia)[iv]

The third period *(2000-2020: the paradigm shift with climate change and the rise to renewable energy)* has seen the issue of climate-change rise to the highest level of societal and political concern. Reducing the release of GHG emissions from all human activities (energy, transport, industry, residential sector, services, agriculture, …) became early a high priority in the European Union. Burning fossil fuels to produce electricity is a major contributor to the production of CO2, besides other pollutants. The declared objective of the COP21 in Paris in 2015 has been to limit the temperature rise to a maximum of 2°C by the end of the century, and even to target a limit of 1.5°C. To contribute to this endeavor, the production of electricity should be drastically decarbonized by 2050.

In Europe, very-low-carbon Renewable Energy sources (RES) have been favored by public opinion and by political leaders, starting already about two decades ago, and strongly supported since then by energy policies and subsidies to foster their take-off and cost reduction. Because these energy sources, wind and solar photovoltaics (PV), are intermittent and non-dispatchable as well as diffuse and decentralized, a large recourse to these energy sources requires adaptation of the whole electricity system, impacting traditional technologies of electricity production, including particularly baseload nuclear power plants, while these are also carbon-free compared to coal- and gas-fired power stations.

This, combined with the evolving liberalization of the electricity market(s), strongly promoted and pushed by the European Institutions, even more when biased by artificial supporting mechanisms for intermittent renewable sources (diverse forms of public subsidies, priority access to the grid, …), are making the analysis and decision processes difficult for the nuclear industry and for investors, at a time when a number of existing large power plants are entering retirement age. Deciding to go for long-term operation or building new plants is even more complex in the specific case of the European Union, where energy policies are the prerogative of the Member States, having very diverse views on the role nuclear energy has to play, while the electricity network is becoming more and more interconnected at the continent level and climate targets are set at the EU level.

The first years after 2000 have seen the so-called “nuclear renaissance”. It was the time when France and Germany decided to plan for the longer term by developing jointly a reactor to replace the existing fleet when the time would come, and to have a common European product for export. That was the origin of the EPR (European Pressurized Reactor). Global nuclear development scenarios were quite optimistic at that time with a doubling, or even a tripling, of the worldwide nuclear capacity by 2020, up to more than 1000 GWe. Worth mentioning, in the EU, a legally binding regional multi-country nuclear framework was adopted, for the first time over and above the national regulations, focusing on nuclear safety beyond radiation protection (Euratom Safety Directive of 2009), and waste management (Euratom Waste Directive of 2011), potentially helping a less controversial debate on the role of nuclear in the EU. The Waste Directive provides for close monitoring of national programs for the construction and management of final repositories, as well as legally binding safety standards. Member States published their first national nuclear- waste management programmes in 2015, and every three years they submit national reports on the implementation of the directive.

One must also mention the launch in 2001 of the Generation IV International Forum (GIF), initiated by the US and grouping nuclear-advanced countries with the objective to mutualize nuclear research on advanced nuclear reactors, aiming for a deployment starting around 2040.Most of the selected reactor designs use fast neutrons, in order to make a better use of the uranium resources by exploiting efficiently (in fact, breeding) the large amounts of U-238 and the resulting plutonium resource. It would also lead to a reduction in the radiotoxicity of the ultimate nuclear waste, and minimize the volume and heat load of the waste to be put in final deep geological disposal. The European Commission, as well as France and the UK are members of GIF. Most European nuclear research organisations and labs are actively involved and a Sustainable Nuclear Energy Technology Platform (SNETP) coordinates the work of the European Sustainable Nuclear Industrial Initiative (ESNII) working on four potential fast-neutron projects: sodium- (ESFR), lead- (ALFRED), and gas (ALLEGRO) cooled reactors and an accelerator-driven transmutation prototype (MYRRHA).

2011 was the year of the third major nuclear accident at Fukushima Daiichi in Japan. It was the first nuclear accident caused by an external event (Richter level 9 earthquake followed by a tsunami of 14 m at the site) which impacted four operating nuclear reactors on the same site (and two others in shutdown mode). It again sent a shock wave resulting in diverse levels of reactions in different parts of the world, even if there were no casualties due to radiation, but 20 000 people killed by the tsunami.

In Europe, one can remember the symptomatic case of Germany, depending on nuclear for 20% of its electricity, where the political leadership reacted very fast, deciding the immediate definite closure of nearly half of the fleet in the days following the accident (8 reactors), and a full nuclear phase-out by 2022 (12 more reactors). This was reversing a previous decision, by the same political leadership a few months before, to prolong the lifetime of the nuclear power plants beyond the initial design lifetime of 40 years. The German decision was taken without consultation with the European partners, while the European Union was launching a very challenging « stress-test » process of all the nuclear power reactors in Europe (at that time, 132 nuclear reactors were in operation in the EU (nearly half of them in France), grouped on 58 sites), aiming at evaluating the risks associated with external events not considered in the plants' design basis. It showed that no reactor in the EU had to be shut down for safety reasons, but recommendations were made for improvements. This process led in 2014 to a revision and strengthening of the Euratom Safety Directive of 2009. In France, dependent for 75% on nuclear for its electricity, the Fukushima accident has probably influenced the political leadership to proceed with the Energy Transition Law (proposed in 2014 and adopted in 2015, under a coalition of Socialist and Green parties) seeking to reduce the fraction of nuclear-generated electricity to 50% by 2025. This was later changed to 2035.

In the UK, public opinion polls on the recourse to nuclear were not affected too much by the accident, in a country where the AGRs (advanced gas cooled reactors, making the bulk of the UK nuclear fleet) are reaching the end of their operating lifetime and the decisions for new nuclear build are perceived as necessary.

Benefits of nuclear to European Region since inception

The European Union economy has benefitted from clean, affordable and reliable electricity produced by the European nuclear fleet - up to 140 power reactors in the years 2000 – 2010, providing one third of the electricity needs. The sector provides around 1 million jobs. Nuclear energy is an indigenous industry not depending on inputs from third countries, except for the supply of uranium which is not an issue due to the diversification of the suppliers. The Union masters the full nuclear cycle – from uranium enrichment and fuel fabrication, to nuclear plants design/construction and operation, spent-fuel management including reprocessing, MoX fuel fabrication, waste management, and decommissioning. As a result, it fosters the strategic energy independence of the Union and has a geopolitical importance.

A vast knowledge and experience have been acquired by all the stakeholders of the sector:

research organisations and labs, reactor technology suppliers and operators, fuel cycle facilities designers and operators, waste management organisations and, last but not least, safety authorities and their technical support organisations. Under the cover of the Euratom Treaty, collaboration frameworks have been developed fostering more effective research and development, exchange of knowledge and good practices, development of common rules for radiation protection, nuclear safety and waste management, dialogue among regulators and waste agencies, safeguards and security measures, all elements making further development easier.

Problems associated with nuclear in the European Region, and steps taken to resolve these problems

One main problem is related to the evolution of the public opinion and the positions of political authorities in some countries of the European Union, much influenced by the antinuclear green lobby. The positions among the Member States are very diverse and, for some, clearly antagonistic, which renders positive decision making difficult on issues related to nuclear. Positions may also change depending on the parties in power, which does not provide the necessary long-term visibility for investors decision making.

The Treaty of the European Union recognises the full freedom for each Member State to choose its energy mix and so to recourse or not to nuclear energy. But at the same time the Euratom Treaty is working by consensus and progress in the nuclear field can only happen if all Member States agree. And even further, while general European Union energy policy documents usually reckon the potential role and contribution of nuclear energy, once discussion starts on the implementation mechanisms and tools, including financing tools, nuclear is usually discarded or even excluded.

Another main problem comes from the combination of the liberalisation of the electricity sector launched in the 1990s, aiming at creating an electricity market to reduce the price of electricity for the consumer, with, at the same time, starting around the year 2000, the subsidised support and priority access given to renewables energy sources, in particular intermittent wind and solar. This combination renders large baseload nuclear plants economically less viable, in particular new built plants, putting a main question mark on the future of the sector as a whole as investors will not engage. To overcome this problem, it is necessary to have a global energy system approach where all costs, including systems costs and external costs are properly attributed. As a clear example, intermittency has a cost which must be properly attributed to intermittent sources.

Nuclear energy is clearly a very hot topic and a main divisive subject at European Union level and this influences also the national policies. This has become even more problematic over time with more countries joining the European Union. The overall energy policy at European Union level is much intertwined, impacting, most of the time negatively, nuclear policies in countries wanting to recourse it. A profound revision is necessary to overcome this problem, starting with a complete reshuffling of the electricity market, to make sure that all low carbon sources of electricity are treated fairly with their strengths and weaknesses, within a global energy system approach and not energy source by energy source.

Advances in nuclear in the European Region since inception

Following the initial push coming from the Atoms for Peace call of 1953, and based on indigenous high-level research competences, Europe is the region where all nuclear technologies have been applied, and most of them developed or improved. All reactor technologies, using thermal and fast neutrons (boiling and pressurized water-cooled, heavy-water-moderated, CO2 or helium-gas cooled, sodium and lead cooled…), have been built and tested, at least in prototype form. Europe has been the most nuclearized region in the world, with a fleet of 140 reactors producing the third of its electricity needs. France is the most nuclearized country in the world, with nearly 60 reactors producing three quarters of the electricity.

On the side of the fuel cycle, all technologies have been applied, developed and tested in research centers and labs. Prototypes and demonstrators have been built for some of these technologies. Enrichment (both gaseous and centrifugal), reprocessing, MOX fabrication are now industrially applied in some European countries to serve the whole reactor fleet.
A number of reactors (including research reactors and prototypes) have been dismantled, allowing the industry to acquire competence in the decommissioning technologies.
Waste-management techniques are now well developed, making sure that the long-term safety is maintained.

And last but not least, safety authorities and their technical support organisations are ensuring the highest level of safety and security of the nuclear facilities in full independence.

All this has happened thanks to the efforts of all the nuclear stakeholders at the national and European level. The Euratom Treaty has played its role to foster cooperation among the stakeholders from the early stages of development, and has further set the ground for a strong regional legally-binding level playing field on nuclear safety and waste management.

Current and Future state of Nuclear in the European Region:

The UK -Current State of nuclear in the United Kingdom

Now outside of the European Union, the UK is pursuing active nuclear programmes, in close cooperation with the USA and Canada. Besides the continuation of the construction of the EPR in Hinckley Point, financed through a Contract for Difference mechanism, another innovative mechanism is developed for future nuclear plants using the Regulated Asset Base concept already used for large public infrastructure. Very dynamic research and innovation programmes are being developed and are pursued by research labs and industry, under the heading of the Nuclear Innovation and Research Advisory Board (NIRAB) in partnership with the Nuclear Innovation and Research Office (NIRO) providing independent, expert advice to Government on the research and innovation needed for nuclear energy to play a significant role in the UK's future low carbon and secure energy mix and to create the environment in which the UK nuclear industry can contribute significantly in the UK and abroad.

Continental Europe-Current State of nuclear in Continental Europe

In continental Europe, the situation is very diverse inside the European Union itself. This diversity of political positions in the Member States is strongly influencing the role the EU seeks for nuclear energy in the fight against climate change. Under its Green Deal, the EU has set very ambitious goals for its decarbonisation, seeking 55% reduction by 2030 (compared to 1990) and a carbon-neutral economy (meaning mainly zero-carbon electricity) by 2050. While the Euratom Treaty was founded as a promotional treaty, some Member States have turned or are turning their back on nuclear energy and have a declared anti-nuclear position when it comes to decide on EU energy policies, and, even more, on related implementation mechanisms and tools, including for financing and fostering investment. On the contrary some other Member States are keen to consider nuclear energy as fully part of their very-low-carbon energy mix. While the (Article 194), a number of EU policies impacting directly or indirectly the energy sector are influenced by this diversity of positions and the rules applying to the EU decision processes. Politics is the art of the possible and this requires compromises. Nuclear power, after decades of side-lining in EU energy policies, is many times the scapegoat or the black sheep to sacrifice to reach common decisions more easily. A good example of this was the discussion at the EU level on the concept of Taxonomy for Sustainable Financing, applying inter-alia to financing in the energy sector. Two sets of criteria are proposed to be used to decide if a technology or project can be considered as sustainable or not, and so have access to "sustainable financing". The first set is related to the impact on climate change. The second is the so-called DNSH criterion (Do No Significant Harm – to the environment). Nuclear has been at the edge of being excluded based on the DNSH – particularly for the issue of high-level waste management – for which some consider there is no sustainable solution. This was hotly debated in the EU Institutions, politically coupled with the fate of gas. The final outcome, nuclear being finally considered as sustainable for the transition to carbon neutrality in 2050, will much influence the perception of nuclear and so the future developments and investments in the sector. One might nevertheless regret that the concept of sustainability used in the taxonomy is restricted to the sole environmental protection dimension, usually limited to the concept of green. It would have been much more appropriate to use the three pillars of a sound energy policy to develop the concept of sustainability: environmental protection AND economics/affordability AND security/reliability of supply. Only a proper balance of these three pillars may result in an energy mix which is sustainable from a societal point of view, more than "simply" an environmental point of view. This approach is even more necessary, in particular in the European Union, after the Russian invasion of Ukraine and its impact on the energy supply (oil and gas). Green is not everything, social aspects become predominant.
Looking more in detail to what is the state of play in some Member States (not exhaustively).

Germany - Current State of nuclear in Germany

Germany is pursuing its post-Fukushima political nuclear phase-out policy targeting 2022, heavily subsidising the deployment of intermittent renewable energy sources (of the order of 500 Billion Euros over 20 years), with an increasing recourse to fossil fuels (lignite, coal and gas) to substitute the closure of the nuclear plants, resulting in near zero benefit until now in terms of decarbonization of the electricity sector. To be mentioned here, the correlated German push to extend the recourse to coal until 2038. Following the Russian invasion of Ukraine, Germany halted the commissioning of the second North Stream gas pipeline that was aimed at increasing the import of Russian gas. As a result of the nuclear phase-out policy, Germany will rely more on coal for the production of electricity until alternatives to the import of Russian gas might become available. Following an amendment to the Atomic Act, the last three NPPs in operation will not be shut down at the end of 2022 but instead shall contribute to lower Germany's gas consumption until mid-April 2023.

France - Current State of nuclear in France

France's political leadership has postponed the decrease of the fraction of nuclear electricity from 75 to 50%, from 2025 to 2035, recognizing the impossibility to maintain the initial politically driven timeline. In 2022 President Macron took the decision for France to engage in the construction of six new EPR reactors, possibly followed by eighth more. The first of these reactors is planned to be commissioned in 2035. This will have a major impact on the decision by the utility EdF to enter into the lifetime extension of existing plants and to pursue the program of construction of the new reactors, while drawing the lessons from the difficulties (over budget and delays) encountered in Flamanville with the construction of the EPR (European Pressurized Reactor). The new EPR plants will be of EPR2 type, redesigned to reduce the costs and timelines by optimising the full construction chain.

Belgium - Current State of nuclear in Belgium

Belgium, with more than 50% of its electricity generated by its seven nuclear reactors, has politically decided a nuclear phase out for 2025. The closure of the first three units expected by law in 2015 had to be politically postponed till 2025, to ensure security of supply. In the wake of the Russian invasion of Ukraine and its impact on security of energy supply, the government decided in 2022 to prolong the operation of two of the seven reactors for ten years beyond 2025. At the time of writing, negotiations are ongoing between the government and the Utility ENGIE on the details.

Spain - Current State of nuclear in Spain

The Spanish nuclear sector faces a rather negative political environment, making lifetime extension decision difficult and new build not expectable. The Spanish nuclear industry has suffered since its inception from public opinion. There has been a significant majority against nuclear power in Spain, though the ratio is slowly changing in favour of fission power. There is too an unsolved stage of the nuclear fuel cycle, the final repository.

Spanish NPPs lead electricity production, giving stability to the system. It is the source that operates the most hours on average, almost 90% of the hours in a year. The seven reactors in operation provide a combined gross installed power of 7,4 GWe, close to 6.5% of the total installed electrical power in the country. It generates around 60 TWh each year - more than 20% of the electricity consumed in the country.

The current future plans for nuclear power in Spain state that by 2035 all Spanish power reactors are to be shut down. The government has approved a closing calendar that would shut down all reactors in a progressive and organized way by 2035. Nevertheless, the Spanish nuclear sector is committed to internationalise its activities in a growing market. Spanish industry is gaining experience in dismantling two reactors.

The Nordic Countries - Current State of nuclear in The Nordic Countries

Sweden, and even more Finland, have a more positive political and public opinion environment. In Sweden, it is possible to build new power plants on the same sites as existing ones, even if there are no such plans for now. In Finland, besides four operating reactors in lifetime extension, one EPR is in the final stages of construction (also over budget and with delays). Important to mention, Finland and Sweden are the two most advanced countries worldwide for the handling of their ultimate nuclear waste. Sites have been selected by experts and authorized by authorities in each country for the geological disposal of all their spent fuel, following decades of research, testing and demonstration, including via deep underground laboratories and the successful direct involvement of local communities. In Finland, the building of the repository is progressing with an entry in service expected in 2025, when the first spent fuel will be disposed underground.

Central and Eastern part of Europe - Current State of nuclear in Central and Eastern Europe

Finally, a specific mention needs to be made of the Central and Eastern part of Europe. The Czech Republic, Slovakia, Hungary and Bulgaria, all having operating reactors of Russian design, and Romania, operating CANDU reactors, are all keen to continue to rely on nuclear power for their electricity supply in the long term, in a decarbonized energy future, keeping their plants in long-term operation and building new power plants when the need arises. Two reactors have been under construction for a long time in Slovakia. Hungary will build two Generation III reactors of Russian design. The Czech Republic and Bulgaria have plans for new build.

Poland - Current State of nuclear in Poland

Poland is seeking to build up to six nuclear reactors in a not too distant future, to help reduce its high dependency on coal. The country is also seeking a role for SMRs (HTGR type) for the production of direct heat for industrial processes, replacing gas.

Elsewhere in Europe - Current State of nuclear in Elsewhere in Europe

Slovenia and the Netherlands, each having a single-unit nuclear plant on their territory, are prone to consider a further recourse to nuclear power and to build more plants in the future. Switzerland is engaged in lifetime extension of its three remaining nuclear plants, after the closure of Muhleberg. Estonia is actively seeking SMRs.

European Union – Future state of Nuclear

The most recent document providing the global perspective for the European Union as a whole is the PINC (Illustrative Nuclear Programme of the Community – Euratom) published by the European Commission in 2017.

The Commission predicts a decline in nuclear generation capacity at the EU level up to 2025, considering the decisions of some Member States to phase out nuclear energy or to reduce its share in their energy mix. This trend would be reversed after 2030 as new reactors are predicted to be connected to the grid and the lifetime of others will be extended. Nuclear capacity would increase slightly and remain stable at between 95 and 105 GWe by 2050. Since electricity demand is expected to increase over the same period, the share of nuclear electricity in the EU would fall from its current level of 27% to around 20%.

Significant investments will be needed to support the transformation of the energy system in line with the Energy Union Strategy. Between EUR 3.2 trillion and EUR 4.2 trillion will need to be invested in the EU energy supply between 2015 and 2050. Investments in the nuclear sector are a small part of the overall effort and must be made within the framework established in EU legislation.

Major investments have been made in the past in conversion and enrichment capabilities, in order to maintain EU technological leadership. Regarding the fabrication of nuclear fuel, the EU-based capacity would be able to cover all its needs for western-design reactors, whereas developing and licensing fuel assemblies for all Russian-design reactors in the EU would take a few years. First VVER fuel fabricated by Westinghouse-Sweden operated successfully in Finland and the Czech Republic. The Commission will continue to monitor the front end of the fuel cycle and use all instruments available at its disposal to ensure security of supply in the EU, diversification and global competition.

Maintaining a nuclear generation capacity of between 95 and 105 GWe in the EU until 2050 and beyond would require further investments over the next 35 years. In the light of information provided by Member States, an estimated EUR 45-50 billion will have to be invested in the long-term operation of existing reactors by 2050. Between EUR 350 and 450 billion would have to be invested in new plants to replace most of the existing nuclear-power capacity. Since new nuclear power plants are designed to operate for at least 60 years, these new plants would generate electricity until the end of the century. A number of factors influence the availability of finance for investments in new nuclear capacity. For the two main cost components, overnight cost and financing cost, the expected construction time and project discount rate play a significant role. Different financing models are used in several EU Member States, such as the

Contract for Difference scheme proposed for the Hinkley Point C project in the UK or the Mankala model used in Finland.

Figure 8: A 3D model of the Hinkley Point C Nuclear Power Station (Courtesy Wikipedia)[v]

Some new, first-of-a-kind projects in the EU have experienced delays and cost overruns. Future projects using the same technology should benefit from the experience gained and should exploit cost-reduction opportunities, provided that an appropriate policy is established. This policy should focus on improving cooperation between regulators when licensing new reactors and on encouraging industry to standardise nuclear-reactor designs. In addition to improving cost efficiency, this would help make new nuclear power plants safer.

The back-end of the fuel cycle will need increasing levels of attention. It is estimated that more than 50 of the 129 reactors currently in operation in the EU are to be shut down by 2025.Careful planning and enhanced cooperation among Member States will be needed. All EU Member States operating nuclear power plants will have to take politically sensitive decisions on geological disposal and the long-term management of radioactive waste. It is important not to postpone actions and investment decisions on these issues as the acceptance of nuclear energy by civil society is closely linked to the ability to demonstrate responsible, safe and sustainable solutions for waste management.

Each Member State is free to define its own fuel-cycle policy. The spent fuel can be regarded either as a valuable resource to be reprocessed, or as radioactive waste that is destined for direct disposal. Whatever option is chosen, the disposal of high-level waste, separated during reprocessing, or of spent fuel regarded as waste, should be addressed.

France has a major reprocessing facility in operation. A number of reactors in France and the Netherlands will continue to use mixed oxide (MOX) fuel. Japan that also uses MOX fabricated in France recently received MOX from France.

Disposal facilities for low-level and intermediate-level radioactive waste are already in place in most Member States. Operators are moving from research to action with the construction of the world's first geological disposal facilities for high-level waste and spent fuel. These facilities are expected to become operational in Finland, Sweden and France between 2025 and 2030.Other European companies should take advantage of this expertise in order to consolidate the required skills and know-how and develop commercial opportunities at the global level. There is scope for cooperation between Member States, including the sharing of best practices or even through shared repositories. Whereas shared repositories are legally possible under the Directive, several issues still need to be resolved, in particular communicating with the public and building public acceptance. Another crucial step is to determine, who is ultimately responsible for the radioactive waste that needs to be disposed of as part of a multinational approach. Member States operating nuclear power plants currently use facilities for storing waste for a period between 40 and 100 years. However, the storage of radioactive waste, including long-term storage, is an interim solution and not an alternative to disposal.

The use of best practices in the various stages of the decommissioning process, including through a staged approach that would allow benefit from the continuous reduction in the radiological hazard, would bring efficiency and safety improvements. Best practices could be promoted by creating a European centre of excellence, that brings together public and private actors, or by establishing it under the Decommissioning Funding Group.

Nuclear and radiation technologies have many applications in the medical sector, industry, agriculture and research, with substantial benefits to society in all Member States. More than 500 million diagnostic procedures using x-rays or radioisotopes are carried out in Europe each year, and more than 700 000 European healthcare workers use nuclear and radiation technology on a daily basis. There is a vibrant market for medical imaging equipment in Europe. It is worth more than EUR 20 billion and enjoys annual growth rates of about 5%. Different types of research reactors are operated in the EU. They are used for material and nuclear-fuel testing as well as basic research and development. Some also produce medical radioisotopes for the diagnosis and treatment of various diseases, including cancers, cardiovascular and brain disorders. Over 10 000 hospitals worldwide use radioisotopes for the in-vivo diagnosis or treatment of some 35 million patients every year, of which nine million are European. Europe is the second largest consumer of technetium-99m (Tc-99m), the most widely used diagnostic radioisotope. Several European research reactors involved in the production of medical radioisotopes are approaching the end of their lifespan, with the supply of medical radioisotopes becoming more fragile and leading to some severe shortages. Action has recently been undertaken to coordinate the operation of research reactors in the European Union and abroad and to minimise interruptions in radioisotope production, for example the establishment of the European Observatory on the Supply of Medical Radioisotopes. Despite these efforts, the issue of medical radioisotope capacity, especially in Europe, still requires full consideration by all stakeholders as it is essential to ensuring key medical diagnosis and treatments in the European Union.

The EU must maintain its technological leadership in the nuclear domain, including the development of fusion through the International Thermonuclear Experimental Reactor (ITER), so as not to increase energy and technology dependence. ITER is a large-scale scientific experiment that aims to demonstrate the technological and scientific feasibility of fusion energy being built in France. It is an international collaborative effort between the Parties of the ITER Agreement: EU, China, India, Japan, South Korea, Russia and the USA. This will in turn support EU growth, jobs and competitiveness.

