Chapter 10

The Case for Nuclear Energy

Harun Ardiansyah

A. Nuclear Energy, The-Once-Antagonist

Nuclear energy is not something that is particularly new in Indonesia. Indonesia is one of the first few countries that ratified the International Atomic Energy Agency (IAEA) Statute, legalizing the establishment of IAEA as the world's nuclear watchdog. Mr. Soedjarwo Tjondronegoro served as one of IAEA's first board of governors (IAEA Statute, 1956). Since then, Indonesia has progressed so well in nuclear technology. Indonesia has three research reactors, namely TRIGA Mark II in Bandung, Kartini in Yogyakarta, and G.A. Siwabessy Multipurpose Reactor in Serpong. These reactors have served public interests since their first operation (Sugiawan & Managi, 2019). However, after the three reactors were built, advancements somehow stopped in terms

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of nuclear reactors, especially to construct of nuclear power plants for energy mix. There is no significant progress in Indonesia in pursuing nuclear energy as part of its national energy mix (Cho et al., 2021). On the other hand, the urgency of using nuclear energy has grown significantly over the last five years. Nuclear energy can be part of Indonesia's energy mix as the baseload, to fulfill the fluctuations from wind, solar, and other renewable energy sources. This chapter will explore the concept of nuclear energy, how it works, unresolved topics in nuclear energy, misinformation surrounding nuclear energy, and how nuclear energy can significantly help Indonesia tackle climate change.

B. Brief History of Nuclear Energy

Nuclear energy has been around for more than seventy years. Since the first nuclear fission reaction happened in Chicago Pile-1 (the first self-sustaining nuclear reactor on December 2, 1942), nuclear energy has transformed how humans can extract energy from the tiniest things in the universe (Atomic Heritage Foundation, 2016). However, the first "official introduction" of nuclear energy to the world came when Hiroshima and Nagasaki in Japan were bombed with atomic bombs in 1945, creating devastation and prolonged misery in the cities of Hiroshima and Nagasaki. This "introduction" creates a horrible perception of nuclear energy (Rhodes, 2012).

As the follow-up of the Manhattan Project—the project that created atomic bombs but was dismissed in 1946, the United States government created an Atomic Energy Commission. The mission of this organization was to develop nuclear energy further so that it could be used for peaceful purposes. Subsequently, these efforts started to come to reality as the Experimental Breeder Reactor-1 (EBR-1) in Idaho managed to produce electricity for the first time in 1951. This started a chain of rapid developments of nuclear reactors not only in the United States, but also around the world (Michal, 2001).

Seeing the progress of nuclear energy, President of the United States Dwight Eisenhower called for the use of "atoms for peace".

He delivered the speech at the UN General Assembly of 1953. This move was then propagated until 1957, when the IAEA was established. The wave of support for nuclear energy continued when the Nuclear Nonproliferation Treaty (NPT) was ratified in 1968 (United Nations, 1968). This marked the wake of the "nuclear golden age" when nuclear reactors were developed very rapidly around the world (Hewlett & Holl, 1989).

The first sign of the "nuclear golden age" is the Obninsk Nuclear Power Plant (NPP) startup in the Soviet Union. Established in 1954, the Obninsk NPP was the first commercial nuclear power plant operated in the world (Semenov, 1983). This story continued with the establishment of more than 150 nuclear power plants in 20 years. The peak of the golden age was in 1974 when the Prime Minister of France, Pierre Messmer, launched a new initiative to build more nuclear reactors in France. This initiative was implemented as the answer from France to tackle the oil crisis that haunted Europe in the 1970s (Funding Universe, 1996).

Source: United States Postal Service (n.d.)

Figure 10.1 U.S. Postal Service Stamp to Commemorate "Atoms for Peace" Speech

Then the tables turned. On April 26, 1986, a devastating disaster happened in the Chernobyl Nuclear Power Plant. This accident was the biggest nuclear accident in the world up until now. The Chernobyl plant was a graphite-moderated, pressure tube of channel-type boiling water reactors (BWR) of the RBMK (*Reaktor* Bolshoy Moshchnosty Kanalny)-1000 design with a large core (12 m x 12 m) cross-sectional area and height of 7m. The accident happened during a test of turbogenerator coast down, which was to provide power to feedwater pumps and the emergency core cooling system (ECCS). This type of experiment was not an urgent case to be done. The decision to perform a non-nuclear-focused test on a large civil power reactor facility reflected the lack of safety culture (Ripon et al., 1986).

The Chernobyl accident shocked the nuclear industry and the whole world. Calls to improve or even shut down nuclear reactors grew in public. This resulted in public perception of nuclear energy hitting its lowest point. As an effect, mistrust from the public created project delays in many reactors around the world, causing the cost of nuclear energy to skyrocket and not economically feasible to build new reactors. Nuclear energy entered its "dark age" due to all the pushbacks that came to the industry. In early 2000, after 16 years without any accident, nuclear energy started to gain its footing again with the emergence of Generation-III, III+, and IV reactors. Generation-III, III+, and IV reactors are new types of nuclear reactors that employ new safety features for better and safer nuclear reactors. Research and development have been growing for this new type of reactor that was told to be the future of nuclear reactors.

