Nuclear Energy – Fuel of the Future

Ever since the late 1930’s science has accomplished great technical leaps forward in its attempts to harness the power of the atom. The first nuclear reactor to generate electricity was at the experimental fast breeder station near Arco, Idaho in 1951. Dwight D. Eisenhower’s 1953 speech “Atoms for Peace” set the US on a course of strong government support for the international use of nuclear power. Since then, the US government has spent millions of dollars each year subsidizing current nuclear power plants and investing money to research the plants of the future. Currently, nuclear energy accounts for approximately 17 percent of global energy output. Many people have very high hopes for the future of nuclear energy, seeing it as the best possible replacement for current energy sources that are high in carbon emissions, contributing to pollution and global climate change.

Even the most ardent environmentalists see the potential of the atom for helping to alleviate the world’s carbon emissions. British ecologist James Lovelock, creator of the Gaia metaphor describing the earth as a living organism, appealed to environmentalists in 2004: “Only one immediately available source of energy does not cause global warming, and that is nuclear energy. I entreat my friends in the movement to drop their wrongheaded opposition to it.” While nuclear energy may not be the permanent eco-friendly energy source that many are looking for, it is still the best available alternative. Right now solar power, wind power, wave generators, and other clean energy sources are not efficient enough to generate the kind of power our society needs. Hopefully, nuclear will be able to advance enough technically to be even more efficient until other clean energy sources can catch up.

Currently there are a number of concerns that make nuclear an unappealing energy source to some. At the forefront of the debate is how to treat nuclear waste. Certain facilities, such as the Yucca Mountain storage facility in Nevada, propose to store the waste underground in caverns and to keep it there for hundreds of thousands of years. Others believe the best way to deal with spent reactor fuel is to process it in specialized and oftentimes very expensive processes. Also, processing spent nuclear fuel in the US is an especially touchy issue because of the American policy to ban nuclear waste reprocessing in other countries. It would set a very poor diplomatic example to tell the world not to do one thing and to turn around and be complete hypocrites about it.

New technologies for nuclear fission reactors are promising to make larger and far more efficient power plants than ever before. Asia in particular is leading the way with innovative nuclear plants that appear very encouraging. India, with the most reactors under construction in the world, is planning a system that relies mainly on thorium rather than uranium fuel. Japan is working on fast neutron reactors that can “breed” plutonium. China has announced that it intends to quadruple its nuclear energy output by the year 2020.

Despite the huge leaps forward for fission technology, fusion still promises to be the nuclear energy source of the 21st century. Fusion reactors are designed to replicate the nuclear reactions that take place at the center of the sun, combining hydrogen atoms under incredibly high pressures and temperatures. One of the most appealing aspects of fusion is its simple fuel. As opposed to using rare, highly radioactive fissile materials, fusion uses two different hydrogen isotopes (deuterium and tritium) to produce high energy neutrons and alpha particles. Deuterium is simply a hydrogen molecule with one extra neutron that can be found in abundance in the ocean and is therefore a nearly limitless fuel source. Other new methods for fusion are currently being experimented with but are not yet close to achieving the breakeven point and may never be commercially possible.

1. Proof of Safety at Yucca Mountain

Carter and Pigford’s 2005 paper on nuclear waste management concentrates on the Yucca Mountain waste storage facility. They begin by discussing the political issues surrounding the problems with the current plan for the facility involving agencies such as the Environmental Protection Agency (EPA) and the National Academy of Sciences (NAS). Later in the paper they discuss the problems surrounding the current design for protecting the spent fuel containers, and propose a very different strategy for containing the spent fuel.
In 2001 the EPA set standards for the Yucca Mountain facility setting the maximum allowed dose at only 15 millirems per year. The U.S. Circuit Court of Appeals in July of 2004 decided that the EPA had failed its legal obligation to heed recommendations of the NAS by requiring compliance only for the next 10,000 years, stating that peak risks could occur tens or even hundreds of thousands of years in the future. In August of 2005 the EPA put forward a two-tiered plan that would stay the same for the first 10,000 years and then up the annual maximum dose to 350 millirems for the next 1 million years.

