IEEE Transactions on Nuclear Science

Ethics of Nuclear Energy Investment in the Twenty-First Century: A Literature Review

Brett Hudson

I. INTRODUCTION

Nuclear energy is experiencing a renaissance with the looming climate crisis as the backdrop. Demand in existing sectors is growing while transportation, manufacturing, and utilities such as indoor heating become increasingly electrified. The need for electrical power is greater than ever, but it is becoming increasingly clear that current renewable sources are not sufficient to replace existing power plants and simultaneously meet rising demand. Nuclear power has accordingly taken center stage once more as a viable alternative to fossil fuel plants. It is a proven source of reliable, safe, and clean power, but nuclear power is not without ethical concerns. Public sentiment proves to be ambivalent at best and outright hostile at worst, which reflects in most public policy relating to nuclear today. The academic discourse on the subject reveals the complexity of implementing nuclear at scale, especially in the shadow of the disastrous accidents at Chernobyl and Fukushima. Given the current climate change crisis, is it ethical to expand investment in nuclear energy? This paper will investigate the discourse for several key ethical issues.

II. NUCLEAR ENERGY AND ENVIRONMENTAL RESPONSIBILITY

At the crux of nuclear energy debate is the current climate crisis. The effects of climate change need not be reiterated here, but the question of how to combat climate change proves to be as divisive a topic as the topic of climate change itself, even amongst those who deem it a credible threat. Among these debates stands the question of whether renewed investment in nuclear is ethically advisable. Friederich and Boudry's paper, "Ethics of Nuclear Energy in Times of Climate Change: Escaping the Collective Action Problem" [1] addresses this very subject in exceptional detail, building a detailed framework for making an ethical analysis of nuclear energy. In it, they argue that nuclear energy as a power source is not only an effective option for reducing reliance on fossil fuels but is an ethical imperative as a result. This is not a universally accepted idea, however. Wealer et al. [2] object to this notion in their paper, "High-Priced and Dangerous: Nuclear Power Is Not an Option for the Climate-Friendly Energy Mix," insisting that the mining detritus and waste products from nuclear energy present an unacceptable risk to the environment whilst also being economically unattractive. The authors write for the German Institute for Economic Research (DIW Berlin), which historically has been against nuclear energy. Recall the "Atomkraft? Nein, danke!" (translated: "Nuclear Power? No thanks!") movement popularized by the green party in Germany; this sentiment is very prevalent here. Nonetheless, the points made in their paper bear consideration.

Carbon emissions are a key consideration in the debate. Among clean sources of energy such as wind, geothermal, and hydroelectric, nuclear stands as a reliable and exceptionally low-emissions source. MacDonald et al.'s paper discussing the implementation of wind and solar in the US [3] posits an achievable 80% reduction in electrical power generation emissions in the US by 2050 (relative to 1990 figures) with the significant expansion of renewables. This is an encouraging figure, but it reveals a potential pitfall. The trouble is mitigating the final 20%, which Tong et al. [4] correctly point out is stymied by environmental conditions and consumer demand. Seasonal strains, unpredictable weather, and fluctuating energy demand renders many renewables unreliable and largely impractical as a primary power source without additional investment in significant energy storage—enough for several weeks' worth of national energy demand, the authors argue. Even in a nation as large as the US where renewables may be spread out to diminish the localized impact of weather, adequate harvest is not always achievable. Moreover, the cost of building energy storage disincentivizes broader investment, perpetuating the use of more consistent fossil fuel plants for baseload (baseline) power generation. Friederich and Boudry [1] explain that this risk of decarbonization failure is significantly lower with the use of “firm” baseload such as hydroelectric, geothermal, and nuclear than it is without, pointing out that nuclear has the most geographic flexibility of the three. This allows the expansion of renewables without risking expansion of fossil fuel plants.

All of this is to say nothing of other sources of carbon emissions, such as aviation, long-distance road transport and global shipping, and industrial production of cement, iron, and steel which cumulatively account for 12% of global emissions alone, according to Davis et al [5] in their 2018 analysis of zero-emissions energy systems. This is compared to load-following electricity (electricity that is produced according to demand), which accounts for an additional 12% of global emissions, while non-load following (electricity that is produced at a constant rate regardless of demand) accounts for another 26% [5]. The aforementioned 12% gap in energy consumption for industrial processes poses a major challenge, as the cost of converting to renewable sources of energy is much higher or requires a mode shift, if alternatives even exist. Moving long-distance shipping onto electric trains, using cleaner burning synthetic fuels, and using electric arc furnaces to produce steel are examples of cleaner solutions to these problems, but they all require immense amounts of base-load electricity generation that is far beyond the capability of current renewable infrastructure to achieve. This is where nuclear energy comes into its own. Not only is it able to provide consistent levels of base-load electrical power, but the heat energy from nuclear reactors can be harnessed directly for industrial uses or even utilities such as heated water, which Steady Energy in Finland aspires to accomplish [6].

