### Nuclear---1AC

#### The advantage is NUCLEAR:

#### Both fossil fuels and traditional renewable energy are unsustainable because of intermittency, mining, and environmental externalities. Only modernized nuclear power solves.

Rehm ’23 [Thomas; March 2023; Ph.D. Ph.D. in chemical engineering from Northwestern University; Current Opinion in Chemical Engineering, “Advanced Nuclear Energy: The Safest and Most Renewable Clean Energy,” vol. 39]

Although legacy nuclear energy has been the safest form of electricity generation, it has been demonized as unsafe since the 1960s. The three well-known nuclear accidents, Three Mile Island, Chernobyl, and Fukushima, were legacy nuclear designs. Even with the best safety record of all types of electricity generation, it is time to move away from legacy nuclear to reap the benefits of a truly renewable source of safe clean energy, advanced nuclear. Solar and wind cannot hold a renewable candle to the vast renewable potential of advanced nuclear energy. The transition to carbon-neutral energy can best be made with advanced nuclear, in safety, waste minimization, true renewability for thousands of years, process heat for manufacturing, and a viable means of replacing our chemical manufacturing dependence on fossil fuels. Some of my colleagues tell me, “There are few opportunities for chemical engineers in nuclear”. I disagree. Opportunities include design and operation of high-temperature (550–750 °C) plants involving molten salts, liquid metal, and helium; application of this high-temperature capability for industrial process heating; recycling legacy nuclear ‘waste’ to provide fuel for advanced reactors; integration of the hydrogen economy into nuclear plant design and operation; improvement in moving pebble-bed advanced reactor technology; mining improvements for uranium and thorium, including mining uranium from seawater; molten salt storage systems for improving load following functionality and to provide process heat functionality; resolving corrosion challenges in molten salt reactors; and retrofitting existing oil-and-gas-based refineries to operate as nuclear biorefineries.

Introduction

Renewables are considered by many to be the solution to global warming. Yes, they can contribute. However, without advanced nuclear energy, we will not solve global warming.

Nuclear energy is much safer than solar and wind renewables and has a lower life cycle carbon footprint. The disadvantage of nuclear is its long-lived nuclear waste. To decay to a nominal background level, legacy spent-nuclear fuel requires tens of thousands of years. This paper argues for advanced nuclear, whose much smaller amount of nuclear waste (about 1% of legacy) will decay to background levels in about 400 years [1].

It is important to note that legacy nuclear waste has minimal risk associated with it [2]:

* There is not much of it. All the nuclear fuel waste generated thus far, on the planet, could be stacked onto one football field to a height of about 30 feet.
* It is a solid, in small pellets contained in metal rods, stored inside ultrastrong 50-ton containers.

With advanced nuclear, this minimal risk is reduced further (Table 1).

Table 1. Vital statistics for renewables (solar/wind) versus nuclear (legacy/advanced).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Renewables** | | **Nuclear energy** | |
|  | **Solar** | **Wind** | **Legacy** | **Advanced** |
| **Life cycle carbon emissions, g-CO2-eq/kWh** | 41–48 | 14 | 12 | No data yet but probably less than legacy nuclear |
| **Industry fatalities per TWe-year** | 0.245 | 1.78–8.5 | < 0.01 | No data yet but probably less than legacy nuclear |
| **Capacity factor (fraction of nameplate power capacity actually produced)** | 10–25% | 30–50% | 90% | No data yet but probably better than legacy nuclear |
| **Waste** | “We risk creating new environmental and economic burdens in the future,” Peter Wright, EPA, 2020 | | Safely stored, no environmental or economic burdens | Waste will be less than 1% of legacy nuclear and about 1% as long-lived as legacy nuclear |
| **Planetary mineral-proven reserves** | Less than 200 years | | About 90 years | Several thousands of years |

**<<<REFERENCES OMITTED>>>**

Solar and wind are not really renewable on a 200-year timescale. Neither is legacy nuclear via current land-based uranium mining. Arguments have also been made that legacy nuclear is not safe.

Advanced nuclear technology is far safer than legacy nuclear. The current widespread fear of nuclear, which is based on legacy nuclear accidents, is unwarranted [11]:

* There were no deaths and no negative health effects from the trivial radiation release from the Three Mile Island accident.
* At Fukushima, one power plant worker involved in recovery died. There were no deaths or incidents of medical harm to any member of the public from radiation exposure. Four years later, thorough medical examinations were given to evacuees from the designated exclusion zone and many concerned residents from outside the exclusion zone. Nearly a third of a million children who were age 18 or less at the time of the accident were screened for thyroid issues. The rate of thyroid anomalies in Fukushima children was less than in other children in Japan.
* Chernobyl was a poorly designed light water boiling reactor susceptible to thermal runaways. Reported fatalities ranged from 50 at Chernobyl to several thousand offsite [12]. Following the Chernobyl accident, other Russian RBMK designs were modified to improve safety. Some RBMK plants have been shut down but not all. No nuclear plants have been built with this design outside of the Russian federation [13].

Advanced nuclear technology

There is only one naturally occurring fissile isotope, Uranium-235 (U235). In a nuclear reactor, U235 atoms split and produce heat.

There are two naturally occurring fertile isotopes, Uranium-238 (U238) and Thorium-232 (Th232). They will not split until they first transmute to fissile isotopes via neutron capture, which does not occur to a significant extent in a legacy reactor. In an advanced reactor, U238 and Th232 transmute to fissile isotopes Pu239 and U233, which then split to produce heat.

As with any new technology, there are challenges associated with Th232, including the production of a small amount of U232 contaminant in the transmutation of Th232. The decay of U232 produces very penetrating gamma rays. These gamma rays are hard to shield, requiring more expensive spent fuel handling and/or reprocessing [14], [15].

Key distinctions between legacy technology and advanced technology:

1. A legacy reactor is designed at about 2000 psig. An advanced reactor is designed at near-ambient pressure as the normal boiling points of heat-transfer media exceed 1200 °C. A huge gain in safety.
2. A legacy reactor operates at about 290 °C. An advanced reactor operates at 550–750 °C, creating a much larger temperature difference with the environment, which allows more options for passive decay–heat removal systems. A huge gain in safety.
3. Advanced reactors operating at 550–750 °C allow for industrial process heating [16], [17].
4. Most legacy fuel is U238, which becomes nuclear ‘waste’ in legacy reactors. In advanced reactors, U238 transmutes to Pu239 that ‘burns’ along with U235, resulting in a waste volume of less than 1% of that from legacy reactors. A huge gain in safety.
5. ‘Waste’ from legacy reactors requires tens of thousands of years to decay. Waste from advanced reactors requires about 400 years. A huge gain in safety.
6. Advanced reactors operate with a negative temperature coefficient. They are not susceptible to thermal runaway such as what happened at Chernobyl. Advanced reactors passively shut down if the reactor temperature gets too high. A huge gain in safety.

Are solar and wind renewable?

