The Nuclear Options: Christian Perspectives on Fission, Fusion, and Our Energy Future

An Invitation Essay

Robert Kaita, Ph. D.

Editor's Note

Do we have any energy source that is available 24 hours every day, releases no CO_2 into the atmosphere, and does not kill birds? Yes. Nuclear fission. Then why do Sweden and France rely on it, but Germany is trying to phase it out to zero? Can we justify burying nuclear waste for thousands of years? Are there security risks? Will fusion ever be less than a few decades away? What insights might Christian perspectives bring to the table?

Robert Kaita has written an essay that informs us about what is currently available in fission and fusion, and raises a gamut of questions. He is well prepared to lead us on this topic after nearly forty years in nuclear fusion research at the Plasma Physics Laboratory at Princeton University. Bob's research interests include plasma heating techniques and plasma instabilities, and he developed diagnostic instrumentation and structural materials for fusion research devices. He also supervised the doctoral research of numerous students in the Plasma Physics Program in Princeton's Department of Astrophysical Sciences, and has served as the president of the American Scientific Affiliation, and is a member of our *PSCF* editorial board.

Readers are encouraged to take up one of the insights or questions, or maybe a related one that was not mentioned, and draft an article (typically about 5,000-8,000 words) that contributes to the conversation. These can be sent to Dr. Kaita at kaita9094@gmail.com. He will send the best essays on to peer review and then we will select from those for publication in a theme issue of *Perspectives on Science and Christian Faith*.

The lead editorial in the December 2013 issue of *PSCF* outlines what the journal looks for in article contributions. For best consideration for inclusion in the theme issue, manuscripts should be received electronically before 30 September 2020.

Looking forward to your contributions,

James C. Peterson, Editor-in-Chief
Perspectives on Science and Christian Faith

I. Introduction

The importance of energy, in the broadest sense, is suggested in the very earliest passages in the Bible. In the first chapter of Genesis, we read "Let there be light,"[1] "God saw that the light was good,"[2] and "God called the light day."[3] Thus, God's first act of creation by fiat, value judgment, and act of naming involves light, the most familiar form of energy known to humankind.

We later find descriptions of divine energy use in the Bible. When we learn that “the Lord rained down burning sulfur on Sodom and Gomorrah – from the Lord out of the heavens,”[4] we see energy as an instrument for judgment. Energy is also a means of salvation for God’s people, as when “a pillar of fire [gave the Israelites] light, so that they could travel … by night.”[5]

The Scriptures conclude by telling us that the necessity for energy will cease only at the end of time. As we read in the last book of the Bible, “The [Holy City, the New Jerusalem] does not need the sun or the moon to shine on it, for the glory of God gives it light, and the Lamb is its lamp.”[6] What we do between now and then for energy is the challenge that faces humanity.

The two nuclear options – fission and fusion – offer the possibility of round the clock energy without polluting the atmosphere. They have liabilities as well, including a popular perception of nuclear energy forever linked to the mushroom cloud that has become an icon of doom. The title of the essay was chosen to acknowledge this obstacle, as “the nuclear option” has entered the vernacular not to represent a hopeful solution to our energy needs, but a last resort that risks disaster for all. Cognizant of this reality, the goal of the present essay, and the papers it hopes to inspire, are to explore their strengths and weaknesses of nuclear energy from a Christian perspective.

II. The Fission Option

The beginnings of fission energy have been often been traced to the pioneering work of Otto Hahn, Lise Meitner, and Fritz Strassmann. In 1938, they were the first to realize that atoms of uranium can split, or fission, when bombarded by neutrons.[7] Most of the world, however, learned about the power of fission at the end of World War II. The Manhattan Project developed nuclear weapons that could be transported in bombers, and their use resulted in the destruction of Hiroshima and Nagasaki in the summer of 1945.[8]

Among the justifications for the atomic bombing of Japan was to avoid the invasion of its home islands. While the loss of life in Hiroshima and Nagasaki was staggering, the casualties among the Japanese and the United Nations[9] were expected to be far greater. They could have included my own *nisei*[10] father, who was in the US Army Military Intelligence Service and assigned to the first wave of the assault.