III. WASTE DISPOSAL AND FUTURE GENERATIONS

Another important ethical consideration is the disposal of nuclear waste. Nuclear waste poses a unique risk to the public and to wildlife because of the risk of exposure to ionizing radiation. Long-term exposure to significant levels of ionizing radiation can cause proliferation of cancer-causing free radicals. High-level radioactive waste can also radiate extreme amounts of heat, which can impact the surrounding environment for decades. Exacerbating the issue is the danger of waste migration. Even buried nuclear waste could eventually leach into the surrounding environment and contaminate the ecosystem if it is not properly contained. This poses an important question: what should be done with the resulting waste from nuclear power plants to protect the public and the environment? Whatever technical solutions are used to resolve the issue, the safety of the public and environment today and tomorrow must be ensured.

Presently, there are several prevailing methods in the nuclear waste management discourse. One avenue for waste management is nuclear fuel reprocessing, wherein used nuclear fuel is taken to facilities which remove impurities from the fuel and refine the fuel to useful levels once more. This process is quite like the initial refinement process for uranium oxide ore. Rogner [7] describes this process in his 2010 paper, “Nuclear Power and Sustainable Development.” Rogner, whose work in the Planning and Economic Studies Section of the International Atomic Energy Agency, makes him especially knowledgeable in—if perhaps a bit partial to—civil nuclear power. He succinctly explains in his paper that reprocessing can reduce high-level nuclear waste production by 95%, recovering most of the usable fuel. This creates a circular, “closed” fuel cycle that reduces the need for mining additional uranium and eases the pressure for long-term storage. While the technical viability of such processes is certain, the extreme cost and difficulty of early reprocessing efforts stymie widespread implementation. Alley and Alley [8] remarked that the nation’s first commercial nuclear fuel reprocessing plant closed in 1972 after only six years of operation. Subsequent projects in Morris, Illinois and Barnwell, South Carolina failed in similar fashion: high cost and operational difficulties prevented reprocessing from gaining traction in the United States. As Friederich and Boudry noted in their paper, substitutes to fossil fuel plants must be cheaper to reduce the risk of decarbonization failure [1]. By their metric, this method of waste management is not sufficient to make nuclear viable. Furthermore, something still must be done with the remaining 5% of waste product and low-level waste byproducts leftover from reprocessing.

Present day consensus is that deep geological burial is the best method for waste disposal currently available, though there remain serious ethical concerns. Nuclear waste which is disposed deep within the earth's crust must be placed in rock which will be stable on geological timelines extending many thousands of years into the future—long enough for the most radioactive fission products of uranium and plutonium to break down into less harmful substances. This period is especially long in the case of technetium-99 and iodine-129—both fission products of Uranium—which have half-lives of 211,000 and 16 million years, respectively [8]. Wherever nuclear waste is buried, it must remain undisturbed until such time they are no longer a threat to the world above. This means designers of repositories must consider the effects of factors such as plate tectonics and water permeation. Until recently, these geological mechanics were poorly understood, presenting potential pitfalls for any geological repositories. Further complicating the matter is the risk of future generations inadvertently unearthing repositories and exposing the outside world to their contents.

The challenge of deep geological burial fell within the realm of expertise of Alley and Alley [8], whose work and the work of their contemporaries on the Yucca Mountain Nuclear Waste Repository over 30 years helped establish humanity's current understanding of how waste repositories will function on geological timescales. The project used sophisticated computer models developed over the course of almost 20 years during the project, involving inputs from hundreds of scientists involved in the project. To wit, Alley and Alley remarked that "Yucca Mountain became the most studied piece of real estate on the planet, involving *hundreds* of studies by federal, State, university, and industry scientists" and that Yucca Mountain NWR was "… the closest the United States has ever come to taking responsibility for its high-level nuclear waste" [8]. Friederich and Boudry [1] and Rogner [7] are equally optimistic about waste disposal, with the latter expressing particular interest in partitioning and transmutation processes. Rogner notes that incorporating P&T processes would reduce the longevity of long-lived isotopes considerably by breaking waste products down such that the resulting products have much shorter half-lives. This would make the radiological impact almost nil, Rogner argues, even in the event of accidental human intrusion into a repository [7].