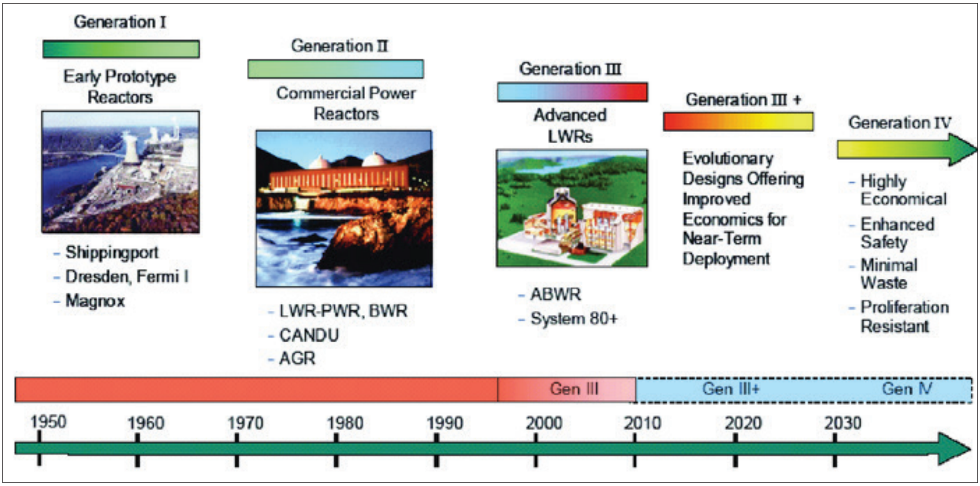
The rapid progress is again facing an obstacle after another accident happened on March 11, 2011. A 9.0-magnitude earthquake shocked the east coast of Japan. This event was followed by a tsunami with waves around 10 to 14 meters. In the Fukushima Prefecture, a nuclear reactor complex was operated by Tokyo Electric Company, Co. (TEPCO) called the Fukushima Daiichi Nuclear Complex. This complex consisted of 6 BWRs of General Electric design and started operation between 1971 and 1979 with power between 439 to 1067

MWe. Seconds after the earthquake, reactor units 1, 2, and 3 were directly shut down as expected. It was followed by the trip of the turbo generator and the main steam valve was closed. Then the tsunami waves hit the nuclear complex causing the electrical diesel generator to malfunction resulting in a station black-out (SBO) for units 1 through 4. Some additional batteries were still used to cool down the reactors. However, as time passed, the batteries started to be depleted and the core temperature started to increase. Eutectic reactions of fuel and zirconium also melted the fuel rod and eventually damaged the core. A significant number of radionuclides were also released into the atmosphere (Japan Nuclear Emergency Response Headquarters, 2011).

After the Fukushima accident, the nuclear industry once again went into another dark age. Public perception of nuclear energy was hit once again to an all-time low. From an engineering view, this pushed innovation towards better safety and the ability to passively remove the decay heat, which drives more support for nuclear energy. The existence of climate change and its effect on future generations also prompted younger generations to support nuclear energy to tackle climate change. Much research done by non-governmental and intergovernmental organizations shows that nuclear energy can help tackle climate change effectively and efficiently. This is an ongoing pursuit, especially since some organizations are still indecisive on nuclear energy. On the other hand, support for nuclear energy is growing larger, reaching more audiences, especially in Europe and Asia (Lovering et al., 2016).

C. Generations of Nuclear Reactors

Since the existence of nuclear reactors in the 1950s, innovations have driven the nuclear industry to produce electricity at the highest capacity (Figure 10.2). Innovations and improvements of nuclear reactors are made to reach better cost, safety, security, and fuel cycle, among other things. These improvements are classified into several "generations" of nuclear reactors.



Source: Goldberg & Rosner (2011)

Figure 10.2 Generations of Nuclear Reactors

1. Generation I

The first generation of nuclear reactors, usually referred to as Generation I, refers to the prototype and power reactors that launched civil nuclear power. This generation of reactors consists of early prototypes of commercial reactors that started commissioning in the 1950s and 1960s. These reactors were early proof that the concept of nuclear reactors was validated and could operate safely. Examples of reactors in the generation I category are Shippingport (1957–1982) and Dresden-1 (1960–1978) in the United States, and Calder Hall-1 (1956–2003) in the United Kingdom (UK) (Figure 10.3). The last remaining commercial Gen I plant, the Wylfa Nuclear Power closed on December 30, 2015, after nearly 45 years of successful and safe operations. This closure marked the conclusion of Magnox reactor generation in the UK (Goldberg & Rosner, 2011).

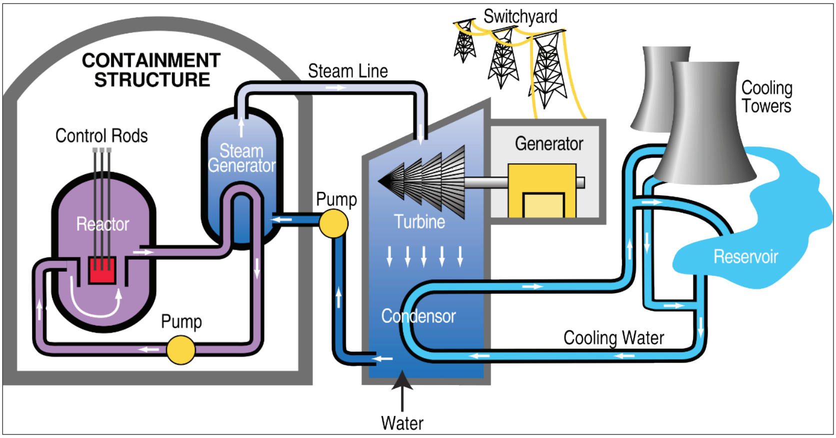
Source: U.S. Department of Energy (n.d.)

Figure 10.3 Calder Hall Power Station in the United Kingdom

2. Generation II

Generation II refers to a class of commercial reactors mainly deployed around the 1970s to 1980s. After proving that nuclear reactors were reasonably deployed, engineers, and designers innovated to create more economical and reliable nuclear power plants. These reactors were typically designed to be operated for forty years. Regarding technical aspects, Generation II reactors have matured some critical components on safety-related issues. For example, active and passive safety features are used to operate the reactors safely and function without operator control or loss of auxiliary power. Generation II reactors include pressurized water reactors (PWR) (Figure 10.4), Canada Deuterium Uranium reactors (CANDU), boiling water reactors (BWR), advanced gas-cooled reactors (AGR), and Vodo-Vodyanoi Energetichesky Reactors (VVER) (Goldberg & Rosner, 2011).