Such explanations were of little comfort to many who worked on the Manhattan Project, including its leader, J. Robert Oppenheimer. In a lecture in 1947, he said the following. “In some sort of crude sense which no vulgarity, no humor, no overstatement can quite extinguish, the physicists have known sin; and this is a knowledge which they cannot lose.”[11]

To continue with Oppenheimer’s theological phraseology, the way such sin may be atoned for could be by works. A path for redemption might then be through peaceful uses of nuclear energy, including fission plants for power generation. The nondestructive uses of nuclear energy were certainly of interest to the military. For the navy, the prospect of ships that did not require refueling for years on end was attractive, particularly for submarines.[12]

Nuclear energy thus had the potential of removing the tethers on navy ships that were imposed by fossil fuels and their associated logistical complexities. Starting from such potential for nuclear energy, it was perhaps not such a great leap to suggest that civilian fission plants could indeed promise power that was “too cheap to meter.”[13] If taken to represent a way to atone for the “sin” of nuclear weapons, two consequences could be traced to this viewpoint.

• Do the benefits of energy on demand – unlike solar or wind power – and the absence of greenhouse gas emissions during plant operation outweigh the liabilities of fission?

While the question is being currently debated, it was not asked at the dawn of the nuclear age. Rather, the first consequence of the desire to atone for the "sin" of nuclear weapons was the incentive to develop commercial fission plants as soon as possible. The US Navy led the way by working with the US Atomic Energy Commission to design pressurized water reactors (PWRs)[14] for shipboard use. In the PWR, water is pumped into the reactor core, where it is heated by energy from fission. Because the water is under high pressure, it does not boil.

The PWR approach was quickly adapted for commercial purposes, and now dominates the world's fission power plants. A PWR does have advantages compared to other light water concepts, including the need for less fissile fuel and a separation between the primary coolant that circulates the radioactive core and secondary coolant loop to produce the steam for the electricity-generating turbines. It has disadvantages as well, in that the PWR needs robust piping and a heavy containment vessel for handling pressurized water at high temperatures, requirements that also drive up its cost.

It might very well be that the pros outweigh the cons for PWRs compared to other light water reactors. However, their commercial adaption in the US could have been motivated at least in part to show the positive side of nuclear energy as soon as possible. Such a desire to atone for the sin Oppenheimer spoke of could have conspired against a more measured evaluation of alternative designs. In boiling water reactors (BWRs),[15] which are the second most popular for commercial power generation, the water circulating around the reactor core is allowed to boil and creates the steam for the electricity-generating turbines. The BWR is inherently larger and has a lower thermal efficiency than the PWR. These are disadvantages for submarines, which put a premium on reduced space and seaworthiness. The relative simplicity and safety of BWRs, however, make them more attractive for commercial power plants.

The choice between PWRs and BWRs is an example where Christian perspective can be brought to bear. Removing the salvific incentive can provide more balance in the decision-making process, not only in the fission reactor question but on other key issues. Our salvation is from

God and not how we generate electricity. We can then honestly weigh concerns of nuclear proliferation and the consequences of terrorism against the challenges of large-scale energy storage if wind and solar become our dominant energy sources, and thoughts on how this could be done are welcome.

Faith in Christ is not necessary for moral imperatives. However, it may be more readily foundational for a call to more humble lifestyles and better stewardship of God's creation that are needed to go non-nuclear without returning to fossil fuels. Views from such a perspective are encouraged, for example, in exploring how effective countries such as France and Germany are in following very different policies toward fission energy.

• What obligation do we have to future generations for safe storage of nuclear waste?
A zero tolerance for failure might be a second consequence of the atonement mindset. Such a goal could be both laudable and necessary, given the public perception that puts any nuclear accident in the highest class of danger. This has practical consequences, however, that are not so attractive. Once a reactor design has been vetted, the need to avoid failure at all costs provides a strong disincentive for innovations that deviate from the tried and true.
The mentality could also be behind the difficulties in finding a suitable site for long term storage of nuclear waste. For the first time in human history, the need to guarantee the performance of a facility for 10,000 years and beyond has essentially imposed the potentially unattainable requirement of absolute safety forever. While not the only hindrance to the construction of the Yucca Mountain Nuclear Repository,[16] such issues might be a testament to the futility of salvation through works.

Alternatively, we can decide that safe, long-term storage of nuclear waste does not matter. If we assume that the earth is 4.5 billion years old and its history was represented by a 24-hour clock, humans would not appear until about a minute before midnight. Humanity, and what we do as part of it, is then of little consequence in light of the entire history of our planet. Critiques of such a viewpoint from the Christian perspective are welcome.