Solar and wind have renewability problems due to planetary mineral resource limits [8], the social impact of mining those resources [18], and mineral recycling challenges at end of equipment useful life [19]

We are disingenuous if we do not look at least 200 years into the future. Psychologists say that a human is sincerely concerned with his/her children, grandchildren, and great-grandchildren. Beyond those three generations, most humans do not care what happens to distant progeny. I may have great-grandchildren born as far out as my 100th birthday in 2050, and they might live 100 years. Our action plan must be at least 200 years out.

Owing to the variability of solar and wind, 100% ‘renewable’ plans depend on energy storage. Battery storage is the hope. Lucas Bergkamp, Editor of Road to EU Climate Neutrality by 2050, does not hold that view. “You cannot, in the near future at least, have an energy storage system that will allow you to power a whole country through batteries,” he told EURACTIV, saying another energy source, such as nuclear or fossil fuels, will be needed to provide baseload electricity [20].

Solar is challenged in far northern latitudes. Earth’s ‘center of population’ latitude is 25.92 degrees north. At that latitude, solar irradiation on the winter solstice is reduced by 35%. One-fourth of Earth’s population lives above 36.37 degrees north latitude, corresponding to a reduction of solar irradiation by 50% on the winter solstice [21], [22]. Sunlit hours also drop with increasing latitude. As the earth heats up, the population will undoubtedly shift farther north, exacerbating the solar energy ‘solution’. Fewer people will live in areas that are good for solar generation of electricity. A nuclear plant can operate anywhere.

But is not nuclear too costly? Nuclear is a better choice than solar and wind on both a land requirement basis and a consumer cost basis [20].

Overly optimistic views of solar and wind, coupled with an unfounded fear of nuclear, are leading many to shutter legacy nuclear plants. The United States currently has 296 GW of nuclear energy capacity. If we do not keep these plants open through license renewals, we will lose 50 GW of nuclear capacity by 2030, 150 GW by 2040, and nearly all of it by 2050 [23]. We must not shut down legacy nuclear plants.

Advanced nuclear energy is truly renewable

Although proven uranium reserves only give legacy technology 90 more years, advanced technology is good for thousands of years. Uranium ore contains 100 times more U238 than U235. Advanced nuclear can theoretically provide 9000 years of renewable energy from those reserves at today’s energy demand, and that is not taking into account the legacy nuclear ‘waste’ now safely stored, which can become fuel for advanced reactors.

Advanced technology can be commercially viable in the United States by the 2030s. In 2001, nine nations formed the Generation IV2 International Forum (GIF) [24] to develop sustainable, economic, safe, reliable, proliferation-resistant, and physically protected nuclear reactors. Founding GIF countries include Argentina, Brazil, Canada, France, Japan, the Republic of Korea, the Republic of South Africa, the United Kingdom, and the United States. Subsequently, Switzerland (2002), Euratom (2003), the People’s Republic of China (2006), the Russian Federation (2006), and Australia (2016) became members.

There are now two operational advanced reactors, one in Russia and one in China. The Russian BN-800 reactor, a sodium-cooled fast breeder reactor, in Zarechny, was connected to the grid in December 2015 [25]. China’s high-temperature pebble-bed modular reactor HTR-PM was connected to the grid in December 2021 [26]. The United States is lagging, but work is underway to catch up. US Department of Energy (DOE) made two awards to build advanced reactors by 2027 [27], one to TerraPower [28] on Natrium technology, and the other to X-energy [29].

TerraPower is working to commercialize three technologies, the molten chloride reactor, the Traveling Wave Reactor, and the Natrium reactor that is a sodium fast reactor incorporating the design features of the Traveling Wave Reactor. Natrium is its premier technology, which will be demonstrated at the Naughton coal-fired power plant in Kemmerer, Wyoming, which is retiring in 2025.

X-energy has a moving pebble-bed high-temperature gas reactor (HTGR) design that will have 220 000 graphite pebbles with TRIstructural-ISOtropic (TRISO) particle fuel. They expect a 60-year operational life [30].

How about thorium? Per the Thorium Energy Alliance [31]:

* Because liquid fluoride thorium reactors (LFTRs) burn virtually all of their fuel, 83% of the waste products are safe within ten years and the remaining 17% become safe after 300 years.
* LFTRs can be used to burn legacy nuclear ‘waste’.
* Thorium is the 36th most plentiful element in the earth’s crust. It is four times as common as uranium.
* LFTRs have no refueling outages. They are continually refueled and continually remove waste product.
* LFTRs can be factory-produced, allowing for lower costs and shorter commissioning timetables.

Kirk Sorensen, Founder of Flibe Energy, details the many LFTR benefits in a short video, those benefits being safety, a 100-fold decrease in waste generated, and immense quantities of thorium on the planet [1].

China is a leader in thorium. Experts say that China could be the first to commercialize thorium technology. An experimental thorium reactor in Wuwei could result in an operational 300 + MW thorium reactor by 2030 [32].

Centrus Energy Corporation and Clean Core Thorium Energy are working on an advanced nuclear fuel that combines thorium with high-assay, low-enriched uranium (HALEU). The new fuel is called Advanced Nuclear Energy for Enriched Life (ANEEL). ANEEL has less than 20% U238, compared with more than 94% in LWR fuel. HALEU is itself enriched to between 5% and 20% U235 [33].

In May 2022, the Norway-based marine group Ulstein announced a concept design for cruise ships using a thorium Molten Salt Reactor [34].

There are significant advantages of molten salt reactors and hot-salt storage. A molten salt reactor has its nuclear fuel dissolved in fluoride salt or chloride salt. The Terrapower/Southern fast reactor is molten chloride. The Moltex design is a molten chloride fast reactor. Kairos Power has a fluoride salt reactor design. Flibe’s salt is Li2BeF4 salt that has a melting point of 459 °C and a normal boiling point of 1430 °C [35]. Molten salt allows a design with a secondary hot-salt loop with storage and a separate ‘power block’ cycle to produce power-on-demand from the stored hot salt, allowing load following functionality as delivery of heat is controlled by a hot-salt pump. As the power block is not coupled to the reactor, it can be built to non-nuclear standards. The salt in the loop is a nitrate salt in common use in concentrated solar power plants [36].

Although molten salt reactors hold much promise, there are challenges, the most significant being the risk of corrosion in reactor structural materials from high-temperature molten salt. A considerable amount of development work remains to be done on salt redox potential measurement and control tools in order to limit the corrosion rate [37].

Advantages of small modular reactors

Small modular reactors (SMRs) are nuclear plants of 300 MWe or less. SMRs have several advantages over large nuclear plants.

1. Onsite construction of large nuclear plants can take many years and have associated cost overruns. SMRs will be factory-built and moved to the site by truck, railcar, or barge. SMRs employ economies of mass production rather than economies of scale.
2. Advanced technology SMRs are now operational. Two Russian SMRs (Pressurized Water Reactor, type KLT-40S) have been in operation in Port Pevek, Russia, since December of 2019 [25], [38], and two Chinese helium-cooled pebble-bed reactors (HTR-PM) were connected to the grid in December 2021 [26]. Advanced technology SMRs could be deployed in very large numbers in the next decade, in time to meet 2050 net-zero goals.
3. The emergency planning zone around a large legacy plant is typically 10 miles. The DOE ‘strongly supports’ an NRC proposal to apply risk-based emergency preparedness requirements for SMRs, which will significantly reduce the size of this zone [39].

