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URB-UY 3834W Nuclear Energy

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Behind the Scene – How Clean do you think nuclear energy is?

Nuclear energy, although negative public perception arises when people mention it, is commonly regarded as a source of clean energy since the nuclear power plants do not burn fuels, and do not generate greenhouse gasses (duke-energy.com). It is the process of generating electricity; however, that doesn't have any harmful impact on the environment and human well-being. Diving deeper into the whole nuclear energy industry, which is composed of ore mining to waste disposal, more factors should be taken into account when evaluating the "cleanliness" of nuclear energy. What are the factors that people ignore when saying nuclear energy is clean? Is nuclear energy harmless?

The nuclear reactor steam supply system and the associated turbine-generator equipment are not the only elements needed in the whole process of generating electricity using nuclear powerplants (MIT Report, 29). Other processes are also vital to the functionality of the power plant and the nuclear energy industry, which are known as the fuel cycle: ore mining, uranium enrichment, fuel fabrication, waste management, and decontamination and decommissioning of facilities (MIT Report, 29). The whole fuel cycle can be divided into "front end," which includes the step from uranium mining to fuel fabrication until the fuel is burnt in the reactor for two to three years, and the "back end," which can include temporary storage, reprocessing, recycling and disposal (iaea.org). There are two main fuel cycle types: the open (once-through) fuel cycle and the closed fuel cycle. The open fuel cycle indicates that all the spent fuel is treated as waste directly, while in the closed cycle, the spent fuel is reprocessed into other products, some of which can be reused or "recycled.". Various indicators (factors) are involved in the evaluation of the whole process; the primary two that the public is concerned with are the environmental indicators and social indicators. The environmental factors take greenhouse gas (GHG) emissions (mainly CO_2), atmospheric pollution, and water pollution (which include SO_x and NO_x emissions) into consideration. The social factors focus on worker's and general public's health impact and fatality rate (caused by significant accidents to small diseases).

Data have shown that the early stage of the US nuclear energy industry wasn't as "clean" as an expert said it would be. Mining is the first step of the whole fuel cycle, in the early stage of uranium mining in the 1950s, the miners were not well informed of the consequence of being exposed to mining dust and radioactive radon gases in the mines. A mortality study done by National Institute for Occupational Safety and Health (NIOSH) and the US Public Health Service (PHS) in the 1970s studied the uranium miners who worked underground more than one month before 1964 and completed a medical exam between 1950 and 1960. Major lung diseases such as lung cancer, pneumoconiosis, tuberculosis, and emphysema were experienced by the uranium miners and caused 66 (out of 757) deaths of non-white miners. These diseases, combined with injuries and other causes, led to a total of 1595 (out of 3283) deaths of white miners(cdc.gov). CDC indicated that they are more confident about the result of white miners. Due to the small sample size of non-white miners, the study pointed out that there existed missed illnesses connected to mining in this group. These data indicated the higher-than-normal mortality rate of uranium miners, which could be as high as 48.6% for white miners (including all causes) and 8.7% (not including injuries and other causes) for non-white miners, led to 41.1% mortality rate of all uranium miners in the 1950 and 1960 in the US. The mortality rate for all US citizens in the same period, however, was only 1.4% (statista.com). One may argue that it could be smoking that led these miners to lung diseases. According to the Biological Effects of Ionizing Radiation (BEIR), it is true that smoking and radon gas exposure result in a higher than additive, while less than multiplicative, risk of lung cancer. Study results also showed direct evidence of increased cancer incidence among never smokers, and a strong relationship existed between lung cancer and mining uranium (ncbi.gov).