The planned containment system has two major components. First, there is a corrosion resistant outer layer made of nickel-based alloy-22 and second, there is a large ‘drip-shield’ of titanium that will be built over the containers shortly before closure of the facility, which will be about 100 years after the waste has been moved to the area. A performance assessment using total system performance assessment (TSPA) showed that the containment system would begin to fail within the first few tens of thousands of years. A number of problems come from this design, not the least of which bring the 100 year delay caused by the installation of the titanium drip shield (due to an extremely complex design). The life-cycle cost of the entire project could be as high as $57 billion.

The authors propose a different method, centering on a man-made capillary barrier. They propose to surround the waste containers with a dry gravel layer, and to have that layer surrounded by a layer of sand. They believe that over time, radioactive elements dissolved in the water will emerge from the corroded containers and diffuse among the gravel surface, where it will remain trapped for hundreds of thousands of years (inferred from a performance assessment). The capillary barrier system would cost as little as $900,000 for each of the 14,700 waste containers, since most of the materials would be obtained locally, and the rare and expensive materials of the other system would be unnecessary.

The authors raise some good questions that must be considered in planning for something like this. The chemical and physical phenomena of the situation must be well-understood, one must have reliable testing and measurement, and there must be adequate theory for predicting far beyond real-time data. Should the Yucca Mountain project succeed it might suggest that hosting nuclear waste in terrain deemed an unusable wasteland could be profitable and safe.

2. Congress Tells DOE to Take Fresh Look at Recycling Spent Reactor Fuel

Kintisch’s 2005 article on new ways of dealing with nuclear waste offers both sides to a complicated problem. On one side you have those pushing for new technologies to safely dispose of spent reactor fuel. On the other side, there are those who would say that the new techniques are too expensive, set a bad diplomatic example, or causes too many security concerns.

The principle goal in recycling spent nuclear reactor fuel is to separate the uranium and plutonium from the used fuel rods. An aqueous method to separate the two, called PUREX, is already in use by the UK, France, and Japan. It works by dissolving the rods with acid and chemically separating the two fuels. So far, the Japanese have found that it is not economically viable, and the French have had mixed experiences. Another method, developed by the DOE’s Argonne National Laboratory, is similar to the PUREX method, but involves extra chemical steps to keep plutonium mixed with uranium and to retain nasty fission products that make the result too radioactive to steal. Another process called pyroprocessing uses electrochemistry to create a metal fuel that could include cerium-144 which remains very radioactive for two years, and therefore too hot to steal. It is also possible that it could be used in an adjacent reactor to provide power.

Many problems come along with recycling nuclear waste without even considering the scientific issues. Since plutonium is also used in nuclear weapons, critics say that producing more of it increases the likelihood that some will get into the wrong hands. The current U.S. ban on reprocessing nuclear fuel gives us the higher moral ground as we look at the North Koreans and the Iranians and tell them not to do it. This is a diplomatic issue that the U.S. has dealt with for nearly thirty years, dating back to 1977 when President Carter halted federal support for commercial recycling after India used civilian reprocessing to build their own nuclear weapons.

Problems with the procedures themselves could totally stop any recycling plans. Physicist Frank von Hippel of Princeton University points out that most U.S. spent fuel is about twenty years old, making the nonproliferation advantages of cerium irrelevant. Most experts say that the present technology is far too expensive to use on a broad commercial scale. A 1996 National Research Council study found that recycling existing U.S. fuel rods could cost as much as $100 billion. The processes could become economically feasible in the future if the price of uranium were to increase tenfold, not something totally unrealistic, because the demand for nuclear power is increasing.
While recycling spent fuel could yield additional nuclear fuel and less need for storage capacity at facilities like Yucca Mountain, one must consider its consequences, mainly the undermining of diplomatic efforts to stop reprocessing abroad. Anyway, for now it is prohibitively expensive.