IV. SAFETY VERSUS ECONOMIC INTERESTS

Considering the significant controls and safeguards required to operate nuclear reactors, another significant ethical consideration is the investment in safety mechanisms. Modern nuclear reactors are incredibly complex facilities are quite expensive to construct and maintain. Considering this, Wealer et al [2] warn that this creates considerable risk of compromise in reactor safety, pointing to Electricité de France (EdF)'s record of substandard reactor safety following more stringent regulation. Mounting costs to meet regulatory demand increased operating costs to the point that, at time of writing, the EdF had accumulated 40 billion euros in debt and was at risk of bankruptcy potentially necessitating nationalization. The risk of corners being cut in their facilities was all but certain.

The most disastrous example of substandard reactor safety is found in Fukushima Daiichi Nuclear Plant in Fukushima, Japan. Davis' [9] scathing report, "The Need for a New, Clear Option: An In-Depth Analysis of Nuclear Energy," exposed several design deficiencies in Fukushima Daiichi Nuclear Plant that resulted in the catastrophic meltdown of three of its reactors in 2011. The plant, a first-generation design which had been constructed in 1971, relied heavily on active safety mechanisms and was a coastal facility built in an area at high risk of earthquakes and tsunamis. Numerous safety mechanisms were inadequately implemented or were missing entirely (in many cases, in violation of established safety procedures), resulting in a cascade of catastrophic failures that ultimately caused three of the plant's six reactors to melt down. The accident resulted in explosions and loss of reactor containment which contaminated the surrounding region, necessitating the evacuation of an area spanning almost 12,000 square miles. The accident exposed tens of thousands to excess radiation and cost $58 billion for the cleanup alone, not accounting for the estimated $500 billion in economic losses due to the incident. Accusations of poor disaster planning and negligence abounded. Davis asserts with no small amount of conviction that the findings regarding the disaster at Fukushima are proof that nuclear energy is not a viable option to power the twenty-first century and beyond [9].

The incident at Fukushima revealed another glaring problem: very little insurance is in place to mitigate the effects of a nuclear disaster. Wealer et al. [2] note that the Price-Anderson Law limits the liability of the domestic nuclear industry in the event of an accident to only $9.1 billion. The authors assert potential costs upwards of $560 billion, in line with Japan's experience in Fukushima and far more than insured liability. This law, which is paralleled in most other countries using nuclear power plants, places sole responsibility of accidents in the hands of operators, excluding suppliers and construction outfits. The buck stops at the operator, making the potential liability of running a nuclear plant extremely unattractive for utilities companies, Wealer et al. argue [2].

Nonetheless, significant advances in reactor technology and the advent of small modular reactors (SMRs) present drastic increases in inherent reactor safety and potential for reduced costs. Friederich and Boudry [1] conclude in their analysis that nuclear energy is not only comparable to modern renewables regarding safety but has the potential to be competitive with them. This sentiment is paralleled by Rogner, who notes that the incident incited the creation of the World Association of Nuclear Operators and the IAEA's International Nuclear Safety advisory group [7]. These organizations both work to establish best practices and strengthen the safety culture of reactor operators around the globe, while also providing a reporting system and forum to ensure existing nuclear plants are as safe as possible. Continual innovation in reactor design and operation, coinciding with increased investment and emphasis on safety culture, Rogner argues, will allow the ethical implementation of nuclear power [7].

V. NUCLEAR PROLIFERATION AND GLOBAL SECURITY

Another perennial concern associated with investment in nuclear energy is the potential for weapons proliferation, especially in or near more belligerent countries. Wealer et al. [2] correctly point out in their paper that the driving force in nuclear programs has historically been military applications such as nuclear bombs or submarines. This was true of the US and the Soviet Union in the 1950s and it was also true for the United Kingdom, France, China, and North Korea. The trouble is that most of the infrastructure used for peaceful commercial applications of nuclear can be retooled for weapons production with little to no modification, Rogner [7] admits. Perhaps even more discouragingly, Naidu and Moorthy's study [10] of the commercial nuclear in Vietnam points to the potential for stolen fuel and production byproducts to be used in belligerent countries' nuclear programs or for terrorism. Despite their belief that nuclear energy would become an integral part of Vietnam's infrastructure, they warned of the need to secure every part of the nuclear power plant production process against weapons proliferation. The risk, they deemed, was far too great to ignore.

