The Italian Navigator (1911-1928)
Presented March 15, 2011

Centennial Salute: Despite the fact that much of the foundation for "The Italian Navigator" began during the first two decades of The Kit Kat Club, nothing whatsoever was written about my subject or about anything closely related. The few papers that survive these early years were dominated by the arts as opposed to the sciences. In fact, my dear friend Al Kuhn would have fit perfectly with Kit Kat gentlemen of the last century. Most papers focused on literature and poetry. One essay was a lengthy poem written by Mr. Herrington on Columbus Dispatch letterhead. Charles Orr wrote about bookbinding. Early members seemed to be fond of writing an essay elaborating on the previous month's essay topic. One unsigned paper about diaries of the nineteenth century fed another paper by Mr. Cherrington about later diarists.

Written eulogies about Claude Meeker, author and reporter, who died in 1929 were impressive. Osman Hooper wrote about Meeker as did Lowry Sater, whose eloquent prose was notable. Notwithstanding the fact that no Kit Kat member of this era wrote about scientific matters, tonight's paper looks at the massive, world-changing developments in theoretical and applied physics that happened during the first four decades of the twentieth century.

The genesis of this essay started with an interest in learning details of and potential solutions to the United States' long-standing nuclear waste disposal problems. As frequently occurs with Kit Kat topics, my interest grew from a focus on the end of the nuclear cycle to the beginning of the cycle, and from there to the origin of theoretical physics that became the conceptual foundation of the science of nuclear physics. In short, where does it come from and how do we get rid of it?

I approach this subject with great trepidation. This is a classic case of a Kit Kat member delving into a topic that is outside of his vocational area of expertise. Indeed, my research has taken me into areas that have required days of additional research and learning, just to understand the content of a single sentence from a seemingly unintelligible paragraph. An early example included "Einstein's special theory of relativity has a wide range of consequences including time dilation and relativity of simultaneity."

I have chosen to start with Max Planck's quantum theory for which he won the Nobel Prize in Physics in 1918. However, it is worth noting that his work could not have been accomplished were it not for the giants who preceded him. These scientific thinkers include Pythagoras, Aristotle, Ptolemy, Copernicus, Galileo, Newton, Faraday, Roentgen, and Curie.

Max Planck enrolled at the age of twenty-five at the University of Munich and elected to study physics despite his professor's admonition against going into physics because "in this field, almost everything is already discovered, and all that remains is to fill a few holes." Planck despised experiments and immediately gravitated to theoretical physics.

Planck's personal life was marked by tragedies including the premature death of his first wife, the death of his second son at the Siege of Verdun and the execution of his favored son, Erwin, at the hands of the Gestapo in World War II after being implicated in a failed 1944 assassination attempt on Adolph Hitler.

Planck was thoroughly frustrated by his five year quest to understand how the intensity of electromagnetic radiation emitted by a black body (a perfect absorber) depends on the color of the light. Specifically, radiation changes color from red, to orange, to blue as its temperature rises. This could only be explained by the assumption or theory that energy existed in quantifiable units the same way that matter does, rather than just as a constant electromagnetic wave, and was therefore quantifiable. Thus was formed Planck's quantum theory as the foundation of quantum physics. Don't feel bad if you do not understand this concept. Indeed, Planck himself considered quantization as only a "purely formal assumption that I actually did not think much about." This failure to foresee a discovery's long term meaning is a recurring theme in the history of scientific research-+.