Gen III+ water-moderated/cooled SMRs have a design advantage over legacy technology. Even though the reactor is designed at 2000 psig, its small size allows for ease of containment manufacture compared with a large legacy reactor. For example, each 3 m-wide NuScale reactor nestles into its own 4.6 m-wide steel containment vessel [40].

Argentina, China, and the Russian Federation are on course to begin commissioning SMRs. North America will likely be the next to deploy an SMR, as the United States is looking at 2027 for the start of operations. Canada also expects to start-up demonstration reactors in 2027 [41].

The HTGR is a moving ‘pebble bed’ SMR design with an exit temperature of 750 °C or higher, ideal for providing industrial process heat. The Japanese HTGR Development Program achieved 50 days of continuous 950 °C operation in a test reactor in 2010 [42].

A major DOE/Industrial program is underway to commercialize HTGRs for industrial applications, being led by Dow Chemical [17]. Each pebble is TRISO coated and is about the size of a tennis ball. Each pebble is its own nuclear reactor, the outer shell being its containment vessel. Each reactor is cooled down by passive natural circulation, usually a gas such as helium, making it impossible for an accident such as Fukushima to occur. TRISO fuels are fabricated by BWX Technologies Nuclear Operations Group (Lynchburg, Virginia) [43].

In 2017, Neutron Bytes reported that China is an HTGR leader. China is actively promoting its HTGR technology in Saudi Arabia, South Africa, the United Arab Emirates, and Indonesia [44]. China is building an HTGR demonstration plant that will have two reactor modules. The objective is a full-scale power plant with eighteen 210 MWe units. In March 2020, China announced that the reactors, steam generator, and hot gas ductwork of the demonstration plant were connected [45].

Penultimate Power in the United Kingdom has partnered with the Japanese Atomic Energy Agency to develop plans for HTGR technology to be operational in Britain by 2029 [46].

Establishment of safety regulations associated with SMRs are not yet resolved. However, the Nuclear Regulatory Commission is working to resolve policy questions such as SMR siting, offsite emergency planning, and security and safeguards [47], [48], which are strongly supported by the U.S. Department of Energy [39].

Uranium and thorium reserves

At current global nuclear capacities, we have about 90 years of proven uranium reserves. There also is uranium in our oceans at a concentration of 3.3 micrograms per liter, which could provide tens of thousands of years of uranium [49]. Scientists from Oak Ridge National Laboratory have demonstrated a material that can adsorb 6 g of uranium for every kilogram of adsorbent material [50]. Rainfall runoff from land masses will renewably replenish any uranium we remove from seawater.

There are about 6.4 million tonnes of thorium reserves. India leads with 846 000 tonnes, and has made utilization of thorium a major goal in its nuclear power program. The United States has the 3rd largest reserves at 595 000 tonnes. Russia and China lag considerably behind the United States with 155 000 tonnes and 100 000 tonnes, respectively. The United States can be a leader in thorium advanced reactor technology [51].

Replacing crude oil: large-scale nuclear biorefineries

Crude oil and natural gas provide about 85% of the feedstocks in chemical manufacturing [52]. More than 500 million tonnes of oil-equivalent feedstock are consumed each year to make nearly 1 billion tonnes of chemical products [53].

If we are to decarbonize, we must figure out how to end our dependency on fossil fuels for chemical feedstocks. This can be done. A nuclear biorefining initiative is being led by MIT and INL. Highlights of this effort [54].3.

* Replacing liquid hydrocarbons will be extremely difficult. In the United States, about 18 million barrels/day of petroleum products are produced.
* To achieve the scale of biorefining capacity necessary to replace fossil fuels, three technologies are needed:
  + Consolidation of biomass into energy-dense, anaerobically stored, economically shippable commodities that are available year-round.
  + Biorefineries at the scale of 250 000 barrels per day.
  + Nuclear energy providing electricity, process heat, and hydrogen to the biorefinery.
* In the United States, one billion tons of biomass will be required each year to match current consumption of refining products. The DOE and the USDA estimate that 1.4 billion tons could be produced, but that number could be tripled if (a) we pay farmers more; (b) we use 10% of semi-arid lands to plant opuntia (prickly pear cactus); (c) we use double-cropping extensively; (d) we integrate food/feed/fuel production; (e) we improve pasture/energy crop productivity; and (f) we rehabilitate saline, retired, and degraded lands.

Nuclear biofuels could be deployed at scale in 20 years.

Conclusions

We must transition to carbon-neutral energy. Solar and wind are not truly renewable. Advanced nuclear is far more renewable with promises of many thousands of years of clean energy. It is also the safest form of electricity generation. Industry fatalities per TWe-year are less than 0.01 for legacy nuclear energy, one to three orders of magnitude lower than solar or wind. Most of those legacy fatalities were from plants designed with high-pressure Generation-II technology. Generation-III technology is safer, having its primary focus on safety. Generation-IV advanced nuclear technology is safer yet. Fear of catastrophic nuclear accidents is driving us away from the best chance we have of solving global warming. That fear is unfounded.

Some say that we must reduce energy consumption! They say we must reduce the planet’s population that will help reduce energy consumption. Wishful thinking will not get us out of this mess. About 1–3 billion people on our planet either have no electricity or have very meager/unreliable electricity. They will burn oil and gas, dung, or anything they can get their hands on, to produce energy. We must figure out a way to replace fossil fuels for firm baseload. Energy demand will likely double during this century, regardless of wishful thinking. Advanced nuclear energy is the only viable option for rapidly replacing fossil fuels as firm baseload. Do not be swayed by the argument that nuclear cannot possibly ramp up in time to accomplish this objective. We can achieve major increases in nuclear energy capacity by 2040 if we put our minds and money to it.

#### U.S. action on nuclear power is modeled globally---a U.S. first move lets other countries copy the design AND it’s the best starting point because we’ve sunk capital and testing into reactor technology.

