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The Nuclear Middle Way

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Abstract

The people of the earth face several existential threats.[a] Among these are proliferation of nuclear weapons and those resulting from the combined threat of energy poverty of 2/3 of the planet and the overuse of fossil hydrocarbons causing global warming and ocean acidification. I propose vastly expanded nuclear power—*the nuclear middle way*— as an answer to these threats. Human health and wellbeing are closely measured by per capita energy consumption. The lack of energy (energy poverty) results in enormous harm. *The nuclear middle way* will simultaneously avoid harm from energy poverty and from overuse of hydrocarbons by the latter part of the 21st century. *The nuclear middle way* emphasizes the nonproliferation of nuclear weapons and avoidance of their use and emphasizes lives saved by the many tens of millions since their two and only uses in 1945. For this to happen, electrical power especially nuclear must be affordable and hopefully lower cost than that from fossil fuels, especially coal, in order to facilitate market penetration. Affordability—lower cost—is enhanced by shipyard factory manufacturing. Historical data has shown that nuclear power is the safest form of energy, which is surprising to many. Let's choose *the nuclear middle way* and get on with responsible vastly expanded use of nuclear power by building 10,000 or more nuclear plants yet this century.

Background

For mankind's benefit, the Hawaiian Goddess Pele hinted at the molten salt power plant design with her continuously flowing molten lava (like molten salt) made molten primarily by the heat from thorium radioactivity in the earth's interior (thanks to the Norwegian God, Thor!). In an analogous fashion, the Molten Salt Reactor (MSR) heats molten salt by fission of any fissile material: ^{233}U, ^{235}U or ^{239}Pu that in turn makes steam while being cooled. The cooled molten salt is pumped back to the reactor and repeatedly heated, as inspired by Pele and enabled by Thor. Safety is enhanced by the molten state being the normal state, rather than accidental, with low pressure aiding safety and low costs. The molten salt reactor appears well suited for *the nuclear middle way.*

In addition, *the nuclear middle way* —being non-carbon based—calls for widespread use of nuclear energy to mitigate global warming and ocean acidification and alleviate energy poverty. To be effective, nuclear power needs to be implemented on a vast scale by the end of the 21st century. We need at least 10,000 or more of the usual size 1-GWe or equivalent size plants

a. By existential threat we mean conditions that pose a threat to a significant fraction of the earth's human population to die or have to relocate or in some other ways drastically accommodate to their new reality. Examples are Neanderthal, Vikings, Romans, dinosaurs, lions, bison…

worldwide. This is 10 TWe.[b] In 2014 there were 2.6 TWe of average electrical power (3,500 typical 1-GWe size plants) of which 1.7 TWe are hydrocarbon based (of which 1.0 TWe is coal based), 0.4 TWe hydro, 0.3 TWe[c] were nuclear based and 0.2 TWe other[1]. Market penetration of such a vast number of nuclear power/non-carbon power plants will be more likely if its electrical power can be made lower cost than that from fossil fuels, especially coal and we have capacity to build such a number of plants especially if we employ shipyard manufacturing

History of nuclear power—the light water reactor was a mistake—good for submarines but vulnerable to safety and cost problems

Alvin Weinberg[2] in the 1960s strongly advocated the molten salt reactor for civilian power use and promoted the Molten Salt Reactor (MSR) as a candidate future, that is, Generation-IV plant that is one generation beyond today's Generation-III plants. This was in spite of the fact that he invented the light water reactor (LWR) to propel submarines and ships. Admiral Rickover and the government subsequently, mistakenly and zealously in Weinberg's opinion, promoted the LWR for civilian nuclear power over his objection and warning about lack of sufficient safety and low fuel utilization. The LWR must be kept cooled at all times to avoid melting and dispersing radioactive materials. Accidents where cooling is lost have been rare but not vanishingly so with notorious results (Three Mile Island, Chernobyl and Fukushima) as discussed in the Table later on.

The Light Water Reactor (LWR) uses uranium resources inefficiently consuming only about 1% of mined uranium, such that uranium resources will limit its deployment in numbers needed to mitigate global warming of over 10,000 plants. MSRs are predicted to stretch uranium resources four times longer than today's LWRs and much more so when processing and recycling are employed. *The middle way* nuclear plants must satisfy the requirements for safety and economics while expanding today's nuclear plants by two orders of magnitude (~400 plants today to >10,000 plants by century's end) in order to limit global temperature rise.