The Integrated Strategic Energy Technology Plan (SET-Plan) further details that the priority for nuclear energy is to support the development of the most advanced technologies to maintain the highest level of safety in nuclear reactors and to improve the efficiency of operation, the back-end of the fuel cycle and decommissioning. As underlined by European research and industrial stakeholders, retaining technological leadership in the nuclear field is possible only if interested Member States maintain diverse and sufficiently funded nuclear research capabilities, including education and training aspects. However, it will not be easy for Europe to retain leadership in all areas in view of the significant increase in nuclear generating capacity and nuclear innovation advances in other regions of the world. This underlines the importance of cooperation at the European level, especially in areas such as the expertise on safety of advanced and innovative reactors, covering Generation IV technologies and SMRs. The ongoing Euratom program contributes to these objectives by supporting nuclear research and training activities aiming at continuous improvement of nuclear safety, security and radiation protection, thus contributing to the long-term decarbonisation of the energy system. Continuing to pursue research and development is instrumental to maintaining the EU at the forefront of nuclear technology and develop the highest standards of safety, security, waste management and non-proliferation. This implies continued investment on research and training/education, as well as on nuclear research infrastructure. It also implies continued participation in major international organisations such as GIF and ITER.

Since late October 2019, the development and deployment of Small Modular Reactors (SMRs) in the EU has been at the core of many discussions. Indeed, since the US-EU High-level industrial forum on Small Modular Reactors which took place in Brussels, things have accelerated, considering them as an ideal partner to complement large scale reactors.

From the one side, the European industry has established an SMR Task Force, the objective of which is to develop the European Nuclear industries' position on the required technical and technology developments, including readiness for implementation and research & innovation progress in the field. Likewise, exploring and analysing the licencing and regulatory aspects is crucial in order to enable a timely deployment of SMR technology. Economic and political conditions to support the development of SMR for applications in Europe are also at the core of the discussions as well as market integration for specific SMR deployment in powering industrial installations, district heating plans, hydrogen production, etc.

From the other side, a workshop organised in late June 2021 by the European Commission (EC) triggered the start of a discussion to launch a European SMR partnership. The industry, in collaboration with SNETP (Sustainable Nuclear Energy Technology Platform), is working in close cooperation with the EC on the establishment of this. The partnership's objectives are to:

- Progress towards the deployment of SMRs within Europe by the early 2030s (investment, market conditions, skills, manufacturing, business case...)
- Ensure supportive market aspects to enable the inclusion of SMRs in hybrid energy systems / high RES power systems: flexibility, ancillary services to power systems, ...
- Develop a collaborative environment for the SMR value chain within Europe
- Establish the conditions and partnerships for SMRs to deliver low-carbon electricity and heat for multiple applications
- Position the European SMR value chain internationally and seize opportunities for the export of the European value chain
- Develop industry standards and SMR deployment conditions in line with European SMR deployment scenarios
- Leverage European R&I for deployment of SMRs
- Support efforts towards licencing and regulatory of SMRs within Europe.

Never before have discussions on SMRs been so in line with the challenges the EU is facing when combating climate change, but also, given today's context, ensuring security of supply, energy independence and the competitiveness of the whole European industry that has to rely on affordable energy 24/7. SMRs, combined with large-scale nuclear reactor new build projects, as well as ensuring long term operation of the existing fleet, are crucial, if not indispensable, to achieve this.

SMR development and deployment are part of an overall strategy that Member States have now embraced openly, and the proof of this is recent announcements by France - but not only, as several EU countries have included them in their National Energy and Climate Plans.

Below are illustrative examples of some key developments in the UK and EU.

UK – National Institute for Advanced Material; Rolls Royce SMR

Led by the Manchester University, the Dalton Nuclear Institute and the National Nuclear Laboratory, the aim is to Increase the UK's existing economic strengths and competitive advantages in nuclear energy, and support its net-zero ambitions, by enabling innovation in research on radioactive materials, including an experiment with-modelling approach, via a co-ordinated network of national laboratories, nuclear user facilities, and expertise, and developing vibrant industry- and academic-led programmes which accelerate the nuclear contribution to deep decarbonisation.

Rolls-Royce SMR Ltd. has raised £450m in funding from investors and the government, has submitted its 470-MW small modular reactor design for entry to the UK's generic design assessment (GDA) regulatory process.

It is the first step in securing clearance from the department for business, energy and industrial strategy through its initial screening process. This will confirm that the Rolls-Royce SMR business is qualified to enter the GDA process, which is run jointly by the Office for Nuclear Regulation, Natural Resources Wales and Environment Agency.

The GDA process is expected to take four to five years, during which time Rolls-Royce SMR will engage in a range of parallel activities, including factory development, siting and commercial discussions. Rolls-Royce had established the Rolls-Royce SMR business to deploy SMRs that could be available to the UK grid in the early 2030s.

The new Rolls-Royce SMR business, which will continue to look for further investment, will now push ahead with identifying sites for the factories which will manufacture the modules that enable onsite assembly of the power plants.

Rolls-Royce will “harness decades of British engineering, design and manufacturing knowhow” to roll out the first of its SMRs, which are based on a similar technology used to propel nuclear submarines.

Rolls-Royce said the potential for this to be a leading global export for the UK is unprecedented. Nine-tenths of an individual Rolls-Royce SMR power plant will be built or assembled in factory conditions and around 80% could be delivered by a UK supply chain.

Rolls-Royce said its SMR can support both on-grid electricity and off-grid clean energy solutions, enabling the decarbonisation of industrial processes and the production of clean fuels, such as sustainable aviation fuels and green hydrogen.

FRANCE – JHR Jules Horowitz Material Testing Reactor; EPR 2; SMR NUWARD

Material Testing Reactors (MTRs) are necessary for the development and qualification of materials and nuclear fuel used in nuclear industry. The related studies contribute to safety and optimization of existing or upcoming nuclear power reactors and to development of future reactors.

Most of the irradiation tools utilized by industry are now ageing in the western world. Sustainability of a high performance experimental capacity and related expertise for the coming decades is mandatory. There is a consensus on the necessity to design and build a new Material Testing Reactor (MTR) to support operation of existing power reactors fleets and qualification of future technologies systems.

The Jules Horowitz Reactor (JHR) will be used for nuclear medicine. It will supply hospitals with short-lived radioisotopes used for medical imaging or therapeutic purposes. This research facility may be promoted through non-nuclear industrial application capabilities. JHR will provide high performance silicon used in electronic power devices, such as those included in electrical and hybrid vehicles or in energy control systems.

Coping with this context, JHR, built on the Cadarache site, will be a major infrastructure of European interest in the fission domain, open to international collaboration. The Jules Horowitz Reactor will be built and operated in the framework of an international cooperation between several organizations bound by a Consortium Agreement. Up to now, the partners are as follows:

- Research Institutes: CIEMAT (Spain); SCKCEN (Belgium); CVR (Czech Republic); VTT (Finland); the French Atomic Energy Commission (CEA) (France); IAEC (Israel); DAE (India); NNL (United Kingdom); STUDSVIK (Sweden);
- Utilities and Industrial Partners: “Electricité de France” (EDF); FRAMATOME (ex AREVA-NP);TECHNICATOME.
- The European Commission

A new small modular reactor (SMR) design has been announced by the French Alternative Energies and Atomic Energy Commission (CEA), EDF, Naval Group and TechnicAtome. The Nuward - with a capacity of 300-400 MWe - has been jointly developed using France's experience in pressurised water reactors (PWRs).

The CEA has contributed to the development of the Nuward design with its skills in research and qualification, while utility EDF has helped through its experience in systems integration and operation. Naval-defence company Naval Group has contributed its structures and modular experience to the project, with TechnicAtome providing its compact reactor design experience.

According to the partners, the Nuward design will be a "modular solution introducing some significant innovations with major benefits to the operator and to the product's competitiveness: compactness and simplicity of an integrated design, flexibility for construction and operation, innovative safety approach in line with the world's best standards".

The partners aim to complete the basic design of the Nuward between 2022 and 2025. The design should be in the "advanced concept phase" between 2025 and 2030, during which time the design is expected to be certified and the supply chain developed. Construction of a demonstration Nuward SMR is scheduled for 2030. The construction of that unit is expected to take three years.

EDF is developing the EPR 2 pressurized water reactor with Framatome. The EPR 2 is the successor unit to the world's most powerful reactor, the 1,650 MW EPR, in operation in China, in final stages of building in Finland (Olkiluoto), France (Flamanville) and now the UK (Hinkley Point C). The "nuclear plant of tomorrow" is a simplification of the design that has caused delays and overrun problems at Olkiluoto and Flamanville.

For each twin unit the same buildings are required relating to the nuclear island, the conventional island and the balance of plant, EDF said. In addition, some buildings would be common to both units -- including tunnels for cooling-water discharge in the event a coastal site is selected. Total concrete volume for all relevant buildings is put at 800,000 cubic meters.

"The goal of the EPR 2 project is to have a competitive model on the new production means market by 2030," EDF has said. Documents indicated France would look at development of new reactors in the 2020s if they proved cost-competitive, with a levelized cost of generation around Eur60-Eur70/MWh.

In addition to EPR 2 (1700 MWe), EDF is also developing an EPR (1200 MWe) for the export market, in Europe and further.

BELGIUM – MYRRHA - Accelerator Driven Lead Cooled Fast Neutron Reactor

The Belgian Nuclear Research Laboratory SCK CEN works actively on the design and construction of a new multi-purpose research plant: MYRRHA, which stands for *Multi-purpose Hybrid Research Reactor for High-tech Applications*. MYRRHA is a versatile research infrastructure but above all unique. It is the world's first research reactor driven by a particle accelerator.

Unlike traditional reactors, cooling the reactor core is not done with water but using a liquid-metal mixture of lead (44.5%) and bismuth (55.5%). This mixture offers the advantage that it does not moderate the fission neutrons. These fast neutrons unlock a variety of applications.

Nuclear energy produces a lot of electricity but also generates radioactive waste. This radioactive waste will need 300,000 years to reach its natural radiation level. In the MYRRHA project, SCK CEN studies the transmutation process. Transmutation converts radioactive substances with a long life span into less toxic substances with a short life span. Thanks to transmutation, the final volume of residual waste is reduced by a factor of 100 and the natural radiation level is already reached after 300 years (as opposed to 300,000 years). In this sense, it offers an opportunity to optimise the geological disposal.

In 2018, an estimated 18.1 million people were diagnosed with cancer, 9.6 million patients died on account of the disease. It is expected that these figures will increase and that, as a result, the demand for radioisotopes will also increase. To be able to meet this increasing demand, MYRRHA will take on the production of theranostic radioisotopes (for diagnostic examinations and therapeutic treatment). With MYRRHA, SCK CEN also focuses on the development of new therapeutic radioisotopes that can fight cancer cells in a more targeted way and thereby significantly reduce the side effects for patients. As from 2027, the accelerator will produce radioisotopes for medical purposes.

Testing materials is essential to warrant and improve the safety of nuclear power plants. MYRRHA offers the opportunity to test current fissile and other materials and to study new materials that will be used in nuclear fusion reactors. Compared to the current research reactors, MYRRHA – thanks to its fast neutrons – will reach irradiation conditions that are closer to that of a fusion reactor.

The research infrastructure paves the way for countless promising technologies and applications, but is also a magnet for fundamental research in various scientific disciplines such as nuclear physics, atomic physics, fundamental interactions, solid-state physics and nuclear medicine. The project attracts scientists from Belgium and abroad, who will benefit from an education here.

FINLAND– ONKALO - the geological disposal solution of HLW

The Onkalo nuclear-waste disposal facility under construction in Olkiluoto, Finland, will be the world's first permanent geological repository for spent nuclear fuel and high-level radioactive waste. The £444m ($555m) underground nuclear-waste storage facility is being developed and will be operated by Posiva, a joint venture between TeollisuudenVoima (TVO, 60%) and Fortum Power and Heat (40%).

Posiva will be responsible for the final disposal of nuclear waste produced by TVO's Olkiluoto nuclear power plant (NPP) as well as Fortum's Loviisa NPP in Finland. Scheduled to commence operations in 2025, the Onkalo nuclear-waste repository is expected to hold approximately 6,500t of spent nuclear fuel over an estimated operational life of 100 years.

The final disposal tunnel will extend up to 450 m deep inside the Olkiluoto bedrock without touching the water column. The total length of the tunnel network including the access tunnels, central tunnels, and final disposal tunnels will be approximately 42 km. The final disposal facility is designed on the basis of KBS-3 technology for disposing of high-level radioactive waste.

The KBS-3 technology was developed by Swedish Nuclear Fuel and Waste Management Company (SKB) which was jointly established by nuclear-power companies in Sweden. The KBS-3 nuclear-waste storage concept calls for multiple barriers to protect the environment from radiation leakage. The spent nuclear-fuel rods will be placed in the double-walled canisters with the inner part of canister made of cast iron which takes the mechanical stress caused by the bedrock. The outer part of canisters will be made of copper which will protect the cast iron and spent-fuel rods from corrosion. The canisters will be installed in 6-8-m-deep shafts within the bedrock at a depth of approximately 450 m below the ground. The Canisters will be surrounded by bentonite clay which will act as another protective barrier from nuclear-waste leakage, while also reducing mechanical stress on canisters caused by the bedrock. Finally, after the installation of canisters, the tunnels will be backfilled with clay blocks and pellets. The entire cavern and shafts will also be backfilled in phases to block human entry as well as surface water.

POLAND – NEWCOMER to nuclear for power and heat

In November 2018, the Ministry of Energy published its draft *Energy Policy of Poland until 2040* (EPP2040) for public consultation. The document reaffirmed plans to develop 6-9 GWe of nuclear energy. This was confirmed in a revised version in May 2019, forecasting the completion of the first of six 1-1.5 GWe units in 2033, with each successive unit to follow every two years, replacing coal-fired generation. The ministry estimated the cost of constructing nuclear at €4.66 million/MWe (Zloty 20 million/MW). In October 2020, Poland's Ministry of Climate announced an acceleration of the plans, calling for technology selection in 2021, and signing of the final contract for the first plant in 2022. The country's cabinet formally adopted the energy policy in February 2021.

In March 2021, the government ratified an intergovernmental nuclear cooperation agreement that gives the USA 18 months to prepare a technology and financing offer for nuclear power plants. In June 2021 the US Trade & Development Agency provided a grant to Polish Nuclear Power Plants (PEJ) to assist front-end engineering and design studies by Westinghouse and Bechtel with a view to building an AP1000 reactor as the country's first nuclear power plant. Further US government funding is anticipated. The studies will be reviewed in mid-2022 by the Polish government to help it select a partner for PEJ.

Deployment of high-temperature reactors (HTRs) for industrial heat production was included in the government's July 2016 draft strategy for development. The Ministry of Energy has estimated that using nuclear high temperature heat for industrial applications could reduce carbon dioxide emissions by 14-17 million tonnes per year in Poland, which has 13 large chemical plants that need 6500 MWt at 400-550°C. The government plans to build a cogeneration HTR of 200-350 MWt for process heat, and before this a 10 MWt experimental HTR at Swierk. The energy minister has nominated the Nuclear Energy Department in the Ministry of Climate & Environment as responsible for proceeding with the experimental HTR. There is close cooperation with the Japan Atomic Energy Agency on HTRs, with a view to hydrogen production.

Future state of nuclear in the European Region based on policy statements by government and stakeholders

According to the Commission's estimate, nuclear energy is expected to remain an important component of the EU's energy mix in the 2050 horizon, both for electricity and for heat applications. Top-level nuclear research, including through the development of state-of-the-art nuclear research infrastructure in the EU, is fundamental to ensure that the EU maintains its competence in the field. Cooperation among national regulators on licensing and general supervision is seen as beneficial. The nuclear fleet in Europe is ageing and significant investments are needed where Member States opt for a lifetime extension of some reactors, expected decommissioning activities and for the long-term storage of nuclear waste. Investments are also needed to replace existing nuclear plants. Such investments could also go in part to new nuclear plants. The total estimated investments in the nuclear fuel cycle between 2015 and 2050 are projected to be between EUR 660 and 770 billion. Finally, the rapid rise in nuclear energy use outside the EU (China, India, etc.) also means that the EU needs to maintain its global leadership and excellence in the technology and safety domains. To this end, continuous investment in research and development activities will be necessary.

LATIN AMERICA REGION

Brief history of nuclear development in the Latin America Region

Nuclear energy first made its appearance in Latin America in the 1950s and 60s, with Argentina, Mexico, and Brazil all establishing governmental organizations to explore the development of a nuclear-energy program.

Figure 9: Atucha Nuclear Plant in Argentina. (Source: Wikimedia Commons)

The 50’s are considered the romantic era for nuclear development in Latin America.
Argentina was involved with the production of heavy water and Brazil was looking for alternative fuel cycles, like the Thorium cycle for producing energy.

But this initiative contributed for the formation of a solid nuclear technical community in both countries.

Of the three countries, Argentina built the first reactor in 1974, in Atucha, which was followed by a reactor in 1983 (see Fig. 9). In total, Argentina’s three reactors provide approximately 5% of Argentina's energy consumption and are overseen by the Comision Nacional de EnergiaAtomica (CNEA and NASA). Brazil followed soon after, establishing its National Nuclear Energy Commission in 1956. By 1982, it built its first reactor, Angra 1 (see Figure 10), which was followed by Angra 2 in 2000.

In 1989, Mexico became the third Latin American state to develop a nuclear-energy program. Despite rich natural-gas reserves, the country built its first and second reactors in 1989 and 1994. The idea of installing nuclear power in Mexico arose within the framework of the international promotion of nuclear technology in the mid-1950s by the "Atoms for Peace" program of the United States and the United Nations. Mexico's interest in nuclear energy was made official in 1956 with the establishment of the National Commission for Nuclear Energy (CNEN).

After decades of relatively low growth in Latin American nuclear energy, there appeared to be an increased interest in developing a more vibrant nuclear energy industry. On the whole, many Latin American countries sought to develop alternative, inexpensive forms of electricity, ostensibly to counteract rising and uncertain gas prices.

The development of renewable energy sources, like wind and solar, came also together and somehow created alternatives to nuclear power with affordable prices and simpler technology application.

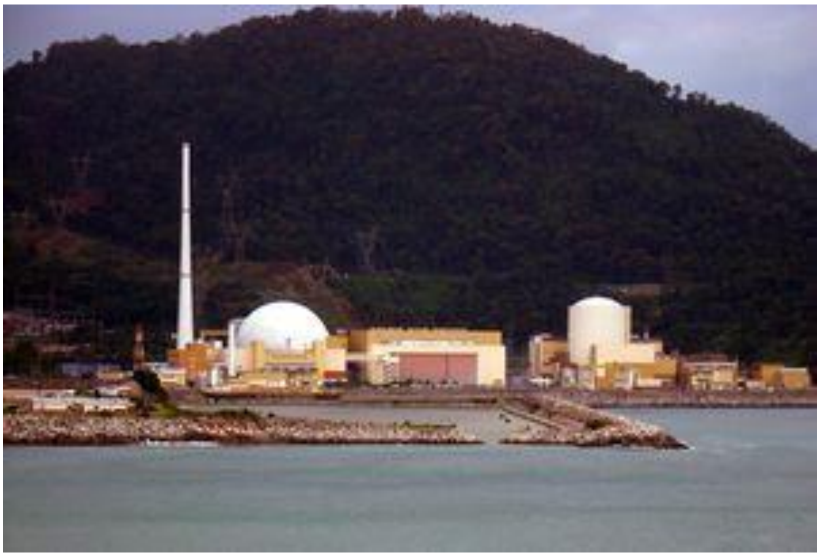


Figure 10: Angra 1 Nuclear Plant in Brazil. (Source: Wikimedia Commons)

As a result, three additional power plants were proposed in Argentina in 2006 as part of a long-term nuclear plan and talks with Russia resulted in a cooperation agreement for the development of two additional sites. Moreover, in 2006 Brazil announced plans for four new nuclear reactors, and in 2021 the installation of 8 to 10 GW in the next 30 years with the potential of many more to come. For Argentina, Russia or China were considered as strong strategic partners. For the Brazilian projects it was not decided yet.
Recently, Bolivia announced a partnership with Russia and Argentina to build a $300 million-dollar research reactor with the hope of establishing a long-term nuclear program; this agreement adds on to existing agreements with France and Argentina.

Despite strong interest in many countries, nuclear energy has also faced many setbacks in Latin America. First and foremost, the 2011 Fukushima Daiichi nuclear disaster has led to a worldwide concern with the safety of nuclear power and dissipating political support for the technology.

The feasibility of nuclear power plants in Chile is still being investigated, but Chile's geological positioning on a fault line presents substantial real and perceived risks that may not be overcome. In Mexico, economic constraints led to the abandonment of its ten scheduled nuclear plants as its extensive oil and gas reserves kept costs of conventional energy lower.

Overall, Latin America accounts for a small percentage of global nuclear-energy production, and nuclear-energy production accounts for only a small part of Latin Americas energy production. The largest source in Latin America continues to be hydropower. However, the hydro representative portion in the total energy generated continues to decrease.

Some LATAM countries have small uranium activities - such as Mexico, Bolivia, Chile, Colombia, Ecuador, Guatemala, Guyana, Paraguay, Peru, and Uruguay.

LATAM has around 25 research reactors: Peru and Chile both have two (one is not operational); and Colombia, Cuba, Jamaica, Uruguay and Venezuela one each (some are critical units), Argentina has 9 and Brazil 7 research reactors.

Following a surge of interest in the 1950s and 60s, plants were built in the 1970s, 80s, and 90s. In the mid-2000s and 2010s, with some plants nearing the end of their lifespan, some countries decided to pursue partnerships with other nations to build additional facilities, while new countries sought to adopt the technology. In the wake of the Fukushima Daiichi disaster, however, political support waned, and many interested countries have since cancelled upcoming projects, while others have found traditional forms of energy to be less expensive and more appealing.

Benefits of nuclear to the Latin America Region since inception

Among the many benefits of nuclear technology, the more relevant is the creation of the culture and the structure in Latin America countries of human resources formation and capacity as well as the nuclear infrastructure in these countries for developing indigenous technology programs and also to receive overseas knowledge in many areas of nuclear technology application such as:

- Nuclear energy
- Nuclear medicine
- Nuclear health and environment (Agriculture)
- Nuclear industry
- Nuclear mining and geology

Argentina

Argentina has developed a long-lasting nuclear education and training programme. CNEA is the main human resources training institution in the nuclear field. Since its creation in the 1950s, CNEA has trained highly specialized human resources in strategic areas of the nuclear field as well as the scientific, technical and national production system. For this purpose, in agreement with Argentine public national universities, three academic institutes have been created, with undergraduate and postgraduate degrees in several specialties. The teaching positions are staffed by active engineers, scientists and technologists. The professional quality of the graduates is assured by full-time dedication, small intensive classes, and supervised hands-on learning in the laboratories of CNEA nuclear research centres, where the students have full access to the different facilities[57].

CNEA has a long tradition of welcoming students from regional countries, and vast experience in the training of foreign students responsible for operating the different facilities sold by the country abroad, as is the case of research reactors.

- **Balseiro Institute (IB)** is located at the Bariloche Atomic Centre (CAB). It was founded in 1955 through an agreement between CNEA and the National University of Cuyo (UNCuyo), as a specialized centre for physics teaching. It later incorporated other careers, mainly related to nuclear technology, including nuclear engineering. It was designated as an IAEA Collaborating Centre.
- **Sábato Institute (IS)** is located at the Constituyentes Atomic Centre (CAC). It was founded in 1993, based on the Training Programme in Metallurgy. It is affiliated with the National University of San Martín (UNSAM) and is mainly focused on material science and technology.
- **Dan Beninson Institute (IDB)** is located at the Ezeiza Atomic Centre (CAE). It was created through an agreement between CNEA and UNSAM in 2006. It is focused on nuclear engineering, methodology and application of radioisotopes, radiotherapy physics and dosimetry. For its part, Argentina, through ARN, has been training people in radiological protection and nuclear safety for more than thirty years. An important part of these activities is carried out in collaboration with national universities, such as the University of Buenos Aires (UBA), and courses are also developed with the support of the IAEA.

To support nuclear education, the national institution, devoted to R&D in the peaceful uses of nuclear energy, fosters technologically innovative activities in the nuclear area and consequently performs development and transfer of new technologies in associated fields. One of its main aims has been to provide robust technological support to the country's nuclear system.

Argentina has engaged in a wide array of R&D activities in the fields of physical sciences, chemistry, radiobiology, metallurgy, science and technology of materials and engineering. CNEA's capabilities in radioisotope production, applications and ionizing radiation underscore its experience as a world strategic leader in the field of nuclear applications in human health.

As the nuclear activity in Argentina is a federal activity, several facilities for the nuclear fuel cycle are scattered across the national territory. It is important to mention that the main activities developed by CNEA are concentrated in the following centres:

- **Bariloche Atomic Centre (Centro AtómicoBariloche** — CAB), mainly devoted to research, development and training of human resources in the fields of physics and nuclear engineering.
- **Constituyentes Atomic Centre (Centro AtómicoConstituyentes** — CAC) performs activities within basic research and technological development, focusing on interdisciplinary activities such as micro and nanotechnology.
- **Ezeiza Atomic Centre (Centro Atómico Ezeiza** — CAE), located in the Ezeiza district, is mainly devoted to nuclear technology applications development.
- **Pilcaniyeu Technological Complex**, located in the province of Río Negro, is devoted to uranium enrichment activities and other technological activities.