Brook ’11 [Barry, Tom Blees, and others; February 24; Australian Laureate Professor and Chair of Environmental Sustainability at the University of Tasmania in the Faculty of Science, Engineering and Technology, formerly an ARC Future Fellow in the School of Earth and Environmental Sciences at the University of Adelaide, Australia, where he held the Sir Hubert Wilkins Chair of Climate Change from 2007 to 2014, and was also Director of Climate Science at the Environment Institute; President of the Science Council for Global Initiatives, member of the selection committee for the Global Energy Prize, considered Russia's equivalent of the Nobel Prize for energy research, and a consultant and advisor on energy technologies on the local, state, national, and international levels; Conference Paper from the 91st American Meteorology Society Annual Meeting, “Advanced nuclear power systems to mitigate climate change (Part III),” http://bravenewclimate.com/2011/02/24/advanced-nuclear-power-systems-to-mitigate-climate-change]

There are many compelling reasons to pursue the rapid demonstration of a full-scale IFR, as a lead-in to a subsequent global deployment of this technology within a relatively short time frame. Certainly the urgency of climate change can be a potent tool in winning over environmentalists to this idea. Yet political expediency—due to widespread skepticism of anthropogenic causes for climate change—suggests that the arguments for rolling out IFRs can be effectively tailored to their audience. Energy security—especially with favorable economics—is a primary interest of every nation. The impressive safety features of new nuclear power plant designs should encourage a rapid uptick in construction without concern for the spent fuel they will produce, for all of it will quickly be used up once IFRs begin to be deployed. It is certainly manageable until that time. Burying spent fuel in non-retrievable geologic depositories should be avoided, since it represents a valuable clean energy resource that can last for centuries even if used on a grand scale.

Many countries are now beginning to pursue fast reactor technology without the cooperation of the United States, laboriously (and expensively) re-learning the lessons of what does and doesn’t work. If this continues, we will see a variety of different fast reactor designs, some of which will be less safe than others. Why are we forcing other nations to reinvent the wheel? Since the USA invested years of effort and billions of dollars to develop what is arguably the world’s safest and most efficient fast reactor system in the IFR, and since several nations have asked us to share this technology with them (Russia, China, South Korea, Japan, India), there is a golden opportunity here to develop a common goal—a standardized design, and a framework for international control of fast reactor technology and the fissile material that fuels them. This opportunity should be a top priority in the coming decade, if we are serious about replacing fossil fuels worldwide with sufficient pace to effectively mitigate climate change and other environmental and geopolitical crises of the 21st century.

#### Absent transition, extinction in six years.

White and Montgomery ’24 [Stuart White, Honorary Senior Lecturer at Brighton and Sussex Medical School, Hugh Montgomery, Visiting Professor at The Netherlands School of Public Health and Care Research, MD from the University of London, 3-1-2024, "The need for radical climate interventions: six years to secure humanity's ‘liveable future’," Anaesthesia Vol. 79, Issue 3, https://associationofanaesthetists-publications.onlinelibrary.wiley.com/doi/epdf/10.1111/anae.16160, accessed 12-8-2024] zayd 🍃

Manmade global heating is occurring more rapidly and intensively than forecast by the Intergovernmental Panel on Climate Change (IPCC) in 2018 111. In July 2023, the Earth experienced its highest mean monthly land and sea surface temperatures since records began 121, global mean surface temperature twice breaching I .50C above pre- industrial levels (the sustained target identified in the 2015 Paris climate agreement) [11. Moreover, there is ‘no credible pathway to 1.50C in place' today [31.

Indeed, several researchers have forecast rises of 2oC (or even as high as 2.40C) by 2045—2050 14—91, highlighting problems in the IPCC's use of pooled models, publication lags, its under-appreciation of positive climate feedback loops and natural conservatism in achieving global consensus ('erring on the side of least drama'). Heating > 2oC would bring ‘numerous risks to natural and human systems' (at 'multiple times (the rates) currently observed' [101), including biodiversity loss; food and water shortages; extreme weather events; outbreaks of infectious disease; mass migration; and geopolitical crises 131. Any further delay in radically reducing so-called greenhouse gas emissions will risk missing 'a brief and rapidly closing window to secure a liveable future’ [10].

Events may accelerate even faster than this. Occurring slowly, and then very rapidly once ‘climate tipping points' are exceeded, self-perpetuating positive feedback loops can interact in ‘climate tipping cascades', amplifying global heating. Five of nine core global tipping elements and their climate tipping points have already been breached, increasing the likelihood of further breaches, and potentially accelerating global heating towards 2-3oC by 2050 [11]. For example, thawing carbon-rich polar ice shelves and permafrost drives the release of methane (83 times as powerful a greenhouse gas as carbon dioxide over the first 20 years after its release), reduces reflection of solar energy back into space and increases the loss of winter sea ice (contributing to sea level rises and altered ocean currents). Some tropical forests have become net carbon dioxide emitters because of heating-related deforestation and altered local weather patterns. The shift of multiple weather systems into new and dangerous states (for instance, through the collapse of major ocean circulations and movement of the northerly jet stream) are likely to precipitate extreme weather events, and thus food and water shortages. Individual and compound cascade effects increase the likelihood of high-consequence ('fat tail’) geopolitical and economic threats to humanity and could plausibly precipitate the collapse of human civilisation within 30 years (360 months, c. 2050) 16, 91.

Humanity has always faced seemingly insoluble existential crises. Virtually all previous civilisations have collapsed, including several after ecological disasters [121, but this will be the first time that humanity has caused a global collapse knowingly and whilst documenting it- The predicted 30-year time horizon should shake humanity’s collective complacency. ‘It won't happen in my lifetime’ becomes redundant as any justification for continuing the current rate of personal or societal contributions to climate change.

The collapse of global civilisation is not inevitable, but all of us need to act quickly and decisively to avoid breaching the 1.5oC threshold identified by the IPCC. Manmade carbon dioxide emissions need to halve by 2030 compared with 2010 levels and reach net zero by 2050 to limit global heating 1.50C, or 45% by 2030 and reach net zero by 2070 to remain 20C. Net zero does not mandate cessation of manmade carbon dioxide emissions, merely that they occur at the same rate as their 'draw down’ (removal) from the atmosphere. Many have called for radical decarbonisation and further research. Radical decarbonisation needs to proceed urgently according to actions based on current knowledge and informed opinion. Certainly, research should be performed (e.g. into carbon capture and storage technologies) but should not delay immediate action to reduce emissions. However, we cannot wait for certainty, or rely on innovation and technology to engineer us out of imminent climate collapse. Even if the IPCC 1.5oC and 2oC target horizons remain valid, we will need to reduce greenhouse gas emissions by over 10% year-on-year to 2030 (i.e. approximately double the 5.4% annual emissions reduction measured during the COVID-19 pandemic ‘anthropause’ of 2020).

### Plan---1AC

#### Thus, the PLAN:

#### The United States federal government should substantially increase its investment in domestic nuclear energy through financial support and market incentives for integral fast reactor development, including relaxing pre-testing licensing requirements.

#### The plan’s investment catalyzes cost-effective reactor development and widespread commercialization.

Stein et al. ’22 [Adam Stein is Director for Nuclear Energy at Breakthrough, Jonah Messinger is a non-resident Senior Energy Analyst at Breakthrough, Seaver Wang is Director of the Climate and Energy team, Juzel Lloyd is a Climate and Energy analyst at Breakthrough, Jameson McBride was a Senior Research Analyst in the energy program at Breakthrough, Rani Franovich, 7-6-2022, "Advancing Nuclear Energy," Breakthrough Institute, https://thebreakthrough.org/articles/advancing-nuclear-energy-report, accessed 3-18-2025] zayd 🍃

9. MECHANISMS FOR ADVANCED NUCLEAR PUBLIC POLICY SUPPORT

Policymakers possess numerous financial and non-financial opportunities to support the suc- cessful deployment of advanced nuclear power plants at scale. Policy mechanisms for financial support can help lower costs and reduce the financial risk associated with early projects while encouraging the growth of a robust industry that includes not only reactor developers but also upstream manufacturers and suppliers. Meanwhile, non-financial policy support can help facilitate power plant siting, train a skilled workforce, formalize management strategies for spent fuel, and improve the efficiency with which the United States advanced nuclear industry can secure customers internationally. Proactive public policy support across this broad range of issue areas will prove crucial for positioning the United States advantageously as a technology leader in advanced nuclear energy.