Alternative nuclear power options for *the nuclear middle way*

The kind of nuclear power plants that could meet *the nuclear middle way* requirements are sometimes called Generation-IV plants whereas the latest nuclear power plants being used and being built today are called Generation-III. They are mostly LWRs. Other Generation-IV reactor designs (those one generation beyond today's Generation-III reactors) can employ shipyard or other factory manufacturing and satisfy our goals if they can meet safety and economic requirements, while, nuclear fusion power plants remain a laudable future dream.

Economics & already demonstrated reactor concept —*shipyard factory production*

The nuclear middle way plants must be both safe and economical. The MSR concept has been tested and proven in a highly successful demonstration over 50 years ago, called the Molten Salt Reactor Experiment (MSRE).[3] This demonstrated prototype could and should be scaled up to full size in one step in well under 10 years according to its advocates including this author.

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b . A typical plant today is 1000 MWe = 1 GWe = 0.001 TWe in capacity. 10 TWe is 10,000-1 GWe plants.

c. Today there are about 400 nuclear plants of 1 GWe size producing an average power of 300 GWe or 0.3 TWe, that is, they operate about 3/4th of the time each day over their lifetime.

Factory built MSRs can arguably do for nuclear power what Henry Ford did for automobiles: the assembly line factory for making millions of Model As and follow-ons. Thorcon, a new company, advocates a similar model for shipyard based factory manufacturing to substantially lower the costs for reactor modules that are shipped to navigable sites where rapid assembly takes place (Jack Devanney, MIT BS and MS Naval Architecture and Management Science, PhD, thorconpower.com). Two features of shipyard construction are notable:

1-components limited only by crane capacity can weigh hundreds of tons each made primarily of steel and

2-owing to their great weight, water is used to transport components to the power plant site for final assembly; alternatively, the whole plant could be towed to the site.

The vast majority of the world's population lives in transmission line distance from navigable waters.

The decision to choose nuclear over some other means to generate electricity has mainly been an economic issue for many years and will remain so provided we learn from past accidents and maintain safety standards.

Nonproliferation of nuclear weapons

We must employ strong measures of nuclear nonproliferation to guard against the threat of nuclear weapons proliferation and use. I strongly support and applaud the global security work of Perry, Shultz, Nunn and Kissinger, who wrote a book[4] and penned Op Eds in the Wall Street Journal.[5] I also support the work of Harold Feiveson, Alexander Glaser, Zia Mian, and Frank von Hipple[6] who seek to limit the proliferation of nuclear weapons. I strongly advocate continuance of their efforts to reduce nuclear weapons and weapons usable materials. Wouldn't it be wonderful if future history books report that 1945 was the last time nuclear weapons were used after which time their use became a taboo, reinforced by various international agreements? However, these authors lack regard or support for *the nuclear middle way,* and instead lead an intensely vigorous campaign against fissile material that could be used in nuclear weapons. This effort to rid the world of weapons usable fissile material— as laudable as it is—fails to support responsible nuclear power and even opposes it partly by neglect and partly by inattention to the consequence of their actions.[7]

Nonproliferation gets mixed up with nuclear's excellent safety record

Opposition to nuclear power owing to its connection to nuclear weapons is understandable and unfortunate. This opposition gets mixed up with the real concern of safety that has been dramatically brought to our attention by accidents in old plants (Generation II and III) in Japan (Fukushima), US (Three Mile Island) and USSR (Chernobyl). New nuclear plant designs (especially generation-IV designs) are expected to have much lower risk of accidents than from the older generation II&III plants whose risks themselves are much lower than those from other documented risks to human life and health. The safety of nuclear power relative to other sources of energy is shown to be very good in Table 1 below.[8] Therefore, this relatively low risk should not be a major factor in considering the benefit of adding many more nuclear power plants. A problem to overcome is fear that too often trumps facts and logic.