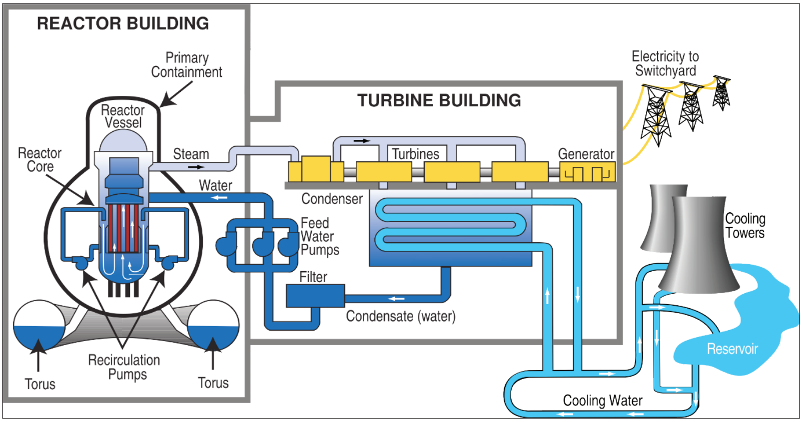
Until now, Generation II reactors have the largest fleet in the world, especially PWR and BWR. PWR is by far the most common civilian nuclear reactor in the world. This type of reactor was originally developed for nuclear submarines. Water is circulated in a pressure vessel to cool the reactor core and extract the heat from the core. The pressure inside the pressure vessel is around 150 bar. Thanks to the pressure, the water stays in its liquid state even at a high temperature. Water passes downward through an annulus between the reactor core and the pressure vessel and then flows up over the fuel elements. It then leaves through a series of pipes to the steam generator. In the steam generator, hot water from the reactor core passes through a heat exchanger. Current PWR technology commonly uses four loops of steam generators to maximize the steam generated in the system. Water at lower pressure is fed to the other side of the heat exchanger. The exchange of heat creates steam that is then passed to the turbine, then to the condenser (Hewitt & Collier, 2000).



Source: United States Tennessee Valley Authority (n.d.)

Figure 10.4 Pressurized Water Reactor Schematic Diagram

BWR is the world's second most common civilian nuclear reactor (Figure 10.5). BWR differs from PWR, where the steam generation process is done directly on a single cycle. BWR generates steam directly with the core without a separate steam generator. The pressure inside the core is about 70 bar. Water passes through the core, and about 10% is converted into steam. The steam is then separated from water molecules in the upper region of the core. The separated water is pumped back to the core using a circulating pump. Then, the steam goes to the turbines and condenser and the water goes back to the core to continue the cycle (Hewitt & Collier, 2000).



Source: United States Tennessee Valley Authority (n.d.)

Figure 10.5 Boiling Water Reactor Schematic Diagram

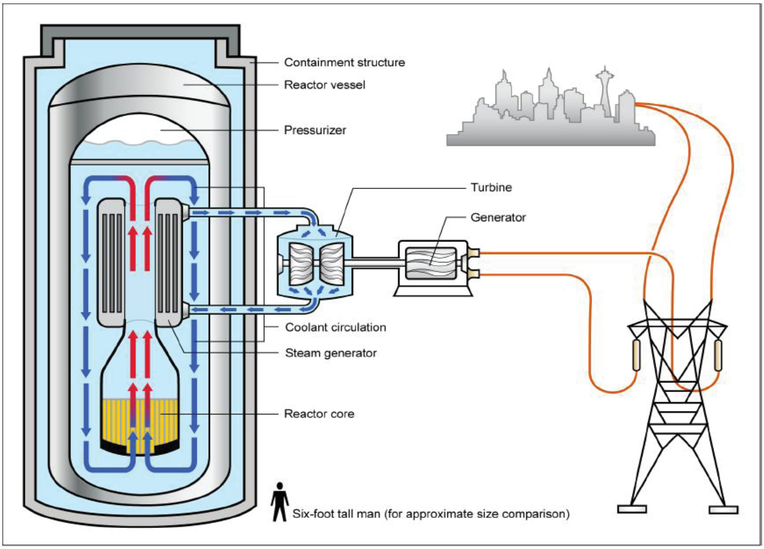
3. Generation III

Generation III reactors are technologically similar to Generation II reactors. However, evolutionary state-of-the-art design improvements are added to the reactors. These measures are added to prevent Fukushima-like accidents from happening. Improvements are added in fuel technology, thermal efficiency, modularized construction, passive safety system, and standardized design. These improvements aim is to extend the operational lifetime of a nuclear reactor up to sixty years without compromising the safety and security of nuclear reactors (Goldberg & Rosner, 2011). Generation III reactors include the Westinghouse 600 MW Advanced PWR (AP-600), GE Nuclear Energy's Advanced Boiling Water Reactor (ABWR), and Enhanced CANDU 6. These technologies are not massively employed around the world yet.

4. Generation III+

In between Generation III and Generation IV, Generation III+ reactors are designed as a development from Generation III reactors, providing more significant safety improvements. The most significant improvement is the passive safety features that do not require any active controls and only rely on gravity and natural circulation to mitigate the impact of abnormal events. Generation III+ reactors include South Korea's Advanced Power Reactor (APR), European Power Reactor (EPR), Japan's Advanced Pressurized Water Reactor (APWR), Russia's VVER-12000, and the United States' AP-600 and AP-1000 (Juhn et al., 2000).

Small and modular reactors (SMR) is one of the nuclear technologies in this category (Figure 10.6). IAEA defined SMRs based on the power and size of the reactors. SMRs typically produce up to 300 MWe (International Atomic Energy Agency, 2014). However, the smallness of its size is not the only advantage of SMRs. SMRs are designed to be modular, which means that the reactor consists of standardized units that are easy to be constructed. It is important that each individual component can be altered or replaced without any significant effect on the overall system. The modularity of nuclear reactors will solve one problem: the inability to standardize any design to simplify reproducibility. Ultimately, this innovation will lead to cheaper and faster construction of nuclear power plants (Hussein, 2020).