9.1 Direct Financial Support Mechanisms

Federal Loan Guarantees

Upfront capital investments will comprise much of the cost of advanced nuclear projects.

Due to the higher financial risk associated with backing emerging advanced nuclear reactor deployments, financiers will likely expect higher interest rates for lent capital. Higher interest rates thus add to the cost of early deployment of advanced nuclear technologies.

To encourage capital investment into US advanced nuclear projects and to reduce project costs, federal programs like those administered by the US DOE’s Loan Programs Office (LPO) can guarantee repayment of loans for advanced nuclear projects, both reducing financial risks for investors and allowing project developers to secure capital at lower interest rates. Such federal loan guarantees can thus play a highly influential role in accelerating the domestic development of an advanced nuclear sector.

At the national level, the DOE LPO seeks to provide directed public support for energy innovation. The DOE LPO currently possesses the capacity to issue up to $40 billion in loans and loan guaran- tees to support a wide range of groundbreaking energy and energy infrastructure initiatives, with up to $10.9 billion in loan guarantees available for promising nuclear energy projects.177

This support has historically been extended to conventional nuclear projects such as the construction of Units 3 and 4 at the Vogtle Electric Generating Plant in Waynesboro, Georgia.178

Demonstration and Cost Share

Publicly funded technology demonstration programs remain a primary driver to assist innovative and transformative research to reach commercial scale.179 Over the last 80 years, the Department of Energy and the world-leading system of US national laboratories have directly driven not only the development but also the demonstration of many new energy technologies nationwide. Demonstration programs represent a critical step in the innovation process by bridging the research and development process and full-scale commercialization of a technology. Public-private partnerships for demonstration projects reduce the burden on the government to solely demonstrate the technology. By participating in project cost-sharing, the government facilitates “buying down” financial risk, thereby reducing overall FOAK costs. Such demand-pull innovation policies have a demonstrated track record of success in commercializing innovative technologies in a variety of sectors.180

The DOE’s recent opening of a new Office of Clean Energy Demonstrations (OCED) emphasizes the value of this public sector role in driving early deployment for emerging technologies.181 The OCED will seek to support a range of important technologies, such as carbon capture, clean hydrogen, grid infrastructure upgrades, and advanced nuclear demonstration. The recently passed Bipartisan Infrastructure Law specifically designated $2.5 billion in OCED funding to support two advanced nuclear reactor demonstration projects through the Advanced Reactor Demonstration Program (ARDP).182

The ARDP is a more established but still recent program launched in 2020 to provide public support and help advanced nuclear developers secure and build their first projects.183 The ARDP currently supports 10 projects, with two full scale demonstration projects. One demonstration project will deploy four of X-Energy’s 80 MWe Xe-100 high-temperature, gas-cooled small reactors at the Columbia Generating Station in Washington state, currently home to an existing conven- tional nuclear power plant.184 The other demonstration project will involve building TerraPower’s Natrium 345 MWe sodium-cooled fast reactor, with an initial reactor slated for construction in Kemmerer, Wyoming at the site of the existing Naughton Coal Plant. Others ARDP projects include the Kairos KP-X/Hermes 50 MWe test reactor intended for construction at the Oak Ridge National Laboratory in Tennessee.185 Other deployment projects include the six-unit NuScale SMR project at INL186 and GE-Hitachi’s BWRX-300 design, at the Clinch River site in Roane County, Tennessee.187

Tax Credits

Tax credits for renewable electricity generation are a well-established policy mechanism for encouraging the greater deployment of new domestic wind and solar capacity.188 Power produced by conventional and advanced nuclear reactors provides the same climate and air pollution benefits as other sources of clean energy.189, 190 To promote wider adoption of clean electricity from a diverse array of sources, optimally-designed clean energy tax credits should be available on a technology-neutral basis. A future low-carbon electricity grid will rely upon an array of technologies, so nuclear power plants, geothermal facilities, and hydroelectric dams should similarly benefit from federal tax incentives intended to accelerate national clean power gener- ation. Such federal tax incentives will further improve the economics of new advanced nuclear projects.

Tax credits require the entity to have a sufficient tax burden for credit to offset. Small organiza- tions pursuing projects with no existing revenue, therefore no tax liability, often have to partner with another organization, which in turn takes some of the tax credit for the service. One option to avoid this issue is a direct payment of the tax credit to the entity. A proposed direct pay mechanism allows a taxpayer to treat tax credits that it has earned as an overpayment of taxes, allowing the tax credit to be received as a direct payment of cash in the form of a refund.

Subsidies

It is our view that technology-neutral subsidies are best employed to promote the accelerated early deployment of innovative clean energy technologies in a fair and efficient manner.

As a promising set of clean energy sources that offer unique strategic and economic advantages for the United States, domestic advanced nuclear energy projects are strongly in the national interest and possess a good case for inclusion in any technology-neutral clean energy subsidy program.

In the long term, inefficient subsidies may discourage innovation and further improvements in efficiency, so such policies might be reconsidered in the future once these technologies have become more established.

Tax Incentives for the Development of Advanced Nuclear and HALEU Supply Chains

Successful commercial deployment of advanced reactors will also depend upon the expansion of robust upstream supply chains, including factory manufacturing capabilities, production of specialized alloys, and components of the nuclear fuel cycle (uranium mining and milling

capacity, fuel fabrication, and spent fuel and high-level waste processing and reprocessing facil- ities). Establishing sufficient capacity across these industries will support the commercial-scale buildout of advanced reactor designs, reducing technology costs due to faster rates of technolog- ical learning in the factory, improvements in the cost and availability of components, and more affordable HALEU fuel inputs.

Tax incentives can spur growth in these upstream and downstream sectors, promoting the development of additional advanced nuclear supply chain capacity beyond that the market alone would produce. Such policy measures would yield benefits not just during the early stage of advanced nuclear deployment, but well beyond as the industry enters successive stages of maturity and scale.

9.2 Supporting Policies and Programs

Support for Environmental Impact Studies and Pre-Qualification of Proposed Sites

Another means of helpful policy support for advanced nuclear would involve federal spending to identify promising sites for near-term deployment and conduct environmental impact studies (EIS) to assess potential candidate locations.

Such efforts would reduce costs for early deployment, first by obviating the need for the devel- oper to fund the EIS, and second by reducing financial risks associated with potential rejection of an EIS. Additionally, pre-qualification of desirable sites for advanced nuclear reactors would accelerate the power plant planning timeline, further reducing costs and minimizing potential delays. Performing EISs in advance is thus an affordable policy measure that can meaningfully increase the efficiency of advanced nuclear deployment at no cost to environmental oversight.