3. Fusion Energy: Just Around the Corner

Brumfiel’s article on new forms of nuclear energy concentrates on the promise of a new fusion reactor built by the international ITER experiment. The concept of nuclear fusion has been around for around 50 years and is intended to generate electricity by mimicking the nuclear reactions that take place in the center of the Sun. Until recently both Japan and France have been competing over who would host the new reactor. In the end Cadarache, in southern France, was chosen as the site of the machine. ITER is sponsored by six countries: China, the EU, Japan, South Korea, Russia, and the United states. With the site of the experiment finally chosen, construction is scheduled to begin this year and should be completed by 2016.

The ITER reactor is designed to heat hydrogen to hundreds of million of degrees centigrade and then extract energy from the resulting plasma while holding it stable for a few minutes. Most fusion researches agree that the reactor will likely be able to generate more power than it consumes but it may be difficult to hold the plasma stable for as long as is hoped.

Fusion is a simple idea but is difficult in practice. Unlike fission, in which heavy nuclei decay to produce energy, fusion generates energy by combining two hydrogen atoms with each other to form a new element, usually helium. These collisions can be very difficult to arrange because of the natural repulsion between the two positively charged hydrogen atoms. To overcome this, the molecules must be moving very fast (hot) and must be very tightly packed together (dense). This is achieved in the Sun by the massive gravitational pull generated by such a massive object. Gravity is strongest at the center of the Sun, and that is why most hydrogen fusion occurs in its core.

Research following World War II by both the United States and Russia lead to the most successful design for a fusion reactor: the tokamak. The tokomak works by holding hot dense plasma within the reactor walls using a series of overlapping magnetic fields configured in a doughnut shape. When ITER was first proposed in 1985 the tokamak was the clear choice because it was the best researched and most well known.

ITER’s goal is to hold a hydrogen fuel composed of mostly deuterium and tritium (both isotopes of hydrogen) together as plasma for between seven and fifteen minutes while heating it to more than one hundred million degrees centigrade, generating about five hundred megawatts of energy. The current record for sustained high pressure, high temperature plasma is only 24 seconds. The ITER reactor is designed to surpass that mark by using superconducting magnets 25 percent stronger than those used the other tokamak reactors. The other main advantage of the ITER machine will be its size. With a plasma volume of 840 cubic meters, the proposed reactor will be twice as big as any other fusion reactor.

A potential problem of the reactor is how to deal with all of the energy of the resulting fusion reactions. Most of the energy released will be in the form of fast neutrons which will irradiate the beryllium coated blanket surrounding the plasma. Some say that beryllium is not suited for such a purpose and believe that tungsten would better. In future commercial fusion reactors the heat will be used to generate steam to drive turbines connected to generators. It is very possible that in the time-span that it takes to get the tokamak reactor to work commercially a new fusion device will get more power output, but at this time it is the best choice, and if this project were not carried out it is possible that fusion research could die out.

4. Nuclear Power’s New Dawn

A group called the Generation IV International Forum (GIF), composed of ten nations, is planning on building the nuclear reactors of the future. Instead of the current reactors which are cooled by water or another water-based coolant, the next generation of reactors will operate at much higher temperatures (around 800 degrees Celsius) and will be cooled by a huge vat of molten lead. Thanks to this higher temperature, the reactor will be made more efficient by generating hydrogen fuel while as well as electricity. The new plants would include simpler safety measures that would not require the complicated backup systems that safeguard our reactors today. Since the reactors would be far less likely to suffer meltdown, whether induced accidentally or intentionally, they would become less of a terrorist target, something that is a constant concern of the nuclear industry.