In total, Argentina operates five research reactors, one in each nuclear research centre and two at public national universities.

Considering education and training on nuclear and radiological safety, the AutoridadRegulatoria Nuclear (ARN) through postgraduate and other training courses, occupies a relevant position on this subject. With support from IAEA, ARN has provided training for nearly 900 professionals from Latin America, the Caribbean and other regions of the world. The IAEA's decision to create competency through training and knowledge management in safety has prompted the IAEA to establish a long-term agreement with ARN to support this activity.

Brazil

Considering nuclear technical formation, few universities offer graduation, specialization and post-graduation courses in the nuclear area. The activities such as specialization and official post-graduation courses are offered by technical-scientific institutes of the DPD/CNEN and universities. There are two undergraduate courses in nuclear engineering offered by UFRJ (University Federal do Rio de Janeiro) and USP (University of São Paulo). However more than 10 universities offer good standard physics and chemistry courses, with background for further technical nuclear formation.

In Brazil, all nuclear R&D activities and post-graduation and specialization courses are developed by government institutions. They are carried out mainly by CNEN's R&D Institutes, which are under the Ministry of Science and Technology and Innovation, and by military technological institutes and technological centers which are under the Ministry of Defense. These ministries are responsible for the establishment of the country's nuclear R&D policies and strategies, as well as for the provision of the necessary budget and financing mechanisms to make the corresponding R&D projects feasible[58].

Nuclear research centers have been established for carrying out R&D in nuclear sciences, and engineering. Research reactors, accelerators and several R&D laboratories, including pilot plant facilities, were progressively set up in these centers. The main research centers are listed below:

- **IPEN (Săo Paulo/SP)** - Institute for Energy and Nuclear Research Reactors: 2 (one 5-MW/pool type and one 100-W reactor/pool type), Cyclotron Radioisotopes Production (^{99m}Tc; ^{131}I; ^{123}I; ^{18}F, etc.), Research on fuel cycle and materials; reactor technology; safety; fundamentals; radiation and radioisotope applications; biotechnology; environmental and waste technologies.
- **IEN (Rio de Janeiro/RJ)** - Institute for Nuclear Engineering Research. Reactor: 1 (100 kW, ARGONAUTA) Cyclotron Radioisotopes production (^{123}I, ^{18}F, etc.). Research on instrumentation, control and man-machine interfaces; chemistry and materials; safety; reactor technology.
- **CDTN (Belo Horizonte/MG)** - Centre for Nuclear Technology Development Research Reactor: 1 (250 kW, TRIGA). Research on mining; reactor technology; materials, safety; chemistry; environmental and waste technologies.
- **]IRD (Rio de Janeiro/RJ)** - Institute for Radiation Protection and Dosimetry Research on radiation protection and safety; environmental technology; metrology; medical physics.
- **CRCN-NE (Recife/PE)** - Nuclear Sciences Regional Centre. R&D on radiation protection, dosimetry, metrology and reactors technology.
- **CRCN-CO (Goiânia/GO) -** Nuclear Sciences Regional Centre of the Centre-west R&D on underground water and environmental technologies.
- Navy Research Centre in Sâo Paulo and ARAMAR. Covering all parts of the Nuclear Fuel Cycle.
- Army Research Centre at Ilha de Marambaia.
- Air Force Research Centre at São José dos Campos. Laser Technology and nuclear engineering studies.

The demand for this type of education and training basically depends on the level of implementation of the Brazilian nuclear program and on expansion of the use of nuclear techniques in industry, health and agriculture. Lately, the number of experts in nuclear medicine application has grown rapidly, based on new development of techniques for applications of medical prevention and cure.

Presently, the human resources of CNEN comprise about 2500 persons, mostly working on nuclear R&D activities. More than 2000 technical professionals hold jobs in the nuclear power-generation and fuel-cycle industries (Eletronuclear and INB). The navy has also more than 1500 technical professionals working in its program. These entire staffs are comprised of high qualified personnel, with 80% of them holding a university degree; of these about 25% are Ph.D. and 25% are M.Sc.

The main concern in the area of human resources is related to the aging of experts. Efforts in the areas of knowledge management and capacity building are being developed to face the current scenario. The hiring of new staff has also occurred, albeit in a moderate way.

Both Argentina and Brazil are having difficulties to get approved and make available the financial resources for their Nuclear Programs. However, the resources required for regulatory and legal commitments are usually delivered.

Mexico

Mexico has followed the same route as Argentina and Brazil. The fundamental difference is that Mexico chose to base the production of nuclear energy in programs of technology transfer.

It can be said that the number of institutions covering the front end of the nuclear cycle is smaller, also the capacity for developing new autonomous projects.

The idea of installing nuclear power in Mexico arose within the framework of the international promotion of nuclear technology in the mid-1950s by the "Atoms for Peace" program of the United States and the United Nations. Mexico's interest in nuclear energy was made official in 1956 with the establishment of the National Commission for Nuclear Energy (CNEN).

CNEN was later transformed into the National Institute on Nuclear Energy (INEN), and in 1979 into the National Institute for Nuclear Research (ININ). The main nuclear research organization in Mexico is the National Institute of Nuclear Research (ININ). ININ has operated a 1-MW Triga Mark III research reactor since November 1968.The Regulatory body in Mexico is called National Commission on Nuclear Safety and Safeguards (CNSNS).It is under the authority of the Ministry of Energy.

As in Argentina and Brazil, the nuclear infrastructure was established, allowing Mexico to implement the NPPs at Laguna Verde as will be described later in this report.

Nuclear Development in Non-Proliferation and Nuclear Safeguards – ABACC an Icon in Latin America

On the subject of nuclear material and installation, Argentina and Brazil acquired a common knowledge in all applications. Both countries, due to nuclear technical development, had enough expertise for nuclear-fuel-cycle development and other uses of nuclear technology.

For a long time, Argentina and Brazil were blamed by the international community to have hidden programs that could lead to nuclear proliferation.

In this situation, and considering the independent political position of these countries, a set of conditions was developed by the two countries that allow creating a body responsible for the control of nuclear material and installations in the two countries, with the supervision of the IAEA.

This was implemented with the creation of a Common System for Nuclear Verification, managed by Brazilian Argentine Account and Control Agency - ABACC, for which both countries offer their human resources, and technical and laboratories support. The capacity and capability for nuclear verification are shared equally.

In applying safeguards as an inspectorate, ABACC had to build a system which had to have competence to fully develop, implement and evaluate safeguards measures. This means that this system must have human-resource capacity, a set of well-developed and useful safeguard equipment, a trained and knowledgeable inspectorate body, and a good headquarters-support system to integrate all data obtained from safeguards activities and to generate its evaluation[59].

The application of nuclear safeguards in the jurisdiction where ABACC operates (Argentina and Brazil) has offered different challenges in a range of different technical aspects. The technical activities are mainly oriented towards the verification of operator-declaredmaterial inventories or facilities usage, as stated in the Common System of Accountability and Control (SCCC) and in the Quadripartite Agreement signed by the parties involved (Argentina, Brazil, ABACC and IAEA).

Problems associated with nuclear in the Latin America Region, and steps taken to resolve these problems

The economic and environmental benefits of nuclear power are clear.

1) Nuclear energy is always on the menu when states look for diverse source of energy. However, the complex and expensive structures required to run a nuclear system (Power stations, structure for licensing, structure for safety, structure for security, and other systems) are not feasible or not worthwhile when the country has a demand that will be met with only one or a few nuclear reactors. (This situation may be reverses with SMRs – see section on advances on nuclear at the region.)

   This economic decision for most countries at the stage of developing countries, leads to sources that may have a higher operational cost but that would be easy to manage as a government policy, making this choice more flexible for those countries. This is applicable for most countries in Latin America, which are small in size and in economic resources.

   This situation may be reversed when small reactors, with lower capital investments, are available in the market.

2) Following the disaster at the Fukushima nuclear power plant in Japan, the safety of nuclear power is undergoing intense scrutiny after 25 years of accident-free operation. Though a legitimate concern, the safety of nuclear energy should not be defined by one occurrence; the two previous accidents occurred in plants with old or inferior technology. The dominant reactor technology in use and planned worldwide is based on light-water-cooled reactors (LWRs). In over 50 years of operation, no serious public injury or death has been attributed to the operation of LWRs.

The Fukushima Daiichi reactors were the world’s first to experience core degradation and to release significant radioactivity off-site as a result of a catastrophic external event. The earthquake and tsunami combination caused complete loss of the power needed for cooling. However, nuclear plants have endured major earthquakes (e.g., in Armenia, Japan, California) and have taken direct hits from Category-5 hurricanes (Andrew at Miami's Turkey Point). Nuclear units have suffered multiple devastating tornadoes, survived tsunamis of lesser magnitude than at Fukushima (approximately 14 meters above normal), and have been battered by floods and a combination of events in multiple locations. None of those cases resulted in radioactive releases affecting health.

The Latin America geographical profile distribution, with many small countries on the western side of central and south America where the seismic profiles for earthquakes and tsunamis have a high probability is an issue when planning nuclear installations.

What must be considered in this context is whether it is possible to build nuclear power-plant structures and emergency systems to withstand the maximum credible natural disaster for a specific region. Nevertheless, like other major industrial complexes with hazardous materials, the system's location and its emergency support structure are critically important. The new LWRs being deployed have design enhancements that focus on increased plant safety, simplicity and standardization, ensuring improvements to core cooling and containment integrity. Furthermore, they have a two-order-of-magnitude improvement in the capacity to prevent or mitigate the consequences of accidents that could result in potentially hazardous offsite radiation doses, including the capability of cooling reactors under complete loss of power. The Fukushima accidents will serve to develop even safer and more affordable nuclear-generated electricity not to be an event that transform this use of energy as a safety prohibition.

Public acceptance does not prevent new projects in many important countries, as the number of plants in construction shows. The biggest problem is the growing capital investment cost and the difficulties to structure projects to fund these long-term maturation investments. However, numbers show a greater difference between these costs in the West and East, where most new constructions are located. Some forms allow this distance to be reduced and to address matters related to nuclear power competitiveness. But matters involving public acceptance are at least partially responsible for the underlying problem of construction costs in the Western world. If Fukushima imposed more obstacles for public acceptance and therefore, for generation costs as well, what can the nuclear industry do about it? The first point to be noted is that public opinion and the level of political support for nuclear power is basically local. There are major differences from country to country, but we know that even in countries with significant acceptance of nuclear power it varies considerably per region. We also know that, even in countries with strong antinuclear feelings there is significant acceptance in regions around nuclear facilities. It would be wrong to conclude that support for nuclear power in these regions is exclusively because of the jobs associated therewith.

Advances in nuclear in the Region since inception

The need for dependable nuclear infrastructure currently favors nuclear deployment by countries that already have operating units and/or have urgent needs for diversification. But this should change as small-reactor technologies with lower initial capital costs become a reality. For countries with political stability, an appropriate regulatory system, and a commitment to environmental protection and to fuel diversification using carbon-free generation, a nuclear-inclusive energy strategy is the best option.

Latin America, even with a low budget for its programs, is following the advances in the nuclear area. Some projects are ongoing in the region, mainly in Argentina and Brazil:

- Small Modular Reactors (SMRs) – Argentina with CAREN and Brazil with The Naval Propulsion reactor
- Production of green hydrogen
- Projects combining nuclear generation with renewables sources (solar, wind and biomass)
- Latest techniques in nuclear medicine applications
- Food processing
- Other applications.

Current and Future State of Nuclear in the Latin America Region:

Argentina -Current state of nuclear in Argentina[63]

Operating nuclear reactors and fuel-cycle activities and intended nuclear-fuel-cycle development plans.

Summary

- Argentina has three nuclear reactors generating about 5% of its electricity.
- Its first commercial nuclear power reactor began operating in 1974.
- Construction has started on a small locally designed power reactor prototype, CAREM25.
- A further planned reactor is to be built by China National Nuclear Corporation.

Nuclear reactors and nuclear energy production

Argentina’s electricity consumption has grown strongly in the last 30 years. Per-capita consumption was just over 2000 kWh/yr in 2002 and rose to about 3000 kWh/yr in 2015. Gross electricity production in 2016 was 147 TWh, comprising 75 TWh (51%) from natural gas, 38 TWh (26%) from hydro, 21 TWh (14%) from oil, 3 TWh (2%) from coal, 8 TWh (5%) from nuclear, and 10 TWh net import[60]. Table 1 shows the installed Nuclear Power Reactors in Argentina.

Argentina's electricity production is largely privatised and is regulated by ENRE (*Ente Nacional Regulador de la Electricidad*). Installed capacity is about 35 GWe, about 10% of which is from auto producers and private generators.

Operating Argentine nuclear power reactors

Table 1: Nuclear power reactors in Argentina (source: WNA- World Nuclear Association)

Reactor	**Location**	**Model**	**Net MWe**	**First power**	**Planned close**
Atucha 1/Peron	Lima, Buenos Aires province	PHWR (Siemens)	340	1974	2024
Atucha 2/Kirchner	Lima, Buenos Aires province	PHWR (Siemens)	692	2014	
Embalse	Embalse, Córdoba province	PHWR (CANDU 6)	670	1983	2049
Total (3)			**1702 MWe**		

The country's National Atomic Energy Commission (Comisión Nacional de EnergíaAtómica**,** CNEA**)** was set up in 1950 and resulted in a spate of activity centred on nuclear R&D, including construction of several research reactors. Today, five research reactors are operated by CNEA and another two research reactors (or prototypes) are under construction.

Argentina has a long tradition in research-reactor technology and has exported this type of reactor to Argelia, Egypt and Australia. It has participated in bids with Belgium and Netherlands with a good competitive profile considering technical project and expertise.

In 1964 it was decided to install a 300-500 MWe unit for the Buenos Aires region. With the country's policy at the time firmly based on using heavy-water reactors fuelled by natural uranium, Canadian and German offers were most attractive, and that from Kraftwerk Union (KWU) was accepted. The 362 MWe (gross) **Atucha 1** plant was built near Lima, 100 km northwest of Buenos Aires.

Atucha 1 entered commercial operation in 1974. It now uses slightly enriched (0.85%) uranium fuel which has doubled the fuel burnup from 6 to about 13 GWd/t or more, and consequently reduced operating costs by 40%. Atucha 2 was planned to follow the same concept. Each has a pressure vessel, in a unique design unlike any other large heavy-water reactor. In April 2018 the Atucha 1 operating licence was extended to 2024.

In 1979, **Atucha 2** was ordered following a government decision to have extra units coming into operation 1987-97. It was a Siemens design, a larger version of unit 1, and construction started in 1981 by a joint venture of CNEA and Siemens-KWU. However, work proceeded slowly due to lack of funds and was suspended in 1994 with the plant 81% complete.

Concurrently with the Atucha project, in 1967 it was decided to install a larger plant at Embalse in the Córdoba region, 500 km inland. In this case a CANDU 6 reactor from Atomic Energy of Canada Li-ited (AECL) was selected, partly due to the accompanying technology transfer agreement, and was constructed with the Italian company Italimpianti. The Embalse plant entered commercial operation in 1984, running on natural uranium fuel. With this agreement Argentina has been granted rights to use this technology (CANDU) in future reactors.

In 2010, an agreement was signed to refurbish the **Embalse**plant and increase its power by up to 7%. The refurbishment, undertaken in partnership with Candu Energy, commenced in December 2015 and was completed in December 2018, with return to service in May 2019[c]. The refurbishment extended the plant's operational lifetime by 30 years and increased power by 35 MWe to 683 MWe.

In 2003, plans for completing the 692-MWe Atucha 2 reactor (745 MWe gross) were presented to the government. In August 2006, the government announced a $3.5 billion strategic plan for the country's nuclear power sector. This involved completing Atucha 2 and extending the operating lifetimes of Atucha 1 and Embalse.

Effective completion of Atucha 2 construction was in September 2011. The Neuquen heavy-water plant completed production of 600 tonnes of heavy water in June 2012. The fuel was loaded from December 2012 to late in 2013 (451 fuel assemblies, each 9.76 metres long). Local content is reported as about 90%. First criticality was achieved early in June 2014, and grid connection was later that month, with full power in February 2015. It entered commercial operation in May 2016[61].

Argentine nuclear power reactors planned and proposed

Table 2: Nuclear power reactors planned for Argentina (source: WNA- World Nuclear Association)

Reactor	**Location**	**Model**	**Gross MWe**	**Construction start**	**First power**
Under construction			47 MWe		
CAREM25	Lima, Buenos Aires province	CAREM	29	Feb 2014	2021
Planned			1150 MWe		
Unit IV (Atucha 3)	Lima, Buenos Aires province	Hualong One?	1150	2020?	?
Proposed			1350 MWe		
?	?	VVER-1200	1200		
?	Lima, Buenos Aires province?	CANDU-6?	750		

Fuel Cycle[63]

1. Conversion

A 150 t/yr (UO2) mill complex and refinery producing uranium dioxide operated by Dioxitek, a CNEA subsidiary, is at Córdoba. This plant converts U3O8 to purified UO2 to feed nuclear fuel for natural or low enriched uranium power reactors. There are plans for Dioxitek to build another plant in the northern Formosa province next to the planned commercial CAREM prototype reactor.

CNEA has a small conversion plant (U3O8 to UF6) at Pilcaniyeu, near San Carlos de Bariloche, Rio Negro, with 60 t/yr capacity. This plant has been shut down for a long period. (since 1990).

2. Enrichment

Enrichment services for nuclear reactors are currently imported. Over 1983-89, INVAP operated a small (20,000 SWU/yr) diffusion enrichment plant for CNEA at Pilcaniyeu, 60 km east of Bariloche in the far west of Rio Negro province. This was unreliable and produced very little low enriched uranium. In August 2006, CNEA said it wanted to recommission the enrichment plant, using its own Sigma advanced diffusion enrichment technology, which was said to be competitive. It was proposed to restart enrichment on a pilot scale in 2007 and work up to 3 million SWU/yr in three years. Eventually, laboratory-scale enrichment commenced in 2014 and the refurbished plant was officially opened in December 2015 with undeclared capacity. The main reason given was to keep Argentina within the circle of countries recognised as having the right to operate enrichment plants, and thereby support INVAP's commercial prospects internationally.

Based on future implementation of PWR rectors (as Hualong One) Argentina is conducting research and development on centrifuge enrichment technology[64].

All operating nuclear power reactors - and Atucha 3 is a PHWR need little or no fuel enrichment. The World Nuclear Association's 2017 Nuclear Fuel Report tabulates no enrichment requirements until 2031, when 245,000 SWU/yr will be required in the scenario of PWR reactor implementation.

Heavy water is produced by ENSI SE (*EmpresaNeuquina de Servicios de Ingeniería*), which is jointly owned by CNEA and the Province of Neuquén where the 200 t/yr plant is located (at Arroyito). It is operated by Neuquen Engineering services, majority owned by the provincial government. This was rebuilt and scaled to produce enough for Atucha 2 and the three following reactors at a cost of about $1 billion, and so now has capacity for export.

3. Fuel Fabrication

Production of fuel cladding is undertaken by CNEA subsidiaries. Fuel assemblies are supplied by Combustibles NuclearesArgentinos (CONUAR) SA, also a CNEA subsidiary, located at the Ezeiza Centre near Buenos Aires. The fuel-fabrication plant has a capacity of 160 t/yr for Atucha-type fuel and Candu fuel bundles.

4. Reprocessing

There are no plans for reprocessing used fuel, though an experimental facility was run around in the early 1970s at Ezeiza. Argentina has yet a large knowledge in reprocessing processes and plutonium handling in different laboratories at Ezeiza and Constytuientes Centers.

Natural resource availability, such as uranium mines and the size of their deposits[63]

Argentina's uranium resources listed in the 2020 *Red Book[62]* total only about 110000 tU, though CNEA estimates that there is some 55,000 to 79000 tU as "exploration targets" in several different geological environments. Most of these sources are not worth exploring commercially.

Uranium exploration was carried out from the mid-1950s, but the last mine closed in 1997 for economic reasons. Cumulative national production until then, from open-pit and heap leaching at seven mines, was 2582 tU from sandstone deposits.

There were plans to reopen the CNEA Sierra Pintada mine in Mendoza in the central west, which closed in 1997. However, objections from the provincial government mean this is now unlikely.

CNEA is also developing feasibility studies for the planned mining of the Cerro Solo deposit in Chubut province from 2018. Reasonably assured resources are 4600 tU in sandstone. Plans are complicated by a provincial ban on open-pit mining.

Some business is conducted by private investments, usually extracting uranium as by-product. In 2017 Canada's U3O8 Corporation leased 4600 ha around the old La Niquelina mine in the north of the province, near the Bolivian border, which produced a little uranium in the early 1950s. U3O8 Corporation also has leases over a superficial uranium deposit at Laguna Salada in Chubut province and is using Marenica's U-pgrade beneficiation process to test samples in Perth.

Australian-based Cauldron Energy Ltd holds leases over 16 km of outcropping uranium-copper mineralisation at Rio Colorado, Catamarca province. This was worked by CNEA in 1950s and 1960s, and Cauldron's exploration target is 6400 tU.

Canada-based Blue Sky Uranium Corp has reported 7360 tU at 0.03%U plus 4600 t vanadium oxide inferred resources (NI 43-101 compliant) near surface in the Ivana deposit, part of its Amarillo Grande uranium-vanadium project in Rio Negro province.

Brazil - Current state of nuclear in the Region[65]

Operating nuclear reactors and fuel cycle activities and intended nuclear fuel cycle development plans

Summary[58]

- Brazil has two nuclear reactors generating about 2.5% of its electricity.
- Its first commercial nuclear power reactor began operating in 1982.
- Construction of the country's third nuclear power reactor is currently stalled since 2015.

- It is expected that Plan 2050 could include planning from 4 to 6 reactors
- The Brazilian Navy has a steady program to build a nuclear submarine. The land prototype is expected to be commissioned in 2022 and the first submarine by the end of the 2020 decade.

Nuclear reactors and nuclear energy production

In 2016, gross electricity production in Brazil was 579 TWh, being 66% from hydro, 10% from gas, 9% from biomass and waste, 6%) from wind and solar, 4% from coal, 3% from nuclear and 3% from oil. However, the growth from wind and solar has changed this picture significantly. In 2018 electricity production in Brazil was 632 TWh and hydro contributed62.3%. Today the wind installed capacity represents 9.1% of the total 167Gw installed and solar 1.3%. However, the installation of a total of 20 GW from these two sources is expected in the next 10 years[65]. Table 3 shows the installed Nuclear Power Reactors in Brazil.

Per-capita electricity consumption in Brazil has had strong growth, from under 1500 kWh/yr in 1990 to around 2400 kWh/yr in 2016.

The high dependence on hydro gives rise to some climatic vulnerability, which is driving a policy to diminish dependence on it. Also, today the application of hydro resources for social requirements supersedes the priority for electricity generation.

Nuclear generation from the two power reactors in operation continues steadily, and today represents around 2% of the electrical energy production. The high load factor for Angra 1 and 2 (more than 90% in the last years) contributes to these figures.

About 40% of Brazil's electricity is produced by the national Eletrobras System. About 20% of electricity is from state-owned utilities, and the rest is from privately-owned companies. No private investment in nuclear power is allowed, though this is under review.

Operating Brazilian nuclear power reactors

Table 3: Nuclear power reactors in Brazil (source: WNA- World Nuclear Association)

Reactor	Model	Net capacity	First power	Commercial operation
Angra 1	PWR	609 MWe	1982	1/1985
Angra 2	PWR	1275 MWe	2000	12/2000
Total (2)		**1884 MWe**		

Nuclear industry development in Brazil[65]

Brazil began developing nuclear technology in 1951 under the newly established National Research Council but accelerated this under a military regime from 1964 to 1985. In 1970, the government decided to seek bids for an initial nuclear plant. The turnkey contract for Angra 1 was awarded to Westinghouse, and construction started in 1971 at a coastal site between Rio de Janeiro and São Paulo.

In 1975, the government adopted a policy to become fully self-sufficient in nuclear technology and signed an agreement with West Germany for the supply of eight 1300 MWe nuclear units over 15 years. The first two units (Angra 2&3) were to be built immediately, with equipment from Kraftwerk Union (KWU). The rest were to have 90% Brazilian content under the technology transfer agreement. To effect this, a state-owned company *EmpresasNuclearesBrasileiras S.A.* (Nuclebrás) was set up with a few subsidiaries focused on particular aspects of engineering and the nuclear fuel cycle.