The hidden story behind the higher-than-normal mortality rate of Uranium miners from 1950 to 1960 was revealed in an article that was published in the National Center for Biotechnology Information (NCBI) in 2019. According to the article, some US officials and scientists did advocate ventilation requirements in US mines as a proactive, preventive measure in the 1950s. The AEC (Atomic Energy Commission) and PHS (Public Health Service) staff revealed in an internal meeting in 1951 that "radon was present in levels that would cause cancer and that ventilation could abate the hazard.", however, the government resisted implementing ventilation and kept the knowledge from the public. It was only until 1970 when the standard for radon in mines was set, and it was not until 1990 was the Radiation Exposure Compensation Act passed and put into action. That is to say, federal regulation came almost 20 years after the need was proposed and when many miners were experiencing life-threatening diseases. The compensation for these miners came another 20 years after some of the miners already died (ncbi.gov). Due to the delayed spread of knowledge and government precautions, the mortality rate of uranium miners from 1950 to 1960 was 36% higher than that of the general US citizens. More hilariously, compensation for those miners' families came 40 years after the negative health impact of uranium mining was observed, which could be counted as one of the greatest scandals in nuclear energy history. Different from the past, things changed as technologies advanced and became mature in the nuclear energy industry. Ore miners today are well protected by laws and regulations.

Nuclear energy is one of the major large-scale energy sources today. The use of nuclear energy was almost 150 years later than the coal, but earlier than natural gas. The four primary sources of US electricity generation in 2018 are natural gas (35%), coal (27%), nuclear (19%), and renewables (17%), which include hydro, wind, solar, biomass, and geothermal energies (eia.gov). A thorough data analysis of death rate (measured as the number of deaths from air pollution and accidents per terawatt-hour (TWh) of energy production) of different kinds of energy sources was published in 2020. It shows that the energy source with the highest death rate is brown coal (32.72%), followed by coal (24.62%), oil (18.43%), renewables (4.713% with biomass account for 4.63%), gas (2.821%) and then nuclear (0.074% including major accidents by 2007). According to an article published in IAEA Bulletin, the risks behind the renewables mainly come from highly conventional tasks like mining the coal, iron, and other raw materials and fabricating them into steel, copper and glass. That is to say, the harm of wind energy doesn't mainly come from a windmill blade falling off and hitting a random person's head; it comes from the very basic tasks, including drilling and constructing. Sovacool et al. did another research in 2016, which didn't take occupational deaths into account and drew the conclusion that nuclear energy has only a death rate of 0.01%. It can be inferred from the data that, although public perception about nuclear energy is negative due to the horrifying impact of nuclear accidents, the total death rate, compared with other primary energy sources, is 442 times fewer than the 'dirtiest' forms of coal; 330 times fewer than coal; 250 times less than oil; and 38 times fewer than gas (ourworldindata.org). Not only does nuclear energy make a high contribution to electricity generation, but it also causes much less death than other sources of energy. Although nuclear energy is proved to be the safest and cleanest energy in researches, it doesn't mean it is completely clean or safe.

A unique attribute of nuclear energy is that it involves radioactive materials. The amount of radioactive waste generated can also reflect the cleanliness of nuclear energy. There are six types of waste, and each of them requires different treatment methods: high-level waste (HLW), intermediate-level waste (ILW), low-level waste (LLW), very low-level waste (VLLW), very short-lived waste (VSLW), and exempt waste (EW). The three major waste types are HLW, ILW and LLW. The two hazardous types are the HLW and ILW, which only accounts for just 3% of the waste volume, while 98% of the total radioactivity of produced waste. The HLW requires deep geological disposal, and the ILW needs intermediate depth disposal while LLW only requires for near-surface disposal. The rest of the waste types are not as potentially dangerous as HLW and ILW, and a large percentage could be disposed of. Due to the radioactivity, both HLW and ILW requires shielding, while HLW also requires cooling and significant attention since it contains both long-lived and short-lived components. It's true that if all of the radioactive wastes are being handled properly and no accidents happen to the stored fuel, the radioactive wastes cannot cause severe damage to the environment and human life. At the current stage, however, there are still many obstacles regarding the construction of the ideal disposal site of spent fuel and HLW such as siting problems, public engagement, technical and regulatory aspects. Moreover, a report from IAEA has revealed that 15% of current spent fuel are undecided for their disposition, while 29% are being reprocessed and 56%.