Fortunately, Planck's close friend, confidant, and music companion, Albert Einstein, did see the value and implications of quantum theory and built on Planck's work in connection with his work on the photoelectric effect for which Einstein won the Nobel Prize in 1921. Study of the photoelectric effect led to important steps in understanding the quantum nature of light (photons.) This was a necessary precursor to understanding fission which, in turn, was a precursor to developing and harnessing nuclear energy. Einstein published his special theory of relativity in 1905, and Planck was one of the few who immediately recognized its significance and validity

The next generation of physicists emerged at the beginning of the 20^{th} century. Enrico Fermi was born in 1901, the year of Planck's Quantum Theory development, and received his Ph.D. in Physics at the age of twenty-one. He was frequently cited as the "universal scientist" because of his rare ability, unlike Planck, to blend excellent, well-disciplined experimentation with theoretical physics. After receiving the 1938 Nobel Prize in Physics (at age 37,) he immediately emigrated to the United States with his Jewish wife, Laura, in order to escape Benito Mussolini's anti-Semitic, fascist Italy.

As the world's greatest neutron expert, Fermi immediately saw the possibility of a nuclear chain reaction based on Hahn's discovery of fission in 1939. Hahn noted that when an atom of uranium was bombarded by neutrons, the uranium atom sometimes was split or fissioned. It was then that Fermi realized he had observed fission during one of his 1934 experiments in which he bombarded uranium with neutrons and produced what appeared to be elements 93 (neptunium) and 94 (plutonium). Once again, the scientist did not fully grasp the significance of his discovery. Nonetheless, Fermi's earlier experiments allowed him to see the potential of Hahn's research and led to Fermi conducting the world's first self-sustaining, controlled nuclear fission reaction.

Fermi's lab was a 30' X 60' foot abandoned squash court beneath the west stands of Stagg Field football stadium at the University of Chicago. In the center of the room, shrouded by a Goodyear balloon, was a pile of black bricks and wooden timbers built in a lattice formation of 57 layers-square at the bottom and rounded at the top. The standing joke among the scientists working on the project was: "If people could see what we're doing with $1.5

million of their dollars, they'd think we are crazy. If they knew **why** we are doing it, they'd know we are."

Fermi coined the term "pile" simply because he continued to pile up nuclear material as it became available. Workers machined almost 400 tons of graphite bricks which were incorporated in the reactor to serve as moderators. Other pile components included six tons of pure uranium metal along with thirty-four tons of uranium oxide. The reactor's very low 1.5 watt output (1/4th the energy required to light a Christmas tree bulb) required no cooling. Despite the fact that scientists had some knowledge of the dangers of radiation, no shielding was provided. Fermi had convinced Arthur Holly Compton, (1927 Nobel Prize in Physics) and The Metallurgical Lab's Director that his calculations were reliable enough to rule out a runaway chain reaction or explosion which would have been catastrophic in one of the world's most densely populated areas. Compton never asked permission to conduct the experiment, nor did he inform University officials about the possible dangers. Better to ask forgiveness than beg permission. On a side note, Jim Kennedy, long-time law partner of Kit Kat member Herb Brown, had Dr. Compton as his freshman physics professor in 1950 at Washington University.

As the pile grew day-by-day, Fermi's calculations were confirmed and he was ready to proceed, and final preparations for the first test began. On the morning of December 2, 1942-the day war-time gas rationing began-about 50 observers crowded together on the squash court's observation balcony. Fermi and Compton manned the console. George Weil was the only person on the floor, adjacent to the reactor and was responsible for withdrawing the “zip” rod in exact increments as instructed by Fermi. If the reaction threatened to grow out of control he would reinsert the “zip” rod which was the last control rod to be removed. An automatic control rod would also insert itself if the reaction reached a pre-set level. In case the floor man became incapacitated or the automatic control rod failed to deploy, another scientist stood on the balcony with a most improbable nuclear safety device: an axe. In an emergency, he would cut a hemp rope connected to a control rod running through the pile and weighted heavily in the opposite end. The last line of defense consisted of a liquid control squad (graduate students) that stood on a platform above the reactor ready to flood the pile with a cadmium-salt solution.

At about 8:30 A. M. the group of scientists assembled in the squash court. At the north end of the court was a balcony about ten feet above the floor of the court. Fermi, Compton and others were grouped around the instruments at the east end of the balcony. Fermi had recently been reading “Winnie the Pooh” to improve his English so he named the instruments Tigger, Roo, Heffalump, Pooh, etc.