III. The Fusion Option

The principle behind fusion energy is to harness the energy released not from the splitting of nuclei as in fission, but by bringing them together to fuse. This occurs naturally in stars, which are made up of hot, ionized gases, or plasmas. They are large enough to allow gravity to overcome the Coulomb barrier that keeps nuclei apart, enabling the strong nuclear force to allow fusion. The leading concept for controlled fusion on earth is to confine plasmas in a toroidal magnetic bottle, or tokamak.[17]

Fusion power production using the tokamak approach was demonstrated in experiments in the 1990's in the Tokamak Fusion Test Reactor (TFTR)[18] in the US and the Joint European Torus (JET)[19] in the UK. They used deuterium and tritium, which were the two isotopes of hydrogen that had the fusion cross section that peaked at the lowest energy. The fusing of deuterium and tritium nuclei results in a helium nucleus and 14 MeV neutron, and output power produced through neutron production in JET and TFTR approached the input power needed to heat the plasma for fusion to occur.

The ratio of output power to input power in fusion is often expressed by the parameter Q, and JET and TFTR achieved a Q of about unity. Because of inherent inefficiencies in any form of electricity generation, considerably higher values of Q are needed for a fusion power plant, and a much larger device is under construction in France to achieve them. Also designed as a tokamak, the project is called ITER.[20] The major partners are China, the European Community, India, Japan, Russian Federation, South Korea, and the US, and they represent about half of the world's population.

The name ITER was formerly an acronym for the International Thermonuclear Experimental Reactor. The project was then rechristened as "The Way," from the meaning of ITER in Latin. It is not clear how aware those responsible for the change were of its implications as Christians might understand them. Its salvific sense, however, seems implicit in a quote on the ITER website, which states that "The challenge [of fusion] to create a source of energy similar to that of the sun itself in a reactor is yet to be conquered. With dedicated research and unprecedented international collaboration, scientists believe that there is light at the end of the tunnel to re-create this energy in a reactor that can deliver energy to the electricity grid."[21]

The rhetoric of fusion is reminiscent of the promises made in the early days of commercial fission. Deuterium is plentiful in seawater and tritium can be "bred" from lithium, which is a common metal. The fuel for fusion has thus been called "nearly infinite," and so too has the potential for generating "electricity too cheap to meter." Such claims, however, belie the enormous remaining technical challenges even if ITER is able to achieve $Q > 10$ as hoped.[22]

Optimization for fusion, unlike fission with options like PWRs and BWRs, is in the direction of higher power densities. This is because for the first time in power production, the containment for the fuel, and not the fuel itself, is what primarily determines the cost of energy. There is thus a premium on containing as much fusion plasma as possible within a magnetic bottle of a given confinement capability. This puts requirements on materials to withstand heat and radiation loads that cannot be reduced by increasing the surface area, since the cost of electricity needed for the magnetic bottle rises nonlinearly with size.

There are alternatives, like fission-fusion hybrids. High Q is then less of a requirement, as long as the fusion neutron production is sufficient to trigger fission in otherwise non-fissionable fuels like U-238 or Th-232. Such an approach does have its drawbacks, including the fusion development still needed compared to breeder reactors.[23] Breeder reactors are fission reactors that generate enough neutrons to create more fissionable fuel than they use. Unlike fission-fusion hybrids, breeder reactors are already operational, and commercial viability as much as technical feasibility governs their further development.

Perhaps a greater psychological burden is from the fission-fusion hybrids presently available. In thermonuclear weapons, a fission explosion in their casings drives fusion in the core of the bomb.[24] An alternative may be to admit such realities, but also see how they led to peaceful uses for fusion. Andrei Sakharov is widely recognized as the father of the Soviet hydrogen bomb. He was also the co-inventor, along with Lyman Spitzer of Princeton University, of the tokamak concept. Fusion research at Princeton also initially supported the development of thermonuclear weapons in the US.[25] Calculations for this effort were conducted under the top-secret Project Matterhorn. The name was chosen by Spitzer, an avid mountain climber, who thought that such an iconic mountain would be inspiring. This was the precursor to the Princeton Plasma Physics Laboratory, where unclassified fusion energy research on TFTR and other devices has been conducted.