In addition, the risk of terrorists' causing serious accidents at nuclear plants or using spent fuels for weapons has also been studied and found to be low provided we continue to follow reasonable precautions. The result is —the overall risks from nuclear accidents and terrorism are very small compared to the more certain eventual risks from overuse of fossil fuels and its degradation of our environment.

Table 1. Safety record of nuclear compared to alternatives

Severe accidents in the energy chain, 1969-1996			
Energy chain	Accidents with ≥ 5 fatalities	Fatalities	Fatalities per GW-year
Coal	185	8,100	0.35
Oil	330	14,000	0.38
Natural gas	85	1,500	0.08
LPG	75	2,500	2.9
Hydro	10	5,100	0.9
Nuclear	1	28	0.0085

Opposing arguments to nuclear power plants

Rather than opposition to nuclear power projects, the goal should be to minimize the proliferation and use of nuclear weapons while still supporting nuclear power. Categorical advocacy of renewable energy has taken away support of nuclear power. It is predicted that the vastly increased use of fossil fuels will cause global warming and ocean acidification in the 21st century with drastic consequences. Renewables by themselves can indeed mitigate this dual threat to some extent. However, they cannot scale up in size to make a sufficient market penetration share in order to remove this threat. The limited market share from renewables is due partly to their intermittency. Nuclear power including MSRs can make significant market share, thereby, largely displacing fossil fuels. I advocate an "all of the above" goal including nuclear right along with renewables because they are all sustainable. The global environmental/climate threat should supersede partisan politics. A dangerous rise in temperature is predicted to impact people globally with great harm to many. Is this not an existential threat to be judged and dealt with on a par with the existential threat of nuclear weapons proliferation and use?

Energy poverty

A surprisingly large fraction (a third) of the world's population has no electricity, no lighting at nighttime and poor heating or far too little of these energy benefits. This is *energy poverty*. Rooftop solar panels, batteries, and LED lights can help a bit, but achieving even China's level of prosperity demands 400 watts average per person. Food production and clean water can also be limited by lack of energy—another aspect of energy poverty. For example, the Haber process synthesizes ammonia for fertilizer from nitrogen and hydrogen—an energy consuming process that supports agriculture. Energy in many forms can be a mitigator of poverty.

Carbon overuse

Very large deposits of coal and other fossil fuels are currently being used to alleviate energy poverty worldwide and their use raises the standard of living and pulls much of the world's population out of poverty and into modern industrial society, as happened in Europe and North America. In the largest population nations of the world, new coal burning plants are coming online weekly with attendant smog and air pollution! This trend increases the production of greenhouse gases, CO_2, with predictions of average temperatures increasing between 3.5 °C and 4.5 °C (6.3 °F and 8.1 °F) by the end of the 21st century.[9] Increasing energy use per person will have the strong effects of improving mankind's lot and decreasing birth rates. With lowering of birth rates we can expect population to reach a lower sustainable level after its peak occurs further reducing carbon overuse.