Source: GAO, based on Department of Energy documentation. | GAO-15-652

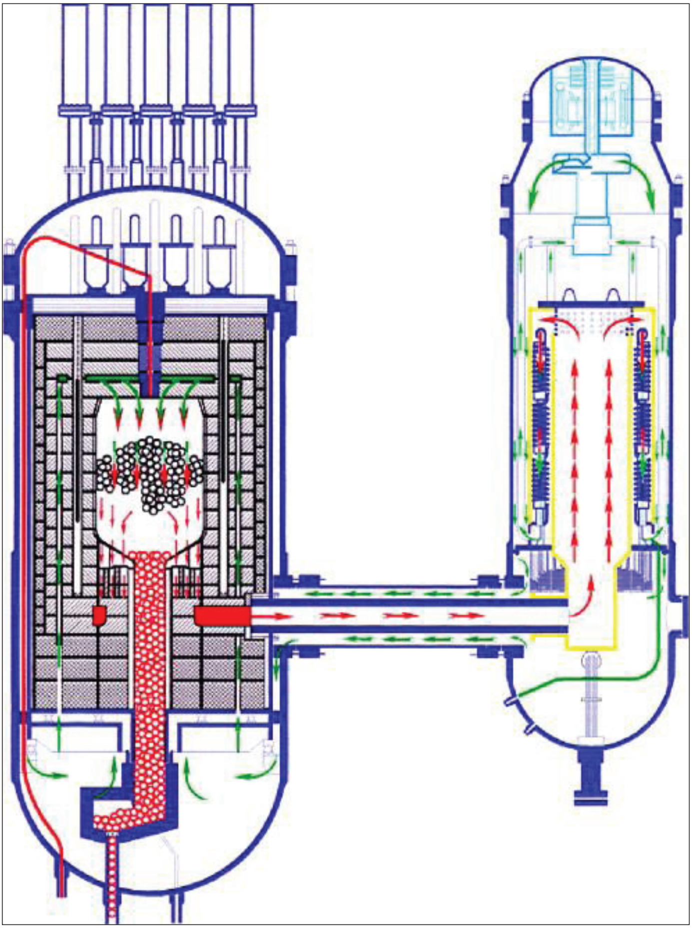
Source: U.S. Government Accountability Office (n.d.)

Figure 10.6 Schematics of Light Water Small Modular Nuclear Reactor

5. Generation IV

The next generation of nuclear reactors, Generation IV, is a brand-new generation that expands nuclear power technology. All Generation IV technology identified by the Generation IV Forum (GIF) is currently in the development phase and seeks to be deployed shortly (The Generation IV International Forum & U.S. DOE Nuclear Energy Research Advisory Committee, 2002). Generation IV offers major improvements in some key areas: economics, safety, sustainability, and proliferation resistance. There are six new nuclear technologies with the potential to fulfill these goals and are currently under development in many countries. Those reactors are the high-temperature gas-cooled reactor (HTGR), the sodium-cooled fast reactor (SFR), the gas-cooled fast reactor (GFR), the lead-cooled fast reactor (LFR), the molten salt reactor (MSR) and the super-critical water-cooled reactor (SCWR) (Abram & Ion, 2008).

HTGRs and MSRs are leading the innovation of Generation IV reactors (Figure 10.7). Multiple startups and companies have designed a lot of new nuclear reactors to be deployed in the near future. For HTGRs, the Chinese HTR-PM reactor, a 2 x 210 MWe HTGR, has been generating electricity since late 2021. This is significant progress to prove that Generation IV reactors are coming sooner or later (World Nuclear News, 2021).



Source: Zhang et al. (2009)

Figure 10.7 High-Temperature Gas-Cooled Reactor Schematics

D. Benefits of Nuclear Energy

Nuclear energy has a lot of benefits to society. Not only as a clean energy source, but also for the livelihood of people around nuclear energy. This part will explain some features to argue that nuclear energy benefits the future.

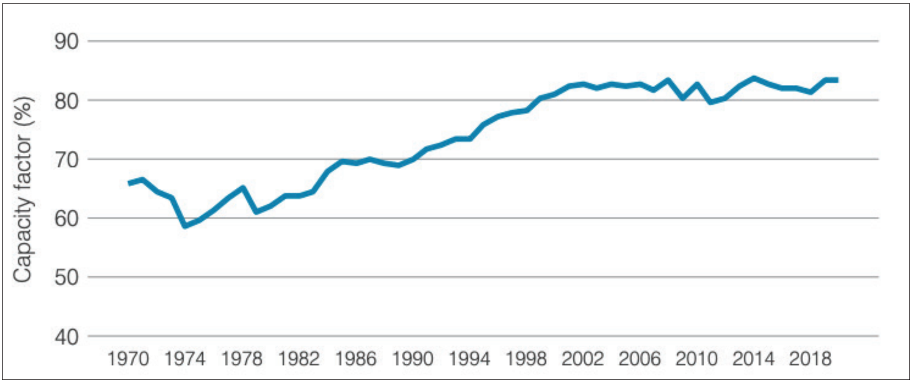
1. Energy Density

Energy density is the amount of energy produced per unit volume of fuel. Nuclear energy is the densest energy source in the world. A comparison by IAEA stated that a chicken-egg-sized amount of uranium fuel provides more than enough power for a lifetime of energy use for an average person. This is because each individual atom of Uranium-235, the isotope commonly used for thermal fission inside a reactor core, can produce energy as much as 200 MeV (equivalent to 3.2044×10^{-11} Joule) in every fission reaction (Lamarsh & Baratta, 2001). Though the number seems very small, 200 MeV is energy produced by each atom in a single fission reaction. This equates to around 85,000,000 MJ/kg, compared to other energy sources such as coal (24 MJ/kg) and natural gas (50 MJ/kg). A nuclear power plant that generates 1,000 MW of electricity will only consume around 3.5 kg of Uranium-235 per day. This means that electricity can be generated using considerably fewer resources than any other source of energy (Williams, 2016).