However, Brazil's economic problems meant that construction of the first two Brazilian-German reactors was interrupted, and the whole program was reorganised at the end of the 1980s. In 1988, a new company, *IndústriasNucleares do Brasil S.A.* (INB) took over the front-end fuel-cycle subsidiaries of Nuclebrás. Responsibility for construction of Angra 2&3 was transferred to the utility *FurnasCentraisElétricas S.A.* (Furnas), a subsidiary of Eletrobrás. However, Nuclen, a former Nuclebrás subsidiary that also had KWU participation, remained as the nuclear plant architect and engineering company. Construction of Angra 2 resumed in 1995, with US$ 1.3 billion of new investment provided by German banks, Furnas and Eletrobrás.Then in 1997, the nuclear operations of Furnas merged with Nuclen to form *EletrobrásTermonuclear S.A.* (Eletronuclear), a new subsidiary of Eletrobrás and responsible for all construction and operation of nuclear power plants.

Angra 3[65]

Angra 3 was designed to be a twin of unit 2. Work started on the project in 1984 but was suspended in 1986 before full construction began. In November 2006 the government announced plans to complete Angra 3 and also to build four further 1000-MWe nuclear plants from 2015 at a single site.

Angra 3 finish-construction approval was confirmed by Brazil's National Energy Policy Council in June 2007 and received Presidential approval in July. Environmental approval was granted in March and all other approvals by July 2009. It will essentially be the same as unit 2 but with digital instrumentation and control systems. In December 2008, Eletronuclear signed an industrial cooperation agreement with Areva, confirming that Areva will complete Angra 3. Areva, today Framatome, is the original technology provider heritage from KWU/Siemens manufacturers.

The plant was expected to be in operation at the end of 2015, after 66 months. In November 2013, in line with the 2008 agreement, a €1.25 billion ($1.7 billion) contract was awarded to Areva for engineering services and components, digital instrumentation and control systems, supervision of installation works and commissioning of the unit. Two Brazilian consortia bid for installation contracts. One was for electro-mechanical assembly associated with the reactor's primary system, valued at around BRL 1.31 billion ($640 million), and another was for secondary-side work, estimated at BRL 1.67 billion ($816 million). Both were awarded in February 2014. Local content is estimated at about 70%.

Following the lack of resources to financing the construction (BNDES and CaizaEconomica) and a corruption probe in mid-2015, Eletrobras suspended both assembly contracts. In January 2017 Eletronuclear formally annulled the electro-mechanical contract. The unit is about 62% completed. At present, construction of Angra 3 is suspended.

During 2017, 2018 and 2019 a new model to finish Angra 3 was discussed and some official decisions were taken in the direction of providing a model with technical, financial and legal frameworks to finalize NPP.

After consideration of many models, the one that is being developed is to transform Angra 3 in a SPE (Specific Purpose Company) which will allow private investors to participate. These investors are technology holders and companies with funds and interest in participating in the nuclear generation. The Chinese (CNNC/SPIC-SNPYC/CGN), Russians (Rosatom), French (Framatome), Korean (Kepco), Japanese (MHI) and most recently North Americans (Westinghouse) had expressed interest.

Some of the milestones for this endeavour are:

- Approval of a new tariff for an Angra 3 selling price- R$ 480/MWh – which will allow return for investment – October 2018
- 2019 – Market Sound (April) and bidding conditions on the second semester
- 2021 – second Semester. Formal signature of the contract
- 2022 – First semester – starting work at the site
- 2027 – start operation. The National Energy Policy Council in June 2017 reviewed ways to restart construction, but the government expected that it would take about five years and BRL 9 billion ($2.9 billion) to complete the unit.[66]

FUEL CYCLE[65]

1. Conversion

Apart from the navy's small experimental plant at Aramar, all uranium conversion is done by Orano, former Areva, in France. INB plans a domestic conversion facility of 1300 t/yr by the 2020 decade.

2. Enrichment

Enrichment of the natural UF_6 has been contracted with Urenco in Europe or USA, but increasingly can be enriched at Brazil's Resende plant. The 2015 Angra 1 fuel refuelling load was from domestically enriched uranium.

Since 1978 the Brazilian Navy have been involved with the enrichment program for guaranteeing the enriched material for a nuclear propulsion program. Four to five cascades of centrifuges were implemented at the Aramar Experimental Center in Iperó (São Paulo state) to test the ultracentrifuges developed as well as to provide enriched material of less than 20% for the submarine program and research reactors. The standard level of enrichment for these cascades is up to 5% U-235 with special campaigns to produce enriched material up to 20% U-235.

Using the enrichment technology developed by the navy at Aramar, and with centrifuges built by the navy and leased to INB, an industrial enrichment plant at Resende is intended to cover much of the needs of the Angra reactors and future reactors. The centrifuges are domestically developed and similar to Urenco technology.

Construction on Phase 1 of Resende officially commenced in 2006 by INB. The first stage of Phase 1 consists of four cascades (module 1). The second stage consists of 3 cascades (module 2 and 3). The seventh cascade (module 3) was commissioned in August 2018, totalling, presently, an operation capacity of 50t SWU/yr. INB declares that the first Phase 1 would involve a total of 10 cascades in 4 modules totalling 70t SWU/yr by 2021. Production commenced in 2009 and keeps going each year. Figure 3 depicts the layout of INB cascade modules.

The plan for Phase 2 is to have 15 modules, with a capacity 500t SWU/yr. It is estimated to have around 30 cascades in operation, but this will depend of the efficiency of the centrifuges being developed. The 500t SWU/yr will be enough to enrich uranium for Angra 1, 2, and 3 and the Brazilian Multipurpose Reactor[67].

In June 2016 INB contracted with Argentina's Conuar, a CNEA subsidiary, to export four tonnes of enriched uranium oxide for the Carem reactor, shipped in three batches with enrichment levels of 1.9%, 2.6% and 3.1% U-235.

Figure 11: Layout of INB centrifuge cascade modules at Resende facilities (Source: INB – IndustriasNucleares do Brasil)

3. Reconversion

Besides the pilot plant at ARAMAR, operated by Brazilian Navy and dedicated to naval and research reactors fuels, INB also operates a reconversion plant to make UO_2 powder, with a capacity of 160 t/yr. The INB plant has capacity for reconverted UF6 to UO2 for all present and future nuclear power reactors (up to 8 reactors).

4. Reconversion and Fuel Fabrication

INB's fuel fabrication plant designed by Siemens is also at Resende, with a capacity of 120 tonnes per year of UO2 pellet production and 280 t/yr of UO2 fuel assembly production. As for reconversion, the INB plant has capacity for fuel fabrication for all present and future nuclear power reactors (up to 8 reactors). Table 4: Uranium load for Brazilian nuclear Reactors (Source: INB – IndustriasNucleares do Brasil)presents the today’s operational data.

Table 4: Uranium load for Brazilian nuclear Reactors (Source: INB – IndustriasNucleares do Brasil)

Reactor	**Core**	**Recharges**	**Enriched U**	**U Production**
Angra 1	121 EC	40 EC	17tU 4%	130 tU
Angra 2	193 EC	56 EC	35 t U 4,25 %	285 tU
Angra 3	193 EC	56 EC	35 t U 4,25 %	285 tU

5. Reprocessing

Brazil has a small capacity and knowledge on reprocessing. Some R&D work is performed at IPEN and theoretical studies at Army R&D Research Center

Natural resource availability, such as uranium mines and the size of their deposits

Resulting from active exploration in 1970s and 1980s, Brazil has known resources of 278,000 tonnes of uranium (310,000t U3O8) – 5% of world total. Brazil occupied today the 6^{th} or 7^{th} position of the countries having uranium in the world. Only 30% of the territory has been prospected and geological profile indicated a high possibility to find other deposits. So, the general assumption is that the uranium resources are greater than the above data.

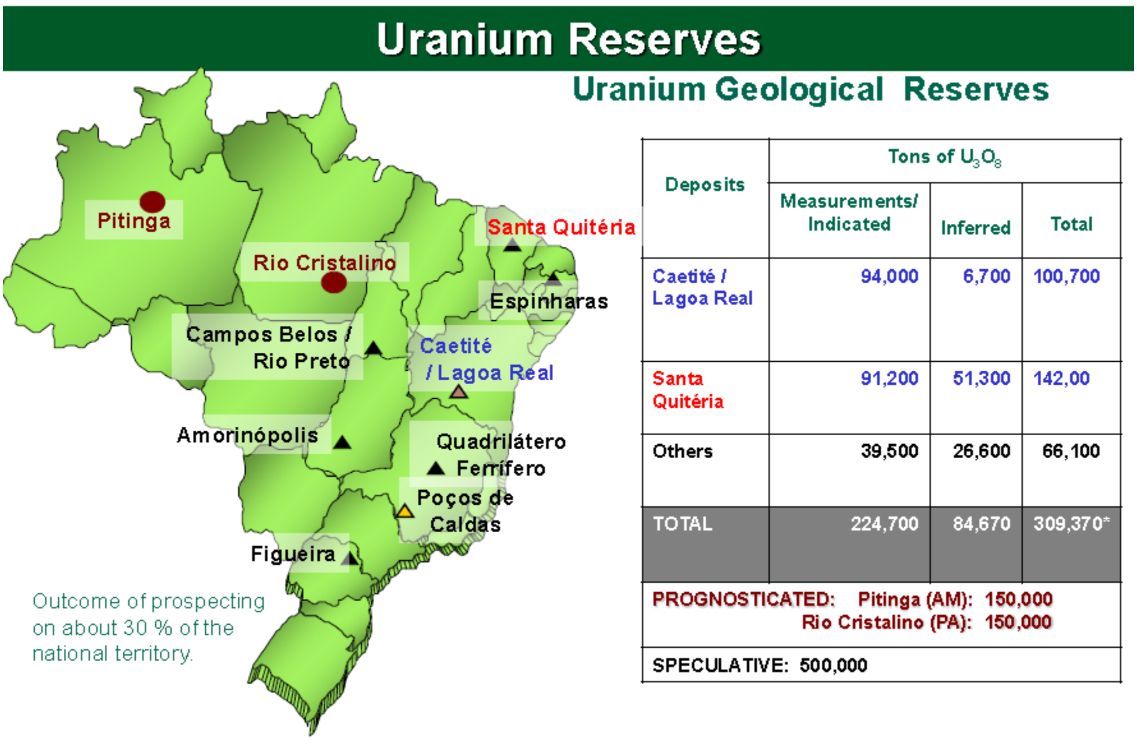
Three main explored deposits are: Poços de Caldas (Minas Gerais state; mine closed in 1997); Lagoa Real or Caetité (Bahia state; operating since 1999); and Itataia, now called Santa Quitéria (Ceará state; phosphate as by-product; production start planned).

In the 1988 constitution the federal government reserved a monopoly over uranium resources and their development. Amendments are proposed to open up uranium exploration and mining to private enterprise, as was done in the oil and gas sector in 1995. All mined uranium is used domestically.

Uranium has been mined since 1982, but the only operating mine is INB's Lagoa Real/Caetité mine on the Cachoeirametasomatite deposit, with 340 tU/yr capacity (400t/yr U3O8). Up to 2013 all production came from Caetite, where open-pit operation finished in 2012 and where underground operations face licensing difficulties, but are expected to begin in 2020. Modest production from heap leaching continues meanwhile. It has known resources of 10,000 tU at 0.3%U.

There has been little investment in exploration since the mid-1980s. INB has commenced developing the adjacent Engenho mine for production from October 2017, a 200-300 tU/yr open pit operation feeding the Caetite mill over 14 years from similar 0.2% ore. The mill is undergoing a $90 million upgrade to increase capacity to 670 tU/yr.

In 2008, INB entered an arrangement with fertiliser producer Galvani to recover uranium from phosphate mined at Itataia/Santa Quitéria in the northeast, Ceara State. The open-pit mine was expected to produce 970 tU/yr from 2016, and ramp up to 1270 tU per year as by-product phosphate. Reserves are 76,000 tU at 0.08%U, with 140,000 tU resources quoted elsewhere. Figure 3 presents Brazil's Uranium reserves and location.



Deposits	Tons of U_3O_8		
	Measurements/ Indicated	Inferred	Total
Caetité / Lagoa Real	94,000	6,700	100,700
Santa Quitéria	91,200	51,300	142,00
Others	39,500	26,600	66,100
TOTAL	224,700	84,670	309,370*
PROGNOSTICATED: Pitinga (AM): 150,000 Rio Cristalino (PA): 150,000			
SPECULATIVE: 500,000			

Figure 12: Brazil Uranium reserves and location (Source: INB – IndustriasNucleares do Brasil)

Mexico - Current state of nuclear in the Region[68]

The CNEN. This organization took general responsibility for all nuclear activities in the country, except for electricity generation. The Federal Electricity Commission (CFE), one of the two state-owned electricity companies at that time, was assigned the role of future nuclear electricity generator and received the advice of the Stanford Research Institute Analysis Group. Preliminary investigations to identify potential sites for nuclear power plants began in 1966, led by CNEN and CFE. In October of 1966 Laguna Verde was mentioned as a possible location, and in 1968, the request for the installation of a nuclear plant with a 654-MWe reactor in Laguna Verde, Veracruz, was formalized. In 1969 CFE invited bids for proven power plant designs with a capacity of around 600 MWe, and in May 1972 a decision was made: a contract was signed with General Electric for the purchase of the nuclear reactor and with Mitsubishi for the turbogenerator. In 1976, construction of two 654-MWe Boiling Water Reactors (BWRs) began at the Laguna Verde site.

The Nuclear Power Plant in Mexico is located on the coast of the Gulf of Mexico at the municipality of Alto Lucero, State of Veracruz. It has an area of 370 Ha. Geographically it is located 70 km to Northwest of the Port of Veracruz and 290 km Northeast of Mexico City. The Laguna Verde Nuclear Power plant has two identical units, each with a GE-BWR/5 type reactor. Construction of Unit 1 on September 30, 1976. It reached first criticality on November 7, 1988, was connected to the grid on April 12, 1989, and started commercial operation on July 24, 1990.Construction of Unit 2 began on May 31, 1977, reached first criticality on September 5, 1994, was connected to the grid on November 10, 1994, and started commercial operation on April 10, 1995. The original thermal power was 1931 MWth (approximately 675 MWe each unit), but in 1990 both units went to a 5% power uprate to 2027 MWth (Net 690 MWe). In 2013 a major power uprate up to 20% of the original power was implemented on both units, reaching 2317 MWth (Net 805 MWet). This power uprate would allow the Laguna Verde NPP an additional annual generation of 2.1 TWh.

License renewal

As a result of the equipment renewal and replacement during the power uprate, there was the possibility of applying for a license extension for the NPP. In March 2015, the NPP operator applied for a license renewal of Unit 1 to the National Commission for Nuclear Safety and Safeguards (CNSNS). In 2019, the International Atomic Energy Agency (IAEA) through SALTO (Safety Aspects of Long-Term Operation) found that CFE had a "good basis" to manage the long-term operation of the NPP.

On July 24 2020, the Regulatory Body approved a 30-year extension to the operating license of Laguna Verde 1, allowing it to operate until July 25 2050 (60 years total since first commercial operation). An application for a similar extension has been lodged for Unit 2 and is expected to be granted in the years following.

Figure 13: A current view of NPP Laguna Verde, Unit 2 to the left and Unit 1 to the right (Photography owned by CFE)

General - Future state of nuclear in the Region

Latin American and Caribbean electricity needs are expected to expand by more than 91% by 2040, reaching over 2,970 TWh. This means the region will need to add nearly 1,500 TWh to meet its electricity requirements. Broadly speaking, this figure equals eighteen (18) times the electricity generated in 2014 by the largest hydroelectric power station in LAC (and the third largest worldwide) – Paraguay-Brazil's Itapúa.

Thus, an unprecedented amount of new energy infrastructure will need to be planned and financed. It is expected that more than 80% of the projected growth would come from the six largest economies in the region. Brazil (37%) and Mexico (19%) alone would account for more than half of the electricity needs of the region in 2040. Total electricity requirements in Brazil would increase by 96%, from 570 TWh in 2013 to more than 1120 TWh in 2040, while Mexico's needs would increase by 87%, reaching over 556 TWh. Among Latin America's largest economies, electricity needs will grow most rapidly, on average, in Chile (3.3%) and Colombia (3.4%), reaching over 175 TWh and 159 TWh respectively; this primarily reflects strong economic performance. Conversely, we project a considerably slower average growth rate for electricity requirements in both Argentina (1.6%) and Venezuela (1.8%), primarily due to expectations of weak economic activity in both economies over the forecast period, though this is subject to much uncertainty.

Clean, abundant and well-distributed electricity generation is critically important for Latin America. In the twenty-first century, energy policies must be affordable over the long term, and they must be sustainable and oriented toward pursuing a diverse mixture of clean technologies that will reduce carbon emissions.

Nuclear power is a reliable, clean and predictable electricity producer that today is ready to fit the economic, environmental and national security needs of Latin American countries, including Argentina, Brazil, Chile, Colombia, Mexico, Peru, and Venezuela. And with small, modular reactors expected to be available on the market in less than 20 years, nuclear power will be able to service the entire region. Multiple independent studies, including work by the United Nations, the Organization of Economic Cooperation and Development and others, have shown that nuclear-generated electricity has the same life-cycle environmental impact as wind and solar.

Nuclear power is the largest contributor to carbon-free electricity generation in the world, accounting for roughly three-quarters of the world's carbon-free power. The economics of nuclear energy generation depend on its capacity to produce enormous and uninterrupted amounts of electricity over long periods, with affordable and stable electricity costs. Nuclear generating plants can operate for 60 years or more. For example, a single 1,000 megawatt electrical (MWe) nuclear power station runs about 90 percent of the time at full power, generating close to 8 million megawatt-hours (MWh) annually. Conversely, 1,000 windmills of 1 MWe capacity (each one running at the high end of capacity, typically less than 30 percent) would generate less than 2.5 million MWh annually.

Nuclear power generation satisfies the need for predictable and economic base-load electrical systems—those that run most of the time and do not go up and down in power during the day cycle. However, getting there isn't easy: it requires a very large initial investment. Nevertheless, once a plant is built, it is relatively economical to maintain—like hydropower. The cost for new nuclear plants ranges from $4,000 to $7,000 per kilowatt-watt electrical (kWe), which is about the same as hydropower, slightly more than coal plants without carbon reduction equipment, more than twice as much as natural gas plants without carbon capture, and less than wind and solar. Nuclear is competitive because the other cost factors (fuel, operation and maintenance and capital improvements) are significantly less for nuclear (about $0.023 per kWh) than for gas (about $0.05 per kWh), and less than coal.

Argentina - Future state of nuclear in Argentina

Future Units - Units IV and V (Atucha 3)[63]

In July 2014 an agreement was signed by the Argentine and Chinese presidents towards construction of Unit IV (Atucha 3) as a PHWR unit, though with NA-SA to be designer, architect-engineer, builder and operator of it. CNNC will assist by providing most of the equipment and technical services under long-term financing (it operates two similar units at Qinshan). Candu Energy will be a subcontractor to CNNC. In September 2014 NA-SA signed a commercial framework contract with CNNC for building a CANDU 6 unit (678 MWe net). There were a series of subsequent agreements and contracts (2014/2015/2016) among NA-SA, CNNC, SNC-Lavalin and other manufacturers to plan the implementation of a CANDU 6 in Argentina.

The agreements also call for the transfer of Chinese PWR technology to Argentina. Under the accord, Argentina could act as a technology platform, supplying third countries with nuclear technology incorporating Chinese goods and services. These agreements point to a Hualong One reactor financed at least in part by China but with significant local content. (See Table 2).

In May 2017 further contracts were signed between NA-SA and CNNC for the construction of Unit IV (as a CANDU 6) and Unit V (as a Hualong One) reactors.

In January 2019 reports suggested that the fourth unit, to be built at the Atucha site, will now be an 1150 Mwe Hualong One unit (which had been planned as the fifth unit). China is to finance 85% of the reactor's construction, which is planned to commence in 2020[69].

Possible sites mentioned but unconfirmed for further plants are in Monte Lindo, La Emilia, RiachoTohué, RiachoPilagá – all on the Paraguay River in Formosa province in the north. Colona Bouvier in Formosa has also been mentioned, but in connection with a full-size (100-200 MWe) CAREM reactor

Proposals from numerous countries in addition to China were considered by Argentina for construction of its fourth and fifth nuclear power units, most notably from Russia. The government had also held earlier talks with reactor vendors from France, Japan, South Korea and the USA.

CAREM reactor[63]

Another aspect of the government's 2006 strategic plan was to build a 29-MWe prototype of the CAREM (*Central Argentina de ElementosModulares*) reactor, and construction is now under way at the Atucha site. Authorization for site use and construction was received by CNEA in September 2013, and first concrete was poured in February 2014. Some 70% of components will be manufactured locally. The reactor pressure vessel is being built by IndustriasMetalurgicasPescarmona SA (IMPSA), making it the first such large component to be made in the country. Target completion date is end of November 2021[70].

Developed by CNEA with INVAPand others since 1984, the CAREM25 nuclear reactor is a modular 100-MWt simplified PWR with integral steam generators, designed to be used for electricity generation (29 MWe) or as a research reactor or for water desalination. CAREM has its entire primary coolant system within the reactor pressure vessel, self-pressurised and relying entirely on convection. Fuel is standard enriched PWR fuel, with burnable poison, and it is refuelled annually.

In June 2016 Brazil’s INB contracted with Conuar, a CNEA subsidiary, to provide four tonnes of enriched uranium oxide for the CAREM25 reactor. It will be shipped in three batches with enrichment levels of 1.9%, 2.6% and 3.1% U-235.

The prototype will be followed by a larger version, 100 MWe or possibly 200 MWe, in the northern Formosa province by 2021. This larger version is intended to be commercialized.

RA-10 Research reactor

In 2013 INVAP was awarded contracts to build the RA-10 research reactor in Argentina, with Australia’s OPAL reactor being the reference design (designed by Argentina). The reactor will be used for the production of medical radioisotopes and irradiated materials for testing and qualification. The location and schedule of the RA-10 unit has not been announced. In November 2014 the Nuclear Regulatory Authority granted a construction licence for RA-10, which will be used to increase the country's production of radioisotopes to enable the country to meet 10% of world demand. Currently radioisotopes are produced at the RA-3 research reactor at the Ezeiza Atomic Centre in Buenos Aires province. RA-3, a 10MWt pooltype, operating since 1967.

RA-10 and the Brazil Multipurpose Reactor (RMB) have a very similar design, both with INVAP participation, and the projects are part of the growing bilateral cooperation in nuclear energy between Argentina and Brazil. Between them, they will provide the capacity to supply some 40% of global radioisotopes.

Brazil- Future state of nuclear in Brazil[65]

The present Government of Brazil has demonstrated a high priority to finish Angra 3 and to continue with a program to build further nuclear reactors[71]. The project will assure baseload security of supply for an interconnected grid of continental dimensions.

Brazilian nuclear power reactors under construction and proposed.[65]

Table 5: Nuclear power reactors planned for Brazil (source: WNA- World Nuclear Association)

Reactor	Model	Gross capacity	Construction start	Commercial operation
		Total under construction: 1**		
Angra 3	PWR	1405 MWe (1270 MWenet)*	June 2010	2027
Proposed			6600 MWe	
Northeast, Pernambuco	PWRx4	6000-6600 MWe		2030
Southeast, Minas Gerais	PWRx4	4000-6000 MWe		2030

* Angra 3: 1405 MWe from Eletronuclear website. Improvement in fuel handling.
** Construction currently restart.

Eletronuclear has studies to build new nuclear plants in the northeast of Brazil. These will be a cluster of 4 to 6 power reactors in the northeast, on a large dam on the Sao Francisco River, between Pernambuco and Bahia states for up to 6600 MWe, and another option would be the north of Minas Gerais state in the southeast of the country. However, any decision for new plans is being studied by the government and will be made public when the 2050 Energy Plan Development for Brazil is published (previewed for November/December 2019).

The Brazil's National Energy Plan 2050 (PNE 2050) will consider new nuclear power plants for baseload generation. Brazil has a large installed hydro-power capacity, but this will not be enough to assure baseload generation and security of supply in the face of growing electricity demand and a growing renewable energy capacity (wind and solar). In the period 2020-2030, Brazil will consider "existing technologies", but advanced technologies such as Generation IV and SMRs must be considered in the period from 2040 to 2050. (See Table 5)

Other reactors:

Reactor Multi Proposita (RMB) -The RMB aims to provide the country with a science, technology and innovation infrastructure of fundamental importance to the nuclear sector. The project comprises a 30-MW research reactor as well as several associated facilities and laboratories to perform the following functions: radioisotope production, with emphasis on molybdenum 99 (Mo-99); irradiation tests of nuclear fuels and materials; and scientific research using neutron beams. The reactor’s site has been chosen to be at So Paulo state, and environmental impact assessments have been conducted. Local Approval and Preliminary Environmental License have been issued to RMB by the corresponding nuclear and environmental regulators. The basic engineering design has been concluded and the detailed engineering design is to be contracted out in early 2016, in cooperation with Argentina.

LABGENE is the installation, comprised of reactor, associated systems and buildings, a naval land prototype reactor to validate the first vessel nuclear reactor for the Brazilian navy program to develop a nuclear submarine. It is a PWR-type reactor with some natural safety re-circulating systems. The planned fuel enrichment is between 18 and 19.9%. The structure to support LABGENE comprises laboratories, pilot plants and auxiliary systems. The structure and human resources allocated to the project give the navy the knowledge to apply this technology to a large variety of fields, including verification activities.