Following the partial meltdown that occurred at the reactor at Three Mile Island, Pennsylvania, in 1979 there have been no new reactors in the US and no plans to build more. Yet, in March of 2004 a
A consortium of US energy companies stated that they intended to apply for a license, the initial step to building a reactor. In April of 2004 France stated that it intends to replace its 59 aging reactors with new ones. Also, Asian countries such as China and India are planning to build dozens of reactors to cope with increasing populations and soaring energy demands. The Bush administration is also in favor of nuclear energy playing a bigger role in the US energy industry. At a 2002 gathering of GIF officials in Tokyo, Spencer Abraham, the US energy secretary, showed the government’s support for nuclear energy arguing that it would help cope with reducing carbon dioxide emissions and the supply the increasing demand for energy.

One of the main limiting factors to the project is the modern nuclear technology at our disposal. For nuclear energy to make a major comeback they will need to be much cheaper to run, meaning more efficient. Of the six new reactor designs proposed by the GIF, only three of them will likely reach the testing phase. Once at that level it will cost about one billion dollars to build a test reactor for each design. All of the proposed designs operate between 500 and 1000 degrees Celsius, while most modern water-cooled reactors operate at around 300 degrees. One of the proposed designs called the very high temperature reactor (VHTR) could squeeze out as much as 50 percent more electricity from the same amount of fuel compared to conventional reactors.

Developing new materials for the construction of the next generation reactors will be a major obstacle that will need to be overcome. All of the designs call for untested engineering, including new ultra hard materials that will be able to resist continuous high temperature, neutron bombardment, and corrosive reagents.

Unfortunately the earliest that any new reactors will be operational will likely be in fifteen to thirty years. According to Alain Bugat, head of France’s Atomic Energy Commission: “This is long-term research; if we have a working demo of some of the designs by 2030 we will be doing well.” Because of the stagnation caused by the small number of reactors built since the seventies and eighties, nuclear energy will likely lose its global energy share of 17 percent without major progress. Government subsidies and proposed carbon taxes will be a crutch that the industry can rely on for a while but to make true progress the nuclear industry must be able to support itself.

5. Asia’s Demand for electricity Fuels a Regional Nuclear Boom

A steadily growing demand for energy across Asia is causing a number of countries to turn to nuclear fission as a reliable energy source that won’t contribute to global warming via carbon dioxide emissions. With recent increases in oil and gas prices, nuclear energy is starting to look more affordable and across the continent many governments are taking action. Sixteen of the twenty five nuclear power plants currently under construction are in Asia. China is building a number of new nuclear power plants, while Korea and India are adding to their already extensive power grids. Japan has plans for expanding its nuclear power network, including a controversial fast neutron reactor.

China has the biggest plans for nuclear energy. Only nine nuclear power plants are currently operating there, supplying about two percent of the national energy output. Two more reactors are under construction in the eastern part of the country and will be online by the end of the year. The two new reactors will raise the nation’s total nuclear capacity by two gigawatts, a 30 percent increase. The government is aiming to have 6 percent of the nation’s power output to be nuclear by the year 2020. To meet this goal, China would need thirty new nuclear plants. Some even see a bigger leap forward after China meets its goals in 15 years. According to Zhang Zuoyi, head of the Tsinghua Institute of Nuclear and New Energy Technology “Nuclear power generation should reach 300 gigawatts by 2040, as it is the only solution to meet demand for energy in China.” Many Chinese experts don’t see these estimates as impossible, citing France building forty nuclear plants in the nineteen seventies and eighties as an example.

Japan’s plans for improving its energy output are not as major as the Chinese, but are still significant. Its 2004 nuclear power development plan projected nuclear power increasing from 25.5 percent of the national energy output in 2003 to 40.4 percent by 2013. Two new plants were brought online last year, two more are under construction, and 12 more are in different stages of design. India has eight plants under construction and Korea is planning eight more plants.