2. Capacity Factor

The capacity factor is the ratio of actual energy output over the maximum possible electrical energy output in a given period. This measure shows how often the energy source is running at maximum power and is used to measure the reliability of an energy source. The capacity factor is a unitless ratio and usually computed over a year. In 2019, the capacity factor of nuclear energy was 83.1%, which means that on average, nuclear power plants produce 83.1% of their maximum possible energy output in a year. Nuclear energy has maintained a capacity factor of around 80% for the last twenty years (World Nuclear

Association, 2021). This value is the largest among other renewable energy sources such as hydropower (40.2%), solar energy (13.4%), wind energy (25.9%), and geothermal energy (79.9%) all in 2019 (International Renewable Energy Agency, 2020).

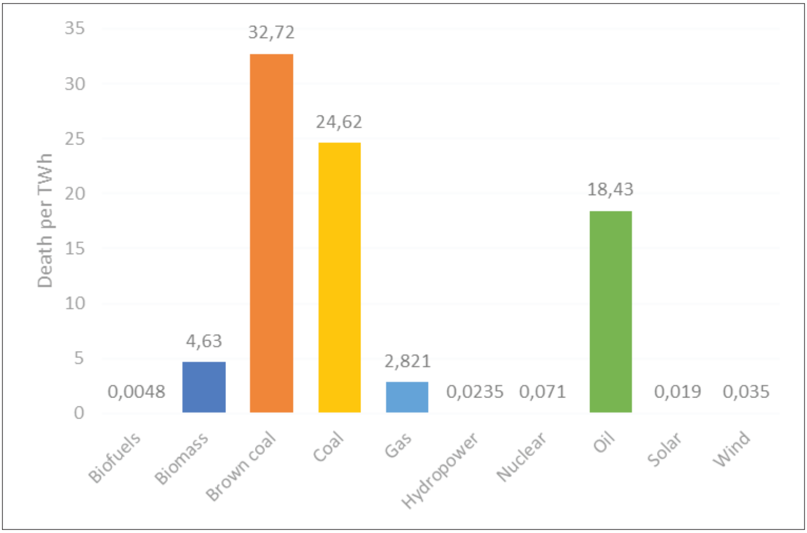


Source: World Nuclear Association, IAEA PRIS (2021)

Figure 10.8 Global Average Capacity Factor of Nuclear Energy

3. Health Effects of Energy Production

Numerous measures can be used to measure the safety of energy production. One parameter that can be used is the health effects of energy production, measured in the number of deaths per energy produced by a given energy source. From this perspective, nuclear energy is among the safest energy sources. The death rate from nuclear energy is 0.07 death per Terawatt-hours (TWh) of energy produced (Markandya & Wilkinson, 2007). This calculation already included death estimation from the Chernobyl disaster (4,000 deaths), death estimation from the Fukushima disaster (one worker death, and 573 indirect deaths from the stress of evacuation), and death estimation from mining and milling activities. This value is very close to renewable energy sources such as wind energy (0.04 death per TWh), hydropower (0.02 death per TWh), and solar energy (0.02 death per TWh) (Sovacool et al., 2016). This shows how nuclear energy can be used worldwide as a safe electricity source.

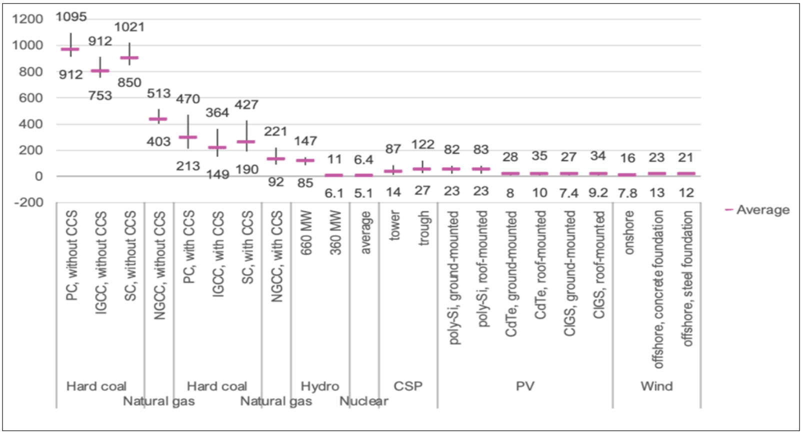


Source: Our World in Data (2020)

Figure 10.9 Death Rates from Energy Production per TWh

4. Greenhouse Gas Emissions

The United Nations Economic Commission for Europe (UNECE) examines the carbon lifecycles of multiple technologies to produce electricity. The report shows that nuclear energy has the lowest greenhouse gas emissions among all electricity sources. Nuclear energy produced on average 5.5 g CO_2 eq./kWh of greenhouse gas. Greenhouse gas is mainly produced during the front end of the nuclear fuel cycle, which includes mining, milling, and fuel fabrication processes. Nuclear energy is among the lowest in other categories such as freshwater eutrophication, human toxicity, land occupation, and fuel resources. This shows that nuclear energy is important to balance the increase in energy demand with greenhouse gas reduction (Gibon et al., 2021).