The installation, in the navy’s facilities in Piero, São Paulo, will house the turbines, pressurizer, and fuel, as well as a submarine waste packaging area. To date, about 65 percent of the industrial infrastructure for the construction, operation, and maintenance of submarines has been completed. When LABGENE becomes fully operational it will have a 48-MW nuclear plant, powerful enough to feed the subsystems required for submarine propulsion. The planned commissioning date is 2021/2022[72].

There is a continuing military influence on Brazil’s nuclear program. Brazil is the only non-nuclear-weapon state in which the military leases uranium enrichment technology to the civilian nuclear program and the navy drives technological advances in the nuclear field. Also, Brazil is the only non-nuclear-weapon state developing a nuclear-powered submarine.

The Roles of nuclear in the future in the Latin America Region based on policy statements by government and stakeholders

Nuclear sciences and technologies have a multidisciplinary application, in domains where society has established priority development challenges, such as health, agriculture, mining, industry and energy, to mention the main ones. Thus, nuclear technologies area relevant actor in the important challenges facing humanity, with applications ranging from the detection and monitoring of diseases and their treatment, the improvement of agricultural species, safety and designation of origin of food products , the monitoring of the environment, watercourses, the migration of animal species, to the monitoring and mitigation of the effects of climate change, in the measurement of soil and sea pollution and its recovery, also counting everything that scientific-technological development reveals as new areas of application.

The current society must solve the problems that economic development entails for the planet, with increasingly scarce resources. These are questions whose complexity and scope necessarily require knowledge, science and technology that provides answers. Human intelligence and its knowledge of how to optimally organize itself in the face of questions will play a key role in the sustainability of life. Nuclear sciences and technologies have can contribute based on the breadth of their action and the evidence of success of several decades.

In conclusion, the areas in which nuclear technologies are present are wide and varied. At the same time, in these areas there are complementary developments that originate from other aspects converge in shared domains and objectives. This analysis allows us to visualize the framework in which nuclear technological activity is inscribed in scientific-technological development, with a common denominator that is the application of **nuclear technologies in the various fields where they are** at **least relevant to produce the expected effects of their use.**

These domains range from:

1. the field of **health,** in the detection of diseases and their treatment
2. **agriculture,** in the improvement of species
3. the **food** industry, food safety and designation of origin of products
4. the monitoring of the **environment** and the ecosystem, in the monitoring of watercourses, the migration of animal species; up to
5. the monitoring and mitigation of the effects of **climate change,** in the measurement of soil and sea pollution and its recovery; counting, in addition
6. everything that scientific-technological development reveals as new areas of application.
7. Reliable, clean and powerful **source of energy** to provide energy locally or remotely.

Nuclear technologies, that is, all those techniques that are derived from the activation of atomic nuclei and that produce ionizing radiation, are in themselves a field of research. Traditionally, technologies of nuclear origin have been those derived from the treatment of materials in nuclear fission reactors. However, in recent years, developments derived from machines, some of small size, which produce dense and hot plasmas and are therefore in the domain of nuclear fusion have provided on-off devices capable of generating neutrons and a series of ionizing and non-ionizing radiations. The consequence of these developments is that there is a set of sources, radioactive and non-radioactive, suitable for different purposes of technological application. It is thus evident that a fundamental area of research, pure and applied, is that which addresses the understanding of the phenomena that are at the basis of the origin of radiation and thus allow, and has already allowed, incorporating new devices that provide useful radiation sources.

The **areas of application** of nuclear technologies are varied and multiply and the research problems range from the understanding of the physical-chemical mechanisms that explain the effects on different materials and chemical and biological systems, to the study of the consequences of radiation on the properties of such systems and materials.

The use of isotopes, both radioactive and stable, in **the monitoring and intervention of the ecosystem,** which is an area where applications proliferate, becoming increasingly relevant due to the advance of the serious effects of climate change, on the availability of water, soil and air pollution, changes in biodiversity and species migration.

The **phenotypic and genotypic modification of living species,** as a measure to mitigate the effects of climate change on biodiversity, is also a way to face the magnitude of a phenomenon whose control is becoming less and less possible.

The importance of the use of nuclear technologies in the domain of agricultural products and food also points to aspects that have an impact on the ecosystem. **Food safety, traceability of agricultural products, monitoring of soil contamination, pest control** without the intervention of **chemical elements,** are unavoidable tasks to ensure the **controlled functioning of the ecosystem.**

In different degrees of application, the countries in Latin America and the Caribbean, based on their development status and economic capacity, are observing and moving towards participating in nuclear technology.

Argentina and Brazil

The future roles of nuclear in the Brazil/Argentina areas are as described in the section “Future state of nuclear in the Latin America region based on policy statements by government and stakeholders (G4, SMR, Fusion, etc)” above.

Mexico

Due to the Mexican government’s international environmental commitments from the COP-21 forum, it was stated that in 2024 the country must generate 35% of its electricity using clean energy sources. In 2015 it was announced by the Mexican government via an official energy prospectus (PRODESEN) that Mexico will increase the nuclear share from the two reactors in Laguna Verde NPP up to five reactors. However, the 2020 PRODESEN version takes up the issue of the nuclear program projecting the inclusion of 1500 MW of additional nuclear capacity for the 2025 – 2031 period as a part of strategic projects in the national electricity sector.

Several studies on available technologies have been performed by the National Institute for Nuclear Research (ININ). One proposed scenario for the expansion of the Mexican nuclear program, that matches the projections of 2020 PRODESEN, could be the construction of a large 1,400-MWe reactor on the site of the Laguna Verde NPP, and a small modular reactor (SMR) of 100 MWe in Baja California Sur. A more ambitious and reasonable proposal has also been studied, consisting of the addition of two 1,400-MWe plants on the site of Laguna Verde NPP for the period 2029-2030, and the addition up to four 100-MWe modular reactors (SMR’s) to be installed in Baja California Sur for the period 2031-2034.

Chile

It is evident that an area of great impact on society of the present activity of the CCHEN is in health, in particular, in **the diagnosis and treatment of cancer.** The challenges are several: the reliability of the diagnosis, the accuracy of the treatment and the attenuation of unwanted side effects, the development of low-cost techniques, and others. While the applications of nuclear technologies are not limited to the diagnosis and treatment of cancer, a focus in that direction can certainly open unsuspected uses in other health domains.

The set of areas of research and development indicated has a profound impact on the sustainable development of humanity. These are domains that are not alien to the activity of the CCHEN, in some cases sporadic or incipient, in others solid and consolidated, but where the common denominator is that they have developed human and material capacities in our institutions.

NORTH AMERICA REGION([77][78][79][80][81][82])

Brief history of nuclear development in the North America Region

United States

The history of nuclear power in the United States begins with the events around the Chicago Pile 1 reactor and the Manhattan Project back in the 1940's during World War II. The immediate years following the war were focused on research and the military use of nuclear technology, but that changed in 1953 with President Dwight D. Eisenhower's famous "Atoms for Peace" speech to the United Nations. In response to Eisenhower's speech, concerned American scientists and engineers began meeting and a year after Eisenhower's speech, the American Nuclear Society was formed to help support and advance the peaceful uses of nuclear science and technology for the benefit of humanity.

What followed was roughly two decades of investment and growth in the U.S. nuclear industry that led (eventually) to over 100 nuclear reactors at the peak, safely and reliably producing power for the grid from the fission of atoms. That investment slowed following the events of Three Mile Island and, to a lesser extent in the U.S., Chernobyl, to the point that many states had moratoriums on new nuclear builds (a trend that is now finally reversing thanks to decarbonization efforts around the country). Following those accidents, there was an extended period of operational review and improvement in both efficiency and safety—both discussed later in the section. These improvements in the nuclear industry in the U.S. paved the way for the nuclear renaissance of the early 2000's.

From 1978, one year prior to TMI, through the turn of the century, there were no new nuclear power plants authorized to begin construction. However, there was a clear enthusiasm at the turn of the century that was building around the nuclear community in the U.S.

Figure 14: The Three Mile Island NPP on Three Mile Island, circa 1979[73]

Larry Foulke, the ANS vice president/president elect in 2003, said at an ANS meeting that "The renaissance of nuclear power in the U.S. is inevitable." There was a lot to be excited about back in 2003. The nuclear industry in the U.S. saw consistent and unprecedented growth in performance and safety improvements that meant nuclear-generated electricity was among the cheapest available at the time.

Then, the Bush administration's National Energy Policy endorsed investing in nuclear power and funded multiple programs within the DOE to help spur new investments at the time. The third point mentioned by Foulke was that Yucca Mountain was "moving along toward becoming a geological repository for all spent fuel—meaning the issue of spent-fuel management would not be an issue for utilities looking to invest in nuclear power".

However, less than 10 years later, the nuclear industry in the U.S. was in a very different state. While the Nuclear Regulatory Commission approved eight license applications for new reactors, construction began on only two (two additional reactors at the Vogtle and Summer nuclear power stations). Nuclear professionals can point to many reasons why the renaissance didn't pan out, but the biggest reasons are:

- The U.S. was facing the biggest financial crisis since the Great Depression
- Nuclear power was competing against a boom in natural-gas production in the U.S.
- Experience with the licensing and construction of the Summer and Vogtle reactors shows that the anticipated efficiencies associated with design certifications and combined licensing in 10 CFR Part 52 have yet to be realized.

Figure 15: Vogtle 3 & 4 under construction[74]

Those were just some of the challenges the nuclear community in the U.S. was facing prior to the tragic events of the Great Tohoku Earthquake and tsunami that killed thousands of citizens in Japan and caused the accident at the Fukushima Daiichi nuclear generating station.

Following the events of the tragic accident, the nuclear industry in the U.S. faced a real downturn despite the clean-energy benefits nuclear power provided to the grid and the wider economy.

Canada

In considering Canada's current nuclear scene, it is important to understand its history and evolution.

Canada was involved in nuclear research from the very outset of the science, starting with Ernest Rutherford's years at McGill University in the early twentieth century. Following the discovery of fission in 1938, experimental work on graphite-moderated subcritical assemblies was performed at the Canadian National Research Council.
The roots of Canada's nuclear industry, however, really lie in the war effort in World War II. An agreement between the Allies during the war gave Canada the mandate to do research on fission in natural-uranium lattices and heavy water. For this effort, a team of scientists from Canada and Europe was put together, first as the "Montreal Group" at the École Polytechnique de Montréal, later moved to a new research establishment at Chalk River, Ontario. Research was carried out using heavy water which had been brought by French and U.K. physicists to Canada. This research led to the ZEEP reactor (Zero Energy Experimental Pile), which went critical a few days after the end of WWII. Canada thus became only the second country in the world, after the USA, to achieve a self-sustaining chain reaction.

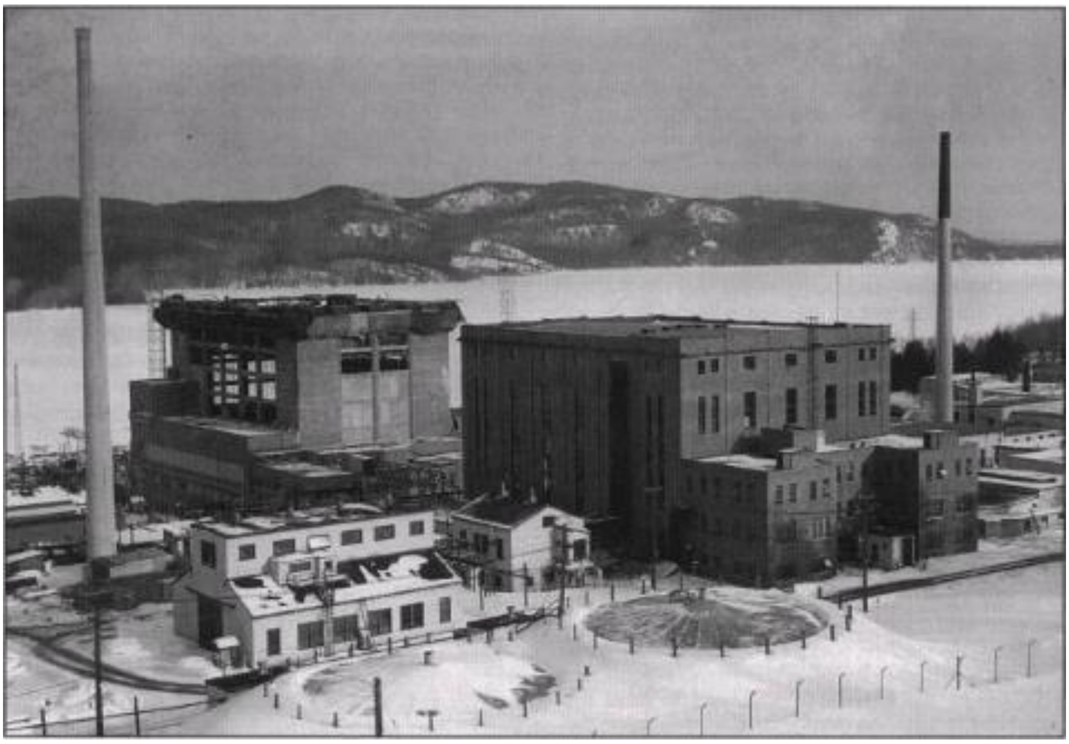


Figure 16 ZEEP in February 1954 with NRX and NRU (under construction, in background[75]

Benefits of nuclear to the North America Region since inception

United States

Currently, nuclear is the largest source of clean power in the United States, with 93 reactors across 55 power stations that generate over 800 billion kilowatt hours of electricity annually, which equates to more than half of the nation's emissions-free electricity. That clean power avoids more than 500 million metric tons of carbon, 200 thousand short tons of both nitric oxide and sulfur dioxide each year. Today, in addition to providing clean energy, a vast array of nuclear technologies helps in many other areas in the U.S. Some of the uses of nuclear technology are:

- Radioisotope production for medical procedures
- Improving medical diagnosis
- Fighting certain diseases like cancer or even COVID-19
- Food irradiation
- Promotion of agricultural productivity
- Enhancing human nutrition
- Space exploration
- Advancing environmental science
- Strengthening industrial quality control
- Industrial sterilization.

Currently, millions of nuclear-medicine procedures are performed each year in the United States, and it is estimated that one in every three hospitalized patients has a nuclear medicine procedure performed in the management of the illness.

The benefits outlined above make nuclear a key national asset for the U.S. if goals like decarbonization are to be met within the next two decades. However, there are problems the community must contend with if nuclear is to flourish in the U.S. and see a new nuclear renaissance.

Canada

After the War, Canada continued fission research at Chalk River Nuclear Laboratories, which became Atomic Energy of Canada Limited (AECL) in 1952.Research reactor NRX (Nuclear Reactor Experimental) was built, and in its time had the highest neutron flux in the world. This made it extremely useful in fuel and material research both for Canada and for the USA's nuclear program. The same can be said about the larger NRU (National Research Universal) reactor, which took over in the research on irradiation of fuels and materials with its record very high flux. In addition, NRU was applied to the production of molybdenum-99, of tremendous importance in diagnostic medicine, and NRU was the main provider of this radionuclide to the world's hospitals until it was shut down in the mid 2010s. Another reactor, ZED-2, was built to follow ZEEP to do crucial reactor-physics studies on fuels and heavy-water lattices.

John Hilborn at Chalk River also developed the SLOWPOKE, a very small, zero-power reactor for use in university research and training of students in nuclear science. SLOWPOKEs were installed in universities in several Canadian provinces and in Jamaica. McMaster University built its own research reactor (5 MW)

Meanwhile, Canada made another wonderful gift to the world, in the application of nuclear technology to medicine. Dr. Harold Johns developed the "cobalt bomb", more appropriately called the cobalt therapy machine. The first of these were installed in Saskatchewan and Ontario in 1952, but its use of course "exploded" in medical therapy worldwide. Cobalt could be provided in Canadian nuclear research reactors, and later in power reactors. In fact, since then, Canada has been a major producer and exporter of various radionuclides to the world.

Problems associated with nuclear in the North America Region, and steps taken to resolve these problems

United States

Cost

Over the past 20 years, U.S. nuclear-power-plant closures resulted in a loss of 8.4 GWe. Some of these plants closed early due to financial issues, including Kewaunee, Vermont Yankee, Fort Calhoun, Pilgrim, Three Mile Island-1, and Duane Arnold. Another 8.2 GWe of U.S. nuclear power capacity is scheduled to vanish by 2025, with some plants scheduled to close for financial issues, including Byron, Dresden, and Palisades. Even more nuclear power plants are at risk of early closure due to financial issues, including LaSalle, Braidwood, Beaver Valley, Davis-Besse, and Perry. Note that other nuclear plants closed due to equipment issues (Crystal River, San Onofre) and Indian Point –2 and –3 shut down permanently under pressure from state authorities. Diablo Canyon is following in Indian Point's footsteps and is slated to close in 2025.

Some U.S. nuclear power plants with financial issues remain in operation due to individual states' action, including zero-emission credit (ZEC) programs. New York, Illinois, and New Jersey ZEC programs thus far have saved multiple nuclear power plants from early closure. Connecticut allowed Millstone to participate in a clean energy auction, and Pennsylvania's plan to join the Regional Greenhouse Gas Initiative was noted as a factor in stopping the planned early closure of Beaver Valley. Davis-Besse and Perry were saved from early closure by the Ohio ZEC program, but these two plants are at risk now because this program was repealed in 2021.

Safety

Following the Fukushima accident, the community in the U.S. faced many questions about safety from both regulators and the general public. The U.S. nuclear industry and the Nuclear Regulatory Commission took actions to evaluate and mitigate beyond--design--basis events, including a new requirement for the staging of so-called Flex equipment, as well as changes to containment venting and improvements to emergency preparedness. The U.S. Department of Energy also addressed beyond-design-basis events in its documented safety analyses. In 2019, the NRC promulgated the new rule, 10 CFR 50.155, Mitigation of Beyond-Design-Basis Events (Federal Register, August 9, 2019), to establish regulatory requirements for nuclear power reactor applicants and licensees to mitigate beyond-design-basis events. A detailed description of the post-Fukushima safety enhancements, which is beyond the scope of this article, is available on the NRC public website.

Following the accident, the NRC requested that licensees of operating reactors reanalyze potential flooding and seismic effects using updated information and state-of-the-art methodologies, which resulted in changes to operating plans and procedures intended to protect certain plant structures, systems, and components important to safety. The enhancements include seismic and flooding protection features to address potential impacts from natural disasters. The DOE updated its facility-safety and natural-phenomena hazards design guides (NPHs), which include DOE O 420.1C, Facility Safety, and DOE-STD-1020, Natural Phenomena Hazards Analysis and Design Criteria for DOE Facilities.

Spent nuclear fuel and waste management

The science behind the Yucca Mountain project was supported by many experts that agreed that Yucca Mountain was safe. Dennis O'Leary a U.S. Geological Survey geologist that spent 14 years on the project wrote in the Spring 2021 issue of *Radwaste Solutions* that "Basically, geologically, there is nothing going on at Yucca Mountain—it is all over and done with". Regardless of the scientific support for the project, however, the political will was no longer there to finish the repository.

As noted in the July/August 2009 issue of *Radwaste Solutions* by editor-in-chief Nancy Zacha, "It all started out so promising". She said that the passage of the NWPA "was meant to solve the nation's HLW/spent fuel disposal problem by creating a finely nuanced program that balanced East and West, government and commercial interests, and state and local views". By 2009/2010, it was clear that Yucca Mountain would no longer be an option for the nuclear community. In 2010 the administration announced the termination of the Yucca Mountain project.

Following the decision to scrap the $14 billion project, the Obama administration set up the Blue Ribbon Commission on America's Nuclear Future under the direction of the U.S. DOE. As noted in the November 2011 issue of *Nuclear News*, the 15-member commission was tasked with conduct a comprehensive review of policies for managing the back end of the nuclear fuel cycle, including all alternatives for the storage, processing, and disposal of civilian and defense spent fuel and nuclear waste.

The commission provided seven recommendations:

1. A new consent-based approach to siting future nuclear waste management facilities.

2. A new organization dedicated solely to implementing the waste management program and empowered with the authority and resources to succeed.

3. Access to the funds nuclear utility ratepayers are providing for the purpose of nuclear waste management.

4. Prompt efforts to develop one or more geologic disposal facilities.

5. Prompt efforts to develop one or more consolidated interim storage facilities.

6. Support for continued U.S. innovation in nuclear energy technology and for workforce development.

7. Active US. Leadership in international efforts to address safety, waste management, nonproliferation, and security concerns.

The recommendations from the BRC above are being revisited again under the current Biden administration, particularly the consent-based approach to siting a future nuclear waste repository. Tackling the waste problem is essential if nuclear power is going to shed the image of being unsafe.

These three issues the community faces have cropped up over and over without creating a long-term solution. Idaho National Laboratory director John Wagner said it best in the January 2022 issue of *Nuclear News* the nuclear community is "perpetually running the hamster wheel, building paper reactors, and grinding its teeth as critics cloud public discourse by regurgitating old fears and clinging to the tired tropes of a bygone era". He added, "There has been progress. Plant closures have been avoided. Advanced reactor projects are progressing, especially small modular reactors and microreactors".

Canada

Like all industries, the nuclear in Canada is not without problems. Some are related to cost, some are political, while some are safety concerns.

A cost-related problem could be seen in the refurbishment of the Point Lepreau reactor. In mid-2005, the decision was made to refurbish New Brunswick Power's 635 MWe Point Lepreau reactor, which provides one-quarter of the province's power. It was the first CANDU 6 type in commercial operation and was the first CANDU-6 reactor to undergo full refurbishment, including replacement of all calandria tubes as well as steam generators. The project is expected to extend the life of the reactor to 2034 or beyond, and provide a 25 MWe uprate. Work began in April 2008 and was originally expected to be completed in September 2009 at a cost of C$1.4 billion including replacement power. However, the project ran some C$ 2 billion over budget and three times over schedule (54 instead of 18 months). In 2010 AECL decided to remove and reinstall all 380 calandria tubes in the reactor core because of problems with the seals obtained for initial installation during the project.

A lot was learned from this project, and was put into use in the ongoing refurbishment in the Darlington plant. Darlington Unit 2 was successfully refurbished on time and on budget.

Refurbishment of Unit 3 has started, and like Unit 2, it is expected to be completed on budget and on time.

In 2008, Hydro-Québec decided to refurbish its 638 MWe Gentilly 2. However, in 2012 the new provincial government decided to close the plant at the end of 2012 instead of refurbishing it. The grid stability and energy security that the plant provided were then lost.

In 2009, 210,000 litres of water containing trace amounts of tritium, was released into Lake Ontario after workers accidentally filled the wrong tank with a mixture of tritium and water at the Darlington Nuclear Generating Station. The amount of tritium released to the environment was less than 1 percent of the regulatory limit and consistent with normal operational activities. Therefore, the resulting concentration of the isotope in the lake did not pose any harm to residents.

Advances in nuclear since inception in the North America Region

United States

Improved Operations

Following the events of TMI and the subsequent review by the Kemeny Commission, the nuclear industry established the Institute of Nuclear Power Operations (INPO) to independently drive the industry to higher levels of excellence. The INPO model includes a level of accountability to the achievement of excellence perhaps not present in any other industry in the world—and it seems to have worked. As reported in *Nuclear News* since the 1980's in the annual capacity-factors issue, by the year 2000, the nuclear industry in the U.S. completed two decades of performance improvement and reliability. The median capacity factor reported in *Nuclear News* in the years 1978-1980 was 62.74-percent and by 1999-2001 that number grew to 88.38-percent. Now, the U.S. fleet has maintained a median capacity factor near 90 percent for over 20 years.

The past 40 years of improving plant performance has been coupled with enhanced safety focus provided by a risk-informed approach that focuses resources on the most safety significant issues.

Risk-informed and performance-based decision making

In the 1990s, the Nuclear Regulatory Commission initiated efforts to put in place regulatory policies and practices to support the use of Probabilistic Risk Assessment (PRA) and risk-informed, performance-based (RIPB) regulations in the commercial nuclear industry.

By 1999, the NRC defined RIPB regulations as "*An approach in which risk insights, engineering analysis and judgment including the principle of defense-in-depth and the incorporation of safety margins, and performance history are used, to (1) focus attention on the most important activities, (2) establish objective criteria for evaluating performance, (3) develop measurable or calculable parameters for monitoring system and licensee performance, (4) provide flexibility* *to determine how to meet the established performance criteria in a way that will encourage and reward improved outcomes, and (5) focus on the results as the primary basis for safety decision-making."*

Efforts to establish a risk-informed, performance-based regulatory structure for advanced reactors will hopefully be informed by that experience applying 10 CFR Part 52 during the licensing of Vogtle and Summer. Many in the community, including ANS, support the incorporation of RIPB regulations by the U.S. NRC, because such approaches will assure protection of public health and safety in the most effective, efficient, and transparent manner. The RIPB approach is a set of methodologies that work to realize graded safety along with efficient priority setting. RIPB approaches to nuclear safety have saved money and improved safety for current reactors and have the potential to offer even greater benefits for advanced reactors.