Although most of the reactors currently under construction are conventional water cooled plants, some Asian countries are experimenting with new “breeder” reactors. China, Japan, and India are all planning on building experimental fast-neutron reactors. Fast reactors do away with water-based coolants and use more highly fissile fuels, such as plutonium or mixtures of plutonium with uranium. They are called “breeder” reactors because they can be used to produce additional plutonium that can be recycled as
reactor fuel. Western governments once saw the fast reactor as the next generation of nuclear energy, but along with it came too many problems. The experimental plants built by the US, UK, Russia, and France were prone to leaks of the molten sodium used as a coolant and relied on complex heat-transfer systems. Commercial hopes were put to rest when it became clear that the fast reactors would cost several times more than conventional water reactors.

These fast-neutron reactors are clearly an appealing idea to growing Asian nations. It makes far more sense to build fewer, more efficient reactors than to build many small ones.

6. India’s Homegrown Thorium Reactor

Since the 1950s, India has paved its own way for its path to successful nuclear power. India’s refusal to sign the Nuclear Nonproliferation Treaty in 1968 and its detonation of a nuclear device in 1974 isolated the nation and prevented it from taking part in the developing technologies created by other nuclear nations. Recently it was excluded from the international group sharing fission technology. Despite its isolation, India has found its own way for efficient and innovative nuclear power that takes advantage of its natural resources.

In 1958 India announced its ambitious three-stage plan to exploit its massive thorium reserves. Despite having a very small amount of uranium ore, India has about 225,000 metric tons of thorium. Thorium is not a fissionable element, but when irradiated with neutrons from another material (such as uranium) some thorium becomes uranium-233, which can fission and sustain nuclear reactions. The first stage of the plan involved building pressurized heavy-water reactors powered by uranium. Twelve of these reactors are currently operational. The water reactors would yield plutonium as a byproduct and would be used for implementing stage two of the plan.

Stage two would go into effect once sufficient plutonium reserves had been extracted from the spent cores of the water reactors. The extracted plutonium would be used as fuel for fast-neutron reactors, which would irradiate thorium and produce uranium-233 as a byproduct.

In the third stage, advanced heavy water reactors would burn a mixture of uranium-233 and thorium, generating most of the power from the thorium. Many other nations have studied this approach to nuclear power production, but none have attempted to use it for electricity.

Stage two began officially in October of 2004 when a government-owned company began building a 500 megawatt fast-breeder reactor that will use fast neutrons to produce the uranium-233. The core of this reactor will use a ‘seed’ fuel containing uranium and plutonium oxide; this will send neutrons into a surrounding thorium blanket, hopefully irradiating it. This new reactor is based on a 40 megawatt fast breeder test reactor that has been running in the township of Kalpakkam in southern India. The test reactor has been running without major problems since 1985 and Indian nuclear energy officials are confident that the larger version will work just as well.

The Indian AEC (Atomic Energy Commission) estimates that the fast breeder will cost around 700 million dollars and produce 500 megawatts. India’s long term goal is to increase nuclear electric output from 3360 megawatts today to around 275 gigawatts by the year 2050, but construction of the Kalpakkam reactor has not been without incident. The December 2004 tsunami flooded the foundation of the construction site and set the project back approximately four months.

Since India’s reactors are still dependent on uranium, and because India has so little of it, the nation cannot fulfill its aspirations completely on its own. At a meeting last month with Prime Minister Manmohan Singh, President Bush called India “a responsible state” with “advanced nuclear technology.” Good relations with countries such as the US will be crucial for obtaining nuclear fuel.

7. Reduced Turbulence and New Opportunities for Fusion

Nuclear energy has always been seen as the future of energy, and fusion energy is the future of nuclear. A simple fuel supply of deuterium and lithium solves many of the problems that come along with conventional nuclear energy. Until recently fusion had been only a dream because of the limitations of technology, but many innovative ideas are breaking down these barriers.

The main obstacle has been the problem of confining a plasma (an ionized gas). Fusion energy is achieved by heating the fuel to thousands of degrees Celsius needed to get atoms to fuse. Recent findings on plasma behavior at these temperatures have led to hope that fusion reactors may become something in the future other than a pipedream.