Vietnam is not alone in pursuing civil nuclear programs, and the need for global oversight is clear. India, Pakistan, Israel, North Korea, and other developing countries have all undertaken their own civil nuclear programs, and each of them now possesses nuclear weapons, Mez [11] points out. This fact demonstrates the prescience of President Eisenhower's "Atoms for Peace" initiative which underpins today's regulation of nuclear programs around the world. The International Atomic Energy Agency (IAEA) and the Treaty of the Non-Proliferation of Nuclear Weapons (NPT) were born from this initiative. Both the IAEA and the NPT established a framework for assisting countries in the development of peaceful applications of nuclear energy while also monitoring for and preventing weapons proliferation. In return for assistance in domestic nuclear programs, signatories of the NPT are subject to legally obligated inspections of nuclear facilities and are prevented from pursuing domestic weapons programs. Nonetheless, Wealer et al. [2] point out examples of countries which developed their own nuclear programs independently of the NPT—notably India, Israel, and Pakistan—and express doubt that the "Atoms for Peace" initiative was entirely successful. Rogner [7] is optimistic, however. He points out the IAEA's discovery that more countries have been verified to have given up their nuclear programs than those who have nuclear weapons. Moreover, Roger notes efforts to place fuel reprocessing, enrichment, and disposal under multinational control, which are closing an important gap the NPT failed to address. By doing this, countries wishing to implement nuclear power can do so without the need for building domestic fuel enrichment and reprocessing plants. These international fuel banks allow NPT signatories to benefit from access to nuclear power plants without pursuing domestic fuel enrichment programs, thus reducing adoption cost and limiting the risk of nuclear weapons proliferation. By providing other countries with access to technology and fissionable material, countries like the US and France possess a "bargaining chip" which can be used to control nuclear weapons proliferation through the NPT. Crucially, the existence of peaceful states with strong civilian nuclear industries enables the continued ethical and peaceful implementation of nuclear power, according to Friederich and Boudry [1]. They assert in their paper that, so long as NPT signatories provide more competitive advantages than countries such as Russia and China (which now provide their own nuclear assistance programs), nuclear power can ethically be developed in other countries. Further development of instruments meant to combat the threat of terrorist activity such as UN resolutions 1373 and 1540 as well as policies such as the Physical Protection of Nuclear Material and the International Convention for the Suppression of Acts of Nuclear Terrorism enable the IAEA to implement effective countermeasures in its 151 member states. According to Rogner [7], these policies ensure the safeguarding of radiological sources and nuclear facilities from theft and sabotage.

VI. PUBLIC CONSENT AND DECISION MAKING

The history of nuclear waste disposal in the United States is a troubled tale of unchecked enthusiasm and poor public relations. William and Rosemarie Alley's book *Too Hot to Touch: The Problem of High Level Nuclear Waste* [8] chronicles this history in rich detail: beginning in the mid-20th century, the United States Atomic Energy Commission began by selecting sites and later informing the public of their intent to establish repositories in those places. The string of incidents surrounding the US nuclear weapons program in places such as Hanford remained fresh in the public mind, and the lack of transparency around the AEC's operations only served to erode public trust even further. Municipalities and entire states would vehemently refuse—and legislate against—repositories within their borders. The approach of announcing sites and then defending their decisions from public outcry (often derided as "decide, announce, defend") became such a divisive issue that when Nevada was eventually chosen as the site for the Yucca Mountain Repository as part of the Omnibus Budget Reconciliation Act of 1987, the bill came to be known as the "Screw Nevada Bill" to Nevadans and sympathetic parties. Clearly, the public felt neglected in the waste disposal discourse. The issue of ethical implementation of waste disposal in United States remained unaddressed throughout the 20th century, stymieing further investment in nuclear energy. This contrasts with programs in Sweden and Finland, where the public is not only deeply involved with the decision process, but is reliably informed of every consideration in the process. Kari et al. [12] note that partnership with volunteer communities has enabled considerable progress in the waste disposal projects, to the point that communities in each country compete for securing disposal site projects. Finland's success in establishing the world's first deep geological repository for Nuclear Waste in Olkiluoto, Finland demonstrates the effectiveness of community engagement and transparency [13].