Advanced reactors

Many of the advanced reactor designs today are improvements on designs from decades ago, such as the Experimental Breeder Reactor II, a sodium-cooled fast reactor that is considered a precursor to several advanced reactor designs. After discussing advanced reactors for decades, the U.S. finally put in place a program from the U.S. DOE to partner with private companies in the development and demonstration of advanced reactors. The U.S. Department of Energy launched the Advanced Reactor Demonstration Program (ARDP) within the Office of Nuclear Energy in 2020.The ARDP is designed to help domestic private industry demonstrate advanced nuclear reactors in the U.S.

The ARDP selected TerraPower's Natrium and X-energy's Xe-100as recipients of an initial $80 million in 50-50 cost-shared funds to help put the programs on a fast track to commercialization. In all, the DOE plans to invest $3.2 billion—with matching funds from industry—over the seven-year demonstration program, subject to future appropriations.

The goal right now for most countries, the U.S. included, is to provide a sustainable, reliable, and secure long-term energy supply. The people of the nuclear community are working every day to realize those goals.

Canada

Bennett Lewis, Canadian Laboratories Chief, insisted that Canada should pursue the neutron economy of the heavy-water moderator, which allowed the use of natural uranium, a plentiful resource in Canada. Thus, a different path was selected, as opposed to following the US's Light Water Reactor technology.

In the 1950s, the largest Canadian Province, Ontario, was running out of hydro resources, but its growing industrial base was hungry for electricity. As a result of Lewis' encouragement, visionary provincial politicians came to be sold on the idea of nuclear power. The CANDU program was born – a major, homegrown scientific-engineering project which spurred major growth in Canada's scientific and engineering human-resource base. Nuclear power started in Ontario and remained largely centred there up to this day. Several other provinces relied sufficiently on hydro resources or on fossil power, so did not consider nuclear generation at the time. In the Canadian Federation, energy is in the mandate of the Provinces, not of the Federal Government

The characteristic features of CANDU reactors have been the same since the outset: natural uranium, heavy-water moderation, pressure-tube design for on-power refuelling. Using natural uranium meant that there was no need to set an expensive enrichment capability - a very important advantage for a relatively small Canadian economical base.

The first CANDU prototype was NPD (Nuclear Power Demonstration), a collaboration between AECL, Ontario Hydro (later to become Ontario Power Generation), and Canadian General Electric. It 1962, NPD went critical and contributed its 20 MWe to the electric grid (the first nuclear plant to be so connected).It ran for 25 years and provided extremely valuable experience not only in design, but equally for operators and for training. The success of NPD led to the first high-power CANDU, the 200 MWe Douglas Point reactor. And Canada exported early CANDU prototypes to India and Pakistan.

Current and Future state of Nuclear in the North America Region:

United States- Current state of nuclear in the United States

The U.S. operates more nuclear power reactors and generates more nuclear electricity than any other country in the world. U.S. plants have established a record of consistent operational and safety excellence – for example, the combined three-year capacity factor for all U.S. plants has been around or above 90 percent since 2000.[vi] The 93 nuclear power reactors produce approximately 20 percent of the electricity consumed in the U.S., and more than half of the electricity that is generated without the emission of greenhouse gases.

All of the 93 reactors are light-water cooled, with 62 pressurized water reactors and 31 boiling water reactors.[vii]Most of the nuclear units began operation in the 1970s and 1980s. Reactors in the U.S. are initially licensed for a period of 40 years by the Nuclear Regulatory Commission, the independent federal agency that oversees the use of nuclear materials throughout the country. Plant operators may apply to the NRC for license renewal, which is a 20-year extension of the operating license. There is no limit to the number of extensions the NRC may grant provided the reactor meets the NRC's safety, environmental and other requirements. Of the 93 operable power reactors in the U.S., 85 have applied for and received an initial license renewal for operation up to a total of 60 years, and six have applied for and received a subsequent license renewal for operation up to a total of 80 years.[viii]

There are currently two nuclear power reactors under construction in the U.S.—the Vogtle 3 & 4 units near Augusta, Georgia. Limited site work began in 2009, and the NRC issued a combined construction and operating license in 2012 for the AP1000 pressurized water reactors designed by Westinghouse. Placement of nuclear concrete began in 2013, but the project experienced substantial schedule delays and cost overruns. Unit 3 is currently scheduled to start up in 2022, and the cost of the two units is projected to be approximately $28 billion. The NRC has issued combined construction and operating licenses for six other large light water reactors (LWRs) in the U.S., but there are no current plans to proceed with construction of any of those plants.

The Unites States has a mature supply chain supporting the operation of its reactors. All of the U.S. reactors operate on a once-through fuel cycle. Uranium, conversion, and enrichment are sourced globally. The U.S. mines a small amount of uranium, but most is imported. The only domestic uranium conversion facility, the Metropolis Works in Illinois, is currently idle, but Honeywell plans to restart the facility in 2023.Urenco USA operates the only commercial enrichment plant in the U.S. in Eunice, New Mexico, and utilities also obtain enrichment from overseas. All U.S. nuclear fuel assemblies are produced domestically at one of three facilities: the Westinghouse fuel fabrication facility near Columbia, South Carolina; the Global Nuclear Fuel (General Electric, Hitachi, and Toshiba joint venture) fuel fabrication facility in Wilmington, North Carolina; and the Framatome fuel fabrication facility in Richland, Washington. The U.S. discharges approximately 2,000 metric tons of used fuel each year. Because the U.S. government has not fulfilled its obligation to remove used fuel from reactor sites, used fuel that has been discharged from the reactor for the last time is stored at the reactor site. Due to limited onside pool storage capacity, almost all reactors have also established onsite dry storage facilities for used fuel. General Electric operates the only commercial offsite nuclear fuel storage facility at Morris Illinois, but the capacity of the storage pool is small and the facility is not accepting additional fuel. The NRC licensed two sites for the consolidated offsite dry storage of used fuel – one in Skull Valley, Utah and the other in Andrews County, Texas. However, neither facility has been developed due to opposition from the host states. Another application for a consolidated storage facility located in Lea County, New Mexico is pending before the NRC, but that facility also faces opposition from the host state. For decades the United States was pursuing NRC approval for a geologic repository for disposal of used fuel and high-level radioactive waste at Yucca Mountain, Nevada. However, the U.S. Department of Energy (DOE) stopped work on the project in 2010, and the U.S. Congress has not appropriated additional funds for Yucca Mountain, nor has it taken action to identify and develop another repository site.

Canada - Current state of nuclear in Canada

The characteristic features of CANDU reactors have been the same since the outset: natural uranium, heavy-water moderation, pressure-tube design for on-power refueling. Using natural uranium meant that there was no need to set an expensive enrichment capability - a very important advantage for a relatively small Canadian economic base.

The first CANDU prototype was NPD (Nuclear Power Demonstration), a collaboration between AECL, Ontario Hydro (later to become Ontario Power Generation), and Canadian General Electric. In 1962, NPD went critical and contributed its 20 MWe to the electric grid (the first nuclear plant to be so connected). It ran for 25 years and provided extremely valuable experience not only in design, but equally for operators and for training. The success of NPD led to the first high-power CANDU, the 200 MWe Douglas Point reactor. And Canada exported early CANDU prototypes to India and Pakistan.

Since early after the end of WWII, Canada established a strong regulator, the Atomic Energy Control Board, later renamed the Canadian Nuclear Safety Commission. The AECB/CNSC has been an effective regulator. Nuclear safety is the responsibility of the nuclear operator. The operator must demonstrate to the regulator how safety is achieved and ensured, within a regulating system philosophy somewhat less prescriptive than the US NRC's.

The first truly high-power CANDUs were 4 x 512 MWe reactors in the multi-unit Pickering-A plant. The great success of this design meant that, while other types of design were tried, the CANDU evolution in Ontario Province would continue along the Pickering line in more 4-unit stations: sister station Pickering-B, then the higher-power Bruce-A, Bruce-B and Darlington (each with units in the range of ~900 MWe).

In a parallel effort, AECL designed the CANDU-6 single-unit plant (~700 MWe).The first CANDU-6 units were built in Québec and in New Brunswick. Other units were exported to Romania (Cernavoda) and South Korea (Wolsong). As the CANDU-6 program was quite successful, Canada became a major exporter of nuclear plants and CANDU-6 sales advanced, with further sales of one unit to Argentina (Embalse), three more to South Korea (Wolsong), and two to China (Qinshan).

The growth of the nuclear industry in Canada and other countries spurred mining for uranium. Canada is blessed with very large deposits of uranium, some with exceedingly high ore concentrations. Saskatchewan Province, in particular, established a number of extremely rich mines. Canada was for a long stretch the world's largest producer/exporter of uranium, losing the number-one spot in 2009 to Kazakhstan. In 2021 Canadian uranium production was only 12% of the world's production which is well below its nominal capacity due to the COVID pandemic (UxWeekly, UxC, 9 May 2022).

Over the last 60 years of nuclear power, CANDU plants have provided reliable, safe, and economical electricity to Ontario. Most years, the share of nuclear electricity generation in the Province has been in the range of 50 to 60%. This has made a lasting and extremely valuable contribution to the Ontario, and by extension to the Canadian, economy. A related hugely significant environmental benefit of its large nuclear base is that Ontario was able to .

Similarly, in New Brunswick, the Point Lepreau Nuclear Generating Station made a major contribution by providing about one third of the Province's electric generating capacity. In Québec, hydro resources have always been very significant, and the Gentilly-2 station was providing a small but reliable percentage of the provincial electricity.

Following the building of the Darlington Generating Station, Canada's operating nuclear fleet numbered 22 reactors:

- 20 in Ontario, 12 operated by Ontario Power Generation and 8 by Bruce Power
- 1 in Québec
- and 1 in New Brunswick.

The gross generating capacity of this fleet was greater than 16 GWe, representing a huge value input to Canada's GDP.

Currently the Canadian nuclear industry contributes more than $6 billion (CAD) to the national economy. It supports about 30,000 well-paid jobs in power generation and mining, and a further

30,000 indirect jobs. Nuclear technology supports also other sectors, such as for example manufacturing, medicine, and food production.

CANDU pressure tubes have a finite life, on account of accumulated fast-neutron bombardment and hydrogen uptake. To extend the plant's life, CANDU reactors must be refurbished and the pressure tubes replaced, typically after about 30 years of operation.

Pickering Units 2 and 3 were shut in 2007 and 2008 respectively, after more than 30 years of operation. Also, the Gentilly-2 plant was shut in 2012, after 29 years of operation, as per a political decision of the provincial government. While there are plans to shut the remaining Pickering A and B units, this is not expected to happen before 2025 earliest. This now leaves 19 reactors in the Canadian fleet.

On the refurbishment side, several units have already been refurbished as of the current date (2022). These include Bruce Units 1 and 2, Pt. Lepreau, and Darlington Unit 2. A second Darlington Unit, number 3, is currently being refurbished, and Units 1 and 4 will follow, one by one. As well, Bruce Unit 6 is in refurbishment. To be noted, importantly, Bruce Power has set in place a major Refurbishment Project, meant to keep the 8-unit Bruce Station operating until the 2060s.

United States - Future state of nuclear in the United States

The future state of nuclear power in the United States will be impacted by a number of factors, some of which are listed below and discussed.

- The lack of an enduring national energy policy in the U.S.
- The extent to which policies to mitigate climate change by reducing greenhouse gas emissions are enacted at the federal and/or state level.
- The ability of reactor developers to bring designs to market that can be constructed and operated at a cost that is competitive with other energy sources.
- The development of a technology-independent, risk-informed, performance-based regulatory framework for new power reactors.
- Public acceptance of nuclear power.

The U.S. has a system of government in which authority is shared between the federal government, state governments, local governments, and individuals. In addition, the U.S. has a capitalist economy in which most energy assets are owned and operated by the private sector. Government does not dictate energy choices, although federal and state governments can encourage some technologies through incentives (e.g., tax credits) and discourage other technologies through tax policy and/or regulation. The U.S. system is further complicated by the fact that some aspects of some energy markets are deregulated (e.g., wholesale electricity in many parts of the Northeast and Midwest) while other markets are regulated by the states.In addition, the Federal Energy Regulatory Commission (FERC) impacts many areas of interstate energy commerce. Accordingly, there is no national energy policy, nor is there a means to implement one directly if it did exist.

As a practical matter, the effective national energy policy is established through periodic federal energy and tax legislation, annual federal appropriations for agencies such as DOE, and actions by regulatory bodies such as the NRC and FERC (which are influenced by personnel appointments to the governing commissions). Control of Congress and the Executive Branch periodically shifts from one political party to another, which can dramatically impact the effective national energy policy. Fortunately, there is currently substantial political support for nuclear energy among both political parties, although not necessarily for the same reasons. That support is reflected in substantial and generally increasing research and development budgets supporting nuclear energy in recent years, as well as recent federal legislation to provide a means of federal financial support for existing nuclear power plants that have difficulty competing in some power markets. Some states have already enacted policies that recognize the environmental benefits of existing nuclear power plants through financial assistance. However, other states have taken actions to encourage the closure of nuclear plants (e.g., Indian Point in New York and Diablo Canyon in California). Among states with regulated wholesale markets, many have taken steps to encourage the development of renewable energy sources such as mandating that regulated utilities achieve certain levels of renewable generation. Rather than mandating particular outcomes, the nuclear industry generally advocates technology-neutral clean energy incentives that would encourage existing and new nuclear generation as well as solar and wind generation.

The Obama Administration (2009-2016) tried and failed to put a federal “cap and trade” policy in place to reduce greenhouse gas emissions. The same administration enacted regulations on carbon emissions by coal- and natural gas-fired electricity generating plants, but the regulations were repealed by the subsequent administration before they went into effect. The current divided political climate does not make the prospect for federal action along these lines likely in the near future. However, many states are calling for aggressive reductions in greenhouse gas emissions, and it appears likely that policy actions at the state and federal level will continue to encourage clean energy sources like nuclear power.

The anticipated “Nuclear Renaissance” of the 2000s failed to materialize, in large part, because of the availability of ample supplies of low-cost natural gas in the United States. New nuclear plants were unable to compete economically with electricity production from combined cycle natural gas plants. There are still ample domestic supplies of natural gas, but because natural gas power plants produce greenhouse gas emissions, there are concerns with excessive long-term reliance on that resource for electricity generation. In addition, there is renewed interest in nuclear energy as a reliable, always-on source of clean power. However, without some means of monetizing the environmental benefits of nuclear energy, it will be difficult to supplant natural gas as the preferred source of dispatchable electricity.

Along those lines, the biggest impediment to deployment of new nuclear generation in the U.S. at this time is the high up-front capital cost of new nuclear plants and the length of time required to put them into service. Experience with delays and cost overruns on Vogtle Units 3 and 4 and similar problems at the Summer 2 and 3 new reactor project in South Carolina, which was cancelled, have made U.S. power generators extremely reluctant to invest in new large LWR projects. At the same time, there is a need to increase clean generation to satisfy state mandates and customer desires for addressing climate change. Solar and wind generation continue to increase, but there is a growing recognition that intermittent renewable sources cannot, by themselves, achieve the deep decarbonization that is desired by many citizens. Accordingly, there is strong interest in firm, dispatchable advanced nuclear energy systems such as light water small modular reactors (SMRs) and advanced non-light water reactors, provided those reactors can be brought into service quicker and with a lower, more predictable cost. Toward that end, DOE has supported the design, licensing, and deployment of the NuScale SMR and is conducting the Advanced Reactor Demonstration Program[ix] (ARDP) to support concept development, risk reduction, and deployment of advanced reactors. As part of ARDP, DOE is cost-sharing the deployment of the Xe-100 high temperature gas-cooled reactor with x-Energy and the deployment of the Natrium liquid sodium-cooled reactor with TerraPower. Both projects are targeting 2027 to begin operation. Carrying out these and other deployment programs successfully and at reasonable cost should encourage additional reactor deployments to meet future clean energy needs.

There is substantial focus in the U.S. not only on new reactor designs but also on new designs for the regulatory framework that provides safety and environmental oversight of reactors. The NRC carries out the nuclear oversight role in the U.S. Over decades, the NRC has developed a prescriptive set of regulations with which aspiring nuclear power plant operators must comply in order to obtain a license for plant operation. Those regulations are focused on large light water reactors, which currently comprise the entirety of the U.S. reactor fleet. The NRC has been called the “Gold Standard” for nuclear regulation, a label that is generally considered to be praise for its comprehensive regulatory structure, large and technically experienced staff, and wide-ranging research activities. However, the agency has also been criticized for lack of flexibility, innovation, and timeliness and for imposing unnecessary regulatory burdens on licensees. Leaving aside the validity of both the praise and the criticism, it is evident that the current LWR-centric regulatory framework will not be both efficient and effective for a new generation of reactor designs. Accordingly, the Nuclear Energy Innovation and Modernization Act[x] directed to NRC to increase the use of risk-informed, performance-based regulation and to put in place a technology-inclusive regulatory framework that encourages greater technological innovation. The agency is in the process of addressing the Act and the extent to which it is successful will impact the ability to deploy SMRs and advanced reactors in a timely and cost-effective manner.

Public acceptance is an important component of a successful nuclear power program. Polls indicated that 74 percent of the U.S. public had a favorable opinion of nuclear power in 2010, but those numbers dipped significantly following the Fukushima accident. However, in 2021 the numbers were back above the previous peak, with 76 percent of the public favoring nuclear power and only 24 percent opposed.[xi]The increased favorability seems to reflect an increased awareness of the critical role nuclear power can play in reducing greenhouse gas emissions and addressing climate change. Chief among concerns about nuclear power is the lack of a demonstrated solution for disposal of used fuel (also referred to as spent fuel). The U.S. waste program stalled due to political reasons in 2010 and has made little progress since then. In order to maintain public support for additional deployment of nuclear power, it is essential the federal government put a credible program in place to address used fuel management.

Canada - Future state of nuclear in Canada

Sometime after Darlington came into service in 1992 and 1993, the prospects for new nuclear-power generation went dim, as people and governments turned their attention to wind and solar power. There has not been any nuclear build in Canada since Darlington.

However, the growing realization that nuclear power will be important and needed in the fight against climate change is expected to effect some change in the future. Another factor is the rising interest in the benefits that Small Modular Reactors (SMRs) can bring, both in terms of lower capital cost and in terms of application in smaller markets or for district heating, or to replace diesel power in remote communities or for mining operations. Another important plus for some SMR designs is the ability to extend nuclear resources by burning wastes (from irradiated fuel).

In 2021, the Federal Government launched Canada's SMR Action Plan. This reflects a marked and increased supportive view by the Government for the role of nuclear power in reaching Canada's Net Zero goal (of carbon emissions) by 2050. in the form of SMRs. The aim of the Action Plan is to help make Canada the world leader in SMR development and deployment. The SMR market in Canada shows promise, and it has been estimated to be in the multi-billion-dollar range in Canada, and a huge multiple of that worldwide. The Plan covers and supports all the activities to help encourage the realization of SMRs in Canada. The Plan has received a very positive and enthusiastic response from developers and vendors, the industry at large, and the academic community.

A number of vendors have recognized the great interest in SMRs in Canada, and have realized the beneficial potential of acting in Canada. Many vendors have established a presence in Canada to pursue design activities, and also to initiate relationships with utilities and other possible customers, with the CNSC and with government organisations. The ultimate aim of these vendors is to develop and deploy their designs in Canada.

At the same time, Canadian Nuclear Laboratories has offered to be a global hub for SMR research and technology and has proposed its Chalk River site for the building and demonstration of an SMR unit.

Also, in 2021, four Canadian Provinces, Ontario, New Brunswick, Saskatchewan and Alberta signed a Memorandum of Understanding to study and support the potential of SMR development and application for the benefit of their jurisdictions.

The first concrete SMR new build was announced by Ontario Power Generation in late 2021.It will be a grid-scale 300 MWe project, a BWRX-300 by GE Hitachi Nuclear Energy. It is to be built on OPG's Darlington nuclear site, and is to be operational by 2028.This would be the first non-CANDU grid-size reactor built in Canada. Following this first unit, SaskPower has an interest in deploying four more in Saskatchewan, to come online in 2032.

Other vendors active in Canada include Terrestrial Energy (with a Molten Salt Reactor concept) and Dunedin Energy (proposing the Nuclear Battery for remote/northern communities.

Meanwhile, there are two vendors very active in New Brunswick, developing different SMR designs. Moltex (with its Stable Salt Reactor) and ARC-100 (a Sodium-Cooled Fast Reactor) aim to have their reactors demonstrated at New Brunswick Power's Point Lepreau site in the early 2030s.

There are also designs proposed for micro-SMRs for remote applications. One such demonstration reactor project initiated by OPG is the Micro Modular Reactor Project, a collaboration between Global First Power and Ultra Safe Nuclear Corporation. The MMRP is projected to be in service at the Chalk River site in Ontario by 2026.

Bruce Power is also interested in the potential of SMRs, and is actively studying an option to deploy an eVinci micro-reactor, a Westinghouse design.
While there will certainly be many challenges in completing the design concepts, prototype testing, going through the licencing process, and securing deployment, there is currently great optimism for good days ahead for nuclear technology in Canada

The Role of nuclear in the future in the North America Region based on policy statements by government and stakeholders

United States

As discussed in the previous section, conditions are favorable for maintaining and expanding nuclear power generation in the U.S. There is growing appreciation among policy makers and the public for the role that nuclear energy should play in the generation of clean, reliable, and secure power in the U.S.

The current generation of reactors is comprised of large LWRs, and it is expected that those large LWRs will remain the primary source of nuclear power in the U.S. for the immediate future. If trends and policies continue many, if not most, of the currently operating reactors will go through the subsequent license renewal process and obtain authorization to operate for up to 80 years after initial startup. However, there are limitations to the large LWRs, which have large fixed operating costs and are best suited for baseload power generation. SMRs and advanced reactors offer potential advantages with respect to cost, safety, and breadth of application. If the drive to deep decarbonization continues, it will be important to use clean energy sources in applications beyond electricity production. Some advanced reactor designs operate at higher temperatures than LWRs, making them more amenable to industrial applications like process steam. The extent to which SMRs and advanced reactors are deployed will depend in large part on how successful their developers are in translating potential advantages into real ones.

Of course, nuclear technology does not operate in a vacuum. There are alternative sources of energy, including clean energy, and all of them have their own set of advantages and disadvantages. It is reasonable to expect renewable energy sources to continue their growth in the U.S., particularly if the federal government and various state governments continue the generous subsidies that currently exist for them. However, solar and wind power face a major challenge in that they are intermittent and cannot, by themselves, support a reliable and secure energy grid. There is a limit to the ability of current energy storage technology to address that challenge, both from a cost and practicality perspective. Technology does not stand still, and technological advances related to energy sources, energy storage, and other areas will undoubtably impact the future energy landscape.

Speaking of which, it is important to acknowledge advances in the field of nuclear fusion and recognize the role it may have to play in the energy future of the U.S. The multinational ITER project continues to move forward, with a goal of producing net energy from fusion. Moreover, applying fusion for energy production used to be the exclusive domain of governments and academia, but over the past decade or so a number of private ventures have arisen which seek to commercialize fusion for the generation of electricity. Fusion devices may join fission reactors in supplying clean energy to the world of tomorrow.

While this discussion has focused almost entirely on large-scale energy production, it is important not to lose sight of other beneficial applications of nuclear technology. Microreactors are being developed to provide secure, reliable energy for military or remote applications. Fission and radionuclide power sources will continue to be essential enablers of space exploration, especially to the far reaches of the solar system and beyond. Radiation and radioactive materials have many medical and industrial applications. Commercial irradiation is used for food preservation, sterilization, hardening and other purposes. These many applications of nuclear technology will continue and new ones will almost certainly arise as we move into the future.

Canada

Nuclear has a significant role to play in various aspects of the Canadian economy and polity, and as part of the Climate Change Solution. To this end, the Government will continue to support Nuclear Initiatives under Mission Innovation and Clean Energy Ministerial Programs, and play a leadership role among like-minded countries to support the use of nuclear technology in a low-carbon economy. It is in the Government's interest to publicly acknowledge the merits and contribution that nuclear energy makes, and address key areas of public concern with science and evidence-based information. According to statements from various Government organs, the Government will identify and allocate accessible funding for new nuclear technology development and for financing nuclear projects, and also for accessing export markets.