The use of magnetic containers to confine thermonuclear plasmas for fusion has been an area of significant research since 1946 when Thomson and Blackman obtained a patent for the concept. Their
research has been the foundation of modern fusion theory. Thomson and Blackman gave rise to the idea of ‘energy confinement time,’ meaning the amount of time taken for the plasma energy to leak out of the magnetic bottle. In a fusion reactor this energy must be replaced by heat produced in the fusion reactions. Current scientists are able to confine plasmas at temperatures of nearly a hundred million degrees for many seconds in a toroidal magnetic field chamber, also known as a tokamak.

Part of the main problem of fusion theory is the behavior of the plasma itself. In an ideal (physically perfect) situation the motion of charged particles in a magnetic field is restricted to a spiral, as dictated by the field lines. At the extremely high temperatures of the plasma, ions are moving at incredibly fast speeds and are constantly colliding with each other. These random and unpredictable collisions pose great problems. Also the diffusion of particles and thermal energy across magnetic field lines should be (according to conventional physical theory) significantly slower and cooler than actually observed in experiments. Truly, if the temperatures were as low as physical theory dictates, fusion energy would hardly be worth the effort as an energy source. This discordance between particle physics theory dictate and experimental results is known as “anomalous transport.”

The factors that dictate how the plasma works are particularly complex. The shape of the magnetic bottle, the profiles of plasma density and temperature, and the dynamics of both ions and electrons play a critical role in plasma behavior. In 1982 at the Max Planck Institute for Plasma Physics in Germany when the ‘H-mode (high-confinement mode) tokamak reactor was invented, physicists found that when the heat leaking out of the plasma reached a critical threshold, a radial electric field, a plasma velocity gradient, and a steep pressure gradient spontaneously arose at the edge of the plasma. In other words they found that when heat leaks from the plasma, temperature, pressure, and speed change, resulting in an electric field. This better understanding of plasma behavior resulted in dramatic increases in confinement time, mostly because of a reduction of turbulent transport at the edges of the plasma.

In the 1990s it was discovered that these sorts of edge barriers could also be produced in the interior regions of the plasma, called internal transport barriers or ITBs. These technological advancements are constantly evolving and making fusion energy more controllable due to a better understanding of plasma and how to handle it.

8. For Nuclear Fusion, Could Two Lasers Be Better Than One?

While the main focus of the international ITER fusion reactor experiment is the standard supermagnetic compression method, another school of thought is also being explored. Advocates of the new laser ignition fusion method claim that it would be less expensive, and more energy efficient than the standard tokamak reactor.

The more commonly accepted fusion theory plans to use huge superconducting magnets to contain hydrogen plasma and heat it enough for the nuclei to fuse. One of the significant problems so far with the tokamak fusion method is that it is often difficult to achieve breakeven, the point at which the energy produced equals that amount put in.

The laser ignition method takes a totally different approach. Using lasers the size of a sports stadium instead of magnets to compress and ignite the fusion, scientists hope to crush millimeter sized capsules of hydrogen to densities far beyond any metal. This extreme compression also yields incredibly high temperatures (essential for fusion) hotter than the core of the sun, but this technique, also known as inertial confinement fusion, is far behind the ITER-style reactors in terms of experimental success. Some of these lasers are already being built at the National Ignition Facility in California and at the Laser Megajoule in France by the French Atomic Energy Commission.

Even within the laser fusion method there is another theory that may prove to be more economical than either of the others. Using such a powerful laser to do two jobs may not be the most energy effective way to get the process done. With the standard laser fusion method one enormously powerful laser accomplishes both extreme compression of the fuel and igniting it. Fast ignition uses two lasers, one for each job. It seems to make much more economical sense to use two much smaller and less powerful lasers to accomplish what one highly costly and energy inefficient one can do.