Fusion untainted by the sin of fission is still attractive, but this may end up being a greater obstacle than technology in preventing its timely contribution to the energy economy. Perhaps Christians can contribute a more balanced perspective by their recognition of the possibility for sin in all that we do. This should not be discouraging, as God expects us not to save ourselves, but to show our obedience as stewards of His creation.

IV. Conclusions and Invitation for Contributions

Both fission and fusion are hampered by legacies that impose conservatism in the way they have developed as energy sources. Both approaches are associated, in the public imagination, with tremendous destructive power. The dramatic effect of fission weapons on Hiroshima and Nagasaki have encouraged parallels with what could have happened to Sodom and Gomorrah. A “nuclear winter” is expected to follow a thermonuclear war, resulting in the wholescale destruction of life on earth. In fact, the very phrase is often used to describe the aftermath of the asteroid impact that wiped out the dinosaurs in the so-called Cretaceous-Paleogene mass extinction.[26]

For fission, the need to assure the public that an explosive nuclear device will not be built in their backyards has encouraged a culture of zero tolerance for failure. Even that has shown its limitations, given the events at Chernobyl and Fukushima. Such considerations are less of a concern for pure fusion, due to the absence of fissile materials in its fuel cycle and the reduced threat of nuclear proliferation. However, decades of research have established the scale for devices that can produce fusion power, and conservative projections based on this work have dictated the large size of ITER. The net result is that both approaches have led to a conservatism in reactor design that critics suggest are hindrances to innovation.

• Are new approaches for fission plants intrinsically safer than more established designs?
Well established companies in the nuclear industry, like Westinghouse, have extensive experience in constructing power plants that meet the necessary regulatory requirements, but at high cost in money and time. The goal of new companies like TerraPower[27] and NuScale,[28] both located in the Pacific Northwest, is to provide more economical alternatives for fission power. Such approaches are attractive because they do not depend on unreasonable leaps beyond existing technologies, and the companies have tried to insure this with strong links to research universities and established industrial concerns. Instead, they seek simplified, safer designs that require less nuclear fuel at each reactor complex.

Answers to the question of fission power safety are welcome, from the perspective Christians can provide in assessing how wholeheartedly we should advocate mainstream and alternative approaches. For the latter in particular, the need to demonstrate how salvific they are might blind us to their unintended consequences. Scripture warns us of the human tendency to worship what we create. As we read in Isaiah, "[wood] is man's fuel for burning; some of it he takes and warms himself, he kindles a fire and bakes bread. But he also fashions a god and worships it; he makes an idol and bows down to it."[29] Such attitudes might then lead to hubris in the recent commercial startups that mainstream fission and fusion has been criticized for, particularly in their nascency. After all, it is Christ, not each Christian, who is intended to be the savior of our world. Rather, we are to be humble stewards of what is ultimately God's creation, which could require more patience than we would like.

• Will commercial fusion ever be possible?

Fusion research around the world has been dominated by government funded research in large national laboratories. Without a reasonable assurance that machines the size of power plants might work, the risk was considered too great for commercial ventures to justify the cost. More recently, however, the founders of private companies like Tokamak Energy[30] in the UK and Commonwealth Fusion Systems[31] of Massachusetts in the US, believe that our present knowledge base is sufficient for commercial fusion energy development. Like ITER, both companies are using variants of the mainline tokamak approach. They also include scientists and engineers that once worked for long-established fusion laboratories. However, they feel that large, international projects like ITER represent conservative approaches that may reduce technical risk, but significantly delay possible commercialization as well.

As with questions related to fission, thoughts on fusion from a Christian perspective are welcome. It may be that in the next few decades, both mainline approaches and commercial ventures demonstrate that there are no known materials that are suitable for fusion reactors. There are precedents for technologies that looked promising but were abandoned because they were impractical at the time. In the nineteenth century, the steamship *Great Eastern* required so much coal for its inefficient side wheel propulsion that there was little room left for cargo.[32] More recently, supersonic jetliners never became widespread, since they were uneconomical for passenger transport. [33]

The steamship concept was ultimately redeemed by the invention of the screw propeller, and similar breakthroughs might be in the offing for fusion. Since salvation for Christians ultimately does not depend on fusion or any other energy source, however, they can provide sober assessments of the present reality. This may not be so easy for those who do not share such transcendent faith. Pascal once stated the following. “Belief is a wise wager. Granted that faith cannot be proved, what harm will come to you if you gamble on its truth and it proves false? If you gain, you gain all; if you lose, you lose nothing. Wager, then, without hesitation, that God exists."[34] Many might be tempted to follow such logic in maintaining their faith in fusion to gain all in spite of what their research tells them. The faith Christians have in God rather than themselves, on the other hand, may keep them from such a trap.