Besides the radioactive waste from spent fuel, another issue is the management of disused sealed radioactive sources, sealed sources of radioactive material that is not currently being utilized and will never be utilized again for the original intended purpose. The disused radioactive sources, according to IAEA, include a wide variety of radionuclides and activity levels, which can range from extremely dangerous to person to unlikely dangerous. Another crucial process in the fuel cycle is the transportation of fuel products: contaminated soils, residues from uranium mining to the spent fuel. If problems occur to the shipping casks or the seals, even worse, if an accident happens, the uncontrollable impact will have on all the people involved in these accidents. A report from the Nuclear Waste Project Office in Nevada estimated the environmental release of nuclides in the worst case during transportation of the spent fuel. If a cask inventory of 14 PWR spent fuel assemblies that each of them are 5 years out of the reactor was impacted, burst and oxidized, could result in "22 latent health effect" (about half cancers and half genetic disorders). According to Sandquist, the exposed urban and rural population would expect to experience about 470,000 and 730 cancer fatalities, respectively. While nuclear waste is harmless to the general public when no accidents happen, all the uncertainties above will inevitably increase the perceived threat level of the general public of nuclear waste. The extremely long decay time of some HLW also makes it challenging to draft a plan for future generations, how can one warn them of the radioactive waste under the land?

After nuclear energy became more widely used globally, researches have been done about the impacts of nuclear energy on current top concerns. Several comprehensive studies have been done to evaluate the environmental impact of the nuclear fuel cycle. A study published in 2016 by Sungyeol Choi, a researcher from Department of Nuclear Engineering in Ulsan National Institute of Science and Technology, Hyo On Nam and Won Il Ko, who are researchers from Korea Atomic Energy Research Institute, evaluates the environmental life cycle risk of nuclear waste recycling under three scenarios: 1. Open fuel cycle; 2. Mono-recycling of Pu in Pressurized Water Reactor (PWR); 3. Mono-recycling (or once recycling) of Pu in PWR and development of a fast reactor (FR) for recycling TRU (figure1). The study measures the CO2 emissions of each step using the direct consumption of energy, which means the use of energy to obtain the fuels to produce energy.

Ore mining consumes diesel fuel and electricity. The conversion of the required thermal energy mainly comes from natural gas combustion. Uranium enrichment includes two types of technology: the gaseous diffusion technology and the centrifuge technology, and this study takes the later one