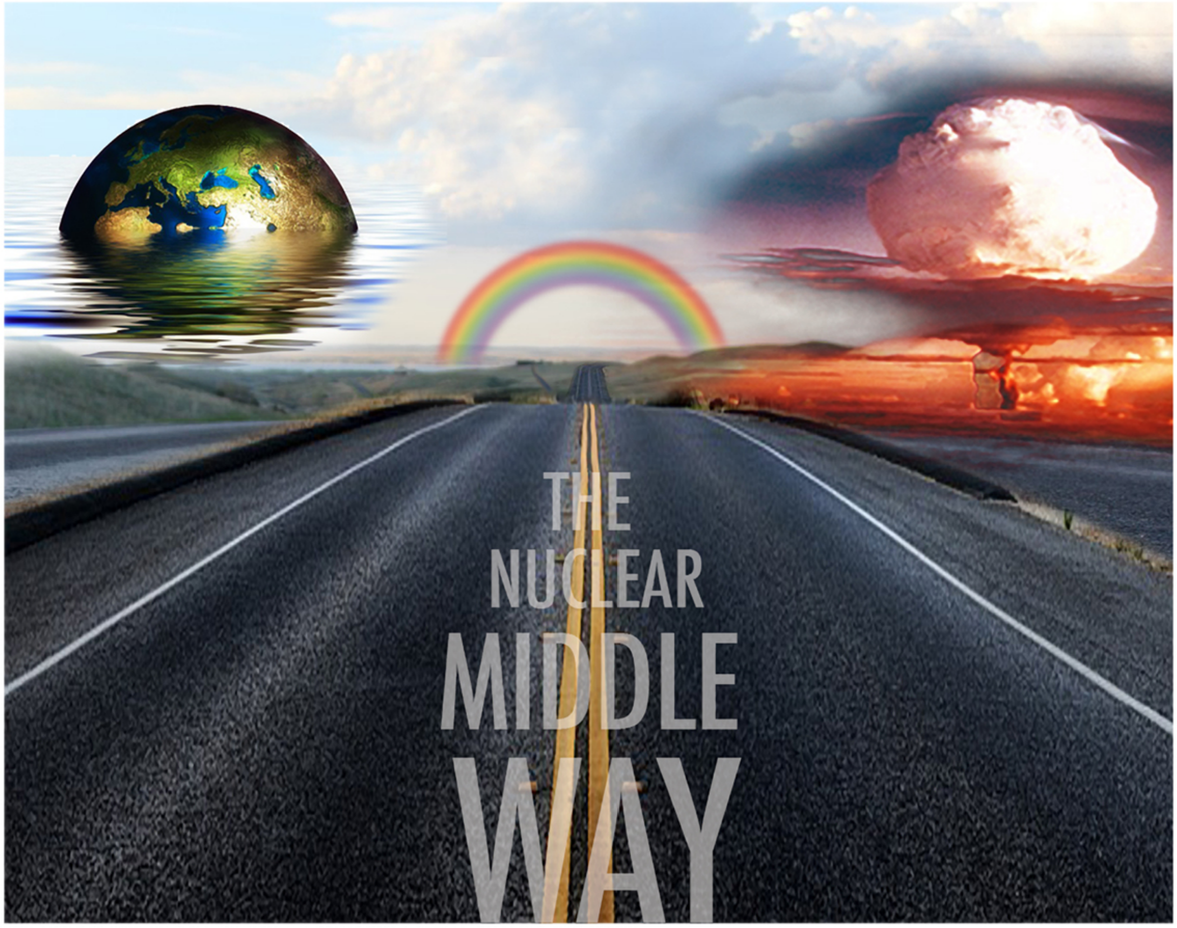
Nuclear weapons have saved lives and avoided war!

Richard Rhodes[10] argues the two nuclear weapons used in WWII ended a horrible world war. He further goes on to say the existence of nuclear weapons to date has saved and continues to save lives by the millions owing to deterrence. The antinuclear movement tends not to acknowledge this good news and instead focuses on the ever-present threat of nuclear weapons use. As horrendous as such use could be, it is often exaggerated and used as a club to bludgeon nuclear power and prevent prescient visions such as President Eisenhower's Atoms for Peace from being fully realized. The point Rhodes makes is the threat of nuclear weapons is minimized by a low but greater than zero number of nuclear weapons. Zero nuclear weapons might be unattainable and if attainable might create an unstable situation, because entities could hide nuclear weapons with the intention of using them to intimidate or control those who are nuclear-weapons free. Therefore, zero nuclear weapons agreements might not be achievable, sustainable or even desirable at least for the foreseeable future.

The peak of the existential threat posed by nuclear weapons arguably happened during the latter part of the 20th century and justifiably required urgent action. The urgent action to deal with the threat of nuclear weapons diverted attention from the other existential threats, such as energy poverty and global warming, which will be increasingly apparent as time goes on. This diversion of attention is understandable and excusable.[11] It is excusable because the dual threat of energy poverty and global warming has the entirety of the 21st century and beyond to be fully addressed. Let's get on with addressing these two threats!

Summary

How many deaths and harm caused by energy poverty and global warming can we tolerate by not following *the nuclear middle way*? I advocate building tens of thousands of Generation-IV nuclear power plants in shipyard like factories during this century, most especially the molten salt reactor or any other design that meets similar objectives, starting now to mitigate both energy poverty and limit global warming and other environmental problems from overuse of fossil fuels. Wise use of nuclear power can avoid the twin existential threats of nuclear war and energy poverty.



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