Source: Gibon et al. (2021)

Figure 10.10 Lifecycle Greenhouse Gas Emission Range for Assessed Technology

5. High-Paying Jobs

The nuclear energy industry has created long-lasting, high-paying jobs for future generations. In the era of post-COVID-19 recovery, the nuclear energy sector has supported economic recovery, keeping the pace of energy transition, creating jobs, and leading the effort towards a more sustainable future. For example, the refurbishment of six reactors by Bruce Power in Canada will provide low-cost, reliable, and carbon-free energy until 2064. These reactors will also provide long-lasting 22,000 jobs during their operation of the reactors (NEA Policy Brief, 2020). A technical report by World Nuclear Association shows that nuclear energy provides about 25% more employment per unit of electricity than wind energy. Nuclear employment also includes comparatively good-paying, long-term job security, and a high degree of localization in the host country (Emsley, 2020). These jobs are not only high-skill technical jobs, but also secondary jobs such as sales and administrative support, construction, management, business and financial occupations, cleaning and maintenance, production, health care, transportation, installation, maintenance, and repair (Berkman & Murphy, 2015).

E. Unresolved Problems in Nuclear Energy

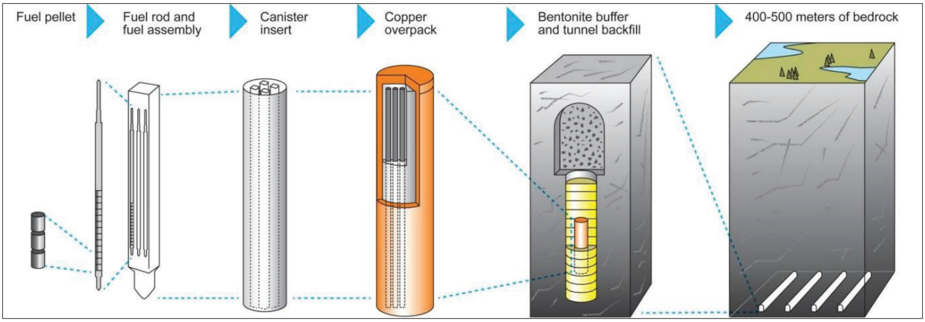
Like technologies, nuclear energy kept improving in many aspects, such as safety, security, and safeguard. However, two particular aspects of nuclear energy considered unresolved until now, namely nuclear waste and cost and time of construction. These aspects are considered unresolved due to technical and engineering problems or policy and political problems as discussed below.

1. Nuclear Waste

Nuclear waste is the most common topic when nuclear energy is being discussed. Some would argue that nuclear waste is why nuclear energy should not be implemented, due to the high level of radioactivity and radiological impact on the future. However, some information and news about nuclear waste might need to be clarified.

Nuclear energy waste is generally classified into three categories: low-level, intermediate-level, and high-level waste. These categories are divided based on how radioactive the waste is. Low-level waste is waste that is exposed to low-level of radiation. These are generally common things that can be found not only in a nuclear facility, but also in laboratories. For example, gloves, laboratory coats, and laboratory equipment. Low-level waste contributes up to 90% of all nuclear waste, yet it can be disposed in near-surface repositories without having any consequences on the nearby environment (IAEA, 2018)

Intermediate-level waste has a higher level of radioactivity compared to low-level waste. This waste is usually found in the form of chemicals, fuel cladding, and some amounts of concretes surrounding the reactor core. About 7% of total wastes from nuclear power plants are accounted for as intermediate-level waste. This type of waste might have some heat deposited within. Should the heat deposit occur, it must be contained in a specific container that can cool down the waste's temperature. The container is specifically designed to maintain its integrity in any situation. The container has multi-barriers to prevent radioactive waste leakage. This type of technology has already been implemented in all nuclear power plants worldwide.

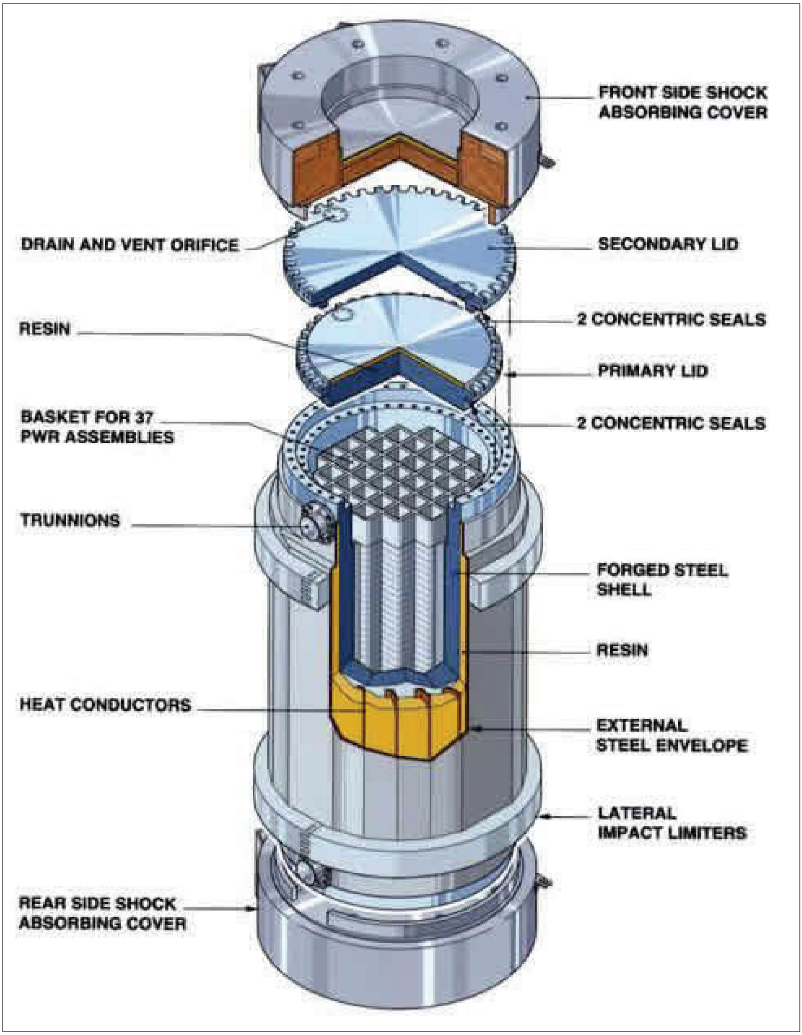


Source: Posiva (2014)