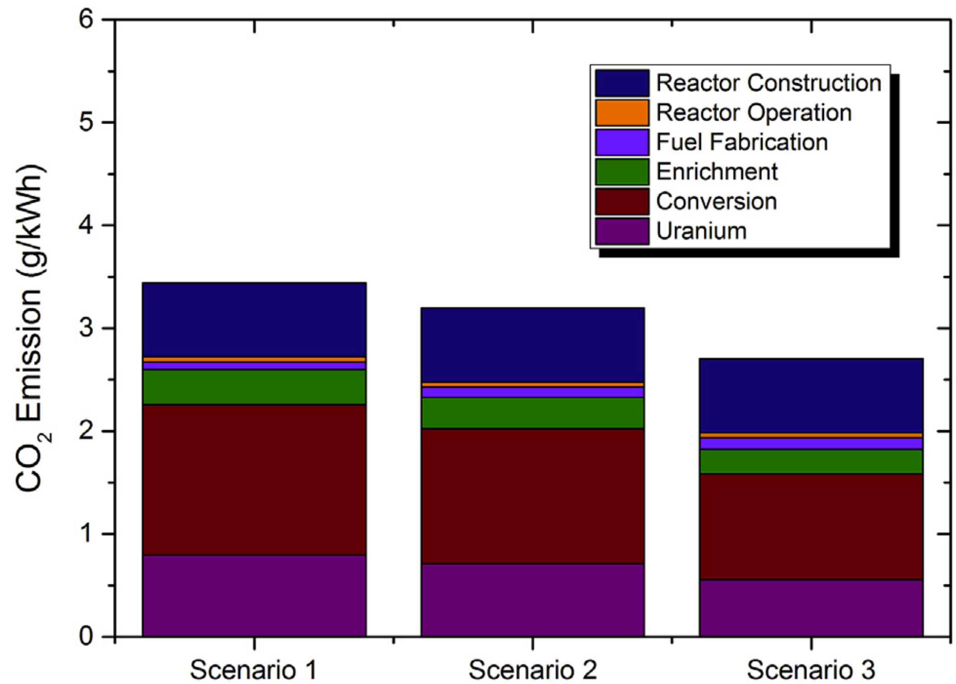

Figure 1: CO2 emission of different fuel cycle stages of nuclear energy

into account. Fabrication, reactor construction, and operation are also associated with direct energy consumption. The result shows that in all three scenarios, the process during which most of the CO2 is emitted is the conversion, which means the burning of the natural gas for thermal energy during the conversion step generates the most CO2 among all the steps. Followed by conversion are uranium mining and reactor construction, which undoubtedly require direct energy consumption.

Although some energy experts claim that nuclear power doesn't produce sulfur dioxide, nitrogen oxides, hydrogen chloride and ammonia, which are the primary pollutants responsible for the acidification of rain that causes the mortality of aquatic organisms, a study was done in 2011 by Laurence Stamford and Adisa Azapagic, faculties at School of Chemical Engineering and

Analytical Science in the University of Manchester, shows that the milling and mining process of