Federal Procurement of and Pre-Orders for Advanced Nuclear Designs

Upstream supply chains for the domestic advanced nuclear industry will require a sufficient level of customer demand to become more established. The federal government is one of the largest single electricity purchasers. Federal procurement of electricity through contract or direct purchase of advanced nuclear projects will provide a strong market signal to industry, incentivizing the production of HALEU fuel, reactor components, and associated services.

The public sector could drive early pre-orders of reactor projects by siting a number of small reactors or microreactors at military installations, government facilities and infrastructure, public universities, and other locations in service of state and national needs. Such public sector projects could help support the Biden administration’s Executive Order on Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability, which directs the federal government to procure 100 percent of all electricity for federal operations using clean electricity, with at least 50 percent produced from 24/7 carbon-free generation.191

#### Reject evidence that doesn’t assume new reactors---the nuclear renaissance unlocks industry revolutions in safety, nuclear waste, and efficiency. It’s comparatively better than every alternative.

Jayanti ’23 [Suriya Jayanti is an Eastern Europe and Middle Eastern policy expert. She served for 10 years as a U.S. diplomat, including in Kuwait and Iraq, and as the Energy Chief at the U.S. Embassy in Ukraine. She currently runs several clean energy companies, sits on the Board of the Institute for Security and Technology, and is a Senior Fellow at the Atlantic Council., 11-6-2023, "Nuclear Power Is the Only Solution," TIME, https://time.com/6342343/nuclear-energy-climate-change/, accessed 3-18-2025] zayd 🍃

Wedged between energy crises and climate change natural disasters, there is no longer the luxury of choice. The industry has responded by seeking to develop new technology that can assuage public concerns about safety. Some are designing micro reactors or SMRs. Others are working with new materials or techniques, such as replacing water in cooling systems with molten salt, or using boiling water instead of pressurized water to make the NPP more efficient. Still others are working on new safety systems, or fuel fabrication innovations, or new approaches to storage of nuclear materials. In the U.S., top tier research outfits like the Electric Power Research Institute are finding their expertise in demand all round the world, creating something resembling nuclear diplomacy. The U.S., U.K, Canada, and South Korea are leading the pack on investment in nuclear.

The nuclear industry has been riding high on a wave of enthusiasm for a few years. In recognition of the cost savings of “going nuclear,” smart companies are already making plans to transition to nuclear power. This includes Microsoft, which announced in September that it will use nuclear plants to power its artificial intelligence operations. With electrification the foundation of any coherent energy transition plan and grids struggling to balance themselves with an abundance of non-dispatchable renewables, nuclear is increasingly acknowledged to be the solution. Just as apex science fiction writer Isaac Asimov fantasized in his 1940-50s Foundation books, nuclear energy may save humanity.

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And yet, recent headlines have revealed some major setbacks. Small modular nuclear reactor (SMR) company NuScale, once lauded as the leading SMR developer and despite receiving almost $2 billion in U.S. government support, has cancelled its flagship project due to rising costs and mismanagement. It is now facing investor lawsuits for fraud. TerraPower, Bill Gates’ SMR company, was delayed several years by the Russian invasion of Ukraine—Russia was the only country that produced the nuclear fuel needed for TerraPower’s SMR design. X-Energy has walked back its plans to go public. The U.K.’s Rolls Royce SMR is plagued by financial problems. France’s EDF is posting record low power outputs and financial status reports. Others are also delayed, struggling, or facing bankruptcy. Setbacks are normal for new technologies and emerging markets, but for nuclear power such bumps in the road have outsized potential to disrupt because many people are still hesitant or downright hostile to nuclear power. The Chornobyl, Fukushima Daiichi, and Three Mile Island catastrophes loom large in the imagination. “Meltdown” itself has entered idiom to mean falling apart rapidly and irrationally and beyond control. The world’s preoccupation with Russia’s attacks on Ukraine’s Zaporizhzhye nuclear power plant (NPP), the largest in Europe, shows how gripped we can be by nuclear disasters. In keeping, a March 2023 Gallup poll found that although support for nuclear is increasing slowly, 44% of Americans still somewhat or strongly oppose it, down from 54% in 2016. Similar polls in Switzerland and the U.K. peg support for nuclear at just 49% and 24%, respectively. In Germany, despite still being in the middle of an energy crisis and desperate for additional power sources, 50% of people under 34 want nuclear power eradicated. With the exception of France, which is 69% nuclear, many of the developed world’s leading economies and governments have been too scared of nuclear power to allow it to flourish. Germany was so spooked by Fukushima it completely phased out its nuclear power program, finally turning off its last three (of an original 17) reactors on April 15, 2023. Belgium and Switzerland decided not to build new plants and to phase out those existing, although the 2021-2023 energy crisis has forced a reconsideration. In the U.S. the trigger was the March 28, 1979 partial meltdown of Three Mile Island in Pennsylvania. No one died or even suffered negative health effects, in the aftermath dozens of planned NPPs were cancelled and almost nothing has been built in decades. Unfortunately, unencumbered by popular opinions against nuclear, the Western world’s great geostrategic rivals are years if not decades ahead. There are sixty nuclear projects in various stages of construction around the world, and 22 of them are in China; and 22 use Russian technology, and 18 use Chinese technology, or technology China stole from other countries and rebranded. Some European countries, notably Hungary and Serbia, and some NATO countries, such as Turkey, are planning new NPPs using Russian designs and supply chains. Ironically, and tragically, even all four of Ukraine’s NPPs are Russian VVER models, entirely reliant until quite recently on Russian fuel. And Russia controls much of nuclear supply chains. The Western world ended up so far behind because of fear. Governments around the world are now struggling to catch up, slowed by still-high public opposition rates and regulatory regimes that institutionalized fear of nuclear into licensing and permitting processes. In countries that never had nuclear power, such as Poland and Egypt, opposition is not baked into law, and so they can paradoxically move faster than some countries with longstanding nuclear programs. In the U.S. the opposite is true; it keeps tripping over the fear-based regulatory regimes that govern its nuclear industry. Tasked by Congress in the 2019 Nuclear Energy Innovation and Modernization Act with liberalizing the licensing process to foster innovation and accelerate the commercialization of nuclear power, the U.S. Nuclear Regulatory Commission (NRC) in 2022 released draft rules and processes for consideration of new nuclear technologies that managed to take all the worst and most burdensome aspects of existing rules and, instead of reducing them, added some new hurdles and standards, some of which nuclear engineers say are scientifically impossible to meet. The draft is twice as long (1252 pages) as the one it was supposed to simplify. Many requirements, both old and new, shouldn’t apply to SMRs and other advanced nuclear designs. The result was decried by experts and companies as a complete failure that will continue to hobble the industry for decades, adding further time and expenses to the already billion-dollar licensing process. The Nuclear Energy Institute, an industry trade group, said the proposal will “increase complexity and regulatory burden without any increase in safety and reduce predictability and flexibility.”