Figure 10.11 Concept of Multi-Barrier Disposal Concept

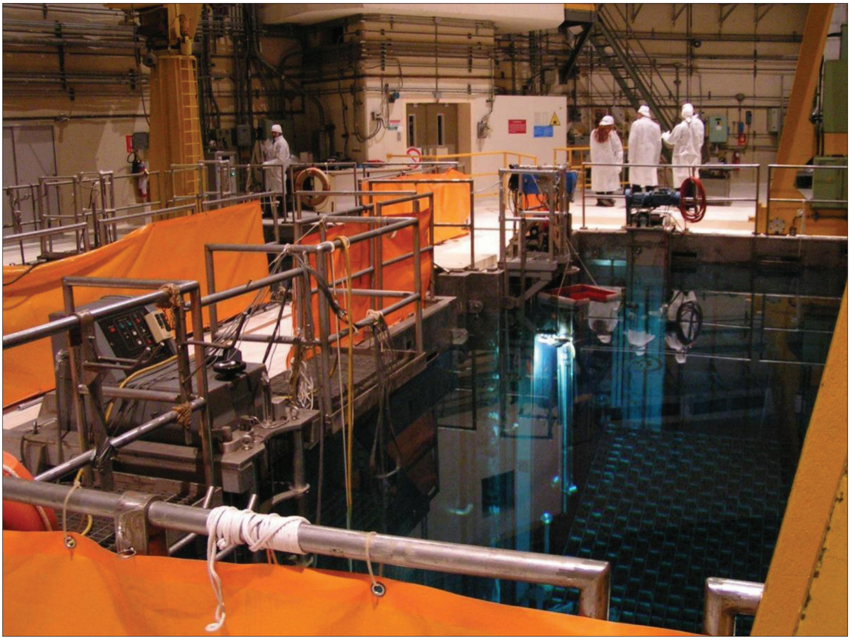
Lastly, high-level waste is the spent nuclear fuel. Spent nuclear fuel is the most radioactive material inside the core. It still generates heat due to delayed fission. Therefore, special treatments are necessary for spent nuclear fuel. After the spent nuclear fuel is taken out of the reactor core, it is placed in a special spent fuel storage pool for about five years. This pool serves two purposes, to cool the spent nuclear fuel and to reduce the number of radioactive materials through the decay process. This process reduced up to 95% of the radioactivity from short-lived isotopes. After five years, the spent nuclear fuel is compacted and placed in a special container. This method of containment has been designed to sustain any type of disturbance. The spent nuclear fuel remains in the container forever (IAEA, 2018).

Although the engineering side of handling nuclear waste is considered resolved, there many debates on where to permanently store high-level wastes. So far, the spent nuclear fuel that has been cooled and contained is placed within the nuclear power plant area. However, it is not considered a long-term solution for high-level nuclear wastes. A deep geological repository, a facility deep down the Earth to store all the containers of high-level nuclear wastes, is the ideal solution. However, debates on this topic are harsh. In the United States, a deep geological repository was proposed in Yucca Mountain, Nevada in early 2000, but it is still not approved (Bowen, 2021). A sign of hope



Source: Orano TN (n.d.)

Figure 10.12 TN24 Cask Produced by Orano TN (Formerly Areva TN)



Source: World Nuclear Association (n.d.)

Figure 10.13 Caorso Nuclear Power Plant Spent Fuel Pool

in this topic is the construction of deep geological repositories in Finland (Gil, 2020) and Sweden (Kombrink, 2022). Hopefully, this can start of progress in the deep geological repository.

2. Cost and Time of Construction

Non-technical problems, namely the costs and construction times of nuclear reactors, are also discouraging arguments used to reject nuclear technology. Nuclear power plants generally take up to ten years from construction to operation. It needs to be realized that the nuclear industry, like any other industry, is constantly adapting. It is worth noting that the construction of nuclear power plants is more effective and efficient than 20 years ago.

On average, nuclear power plants currently being built around the world can be completed and operational within 86 months from the previous 120 months (World Nuclear Association, 2021). It uses

Generation III+ technology that has been standardized and cost-effective. If a small modular type of nuclear power plant is used, a nuclear reactor can be built in as short as 2–3 years.

Regarding the cost, several types of financing schemes can also be used as examples if Indonesia wants to build nuclear power plants. Many countries have carried out these schemes, either in the form of government-to-government agreements, such as South Korea with the United Arab Emirates, and Pakistan with China, or in a government-to-business model, i.e., the British government with the Rolls Royce company. To push for innovations, policies such as incentives or acceleration programs to speed up the nuclear power plant construction process can also be a solution to boost the use of low-emissions energy around the world. Some examples of those policies can be adopted from countries like France, the UK, Ukraine, Japan, China, and the United States. Those countries have recently started the development of new nuclear power plants, as well as restarting units that were previously turned off. The United States supports developing nuclear power plants through a grant program for the development of prototypes of nuclear power plants with the latest technology (World Nuclear Association, 2020).

F. How Nuclear Energy Can Help Indonesia

After examining the ups and downs of nuclear energy around the world, this part will focus on whether Indonesia should give attention to nuclear energy and the role of nuclear energy in the future. Two major problems Indonesia faces are climate change and economic recovery post-COVID-19.