It could be that the issues raised in this essay are indeed all technical, in that they solely involve science and engineering. They can then all be addressed independent of a Christian perspective, and our faith only becomes relevant in our personal behavior. This could suggest that our work in fission and fusion is morally neutral, but we must be careful about what this might mean in a fallen world. Technology creep[35] provides a cautionary tale. After the acquisition of nuclear weapons by the former Soviet Union as well as the US, their leaders concluded that their use was simply unthinkable. The very appropriate acronym for their position was "MAD", which stood for Mutually-Assured Destruction. Ironically, the approach required that each side maintain an arsenal to carry out this threat, and an army of scientists and engineers was needed to insure its reliability. This led to improvements in warhead miniaturization and targeting accuracy that transformed weapons intended for MAD, and thus never supposed to be used, into a means of "winning" a nuclear war if used in a first strike. Nuclear warfare thus became thinkable, not because of anyone with an insidious agenda, but because of scientists and engineers simply doing their jobs.

[1]*New English Bible,* 1985 (Grand Rapids: Zondervan) Genesis 1:3

[2]*ibid.* Genesis 1:4

[3]*ibid.* Genesis 1:5

[4]*ibid.* Genesis 19:23

[5]*ibid.* Exodus 13:21

[6]*ibid.* Revelation 21:23

[7]O. R. Frisch, Nature **143**, 276 (1939)

[8]Richard Rhodes, *The Making of the Atomic Bomb*, 1986 (New York: Simon and Schuster)

[9]Official name of the alliance against the Axis countries during World War II

[10]Second generation American of Japanese ancestry

[11]J. Robert Oppenheimer, *Physics in the Contemporary World*, Arthur D. Little Memorial Lecture at M.I.T. (25 November 1947)

[12]Francis Duncan and Richard G. Hewlett, *Nuclear Navy: 1946-1962*, 1974 (Naval Institute Press (Annapolis: Naval Institute Press)

[13]Lewis L. Strauss, Chairman, US Atomic Energy Commission, in presentation to National Association of Science Writers in New York (September 1954)

[14]Samuel Glasstone and Alexander Sesonkse, *Nuclear Reactor Engineering,* 1994 (London: Chapman and Hall)

[15]James J. Duderstadt and Louis J. Hamilton, *Nuclear Reactor Analysis,* 1976 (Hoboken: John Wiley and Sons)

[16]Lee H. Hamilton and Brent Scowcroft, *Blue Ribbon Commission on America's Energy Future Report to the Secretary of Energy* (26 January 2012)

[17]John Wesson, *Tokamaks, 4th Edition,* 2012 (Oxford: Oxford University Press)

[18]J. D. Strachan *et al.,* Plasma Physics and Controlled Fusion **39,** B103 (1997)

[19]JET Team (prepared by M. L. Watkins), Nuclear Fusion **39,** 1227 (1999)

[20]www.iter.org

[21]*ibid.*

[22]*ibid.*

[23]A. E. Waltar and A. B. Reynolds, *Fast breeder reactors*, 1981 (New York: Pergamon Press)

[24]Richard Rhodes, *Dark Sun: The Making of the Hydrogen Bomb*, 1995 (New York: Simon and Schuster)

[25]*ibid.*

[26]L. W. Alvarez, W. Alvarez, F. Asaro, and H. V. Michel, Science **208**, 1095 (1980)

[27]www.terrapower.com

[28]www.nuscalepower.com

[29]*New English Bible,* 1985 (Grand Rapids: Zondervan) Isaiah 44:15

[30]www.tokamakenergy.co.uk

[31]www.cfs.energy

[32]Chester G. Hearn, *Circuits in the Sea: The Men, the Ships and the Atlantic Cable,* 2004 (Westport: Prager)

[33]G. Endres, *Concorde: Aerospatiale/British Aerospace Concorde and the History of Supersonic Transport Aircraft (Airlife's Airliners),* 2001 (Eastbourne: Gardners Books)

[34]B. Pascal, *Pensées*, 1670 (Paris)

[35]D. Shapley, Science **201,** 1102 (1978)