Both methods aim to achieve fusion in much the same way. Light beams are focused on a small, spherical shell containing the hydrogen isotopes deuterium and tritium. The high temperatures cause the outer shell of the capsule to boil off, and the material inside shrinks in then implodes. The enormous pressure inside the center of the sphere then strips electrons from the isotopes creating hydrogen plasma.

Experimental evidence so far is promising. A team of researchers in Japan have already demonstrated that fast ignition can in fact achieve fusion. Unfortunately the method is still far from
achieving breakeven. The next step for experimental fast ignition is to upgrade existing lasers so that larger scale fusion experiments can occur (hopefully yielding enough energy for breakeven). One of the main positives to fusion is that it takes only a third of the confinement necessary for standard inertial confinement. “This translates into savings of a factor of 10 in the amount of energy needed to drive the compression” says Peter Norreys of the Central Laser Facility in Didcot, U.K. The potential implications of these experiments are enormous. If fusion can be achieved in a way that can generate enough energy at a much lower energy cost it, it would be a much more commercially viable method than the ITER reactors.

9. Fusion Power: Will it Ever Come?

Although the substantial power that nuclear fusion can yield has been known for half a century, engineers have had quite a difficult time harnessing that power for usable energy. At one point in our history even nuclear fusion was a pipe dream that some thought impossible, and now 14% of the world’s electricity is generated by commercial nuclear fission reactors. The two requirements that need to be accomplished to generate electricity from a fuel are to get it to a high enough temperature needed to convert the fuel into heat, and then converting that heat into usable energy (electricity).

One of the greatest benefits of nuclear fusion reactions is the ample supply of fuel since only heavier water and other light elements are needed. The main problem with commercial fusion is getting the isotopes to a high enough temperature to collide and fuse. The principle goal for many of these reactions is to achieve ‘breakeven,’ the point at which the total energy output is greater than the energy spent to achieve the reaction. The lowest temperature fusion reaction is the fusion of deuterium and tritium which requires stable plasma at a very high density at about 100 million degrees Kelvin. Obviously it takes an enormous amount of energy to achieve such a high temperature, and it is therefore very difficult to get net power-producing plasma from this reaction.

Considering the next part of the problem of having a usable fuel, it is also problematic converting the heat of the reaction to usable energy. Each fusion reaction between a single tritium and deuterium molecule yields about 17.4 MeV of energy. 14 MeV of this is contained by the free neutron yielded by the reaction. The neutron is slowed and absorbed by a blanket of lithium, yielding more usable tritium. Also, the neutron causes everything in the reactor to become radioactive. Because of this the shield beyond the blanket, the reactor vessel, and the reactor vacuum vessel all become more brittle and therefore unsafe.

Vacuum leaks in the reactor are also a concern because of the great size of the proposed new fusion reactors. A fusion reactor 20 meters in diameter would need many more connections for heat transfer to maintain the integrity of the vacuum within the reactor. Due to the very high temperature and the continual stress of the reactions leaks would eventually occur and would be very difficult to repair.

Materials costs are another factor that significantly affects the future of the fusion reactors. The amount of material used is dependent on the nature of the reactor. The blanket-shield component must be at least the area of the vessel and the thickness is dependent on the heat transfer rate desired. To absorb a 14 MeV neutron and to achieve a controllable heat transfer rate of about 0.3 MW/m² the shield must be about 1.7 m thick. This amounts to a total volume of 3400 m³ of a metal with a density of 3 g/cm³. The total weight would be about 10,000 tons and at a cost of $180 per kilogram this would amount to a cost of $1.8 billion for the materials cost of the shield component alone.

The estimated total plant cost comes out to about $15 billion. Since the plant yields 1,000 MWe, this would make the cost of each kWe about $15,000, far outside of the competitive price range for commercial energy. So far the US government has spent about a quarter of a billion dollars each year researching fusion development for the past fifty years. The enormous advancements in the nuclear and materials technology are significant, but at this point fusion is not, and very likely never will be an economical power source. Fusion is being marketed to the public as the sensible alternative to carbon-emitting energy sources that are contributing to global warming, but until this technology becomes both technically and economically feasible fusion will only be physical theory rather than practical energy.