On the climate change part, the Indonesian government has targeted net-zero carbon emission in Indonesia in 2060, with the share of renewable and new energy (including nuclear energy) gradually increasing from 23% by 2025 to 100% in 2060 (Humas ESDM, 2021). This scenario would be possible if there is a good replacement for fossil energy that accounts for 60% of Indonesia's energy mix and becomes the baseload of energy in Indonesia. A just transition is necessary, including justice to consider all types of energy that have the potential to help Indonesia thrive. Until now, Indonesia's nuclear energy is still considered as the last energy option. With the continuous threat from climate change, that consideration is no longer relevant. Nuclear energy can be used to replace fossil fuels to become the baseload of energy in Indonesia. With consistently more than 80% capacity factor, nuclear energy is reliable. A reliable electricity grid is necessary for Indonesia, which still needs to industrialize and speed up development. Collaborations between nuclear energy and other renewable energy sources such as wind, solar, hydro, and geothermal are necessary for Indonesia to tackle climate change. Nuclear energy can be the baseload, and renewable energy can be the adjustable energy depending on necessity at a given time. This collaboration will result in more reliable electricity for homes and industries, which will ultimately boost Indonesia's productivity and economy.

Another way for nuclear energy to contribute to Indonesia's economy is through job creation for nuclear power plants. Post-COVID-19, Indonesia needs to economically bounce back to levels seen in previous years or even better. Nuclear energy can also create many new and sustainable jobs for the current and future generations. These jobs are not only highly skilled jobs like engineers and doctors, but also a lot of secondary jobs such as administrative jobs, affecting all levels of society. Since licenses for nuclear power plants are generally valid for forty years, these jobs will always be part of the neighborhoods.

Calls for support on nuclear energy also resonated in the COP26 in Scotland, UK. These calls came from many clean energy advocates around the world. Those energy advocates, including Indonesia, questioned nations' commitment to net-zero carbon emission. The nationally determined contribution (NDC), the official document that has been submitted by the Indonesian government explaining Indonesia's pathway to net-zero carbon emission, has mentioned the important role of nuclear energy. However, based on the pathway, nuclear will be part of the energy mix in Indonesia by 2049, which is too long considering Indonesia's pathway (Humas ESDM, 2021).

Indonesia can also look for examples in Asia. The center of excellence in nuclear energy has already been shifted to the East. Countries like China and South Korea have done or pledged to include more nuclear energy as part of their strategy to tackle climate change. The unresolved nuclear problems, especially cost overruns and delays in construction, have been solved by using design standardization.

However, a concrete strategy must exist to deploy nuclear energy in Indonesia. Based on the Integrated Nuclear Infrastructure Review (INIR) Mission from IAEA in 2009, Indonesia almost fulfills all 19 infrastructure points in Milestone 1 of the nuclear infrastructure necessary to build the first nuclear reactor. Three key areas were not fulfilled: the national position, management, and stakeholders involved. These areas can be completed by establishing the nuclear energy implementation organization (NEPIO) (Forsström et al., 2009). NEPIO is an organization tasked to prepare and organize all necessary infrastructures in a country to build its first nuclear power plants. NEPIO is also responsible for preparing the plan for future nuclear energy implementation. NEPIO will directly be responsible to the head of government of the country. NEPIO will coordinate with all the nuclear energy stakeholders to ensure that all the necessary policies and instruments are fully equipped to launch the nuclear energy program (IAEA, 2015).

NEPIO is the first step to ensuring a national position exists on nuclear energy. This step will have a crippling effect on inviting all the stakeholders to get involved in the national nuclear energy program. Local- and state-owned companies can see the opportunities to get involved in the project. Foreign investment will possibly come to Indonesia to build nuclear reactors. Three key issues that need to be considered in foreign investment are the financial scheme of the investment, the transfer of knowledge, and the national participation scheme. The financial scheme of the investment needs to consider Indonesia's economy and future prospects. The transfer of knowledge and national participation scheme is important to ensure that Indonesia's sovereignty over the technology is achieved and to limit dependency on foreign experts if things go wrong with the reactors.

NEPIO also can select technologies to be used as the first nuclear power plant in Indonesia. Many options are available around the world. Indonesia can take advantage of the development of current nuclear fleets. When the technology is chosen, Indonesia can start its nuclear energy program as soon as possible. Recent projections from the Ministry of Energy and Mineral Resources stated that the first nuclear power is targeted to be operational by 2045 (Humas ESDM, 2021). If all necessary infrastructures are met, including the establishment of NEPIO and all the milestones necessary to achieve it, the target can be pulled to earlier than 2045.

Arguably, a nuclear reactor is one of the world's most complicated types of machinery. Adding the known risk of radiation, the safety, and security level of nuclear power plants should have been one of the toughest and most over-engineered of all the technologies made by humankind. Consequently, this makes the overall cycle of nuclear power plants longer than any other technology. Those tough measures and over-engineering are being placed to ensure the robustness and the highest safety standard, especially during the first construction of a nuclear power plant known as First-of-a-Kind (FOAK). Just like any technology, construction will be the most expensive part. This is due to a lack of experience and the dependence on importing all the technologies. This was what happened to South Korea in the 1970s. At the time, South Korea constructed its first nuclear power plant with the help of the United States. Eventually, South Koreans gained experience building their nuclear power plants, and now they are exporting their nuclear power plants design (Lovering et al., 2016). Another reason that makes nuclear power plant construction slow is that there is no standardization of the design of the nuclear power plants. Every nuclear power plants are unique and designed specifically for the site where they are about to build. This makes the cost of construction rise. Some designs have accommodated the standardization of nuclear power plant design. It is expected that with this standardization, the high cost due to the site's uniqueness can be reduced significantly (Raetzke, 2010).

Nuclear energy is not the perfect technology, just like anything else. However, it is arguable that nuclear power plants can provide a significant societal impact on their existence. The secondary part of nuclear power plants is very common for any generating power station. This makes the job created by nuclear power plants not very unique to nuclear engineers. The existence of nuclear power plants—which are 40 years in minimum and can be extended up to 60 years—will create long-lasting, high-paying jobs at all levels. This will create a huge economic impact on the society surrounding nuclear power plants. Nuclear energy should be part of Indonesia's energy mix, and must be installed as soon as possible.

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