At 9:45, Fermi ordered the electrically operated control rods withdrawn. A small motor whined as the rods were removed. The balcony group quickly focused its attention on the radioactivity counters which had begun to click.

Shortly after 10:00, Fermi ordered “rod out,” which Zinn did and tied its rope to the balcony rail. Weil stood ready to remove the rod upon receiving instructions from Fermi.

At 10:37, Fermi said quietly "pull it to thirteen feet, George." The counters clicked faster. The graph pen moved up. All the instruments were studied, and computations were made.

At 10:44 Fermi ordered the rod out another foot. Again the clicking stepped up but soon leveled off. The pile was still not self sustaining.

Each time the clicking increased and leveled off. Fermi's slide-rule calculations had accurately predicted every movement of the indicators. He knew the time was near but he wanted to check everything one more time. The automatic control rod was reinserted manually and Fermi said famously "I'm hungry. Let's go to lunch."

They returned at 2:00. At 2:20 the automatic control rod was reset and George Weil stood ready at the zip rod. Fermi said "all right, George" and Weil removed the control rod to 12 feet. At 2:50 Weil removed the rod to 13 feet; at 3:20 to 13.5 feet. Each time the clicking increased dramatically but leveled off. Fermi said the next rod-removal-increment would "become self-sustaining…and will not level off." Finally, at 3:25, Fermi ordered: "Pull it out another foot," and the world's first controlled sustained nuclear reaction had begun. Everyone waited as Fermi ran through some final calculations on his slide rule, turning it over occasionally to jot down some figures on its ivory back. Many of those present reported later that they wished Fermi would have ordered the emergency rod replaced immediately. However, he was supremely confident that his hypotheses were consistent with calculations as verified every step of the way by his on-the-spot slide rule calculations. He allowed the reaction to proceed for twenty-eight minutes before ordering replacement of the emergency control rod.

Try to imagine the group's relief that the worst had not prevailed. They passed around a bottle of Chianti and offered a silent toast to the world's first controlled, self-sustained nuclear reaction. Compton called James B. Conant at Harvard and said famously "the Italian navigator has landed in the new world." The response: "How were the natives?" drew Compton's reply: 'Very friendly.'"

Thus began the race for "The Bomb," which America won in large part due to the efforts of many of the brilliant Jewish scientists who escaped Hitler's maniacal grasp. On March 15, 1943, (exactly 68 years ago this evening) Oppenheimer moved his testing operation to Los Alamos, New Mexico.

A few years before Fermi died of stomach cancer at the age of 53, he questioned his own faith in society's ability to make wise choices about nuclear technology. He said: "Some of you may ask what is the good of working so hard merely to collect a few facts which will bring no pleasure except to a few long-haired professors who love to collect such things, and will be of no use to anybody because only a few specialists at best will be able to understand them? In answer to such questions I may venture a fairly safe prediction.

"History, of science and technology has consistently taught us that scientific advances in basic understanding have sooner or later led to technical and industrial applications that have revolutionized our way of life. It seems to me improbable that this effort to get at the structure of matter should be an exception to this rule. What is less certain, and what we all fervently hope, is that man will soon grow sufficiently adult to make good use of the powers that he acquires over nature." Unfortunately, mankind's triumphs over nature have not been well managed.

We have talked about the conceptual foundation of nuclear physics and the dawning of the nuclear age. Now, let us look at how we get rid of nuclear waste.

Where does nuclear fuel come from?: Uranium ore, which typically contains about 0.5%-0.7% uranium is mined, crushed and concentrated. The first step in the concentration process produces the now-famous yellowcake concentrated powder. Yellowcake is obtained by mixing acid, alkaline, or peroxide solutions with raw ore to leach out uranium.