VII. CONCLUSION

By now, the current points of contention in the nuclear energy debate should be apparent to the reader. Nuclear energy presents both significant benefits and significant risks, and the current discourse reflects differing opinions on nearly every facet. The growing demand for power requires investment in renewable alternatives to fossil fuels which are currently lacking both in reliability and scale, leaving nuclear as one of the few options for low-carbon base-load power. This makes it an attractive source, but concerns about waste management, operational safety and costs, weapons proliferation and security, and public consent present significant ethical challenges which must be carefully navigated if nuclear power plants are to become a fixture of future power generation. Despite the terrible accidents at Chernobyl and Fukushima, there has been a growing consensus in recent years that nuclear energy is necessary—if perhaps a necessary evil—to combat climate change. However, important questions remain to be definitively answered. Exactly how effective will current-generation reactors (particularly SMRs) be in replacing fossil fuel plants? Can existing coal and natural gas plants be economically and safely retrofitted to use nuclear fission? What systems can be implemented to mitigate the damaging effects of an accident? Will there be a significant international effort to address waste disposal? Is it even possible to scale nuclear power in time to make a significant mitigating impact on climate change? These are all questions which past and present research has addressed to some degree but has not satisfactorily answered. Continued research and real-world testing will be necessary to answer these questions, but considering the current climate crisis, one thing is certain: it would be unethical to not at least try.

REFERENCES

[1] S. Friederich and M. Boudry, “Ethics of Nuclear Energy in Times of Climate Change: Escaping the Collective Action Problem,” *Philos. Technol.,* vol. 35, no. 2, pp. 1-27, June 2022. doi: 10.1007/s13347-022-00527-1.

[2] B. Wealer, S. Bauer, L. Göke, C. V. Hirschhausen, and C. Kemfert, “High-Priced and Dangerous: Nuclear Power Is Not an Option for the Climate-Friendly Energy Mix,” *DIW Weekly Report,* vol. 9, p. S. 235243, 2019. doi: 10.18723/DIW_DWR:2019-30-1.

[3] A. E. MacDonald, C. T. M. Clack, A. Alexander, A. Dunbar, J. Wilczak, and Y. Xie, “Future cost-competitive electricity systems and their impact on US CO2 emissions,” *Nature Clim Change,* vol. 6, no. 5, pp. 526–531, May 2016, doi: 10.1038/nclimate2921.

[4] D. Tong et al., “Geophysical constraints on the reliability of solar and wind power worldwide,” *Nat Commun,* vol. 12, no. 6146, Oct. 2021, doi: 10.1038/s41467-021-26355-z.

[5] S. J. Davis et al., “Net-zero emissions energy systems,” *Science,* vol. 360, no. 6396, p. eaas9793, Jun. 2018, doi: 10.1126/science.aas9793.

[6] Steady Energy, “Steady Energy | Solution.” [Online]. Available: https://www.steadyenergy.com/solution. [Accessed: Feb. 20, 2025].

[7] Rogner, H.-Holger. “NUCLEAR POWER AND SUSTAINABLE DEVELOPMENT.” *Journal of International Affairs*, vol. 64, no. 1, pp. 137–160, 2010. Available: http://www.jstor.org/stable/24385190.

[8] W. Alley and R. Alley, *Too Hot to Touch: The Problem of High-Level Nuclear Waste.* Cambridge University Press, 2013.

[9] Z. Davis, “The need for a new, clear option: An in-depth analysis of nuclear energy,” *Consilience: The Journal of Sustainable Development,* vol. 13, no. 1, pp. 217–246, 2015. [Online]. Available: http://www.jstor.org/stable/10.2307/26427280.

[10] L. Naidu and R. Moorthy, “Ethics and risks in sustainable civilian nuclear energy development in Vietnam,” *Ethics. Sci. Environ. Polit.,* vol. 22, pp. 1–12, Feb. 2022, doi: 10.3354/esep00198.

[11] L. Mez, “Nuclear energy–any solution for sustainability and climate protection?,” *Energy Policy*, vol. 48, pp. 56–63, Sep. 2012. doi: 10.1016/j.enpol.2012.04.047.

[12] M. Kari, M. Kojo, and M. Lehtonen. “Role of the Host Communities in Final Disposal of Spent Nuclear Fuel in Finland and Sweden.” *Progress in Nuclear Energy,* vol 133, no. 103632, March 2021. doi: 10.1016/j.pnucene.2021.103632.

[13] L. Gil, “Finland’s spent fuel repository a ‘game changer’ for the Nuclear Industry, director general Grossi says,” *IAEA,* Nov. 26, 2020. [Online]. Available: https://www.iaea.org/newscenter/news/finlands-spent-fuel-repository-a-game-changer-for-the-nuclear-industry-director-general-grossi-says. [Accessed Mar. 3, 2025].