10. Researchers Raise New Doubts About Bubble Fusion Reports

Bubble fusion is a new type of fusion created by Purdue University nuclear engineer Rusi Taleyarkhan. This new field is being called into question based on reports from Purdue University colleagues saying that Taleyarkhan removed shared equipment, refused to share raw data, and has attempted to stop them from publishing results that were contrary to his own published work. After the allegations were first made public in March 10th’s issue of Nature a meeting was scheduled in
Taleyarkhan’s lab to verify the results. The meeting was attended by other researchers attempting to replicate the experiment.

The trial experiment was less than awe inspiring and cast even more doubt on the source of a purported signature of fusion. The concept that fusion can occur at the heart of collapsing bubbles has been controversial since it was first reported. Fusion normally takes place under the intense pressures and temperatures required for atomic nuclei to smash together at a high enough speed to combine and give off a large amount of energy. So far the conventional ideas have been to use intense lasers and powerful magnetic fields to achieve fusion. Four years ago in Science, Taleyarkhan claimed that the pressure and heat at the center of collapsing bubble in an organic solvent had also produced the typical signature of fusion. Hopes for the field were high, because if the process could be scaled up to produce significant amounts of energy it would likely be far less costly than typical fusion reactors.

In the experiment Taleyarkhan started with a small cylinder of acetone (an organic solvent) in which all of the hydrogen atoms had been replaced by deuterium (a hydrogen atom with an extra neutron). The cylinder was bombarded with intense ultrasound and hit with a pulse of neutrons (or alpha particles). The two treatments combine to cause bubble to form, swell, and the collapse, producing a tiny flash of light (a common phenomenon known as sonoluminescence). The authors also claim the experiment caused pairs of deuterium atoms to fuse, creating either tritium and a proton or helium-3 and an extra neutron (counted by the detectors in the experiment). One of the major problems other researchers have is based on the specific detectors used in Taleyarkhan’s experiment. Rather than accounting for loose neutrons from the reaction with a scintillation detector (the standard device for such a purpose), Taleyarkhan used plastic neutron traps. The principle drawback to these neutron traps is that they only measure the presence of the neutrons, but fail to actually record their precise energy level. Taleyarkhan supports his choice of the neutron traps by noting that unlike the scintillation detectors the traps need not be calibrated and that they still show irrefutable proof of neutrons.

One of the professors at the meeting presented some of the damaging evidence collected by one of his graduate students. The student’s calculations suggested that the energy levels of the neutrons that the bubble fusion experiment reported are not what the Purdue group should have seen had deuterium fusion actually been achieved. The report goes further to say that the results are a much better match for what the scintillation detector would have registered in the presence of Californium-252 (a radioactive isotope commonly found in nuclear laboratories). Despite the discouraging evidence that the reports of bubble fusion could be based on faulty data the field is still a promising idea that is a field that shows potential if it can be made to work effectively.

**Conclusion**

For nuclear power to maintain its current global energy share, significant technical advancements must be made. Since many of the world’s 441 operational nuclear energy facilities were built in the 1970s and 1980s many of them are falling into disrepair and a significant amount of money must be invested to maintain these reactors and to build new ones once the older generation is decommissioned. Larger and more efficient reactors are being researched and will likely be the most significant energy sources in the early 21st century. The new reactors being built by Japan, China, India and other Asian countries promise to be efficient and safe enough to be put into use on a larger scale. Unfortunately fusion power will not be a practical source of energy until at least 2050. No fusion reactor constructed has managed to generate more power than it has taken in. Also the reactors at this point are simply not economical. Even if the reactors were to generate enough energy, the cost of the reactors is prohibitively expensive to even consider for commercial use. Until nuclear technology can make substantial strides, fusion power will only be a pipe dream and nuclear fission will still remain the dominant form of nuclear energy.

**Papers Cited**