According to Natural Resources Canada (NRCan) that has authority over Nuclear Research & Development, uranium resource development and nuclear regulation through the Nuclear Safety and Control Act, the Nuclear Vision to 2050 include:[76]

- Strategic alignment with other nuclear nations to address trade, environment & disarmament issues
- Embed nuclear as part of a low-carbon future from an international, federal and provincial government policy position
- Enhance public support and social license for nuclear to underpin consistent policy
- Successfully life extend and operate 10 CANDU Reactors in Ontario
- Build new CANDU reactors in Canada for domestic electricity consumption and export

- Develop and export new CANDU Reactors abroad
- Develop new nuclear technologies
- Deploy and localize SMR technology for remote & non-nuclear applications in Canada
- Sustain and renew R&D facilities in Canada
- Successfully implement long-term facilities for low, intermediate and high-level waste storage
- Successfully decommission nuclear facilities in Canada and abroad
- Renew the nuclear workforce in Canada
- Be a leader in the nuclear medicine field

Conclusion

Nuclear technology plays an important role in the U.S. and Canada, particularly in energy production, and that role is expected to continue and expand. Worldwide concern over climate change and the desire to minimize greenhouse gas emissions are major factors in the expectation of an expanded role for nuclear energy, along with the inherent advantages associated with a high-power-density, zero-emissions power source, and its uses in various aspects of life that include medicine, agriculture, and transportation. That being said, nuclear energy in the U.S and Canada faces a number of challenges, including a sometimes cumbersome regulatory structure, challenging economics, and the lack of a demonstrated and clear pathway for used fuel and high-level radioactive waste disposal. The American Nuclear Society and the Canadian Nuclear Society members are fully engaged in addressing these challenges and concerns in order for nuclear technology to continue its vital contributions to improving peoples' lives and preserving our planet.

Assumptions:

- *Report is based on nuclear power, but does acknowledge other areas of nuclear technology.*
- *Report focuses on power production but also touches on aspects of the fuel cycle.*

[1] U.S. nuclear capacity factors: Reliable and looking for respect, May 28, 2021, NuclearNewswire. https://www.ans.org/news/article-2935/us-nuclear-capacity-factors-reliable-and-looking-for-respect/

[1] U.S. Nuclear Regulatory Commission website. https://www.nrc.gov/reactors/power.html

[1]*Nuclear News*, March 2021, pp.84-85.

[1] Advanced Reactor Demonstration Program of the Department of Energy. https://www.energy.gov/ne/advanced-reactor-demonstration-program

[1] Public Law No. 115-439, Nuclear Energy Innovation and Modernization Act, January 14, 2019.

[1] Support for nuclear energy grows with climate change concerns, June 10, 2021, NuclearNewswire. https://www.ans.org/news/article-2974/support-for-nuclear-energy-grows-with-climate-change-concerns/

REVIEW OF AFRICA'S NUCLEAR ENERGY DEVELOPMENT

(Courtesy of Nuclear Energy Market Report 2021 By Nuclear Business Platform)

Foreword

Despite the backdrop of the COVID pandemic now into the second year, many African countries remain resolute that nuclear energy could be the answer to their energy woes and to increase their level of energy security. What is heartening is the increase in government support for nuclear energy development in countries like Ghana, Uganda, Nigeria, Zambia, Rwanda and Niger.

During the Africa Nuclear Business Platform meeting in April, Rafael Grossi, Director General, International Atomic Energy Agency (IAEA) remarked in his keynote address that of the nearly 30 so-called newcomer countries that are embarking [on] or considering nuclear power, almost one-third are in Africa. Why are countries in Africa looking at nuclear? Very simple. The reasons vary, but they all come back to one word: reliability. Nuclear power is a present solution. It is also a future energy alternative. It may not be for everyone. But for many countries in Africa, it is an option worth looking at.

It is no secret that Africa has a massive need for energy and increasingly a number of the 50+ countries on the continent are looking at nuclear as a reliable baseload energy. Having engaged with officials from all the key African countries this past year, we have divided the countries into 3 tiers based on government support for nuclear energy, timelines and infrastructure activities as per the below:

TIER 1(Government firmly committed to start/expand nuclear power program with timeline set)

Egypt, Ghana, Uganda, South Africa, Nigeria, Zambia

TIER 2(Government supportive to start nuclear power program and actively developing nuclear infrastructure)

Niger, Sudan, Kenya, Rwanda, Tunisia

TIER 3 (Plan to have nuclear energy in the long term and actively developing nuclear infrastructure)

Morocco, DR Congo, Ethiopia, Tanzania, Namibia, Senegal, Algeria, Zimbabwe

Looking back at 2021, key developments in the nuclear energy sector in Africa include:

- Ghana issuing a Request for Information (RFI) to assess the nuclear power plant technologies available on the market in June, which saw fifteen vendors from China, France, Canada, Korea, Russia and USA responding to the RFI
- The IAEA holding two Integrated Nuclear Infrastructure Review (INIR) missions in Africa, in Kenya (June) and Uganda (November), to assess the countries' progress on their nuclear infrastructure development

- The government of Nigeria approved and passed into law five nuclear regulations in January
- South Africa affirming plans for a new 2,500 MW nuclear power plant to end the procurement process by 2024
- Radiation Protection Authority announcing in October that it is ready to regulate the use of nuclear technology in Zambia
- Rwanda planning to sign the contract for the feasibility studies in the near term
- Niger confirming that it is resolutely committed to carrying out a nuclear power program included in all its political development programs

The only setback on nuclear energy developments in Kenya which in October announced plans to dissolve the state corporation, Nuclear Power and Energy Agency (NuPEA), which is responsible for promoting and implementing Kenya's Nuclear Power Programme.

The report summarizes the key industry updates and developments in the African nuclear energy market in 2021. We hope it will provide readers with vital insights, which shall help you to develop key sustainable strategies for your business.

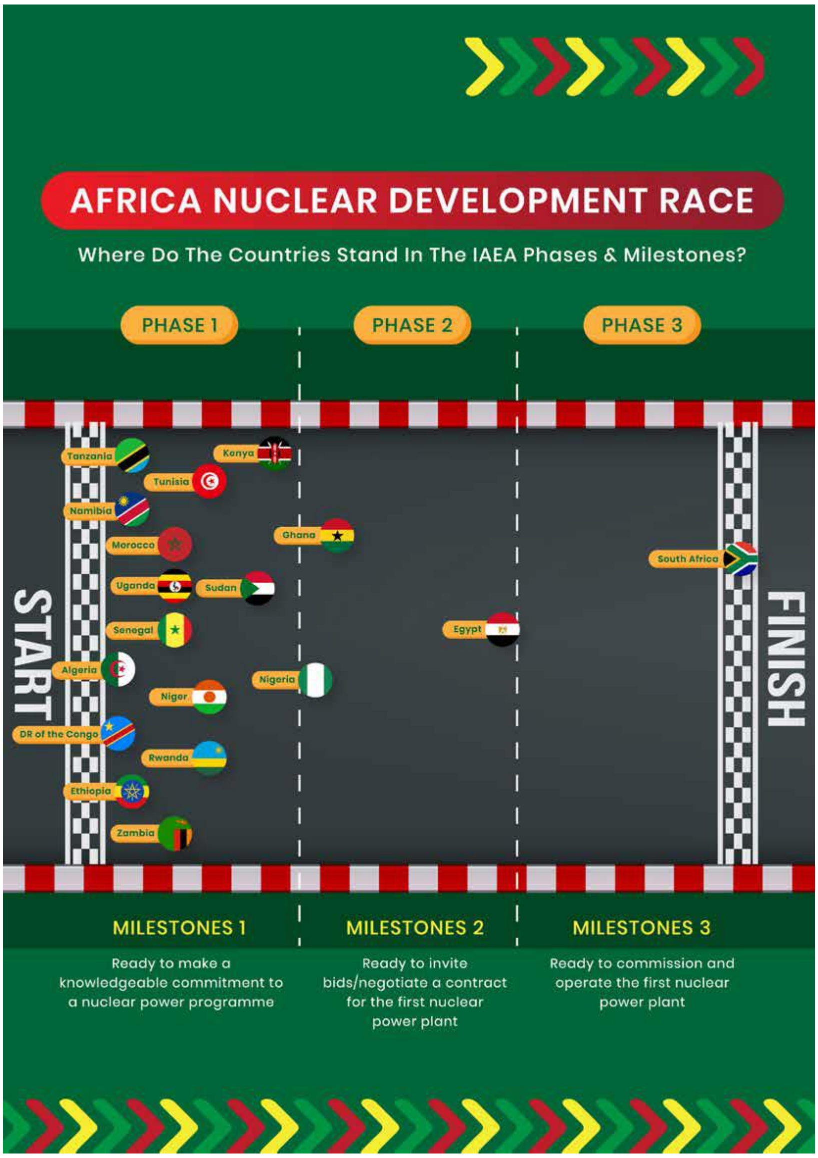


Figure 17: Current status of the African status in nuclear development

Tier 1

Ghana steps closer towards nuclear energy

Ghana expects to start the production of nuclear energy by 2030. Nuclear Power Ghana (NPG) was established in 2018 to drive the country's nuclear power programme and is undertaking feasibility and preparatory studies. NPG, which will be the owner and operator of Ghana's first proposed nuclear plant, has already completed the first phase of the three-stage project.

The first stage includes technical considerations to enable Ghana to make a knowledgeable commitment and take a policy decision. Scheduled between 2020 and 2024, the second stage involved preparatory work for contracting and construction of a nuclear power plant after a policy decision has been taken. Spread over six years, the last stage will include activities to construct the first nuclear power plant.

In June the Government of Ghana, through Nuclear Power Ghana (NPG) and the Ministry of Energy, issued a Request for Information (RFI) to assess the nuclear power plant technologies available on the market and which could be considered under the Ghana Nuclear Power Programme (GNPP). The RFI aimed to gather information which will enable informed decisions and facilitate further discussions with potential vendors to develop a procurement strategy for the Ghana Nuclear Power Programme.

Later in October, NPG announced that fifteen vendors from China, France, Canada, Korea, Russia and USA had responded to the RFI. The vendors comprised six companies providing large reactor technologies and nine companies providing Small Modular Reactors (SMRs) technologies. The Ghana Nuclear Power Programme envisions the baseload power to comprise large reactors (700 MW – 1200 MW) or SMRs (60 MW – 300 MW) or a combination totalling around 2400 MW.NPG will be evaluating the RFI submissions and a report would be submitted to the Ministry of Energy for action after the assessment.

USA and Ghana signed a Memorandum of Understanding (MoU) in July concerning strategic civil nuclear cooperation, "which improves our cooperation on nuclear energy and strengthens our diplomatic and economic relationship," the US State Department said. It added that the USA and Ghana" have an enduring diplomatic relationship, which includes long-standing cooperation in the fields of security, energy and commerce". Cooperation in nuclear energy, science and technology can lead to significant contributions to clean energy, agricultural improvements, clean water, advanced medical treatments, and more.

Another MoU was penned between NPG and the Ghana Journalists Association (GJA) in September. The MoU provides a framework for the two parties to manage the communication and education of information to the general public on Ghana's Nuclear Power Programme. Journalists needed the right information on the energy sector, particularly on nuclear power to be able to educate the public.

Following up on the MoU, NPG and GJA organised a workshop in December for journalists in Ghana which aimed at promoting and sustaining media involvement in efforts to include nuclear power as an alternative source of power. The training would provide journalists with the opportunity to refresh their knowledge and advance their capacity to support Ghana's nuclear power efforts.

In August, Director-General of the Ghana Atomic Energy Commission (GAEC), Professor Benjamin Nyarko remarked that Ghana's nuclear power programme was expected to generate at least 20 per cent local content ($1.2 billion) and participation. The implementation of the nuclear power project will generate a lot of local content in the areas of engineering, manufacturing, civil construction and assembling services, among others. He added though that the country's ability to fully participate in the project would depend on the capacity of the local industry. Prof. Nyarko called for deepening of the partnership between the Association of Ghana Industries (AGI) and the GNPP organisation to prevent reliance on foreign companies for goods and services in building the power project.

The inauguration of Ghana Atomic Energy Commission (GAEC) Board by Dr Kweku Afriyie, the Minister of Environment, Science, Technology, and Innovation took place in November. The Board is chaired by Dr Kwesi Aning, a former Deputy Director-General of the International Atomic Energy Agency (IAEA).Comprising seven members, other members of the Board include Dr. Elsie Kaufmann of the University of Ghana, Justice Adjei, a Justice of the Court of Appeal, Dr. Robert Adjaye, Director of Research Survey and Administration at AIESEC, Professor Benjamin Nyarko, Director-General of GAEC and Cynthia Bediako, Chief Director from the Ministry of Environment, Science, Technology, and Innovation. TGAEC Board will provide direction to Management.

Nigeria makes progress on the nuclear regulatory front

During the first month of the year, five regulations, prepared by the Nigerian Nuclear Regulatory Authority (NNRA) were approved and signed by the President of Nigeria. The five regulations being:

1. Nigerian Nuclear Safeguards Regulations, 2021
2. Nigerian Safety of Research Reactors Regulations, 2021
3. Nigerian Physical Protection of Nuclear Materials and facilities Regulation, 2021
4. Nigeria Safety Regulations for Licensing of site for Nuclear Power Plant, 2021
5. Nigerian Uranium Exploration, Mining and Processing Regulations, 2021.

The bills are part of Nigeria's preparation towards nuclear power plants for generation of electricity. They cover aspects of licensing of a Nuclear Power Plant, uranium mining and also transportation of radioactive materials. The bills are specifically based on nuclear power , which demonstrates the commitment of the government toward achieving the nuclear-power programme.

In July Nigeria and Russia reconstituted an agreement which included plans for two sites for power plants: the Geregu nuclear power plant site (central Nigeria) and the Itu nuclear power plant site (southern Nigeria). The power plants are expected to be twin reactors that will each cost around $6 billion. The choice of the two sites is guided by the availability of water and their being out of seismic fault lines, which make them not prone to earthquakes.

Nigeria's installed capacity for electricity generation was 14,000 MW while the available power was just 6,000 MW. The demand for power in the country was 28,000 MW, which indicated a massive gap between demand and supply.

Nigeria currently has a nuclear research reactor in Ahmadu Bello University and has signed a cooperation agreement with the Russian Federation for the construction of a multi-purpose nuclear plant for the production of isotopes for the treatment of cancer, among other things. During the COP26 UN Climate Summit in Glasgow, Nigeria's President Muhammadu Buhari reiterated Nigeria's commitment to pursue nuclear energy – "We can also invest in nuclear. Though not renewable it is carbon neutral and capable of producing a baseload, constant electricity production on which sustained economic progress can be built. Nigeria is among

a handful of African countries exploring nuclear power, with a research reactor already operational". Nigeria had made a political commitment in the area of building nuclear power plant for electricity generation. Two key agencies were established, as the promoter, the Nigerian Atomic Energy Commission (NAEC), and also the regulator, the Nigerian Nuclear Regulatory Authority (NNRA).

At the end of the year in December, a two-day national workshop on industrial participation in the construction of a nuclear research reactor was held in Lagos. The workshop was aimed at gauging the readiness of local industries to provide local content for the proposed nuclear plant, since it is designed with high local content. During the workshop, the Chairman and Chief Executive of Nigeria Atomic Energy Commission (NAEC), Prof. Yusuf Ahmed, said bids for the contract for the construction of the nuclear power plant would soon be opened.

On the private sector front, Transcorp Energy Ltd, a unit of Transnational Corp. of Nigeria Plc, announced plans in July to develop nuclear power in Nigeria. This forms part of plans to improve access to electricity in Africa's most populous nation. Said to be a "less expensive and less complicated solution", the company plans to use OPEN100 model technology. Transcorp Energy is seeking to partner with the federal government on this programme.

The Minister of Science and Technology, Ogbonnaya Onu, affirmed the commitment of the federal government, particularly the ministry of science and technology, to support Transcorp and directed that a joint committee comprised of Transcorp and all the relevant stakeholders be established to execute the project.

The OPEN-100 model, launched by the US Energy Impact Center (EIC) in February 2020, is the world's first open-source blueprint for designing, constructing, and financing nuclear power plants to deliver low-carbon electricity generation.

In December, the Nuclear Business Platform spoke with Dr. Yau Idris, Director General of the Nigerian Nuclear Regulatory Authority on Nigeria's regulatory highlights in 2021 and what the industry can look forward to in 2022.

Kenya's nuclear power programme push back by a decade

In October, the Presidential Task force on the Review of Power Purchase Agreements, led by John Ngumi, recommended the dissolution of the Nuclear Power and Energy Agency (NuPEA), citing the country's least-cost Power Development Plan (LCPDP) in which the first nuclear power plant is expected to start generating electricity in 2037 and adding that NuPEA serves no major purpose at the moment. The task force highlighted that the functions that NuPEA is currently undertaking could be easily handled by a department within the Ministry of Energy. The task force was formed to look into modalities for bringing down the cost of power.

NuPEA is a State Corporation established under the Energy Act 2019.It is charged with the responsibility of promoting and implementing Kenya’s Nuclear Power Programme, carrying out research and development for the energy sector.

Kenya started considering nuclear electricity in 2008 and had initially aimed for 2020 for their first nuclear power plant. The target was subsequently moved to have nuclear power in 2027 and later by another ten years, citing slow demand for power in the country.

Earlier in the year, in June, the International Atomic Energy Agency (IAEA) conducted its second Integrated Nuclear Infrastructure Review (INIR) mission to Kenya, following the first mission in 2015.The 2021 mission assessed the country’s progress on recommendations from the 2015 INIR mission. It reviewed the status of nuclear infrastructure development using the Phase 1 criteria from the IAEA’s Milestones Approach, which provides detailed guidance across three phases of development (consider, prepare, construct).

The INIR team noted that Kenya had made considerable efforts to address all the recommendations and suggestions made by the INIR team in 2015 with the preparatory work needed to inform the Government’s decision has progressed. The follow-up INIR team noted progress in areas including:

- Kenya developed the National Nuclear Policy and the National Policy and Strategy for Safety to enable the Government to make an informed decision on whether to introduce nuclear power.
- The country enacted a national nuclear law and established a regulatory body with clear responsibilities for safety, security and safeguards.
- The Government completed an assessment of the national legal framework and identified other laws needing review.
- The Government enhanced the coordination among its key stakeholders in the development of its nuclear power program.

Uganda enjoying strong government support for nuclear power programme

Nuclear energy is considered a critical source of energy that will satisfy Uganda’s energy demand for the future and play an integral role in UG Uganda’s Vision 2040.Pre-feasibility studies for launching the first nuclear power plant in Uganda have been completed. The studies confirmed that the generation potential from hydro, if fully developed, cannot meet the country’s future energy needs. Therefore, nuclear among other sources needs to be integrated into the future energy generation mix. It is estimated that Uganda will require a generation capacity of 41,738 MW by 2040.

In November, the second IAEA Integrated Nuclear Infrastructure Review (INIR) mission in Africa for 2021 took place in Uganda. At the request of the Government of Uganda, the eight-day mission to Uganda reviewed the country’s infrastructure development for a nuclear power programme. The INIR team reviewed the status of nuclear infrastructure development in Uganda using Phase 1 of the IAEA's Milestones Approach.

The surplus of energy which Uganda currently enjoys can last for only 6-7 years. Hence nuclear power is very much an option for the government. Okaasai Opolot, Minister of State for Energy, highlighted that the amount of energy Uganda needs to drive the economy falls short in a short time - by 2027, based on the trajectory of the country's development. According to the Minister, nuclear energy is very important and there is no need to wait until 2027 to start thinking about it.

The INIR team concluded that the Government of Uganda is committed to developing the required infrastructure for nuclear power in a coordinated approach with all concerned stakeholders. Uganda drafted an energy policy that includes nuclear power and established a Nuclear Energy Programme Implementing Organization (NEPIO). Uganda's NEPIO has completed several studies on different infrastructure issues and drafted a Nuclear Power Roadmap for Uganda that makes recommendations for key decisions on the

development of the infrastructure for nuclear power in the short, medium and long term.

Recommendations by the INIR team for Uganda to make further progress in their nuclear power programme included:

- Updating and completing the Nuclear Power Roadmap for Uganda by conducting further studies that provide a basis for informed decisions and commitments for the nuclear power programme
- Finalizing the country's energy policy
- Solidifying its plans to join the relevant international legal instruments and to develop an adequate legal framework
- Further assessing and planning for the development of the human resources
- Analysing further the preparedness of the electrical grid
- Continue working in the areas of siting, environmental protection, financing, and radiation protection

"The Government of Uganda is well aware of the importance of energy for socio-economic development to improve the lives of all our people. Nuclear power is envisaged to contribute to the electricity generation mix by 2031.As the country implements the National Development Plan III, the Government has taken the initiative to assess its readiness towards construction and operation of the first nuclear power plant by using the IAEA Milestones Approach. This Integrated Nuclear Infrastructure Review mission will assist Uganda in reviewing the current status of development of our nuclear infrastructure and support identifying those areas where further work is required."

- Dr. Ruth Nankabirwa Ssentamu, Minister of Energy and Mineral Development during the INIR mission

Egypt on course to be the next African country with nuclear power

In 2015, Egypt signed an agreement with Russia to build nuclear power plants in the country. The El-Dabaa NPP Project will have four 1200 MWe Pressurized Water Reactor units, each utilising the Russian VVER-1200 design. The El-Dabaa site is located along the Northern West Coast of Egypt on the Mediterranean Sea. The Project Owner and the Operator of El-Dabaa NPP Project is the Nuclear Power Plants Authority (NPPA) of Egypt and the Main Contractors are entities from Russia's Rosatom, which will provide engineering, procurement and construction services, nuclear-fuel supply, operation support and maintenance, and spent nuclear-fuel treatment. The first reactor is expected to come online between 2026 and 2030.The investment cost of the project is $30 billion, 85% of which is financed through a $25 billion Russian loan.

Localization for the first unit is expected to be 20%, and as high as 35% for the fourth unit. In line with this, Egypt's engineering, construction, and infrastructure company Hassan Allam Holding announced in December that it has partnered with the Russian company Titan Holding to launch a joint company to carry out construction works of the El-Dabaa NPP. The key objective of this partnership is to increase expertise in carrying out construction works at the El-Dabaa NPP, as well as unify efforts and use equipment and devices in carrying out the tasks assigned to the two companies.

In March, Egyptian Nuclear and Radiological Regulatory Authority's (ENRRA) safety culture and communication strategies were published. I n the strategies, ENRRA indicated how to map stakeholders and highlighted the fact that they are the only regulatory body in Egypt. However, while there is only one regulatory body, there are many stakeholders in need of information. Later in June, the ENRRA received the licensing documentation for Units 1 and 2 of El Dabaa NPP construction from the Nuclear Power Plants Authority (NPPA). Crucially, this marked an important milestone in the implementation of El Dabaa NPP Project in the path forward to issue the construction permit for the first two units. Once the permit has been obtained, construction of the plant can commence and also all works relating to construction, installation, training and preparations to commence the operational tests. Construction is expected to take 5 years. It is expected that a construction permit for the El-Dabaa site will be issued in July 2022.

In late July, Rosatom signed an agreement with Egypt's Ministry of Electricity and Renewable Energy to start production of the core catcher devices for power units 1 and 2 of Egypt's El-Dabaa NPP. The agreement was signed during the visit of Dr. Mohamed Shaker (Egypt's Minister of Electricity and Renewable Energy) to Russia's machine-building enterprise, JSC TYAZHMASH.

The Egyptian Atomic Energy Authority and the IAEA signed Egypt's Country Programme Framework (CPF) for the period of 2022–2027 Technical Cooperation in September. The CPF is a frame of reference for medium-term planning of technical cooperation. In CPF identifying priority areas of nuclear technology and technical cooperation, resources are going to be directed to support domestic development goals.

Egypt's priorities for 2022–2027 are:

1. Nuclear and Radiation Safety and Nuclear Security
2. Energy Planning and Nuclear Power
3. Industrial Applications /Radiation Technology

4. Water and Environment
5. Food and Agriculture
6. Human Health
7. Nuclear Knowledge Development and Management.

Later that month, the first groups of specialists from Egypt's El-Dabaa NPP began training at the St. Petersburg branch of Rosatom's Technical Academy. The training programme is being carried out in the framework of contracts pertaining to the construction of Egypt's first nuclear power plant.

South Africa plans to procure more nuclear power

Currently the sole member of Africa's nuclear energy club, South Africa has two pressurised water reactors (each 970 MW) at Koeberg located just outside Cape Town.

In August, South Africa's energy regulator, the National Energy Regulator of South Africa (NERSA) agreed with Minister of Energy, Gwede Mantashe, that South Africa needed to tap into nuclear energy for the country's power needs. The regulator says that South Africa needs to strengthen its baseload energy, arguing that renewable energy is too inconsistent to meet the base needs for the country. The Minister is pushing to procure 2,500 MW in nuclear energy as part of the post-2030 power mix. New nuclear capacity is expected by 2035.

During the IAEA General Conference in September, Deputy Minister of Mineral Resources and Energy, Nobuhle Pamela Nkabane, further affirmed that South Africa is forging ahead with plans for a new 2,500 MW nuclear power plant in a bid to boost energy security and wants to end the procurement process by 2024.The aim is to issue the Request for Proposal (RFP) for 2,500 MW nuclear programme at end of March 2022.It is worth noting that the government having launched a Request for Information (RFI) in June last year to test the market's appetite for the new plant. The RFI had received positive responses from 25 companies that showed an interest in the new programme

Zambia's government committed towards nuclear energy implementation

Last December, Zambia launched a National Nuclear Policy and the Nuclear Programme Implementation Plan meant to provide guidance to the country's national nuclear program. The policy will provide an overall framework and guide the country in the implementation of nuclear programs. It is also expected to strengthen the legal, institutional, and operational framework of nuclear science and technology in the country.