**<<<PARAGRAPH BREAKS RESUME>>>**

Meanwhile the U.S. is trying to export this same cumbersome nuclear regulatory regime, including to Saudi Arabia. Calling it the “gold standard” of nuclear regulation, the U.S. has refused to allow Saudi, much like it did with the United Arab Emirates, to use U.S. nuclear technology unless the Kingdom also adopts prescribed U.S. safety regulations. What a surprise that Saudi is actively considering Russian nuclear technologies instead.

Yet, the scientific reality is that the rising generation of nuclear innovation doesn’t need to be subjected to a crippling approval process—it is safe. The risk profile of new reactors and other technologies in development is very low. This is especially true relative to the risks of climate change fallout or, for example, the health risks of burning fossil fuels or inhaling combustion engine exhaust. And the waste from a new nuclear plant is far less problematic than that of spent solar panels, for example. The nuclear renaissance is not just more nuclear power, it’s also better, cleaner, safer, more efficient.

SMRs, for example, are much safer than full sized NPPs. They have outputs of 50-300 MW depending on design, compared to 800-1600 MW for traditional NPPs. Microreactors, “pocket nukes” with 1-50 MW outputs, are even more resilient because simple physics means they are harder to damage and so it’s less likely that an accident could result in a radioactive release. Whereas seismic activity is a grave concern for large NPPs like Fukushima, smaller technologies soon to be built do not require the seismic cushions that were needed under previous plants to protect them from even the smallest earthquakes. Micros and SMRs can also be manufactured in a factory—that’s what the “modular” in small modular reactor means — allowing for standardization and systematized security measures, as well as sealed transport. And smaller amounts of radioactive fuel in smaller reactors mean less that could go wrong even in the case of an accident.

One persistent concern opponents of nuclear power often voice is the risk of reactor cooling systems failing, but this not an issue with the new generation of nuclear designs. Fukushima Daiichi NPP’s water-based cooling system stopped when a tsunami disabled the electricity source powering the circulation. This is the same risk Ukraine’s Zaporizhzhye NPP is facing thanks to Russia bombing the dam that held the water that kept the plant’s water cooling system operating. In emerging advanced reactor technologies, however, this vulnerability is eliminated entirely. Many of the new designs have entirely reconsidered systems with passive safety features that maintain cooling without reliance on external power. Others use water in innovative ways. GE Hitachi’s BWRX-300 SMR is designed for the water inside to boil, creating its own convection that in turn powers its own cooling circulation. This eliminates the need for an extensive circulation system of pipes and keeps all potentially contaminated water inside the plant. Some also use materials other than water, such as molten salts.

Another common objection to nuclear power is the disposal of radioactive material. But new technological innovations are mostly eradicating the need to store spent fuel at all. New fuels have a lower enrichment level, which is less radioactive and thus safer. And there’s no such thing as nuclear waste unless the material is wasted. Canada’s Moltex, for example, is developing a fuel recycling “waste to stable salt” technology that repurposes spent fuel into new fuel, reducing waste by over 75% and cutting its radioactive half life to approximately 300 years, down from thousands. Moltex is also designing an SMR, the Stable Salt Reactor-Wasteburner, to run on the recycled fuel, which will cut down the transport of radioactive materials. Other technologies are reducing risk in parallel.

Nuclear energy will never be absolutely, perfectly, guaranteeably safe because nothing is. Wind turbines can fall over, and they can kill birds and negatively impact marine life. Solar panels produce significant volumes of toxic waste, and they take up space that impedes whatever is trying to live under them. Both wind and solar rely on minerals and manufacturing mostly controlled by China, and neither is entirely reliable as a power source. They’re also not dispatchable at times of peak electricity demand. Hydropower only works with abundant water, and droughts are eviscerating rivers across the world. Coal is killing our children and our planet. So is oil. So is natural gas. Geothermal, biofuels, hydrogen, et cetera—these aren’t able to satisfy even a fraction of the demand for energy.

#### Integral reactors are the safest method for generating energy AND eliminate nuclear waste---overwhelming statistical and comparative evidence.

Snyder ’23 [Van; March 16; spent 53 years as a mathematician and engineer at the Caltech Jet Propulsion Laboratory, MS in Applied Mathematics and System Engineering, spent seventeen years as an adjunct associate professor; “Five Myths About Nuclear Power,” https://substack.com/home/post/p-108860660?utm\_campaign=post&utm\_medium=web]

Popular discussions about nuclear power eventually get around to at least one of five objections: It's not safe; no one knows what to do about waste; it's too expensive; it leads to nuclear weapons proliferation; or there isn't enough uranium. All of these objections are baseless.

Revised to incorporate valuable comments from Dr. Yoon Il Chang, Tom Blees, and Eric Loewen.

It's not safe (yes it is)

The Paul Scherrer Institut in Villigen PSI, Switzerland is a frequent European Community consultant concerning safety. Their collection of more than 33,000 records of accidents related to electricity production shows that nuclear power is the safest-ever way to make electricity, by a very wide margin. Only 46 fatalities are directly attributed to municipal nuclear power in its entire six-decade worldwide history, all due to one accident, ironcially a botched safety test at Chernobyl.

Bigger means safer. There have been only 46 fatalities in the entire six-decade worldwide history of municipal nuclear power, all due to one accident at Chernobyl

The Chernobyl reactor was the Hindenburg of nuclear reactor designs. It is irrelevant because another one with similar defects will never be built. It is described here only because of the fear it engendered.

The Soviet Union’s safety culture was different from the west’s, and reactors were not licensed because there were no licensing criteria. The Chernobyl reactor was a scaled-up version of one purpose-built to produce plutonium for weapons. As it got hotter, or if the cooling water boiled, the fission reaction ran faster, so it got hotter faster. The operators lost control of it, ironically because they bypassed the inadequate shutdown mechanisms during a safety test. The ensuing calamity was a steam explosion and a graphite fire, that dispersed several tonnes (1000 kilograms/tonne) of spent fuel near the reactor, and radioactive dust throughout the region.

The BORAX test reactor in Idaho was intentionally destroyed by prompt criticality, but licensed reactors are designed so that it is impossible to cause a nuclear explosion, either by mistake or intentionally.

The United Nations Scientific Committee for the Effects of Atomic Radiation (UNSCEAR) reported to the General Assembly in 2008 that 134 plant operators and emergency responders at Chernobyl were exposed to sufficient radiation to develop acute radiation syndrome, which caused 28 deaths. Two others died from injuries not caused by radiation (falling debris), and one from coronary thrombosis. The report noted there is “no scientific means to determine whether a particular cancer in a particular individual was or was not caused by radiation,” and there is “no scientific evidence of increases in overall cancer incidence or mortality rates or in rates of non-malignant disorders that could be related to radiation exposure.” Nonetheless, the report speculated that fifteen excess cases of fatal juvenile thyroid cancer, compared to earlier decades, out of 6,000 cases reported between 1991 and 2005, might have been caused by the accident.