Yellowcake, which contains about 80% uranium oxide, is mixed with fluorine gas and converted to uranium hexafluoride, a powder at room temperature. Uranium hexafluoride is heated, creating a gas, which is sent to a centrifuge. Here the process of separating the U-238 isotope from the U-235 fissionable isotope begins. The gas is passed through many centrifuges until a U-235 concentration of 5%-7% is achieved. The concentrated gas is converted back to uranium oxide and formed into small ceramic pellets. These pellets are loaded into metal tubes that are bundled into fuel assemblies (12-17 feet tall) and shipped to nuclear power plants.

Three options exist for spent fuel storage: on-site pools, on-site dry cask storage systems, and centralized storage in dry casks.
When removed from a reactor, spent fuel is radioactively and thermally hot. It is stored in pools where active circulation of the surrounding water cools the radioactive content. As long as a nuclear reactor is operational, it requires a cooling pool for the hottest spent fuel.

About 30% of the total fuel load is removed to storage pools from the reactor every 18-24 months and replaced with fresh fuel. The spent fuel rods are immersed under at least 20 feet of water, which provides adequate shielding for nearby personnel. Spent-fuel pools have been managed safely around the world for 60 years.

To make room for more hot spent fuel, older and cooler fuel can be moved to dry cask storage. Fuel that has been stored at least five years in water has cooled enough both thermally and radioactively for it to be placed in dry-cask storage. Dry casks consist of a sealed metal cylinder containing the spent fuel inside a metal or metal/concrete structure. Dry-cask storage capacity is unlimited, safer than pool storage, passively cooled, and easily decentralized. Ohio has one such facility at the Davis-Besse plant near Toledo. Dry cask storage has been in use in the U.S. for over forty years without a single incident of radiation release.

One way to reduce spent fuel waste and its associated disposal cost is reprocessing. At commencement of research for this paper, I believed that reprocessing was the way to go. However, I have now concluded otherwise due to proliferation and safety concerns. No commercial reprocessing of nuclear fuel is currently undertaken in the U.S.

If Yucca Mountain survives President Obama's announcement that he intends to shut down the facility and begin a search for a replacement site, the most optimistic date for first emplacement of waste would be 2021. Even if the Yucca Mountain site is licensed over Obama's objections, the spent fuel must be transported. Total shipment of waste is expected to take 24 years to complete. Since 1965 there have been more than 2,700 small shipments in the U.S. covering about 1.6 million miles. Though four rail and four highway accidents have occurred, no one has been injured, no containers were breached and no radioactivity was released.

Safety and Security: Release of toxic radiation as a result of accidents continues to arouse public concern, even though evidence suggests the threat is much less than the public fears. Radiation release after the 1979 Three Mile Island accident was extremely small. Background radiation in the area is about 110 millirems per year. The average additional dose received by each of the two million residents in the area was one millirem. The maximum dose to any person inside the site boundary at TMI was 100 millirems-less than one year's background dose. Nonetheless, as a result of the accident, the industry was subjected to intense regulatory scrutiny resulting in a 47% drop in production of the 69 then operational reactors.

Conclusion: We have seen that nuclear energy's place in global society is both complex and highly charged. From concerns about greenhouse gases to weapons-grade fissile material proliferation and high capital costs, we are not offered a clear path to an optimal solution. My best guess is cost issues will sort themselves out as the cost of fossil fuels rise, the cost of nuclear power plants escalate dramatically, and the cost of solar declines. In the meantime, hedging our bets with a combination of fossil-fuel alternatives seems prudent.

Weapons grade proliferation is a major concern that is not likely to go away any time soon. Simply put, the have not countries want to join the club and the haves want to keep it to themselves. Absent new technology, conservation must play a major role in balancing the energy/cost equation.

Finally, we have learned that one thing leads to another. Just as Newton developed his innovations based on the previous work of Aristotle, Ptolemy, Copernicus and Galileo, Fermi's successes with nuclear fission could not have happened without the efforts of Max Planck and Albert Einstein.