During a workshop on Zambia's Nuclear Infrastructure Country Self-Assessment Report, held in May, Higher Education Permanent Secretary Kayula Siame said that the government is currently working on the legal framework of the nuclear programme in Zambia.

Zambia is in the process of establishing a nuclear centre that will be located in Chongwe, 10 kilometres away from the capital of Zambia, Lusaka. The construction of this centre is part of the first phase of the country's nuclear programme. The Center for Nuclear Science and

Technology (CNST) will include a nuclear research reactor facility, a state-of-the-art laboratory complex, a multipurpose irradiation centre as well as a cyclotron-based nuclear medicine centre. The project will be implemented in several stages over a period of 3-6 years.

With Zambia in the process of introducing the use of nuclear science and technology, the government has already sent young Zambian students to study in different fields of nuclear science and technology in Russia.

In July, 15 Zambian students graduated from the Moscow Engineering Physics Institute (MEPhI) and received their BS diplomas. The ceremony took place at the Obninsk Institute for Nuclear Power Engineering. Training young specialists from Zambia in the field of nuclear energy will encourage the creation of innovative sectors in the country's economy. It is capable of improving the quality of education, creating new highly paid jobs and the emergence of new specialists.

The Radiation Protection Authority (RPA) announced in October that it is ready to regulate the use of nuclear technology in Zambia. RPA has been engaging with international stakeholders such as the Russian counterparts and the IAEA to conduct various training staff on handling and managing nuclear materials such as radioactive waste and spent fuel.

Dr. Boster Siwila, CEO of RPA said following consultations with line ministries, mining companies and the IAEA had come up with a draft nuclear and radiation protection bill that proposed the inclusion of many aspects which will empower RPA to regulate nuclear technology. RPA is the country's regulator for the application of nuclear science and technology. It regulates radiation-protection aspects at a higher scale and at a lower scale nuclear technology in the medical sector.

In December, the Ministry of Technology and Science and the IAEA signed Zambia's Country Programme Framework (CPF) for the period of 2022–2027 Technical Cooperation. The CPF is a frame of reference which is for medium-term planning of technical cooperation. In CPF identifying priority areas of nuclear technology and technical cooperation resources are going to be directed to support domestic development goals.

Tier 2

Tunisia is looking to nuclear to overcome energy deficit

Tunisia is seriously considering the introduction of nuclear energy in the country. The country has been facing a continuous energy deficit since 2001.In order to diversify its energy mix, the nuclear option has been studied by following the IAEA Milestone Approach including the analysis of the 19 nuclear infrastructure issues. The feasibility study was performed and shared in 2015 by the Tunisian Company of Electricity and Gas (STEG) with the IAEA experts for review.

In January, as part of the feasibility study held by Tunisia, a new seismic catalogue and a new seismic source model have been proposed, in order to study and evaluate the seismic hazard for the two selected nuclear power plant sites, which are Marsa-Douiba in the north and Skhira in the southeast.

The hazard evaluation is conducted at a national level, to capture uncertainties related to the characterisation of both seismic sources and ground-motion.

In this study, the recommendations of the International Atomic Energy Agency were applied, as well as a hazard map of Tunisia for the return period of 475 years was generated to compare it with the ones obtained within previous studies, to determine the uniform hazard spectrums and perform disaggregation for the selected sites.

Sudan to focus on developing a capable regulator

In April, the US National Nuclear Security Administration (NNSA) and the Sudanese Nuclear and Radiological Regulatory Authority (SNRRA) held a virtual workshop in support of Sudan's efforts to effectively regulate the safe, secure, and peaceful uses of nuclear technology for medicine and human health; scientific research and education; agricultural, environmental, and industrial applications; and energy.

The country plans to pursue nuclear energy in the coming years to meet its growing demand for electricity, with a capable regulatory body as a precursor. The virtual workshop is part of a new era of cooperation with the United States.

Sudan recently strengthened its safeguards agreement with the International Atomic Energy Agency (IAEA) by modifying its Small Quantities Protocol. This modification enhances the IAEA's ability to verify the country's peaceful uses of nuclear material and represents an important step in Sudan's progress toward adhering to the IAEA's highest standard of safeguards verification.

Rwanda Atomic Energy Board to accelerate nuclear development

Rwanda believes that nuclear technology will support the current government's ambition of transitioning to a low-carbon emission by generating and developing a nuclear power plant that is a clean source of energy, considering its zero-carbon emission.

In August, Rwanda and Russia approved an agreement to set up a Centre for Nuclear Science and Technology by 2024.The Rwandan government maintains that the nuclear project will help in the advancement of technology in agriculture, energy production and environment protection. Rosatom has already committed itself to execute the project.

Later in October, a Cabinet meeting chaired by President Paul Kagame appointed a seven-member board to the Rwandan Atomic Energy Board (RAEB) which was created in December 2020.RAEB will coordinate all research and development of nuclear energy activities in Rwanda, monitor and coordinate safety and security and support nuclear energy applications for sustainable social economic development aligned with the National Strategy

for Transformation and Vision 2050.

Fidele Ndahayo, Chief Executive of the Rwanda Atomic Energy Board, said "We plan to sign the contract for the feasibility studies by the end of this year. One for the centre will last for eight to nine months, then the nuclear power-plant feasibility study will follow using some elements of the information that will have been gathered". He added "The studies will determine when we start, where the facilities will be located, and cost estimates".

Niger resolutely committed to carrying out a nuclear power program

In May, the IAEA completed a Nuclear Security Advisory Mission to Niger. The scope of the two-week International Physical Protection Advisory Service (IPPAS) mission included reviews of the legislative and regulatory framework for the security of radioactive material, regulatory practices (licensing, inspections and enforcement) and coordination between organisations and stakeholders involved in nuclear security. The team observed that Niger has established a nuclear security regime with essential elements of the IAEA's guidance on the fundamentals of nuclear security.

During the IAEA General Conference in September, Niger announced that it is resolutely committed to carrying out a nuclear power program included in all its political development programs. This is to ensure its energy independence and sustainable economic development. In addition, Niger strongly supports the implementation of a sub-regional nuclear power program, in order to guarantee access to electricity to the populations of the member countries of the Economic Community of West African States (ECOWAS). Niger remains convinced that nuclear power is clean energy that can combine economic development and environmental protection.

The Ministry of Petroleum, Energy and Renewable Energies and the IAEA signed Niger's Country Programme Framework (CPF) for the period of 2022–2027 Technical Cooperation in September. The CPF is a frame of reference which is for medium-term planning of technical cooperation. In CPF identifying priority areas of nuclear technology and technical cooperation resources are going to be directed to support domestic development goals.

Tier 3

Tanzania sees research reactors as first step for nuclear introduction

In April, the Tanzania Atomic Energy Commission (TAEC) held a meeting with stakeholders to review and receive opinions and recommendations on the proposed amendments of the Atomic Energy Act No. 7 of 2003 and its regulations. During the meeting, TAEC's Director General explained that the improvements of the law and regulations will include the Non-ionizing Radiation regulations that will be able to assist in managing and controlling safe applications of non-ionizing radiation and facilities in Tanzania.

Through TAEC, Tanzania is working tirelessly toward introducing a research reactor in the country. TAEC had previously collaborated with other stakeholders and conducted a prefeasibility study for consideration of a first research reactor in the country. This came after careful considerations that concluded if a research reactor was appropriately conceived, managed and supported, it will be an extraordinary tool that can contribute to a country's scientific resources, improve health care, and help to increase industrial and agricultural productivity.

During the IAEA General Conference in September, Tanzania announced that the country is planning to establish a Radiation Protection Training Centre, which will provide Diploma Courses in the fields of Radiation Protection and Safety and Electronics and Nuclear Instrumentation.

First African Collaborating centre of the IAEA in Morocco

Morocco's biggest nuclear installation, the TRIGA Mark II research reactor, began operation in 2007 and is part of the National Centre for Nuclear Energy, Sciences and Technology (CNESTEN).

In January, Morocco's Ministry of Energy, Mines, and Environment and the Hungarian Ministry of Innovation and Technology signed a Memorandum of Understanding (MoU). The MoU seeks to enhance cooperation between the two countries, pertaining to the training of the nuclear industry and education regarding the peaceful uses of nuclear energy. Under this agreement, both parties aim to facilitate the establishment of long-term cooperation on nuclear science and technology applications, education, and training. The collaboration will contribute to Morocco's economic development.

Morocco's then Minister of Energy, Mines and the Environment, Aziz Rabbah, inaugurated in March Morocco's first national Training Centre in Nuclear Science and Technology as an extension of the National Centre for Nuclear Energy, Sciences and Techniques in Maamora, near Rabat. The new centre aims to equip Morocco's nuclear scientists with the necessary skills to be qualified.

CNESTEN is a collaborative centre to the International Atomic Energy Agency (IAEA) specialising in the use of nuclear techniques in the management of water resources, protection of the environment, and industrial applications. CNESTEN is also recognised as a "centre of excellence" by the African Nuclear Threat Initiative, which brings together 40 African countries.

The centre's strategic vision for 2030 revolves around four main objectives:

- Strengthen and expand the uses of nuclear sciences and techniques in sector strategies and programmes
- To enrich the national human capital in the field of nuclear sciences and technologies
- Strengthen the operational nuclear and radiological safety and security regime at the national level
- Establish the positioning of CNESTEN at the regional level in nuclear science and technology in the service of the regional influence of Morocco.

Later in July, the Moroccan Agency for Nuclear and Radiological Safety and Security (AMSSNuR) and the IAEA signed an agreement for AMSSNuR to become the 1st African Collaborating Centre of the IAEA for capacity building in nuclear security, for the period 2021-2024.According to a specific action plan aimed at:

- Assisting Member States in the development of the regulatory framework relating to the nuclear security of their respective countries
- Developing national and regional capacities, particularly in Africa
- Strengthening regional and international cooperation in the field of nuclear security.

Ethiopia seeks to increase public acceptance of nuclear energy

In April, Ethiopia signed two memorandums of understanding (MoUs) with Rosatom. The documents set out the framework for interaction in two areas:

1. One related to education and training in the field of nuclear energy
2. The other one on the formation of a positive public opinion regarding nuclear energy in Ethiopia.

The efforts of the Ethiopian government will be focused on building human resources for the Ethiopian nuclear industry, through developing interaction between specialised educational institutions, including the organisation of joint short-term programs, teacher training, the development of educational and scientific literature and student exchange.

Regarding shaping positive public opinion, the MoU proposes the preparation of events aimed at working with the public and the Ethiopian media, as well as informing the population about nuclear technologies.

Human capacity building and preparing public acceptance are two crucial elements any newcomer country trying to pursue a nuclear power program need to early on enact and implement strategies to develop those two sectors. Otherwise, no matter the effort taken by government without those two elements the nuclear program would fail.

Research reactor updates and developments in Africa

In January and February, Nuclear Business Platform hosted a series of regional meetings focusing on the developments of nuclear research reactors in West Africa, Maghreb, Central & Southern Africa and East Africa.

Senior officials from the following organisations participated in the meeting, including:

1. South African Nuclear Energy Corporation
2. National Nuclear Research Institute, Ghana
3. Ministry of Petroleum and Energy, Senegal
4. Nuclear Radiation Protection, Safety and Security Authority, Ivory Coast
5. Nigeria Atomic Energy Commission
6. National Center for Energy and Nuclear Science and Technology, Morocco
7. National Authority for Radiation Protection, Safety and Nuclear Security, Mauritania
8. Nuclear Energy Programme Implementing Organisation, Zambia
9. Tanzania Atomic Energy Commission
10. National Center for Nuclear Sciences and Technologies, Tunisia
11. Ministry of Infrastructure, Rwanda
12. Uganda Atomic Energy Council
13. Nuclear Power and Energy Agency, Kenya
14. General Commissariat for Atomic Energy, DRC
15. African Commission on Nuclear Energy
16. International Atomic Energy Agency.

For countries considering introducing nuclear power, a research reactor generally serves as a platform to facilitate the development of the necessary infrastructure. Currently 8 African countries operate 11 research reactors on the continent, while a few others are looking to establish and build their own research reactors. Africa's research reactors are a vital component of the societal role played by nuclear science and technology.

The first meeting focusing on the West African region had officials from Senegal, Ghana and Ivory Coast participating. During the meeting, Senegal's Ministry of Petroleum and Energy stated that the government has decided to install and commission a neutron source reactor for specific applications, in particular health, agriculture, industrial, environment and minerals exploration.

The timeline for the establishment of the research reactor is as follows:

- 2020 - 2022: Conduct of feasibility studies and building the required infrastructure for research reactor
- 2023 - 2026: Construction, commissioning and operation of the research reactor. This will include sitting, construction, licensing and commissioning of the research reactor within the IAEA approach for building a research reactor
- 2026: Operation, maintenance and development of other related techniques into the research reactor facility.

The second meeting focusing on the Maghreb region had officials from Morocco, Tunisia, Mauritania and the IAEA participating. During the meeting, the Director General of the Tunisia Nuclear Energy Centre (CNSTN) shared that a subcritical assembly will support the development of national human resources and perform applied research and development in the nuclear field. It will be located at the CNSTN site in Sidi Thabet, 35 km from Tunis, and will enable scientific research projects to develop an understanding of specific concepts relevant to nuclear reactor physics.

The third meeting focusing on the Central and Southern African region had officials from South Africa, Zambia, Democratic Republic of Congo (DRC) and the African Commission on Nuclear Energy (AFCONE) participating. Participants shared the experiences and challenges faced by the region in operating nuclear research reactors and for Zambia its plan to build its first research reactor as the main facility of the new nuclear research centre. During the meeting, DRC's nuclear agency CGEA (Commissariat Général à l'Energie Atomique) announced that it should be able to restart the research reactor at the end of 2022.

The concluding meeting focusing on the East African region had officials from Tanzania, Kenya, and Uganda participating. Officials shared their respective quest to build a research reactor and Kenya explained the steps taken to build a nuclear power plant.

The Tanzania Atomic Energy Commission also highlighted that it has conducted a pre-project assessment and preparations for considerations of a first research reactor in collaboration with the IAEA. The pre-feasibility study considered the following items:

- Time and cost to design, construct and commission
- Safety and regulatory requirements
- Resources required to operate and maintain the facility (including fuel costs)
- Resources to dismantle and decommission
- Impact on the costs of radioactive wastes and spent fuel management and disposal

- Regulatory requirements.

This pre-feasibility study and preliminary strategic planning document together comprehensively justify setting out the context for the follow-up detailed feasibility study. In conclusion, the national position on nuclear and associated issues will have to be clear and specific in order to ensure that the research reactor project objectives are demonstrably compatible with government policy and strategy.

RUSSIAN FEDERATION NUCLEAR ENERGY

Overview

The year 2020 was the jubilee year for the Russian nuclear sector. The 20th day of August in 1945 became the starting point of the history of the national nuclear industry, which for more than 75 years has provided global nuclear arms balance, fed cities with energy, and fostered the development of science and technology far beyond traditional “nuclear” objectives.

The following provides several highlights of nuclear power in the Russian Federation. Additional details can be found in the Russian Federation Country Profile, found on the IAEA website: https://cnpp.iaea.org/countryprofiles/Russia/Russia.htm.

Nuclear electricity generated by Russian nuclear power plants (NPPs) reached 214 billion kWh by the end 2020.This will bring growth up by 2.4% compared to 2019, in spite of the global COVID-19 pandemic. The load factor by the beginning of September was 77.9%, (the 2019 figure was 78.4%). This is an absolute record in the country's nuclear power industry since Soviet Union times. According to Rosenergoatom forecasts, in 2021, it is expected to generate electricity at the level of 218 billion kWh at the Russian NPPs.

In total, 38 power units are currently in industrial operation at 11 NPPs in Russia. The total installed capacity of all Russian NPPs is 30.3 GW. The total capacity of nuclear power units in operation is 26.3 GW. The share of nuclear energy in total energy generation in Russia is 19%, with European and north-western parts of Russia having 30% and 37% of nuclear generation, respectively.

In August 2020, a physical start-up of a new nuclear reactor took place at the Leningradskaya NPP-2. Its commissioning would begin in 2021.This will be the last unit of the first series of VVER-1200 reactors of the Russian “AES-2006” design developed in the 21st century. The VVER-1200 is today the main product exported by the State Atomic Energy Corporation, Rosatom.

Test operations of the floating nuclear thermal and electric power plant (FNPP) “Akademik Lomonosov” are underway, and are showing stable and accident-free operation at design parameters. More than 80 million kWh of electricity have been generated by 1 September 2020.The FNPP is recognized as a base element of the Northern Sea route. Rosatom also commenced development of the second generation of FNPP – an optimized floating nuclear power plant (OFNPP), which is planned to be smaller than its predecessor and equipped with two RITM-200M type nuclear reactors of 50 MW each.

Within the Northern Sea route development programme, the series-leading ice-breaker “Arctica” came out of the shipyard of the Joint Stock company, “BaltiyskiyZavod” (Saint-Petersburg), in September 2020, and will pass the acceptance “ice-breaking” tests. After passing these tests, Arctica will go to Murmansk in the context of a transfer to Rosatom’s Atomflot company. Two other icebreakers, “Sibir” and “Ural”, are scheduled to be commissioned in 2021 and 2022, ensuring that tank ships are carrying hydrocarbons from Yamal, Gydan peninsulas to markets in the Asia-Pacific region year-round.

Russia is today a world leader in new nuclear construction abroad. Rosatom also ranks first in the number of simultaneously implemented projects for the construction of nuclear power units (3 in Russia and 36 abroad).The current Rosatom portfolio includes: Hanhikivi-1 (Finland), Akkuyu NPP (Turkey), Kudankulam (India), Paks-2 (Hungary), Ruppur NPP (Bangladesh), Cuidapu (China), Tianwan (China), El Dabaa NPP (Egypt), Belorusskaya NPP (Belorussia) and Busher (Iran). In August 2020, nuclear fuel loading started at the first power unit of Belorusskaya NPP in Ostrovets (Grodno region). Commissioning of the first unit is scheduled for the beginning of 2021, and the second unit in 2022. With both reactors in operation, Belorussia will have an additional 2400 MW of generating capacity.

Russian NPP designs are based on Gen- III+ reactors, equipped with both passive and active safety systems, and in full conformity with modern international requirements and recommendations of the International Atomic Energy Agency (IAEA). Russia is further improving the VVER technology to enable transition from the open to the closed nuclear fuel cycle, and to ensure efficient operation of two-component nuclear power. The VVER-1200 is a flagship nuclear reactor and the main product of Rosatom’s complex offer. Evolving from the VVER-1000 design units that were recently built in China, India, Iran VVER-1200 design units have improved characteristics in all design parameters.

Rosatom signed an agreement with the Russian republic of Yakutia on the construction of a low-power ground-based nuclear power plant based on SMR RITM-200 in Ust-Yansky Ulus, the number of units to be constructed is 4, a license for the construction has been obtained.

Perspectives of nuclear technologies

Russia is a recognized leader in the field of sodium-cooled fast reactors (BN or SFR). At present, two power units of the Beloyarsk NPP are in operation, the BN-600 and BN-800 reactors Also the BOR-60 research reactor in NIIAR, Dimitrovgrad, is in operation. The total BN operation experience accumulated in Russia and the former Union of Soviet Socialist Republics (USSR), as of September 2020, exceeds 160 reactor-years. The lifetime of the power unit BN-600 reactor has reached 40 years.

To solve the task of closing the nuclear fuel cycle, along with the transmutation of long-living isotopes, the hybrid core of the BN-800 was designed to have both uranium and uranium-plutonium mixed oxide (MOX) fuel assemblies. The first serial batch of 18 MOX fuel assemblies was loaded into the BN-800 in December 2019, and during 2020 demonstrated an incident-free operation without degradation of economic performance. In July 2020, at the Mining-Chemical Combine (Krasnoyarsk region), a full reload batch of 169 MOX fuel assemblies for the BN-800 was manufactured and tested. Transition of the BN-800 at Beloyarsk NPP to 100% MOX fuel operation is planned for 2022.

In the framework of the PRORYV Project (proryv means breakthrough in Russian), construction of the lead-cooled fast-neutron reactor BREST-OD-300 commenced. Irradiation tests continued for the innovative mixed nitride uranium-plutonium (MNIT) fuel; its manufacturing is planned to start in 2022 at the BREST-OD-300 site in Seversk. This type of fuel is aimed to be used in both the BREST-OD-300 and BN-1200 reactors. All of the MNIT fuel elements irradiated in the BN-600, under close to design conditions, have reached 6% burn-up levels, which is a target level for the first loading of the BREST-OD-300.Safe fuel operation up to 8.5% burn-up of heavy atoms has been demonstrated, and testing continued to reach a 9.2% burn-up level. The fuel-element cladding damage dose reached a record value of 110 displacements per atom (dpa).

At the NIIAR site in Dimitrovgrad, the MBIR fast research reactor with sodium coolant is being constructed. It is intended to replace the BOR-60 reactor, whose operation lifetime has already reached 50 years. Russia established the International Research Center on the basis of the MBIR reactor (IRC MBIR), and has approved the new construction schedule for full development. Construction work of the research reactor thus started at the construction site in accordance with this new schedule. Key research directions enabled by the IRC MBIR are materials science (e.g., new fuel, structural materials, coolants, data verification), safety (e.g., justification of new safety systems, transients and beyond-design conditions research), physics (e.g., closed-cycle studies, minor actinides and long-lived fission product treatment, reprocessing, computer code verification), resource tests (e.g. fuel, control-system elements, core elements, cooling loops monitoring and diagnostic systems).

An important addition to the IRC MBIR research capacity is the inclusion of the poly-functional radiochemical complex, which will be able to carry out a series of irradiation tests and post-irradiation investigations at the same site.

Under the strategic framework of future Russian nuclear scenarios, nuclear power development is scrutinized in a two-component closed fuel cycle: fast-neutron reactors and standard VVERs with thermal neutrons. Options assuming the use of MSRs are also under consideration.

Transition to the closed fuel cycle and its transient phase (i.e., two-component nuclear power) puts a stop to the accumulation of spent nuclear fuel (SNF) from thermal reactors and eliminates any increase in the growth of corresponding costs of spent-fuel management. Substituting a thermal reactor with a fast neutron reactor leads to: the elimination of approximately 1 000 tonnes of spent fuel (i.e., for the VVER reactor operating for 60 years) and expenditures for its storage before reprocessing; an increase by a factor of 15 of the plutonium from spent-fuel reprocessing, which is reused as fuel (15% of plutonium in fast-reactor spent fuel).Use of nuclear materials from spent-fuel reprocessing for the commissioning of fast reactors, as well as the closed fuel cycle, is an efficient way of coping with the problem of accumulated spent fuel from VVERs: one fast reactor is capable of using a lifetime of spent fuel from one VVER; substitution of 10 GW of thermal reactors by fast reactors almost completely resolves the problem of all accumulated spent fuel from Russian VVERs (~10 thousand tonnes), while at the same time ensuring economical results from fuel reprocessing.

Generation 4

The optimization of the competitiveness of the BN-1200M project has been completed and a recommendation has been received from the ROSATOM's Scientific and Technical Councils on its construction as the 5th unit of the Beloyarsk NPP.

A full-scale industrial production of MOX fuel for the BN-800 fast-neutron reactor has been put in place at FSUE GHK. In 2020, the first reloading of the BN-800 reactor core with MOX fuel (one third of the core) was successfully completed, confirming the possibility to provide the fuel supply for the BN-800 reactor in full. In the same year, the first batch of BN-800 fuel assemblies was manufactured with MOX fuel from highly-radioactive plutonium dioxide extracted from the VVER reactors' SNF.

In 2022, it is planned to load the next batch of BN-800 MOX fuel assemblies, which will completely transfer the core of the BN-800 reactor to this type of nuclear fuel.

Construction continues at a good pace at the site of multi-purpose fast neutron research reactor MBIR. In 2021, construction and installation are ahead of schedule by 10-15%.

The reactor vessel was manufactured at the Atommash factory. An intermediate slab was installed at the base of the reactor shaft, on which the installation of related equipment has begun.

In July 2021, the international consortium agreement was signed that legally formalized the relations of the first key participants of the Consortium, as well as fixed the rights and obligations of participants for the use of the MBIR reactor resource after reactor commissioning.

Rosatom is open to the access by international partners to the International Research Center Consortium.

Rosatom in Russia has begun to shape the appearance of a new technological platform for nuclear generation in the horizon after 2030 - two-component nuclear energy with a closed nuclear fuel cycle (CNFC). It allows to multiply the available fuel supply and solve issues related to the management of spent nuclear fuel.

In June of 2021, the construction of a nuclear power unit with the fast-neutron reactor BREST-300 was launched in Seversk, Tomsk region. For the first time in the world, a nuclear power plant with a fast-neutron reactor and facilities for the closed nuclear fuel cycle will be constructed at the same site. This is, without exaggeration, a milestone for the global nuclear power industry.

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