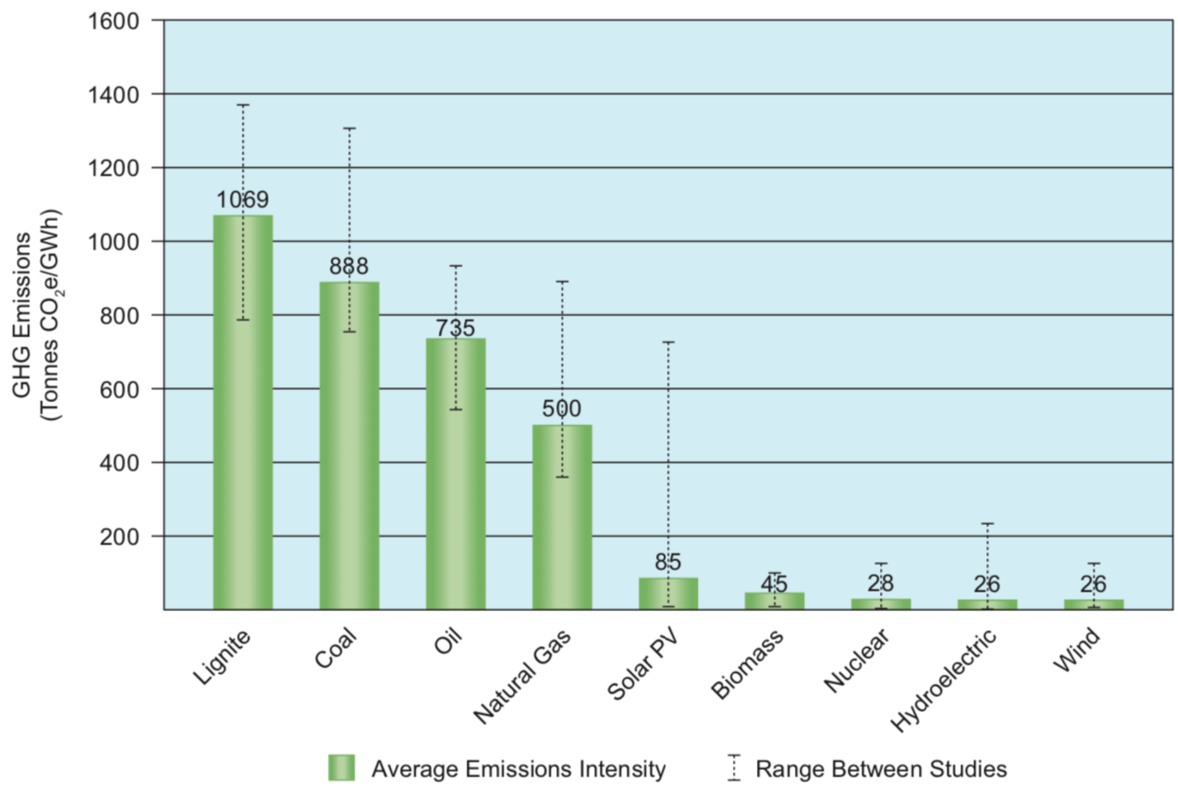

Figure 2: GHG lifecycle emissions among 9 electricity generation facilities

fuel cycle can lead to acidification. The drilling and mining processes also contribute to ozone layer depletion due to the emissions of chlorofluorocarbons; water eutrophication, which can deplete local oxygen and affect aquatic organisms; and photochemical smog. A comprehensive study done by the World Nuclear Association in 2011 compares lifecycle GHG emissions of dif-ferent electricity generation facilities. By looking at the lifecycle GHG emission intensity among different energy sources (figure 2), it's clear to see that the nuclear energy emits around 30 times less GHG than burning coal in producing electricity, but it still emits relatively slightly more GHG than hydroelectric and wind energy but less than solar PV!. While the amount of these pollutants may not affect the overall environment strongly, the fact remains that the nuclear fuel cycle is emitting these pollutants.

Another noticeable impact of nuclear electricity generation is thermal water pollution. According to research done by Brandon Clark in 2019, a chemical engineering Ph.D. student from Sandford University, the change of ambient water temperature due to the discharge of cooling water into a natural waster system is observed. The temperature of the cooling water is around 30ºC to 40ºC; if discharged into the aquatic ecosystem continuously, it will lead to a decrease of oxygen level, rise of PH value, and boost the decomposition of nutrients in the water, leading to the algal bloom. In animals, the acceleration of metabolism due to the rise of water temperature can cause malnutrition to cold-blooded aquatic creatures. Overall, these consequences change the biodiversity of the affected area. If a plant is located on a coast and discharges water into the ocean, coral bleaching is sometimes observed. The thermal water pollution of nuclear powerplants not only has an impact on water near the power plant but also has lasting effects on deepwater biogeochemical cycles. Clark argues that "the Danube River in Romania exhibits a 6km thermal plume that extends downstream, where temperature changes up to 1.5°C between plume and non-plume areas can still be measured." In the book Competition for Water Resources, published in 2017, indicates that the thermal pollution surrounding which the power plants are operated can also lead to reduced performance due to the hampered powerplant efficiency. The book reasons that 16-17 of 58 nuclear reactors in France are at risk of violating thermal pollution limits in 2010: the rivers were too hot and the water levels too low to guarantee adequate cooling of nuclear power plants. The discharge of used hot water is one drawback of some nuclear powerplants since much water is required to absorb the heat of the nuclear reactor. If the used water is discharged into the water body directly without any treatment, the gradual rising temperature of the water will not only harm the biogeochemical cycles within the affected area but will also put pressure on the performance of the nuclear reactors.

The nuclear energy industry is still facing many problems, from technical to ethical. Although from a critical point of view that nuclear energy is relatively cleaner than most types of energies, the uncertainty of chance of accidents and the hugely negative impact on people make it “unclean” and “harmful.” Although the fuel cycle does not generate a significant amount of GHG, because the fuel cycle of the nuclear energy generates pollution, and the reactor cooling water affects the aquatic systems, it would be improper to say that the nuclear energy is immaculate and does not generate greenhouse gases. I would say the word “clean” in the nuclear energy field is perceived clean, which means different aspects are taken into consideration for each individual. For a nuclear energy activist, he or she may focus on the point that the energy generation process is much cleaner than burning coal and fossil fuels. However, for a victim who survived a nuclear accident, he or she may strongly oppose the point that the energy is clean since the radiation posed a massive threat to the lives of people involved in the accident.

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