In the most affected areas (Ukraine, Belarus, and southwestern Russia) the average additional radiation dose to the general public over the period 1986-2005 was about nine millisieverts (mSv). Residents “need not live in fear of serious health consequences,” according to the report.

UNSCEAR reported in October 2013 that “Japanese people receive an effective dose of radiation from normally occurring sources of, on average, about 2.1 mSv annually and a total of about 170 mSv over their lifetimes…. No radiation-related deaths or acute diseases have been observed among the workers or general public exposed to radiation from the accident…. For adults in Fukushima Prefecture, the Committee estimates [the increase in] average lifetime effective dose to be of the order of 10 mSv or less… discernible increase in cancer incidence in this population that could be attributed to radiation exposure from the accident is not expected.”

The dose from one abdominal and pelvic CT scan with and without contrast is about 30 mSv. The annual dose on the Tibetan plateau is 13-20 mSv. The annual dose on Guarapiri Beach in Brazil is 1154 mSv.

Although radioactive materials from a municipal nuclear power plant outside the Soviet Union have never caused an injury, illness, or fatality, Argonne National Laboratory (ANL) and Idaho National Laboratory (INL) believed they could develop an even safer design. During a meeting on 26 April 1944 (see Appendix B of ANL report 49168), Enrico Fermi described an energy system consisting of fast-neutron reactors with fuel reprocessing. A concept that led to the design of Experimental Breeder Reactor II, or EBR-II was described during that meeting by Leo Szilard. Leonard J. Koch became the project manager, and filled in many details during subsequent years. EBR-II was a 20 megawatt (MWe) reactor near Arco, Idaho. The Integral Fast Reactor, or IFR project, led by Charles E. Till and Yoon Il Chang, using concepts developed at EBR-II, had a goal to tie up absolutely all loose ends related to nuclear power (Although Koch had retired from ANL before the official start of IFR, his vision for the experimental program to develop it is clear in a memorandum dated September 2, 1953). An important new component was the fuel processing system that uses pyroelectric refining, instead of the melt refining method that had been used in the early years (See Chapter 8 of Plentiful Energy).

Detailed nuclear, thermodynamic, and mechanical calculations, and computer simulations, had shown that the EBR-II design was inherently safe. To demonstrate this, in 1986 Pete Planchon conducted a demonstration for an invited international audience. Automatic safety interlocks were turned off. Coolant circulation was turned off (the cause of the destruction of the Three Mile Island reactor). Core temperature rapidly increased from 1010 degrees (Fahrenheit) to 1430 degrees. Liquid sodium coolant boils at 1621 degrees. Within seven minutes the core was below operating temperature, without action by operators, computers, valves, pumps, auxiliary power, or any moving parts. The operators were not injured. The reactor was not damaged. There was no release of radioactive material. The reactor was restarted with coolant circulation restored, but the steam generator disconnected. The same scenario recurred. Two months later, the operators at Chernobyl repeated the second experiment, using a very different reactor, with tragic consequences.

The demonstrated safety of EBR-II depends only upon immutable laws of physics and thermodynamics, and the geometry and materials of the reactor core.

No one knows what to do about waste (yes we do)

Pressurized light-water power reactors produce about twenty tonnes of spent fuel per gigawatt year (GWe-year) of electricity. Spent fuel is dangerously radiotoxic for 300,000 years, an apparently intractable problem.

Examining the composition of spent fuel leads to a different conclusion. A tonne of spent fuel from contemporary light-water reactors (LWR) consists of about 52 kilograms of fission products and 948 kilograms of uranium and metals with greater atomic number, i.e., unused fuel.

**<<<FIGURE OMITTED>>>**

Fission products are less radiotoxic than uranium in nature after 300 years, not 300,000 years.

**<<<FIGURE OMITTED>>>**

Fission products are produced at the rate of about one tonne per GWe-year. Custody of fission products separated from uranium and transuranic metals would be much simpler than for spent fuel taken as a whole. After ten years' storage, two elements, strontium and caesium, produce 99.4% of radiotoxicity, but constitute only 9.26% of the mass of fission products — five kilograms per tonne of spent fuel, or about 92 kilograms per GWe-year. 47 kilograms per tonne, or 900 kilograms per GWe-year, are low-level waste, less radiotoxic than uranium in nature, and much simpler custody is adequate.

**<<<FIGURE OMITTED>>>**

The PUREX (Plutonium-URanium EXtraction) process separates chemically pure but isotopically mixed plutonium and uranium from spent fuel, leaving transuranic metals with the fission products. It therefore does not reduce the duration of custody. Process fluids are good moderators that efficiently adjust the average speed of neutrons into the range that causes fission. The concentration of spent fuel must be kept very low to avoid criticality accidents. A facility to process hundreds of tonnes per year occupies several thousand hectares, has several kilometers of pipes and large numbers of pumps, mixing devices, and other components, and is very expensive.

An alternative method to separate fission products from unused fuel, based upon well-known metal electrorefining methods, was developed as part of the IFR project. There is no moderator in the device, so larger amounts can be processed in a much smaller space. The pyroelectric refining device consists of an anode, composed of spent fuel, and a cathode, immersed in an electrolyte of molten lithium/potassium chloride salts.

Because of different chemical potentials, when a carefully controlled voltage is applied, uranium, transuranic metals, and active fission products such as strontium and caesium diffuse from the anode into the electrolyte and are carried through it by the electric potential gradient. Nearly pure fuel is deposited at the cathode. Active fission products remain in the electrolyte. Noble metals such as rhodium and palladium remain in the anode.

Fission products can be separated from the electrolyte by absorption into zeolyte (similar to the active material of a water softener), thereby cleansing the electrolyte for further use. Contaminated zeolyte can be mixed with powdered glass, and compressed and sintered into an impervious insoluble ceramic, ideal for storage, called sodalite. The metals remaining in the anode basket are disposed separately. This leaves the actinides.

Actinides in spent fuel consist mostly of uranium, but include significant amounts of plutonium and heavier transuranics. Odd-numbered isotopes of uranium and plutonium can be fuel in existing reactors, but even-numbered isotopes do not fission, and heavier transuranics do not fission efficiently, in light-water reactors. Using recycling, about 30% of the original fuel can be converted to fission products and electricity in an LWR, before the only slightly-smaller problem is right back where it started: A substance needing 300,000 years' custody.

If the average speed of neutrons is higher, as in IFR, all uranium and transuranic isotopes are fissionable or can be transmuted to fissionable isotopes by neutron absorption; they are fuel, not waste. Rather than 20 tonnes of intractable waste per GWe-year, a fast-neutron reactor produces one tonne of substances that require much simpler custody. Spent fuel, the substance currently and mistakenly called “nuclear waste,” of which the world is desperately eager to be rid, is effectively destroyed — and nothing else other than hideously expensive laboratory-scale toys can do it.

Fast-spectrum metal-cooled reactors should be built instead of light-water reactors because of their demonstrated safety, and their ability to destroy nuclear waste.