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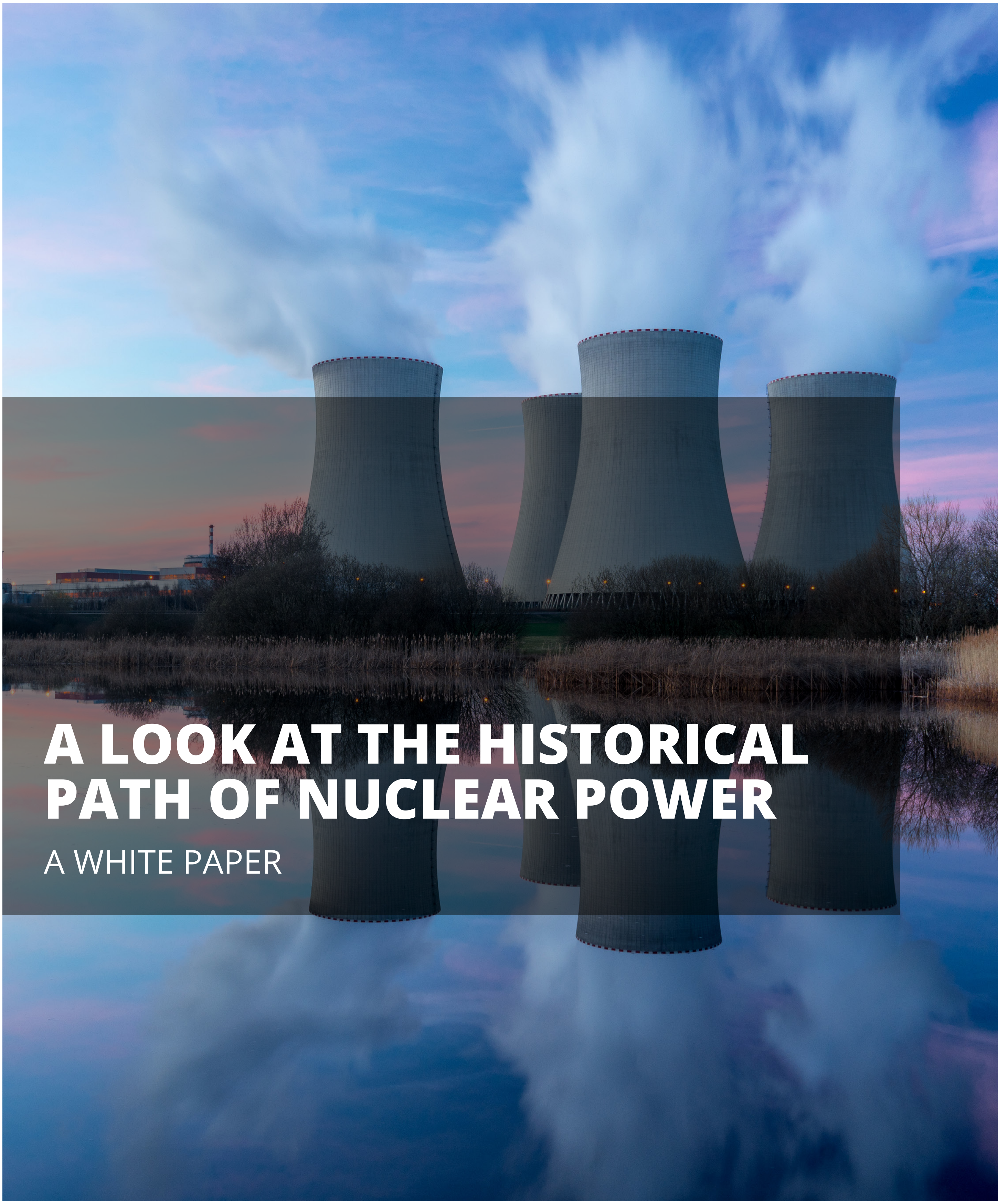

A LOOK AT THE HISTORICAL PATH OF NUCLEAR POWER

A WHITE PAPER

CONTACT INFORMATION

Jimmy Sneed
Managing Director, Critical Facilities
WB Engineers+Consultants

p. 737.263.3631
e. jsneed@wbengineering.com

THE DISCOVERY OF FISSION

In 1904, British physicist Ernest Rutherford, who many call the father of nuclear science, wrote the following about the theory of atomic structure:
“If it were ever possible to control at will the rate of disintegration of the radio elements, an enormous amount of energy could be obtained from a small amount of matter.”

The following year, Albert Einstein developed his theory of the relationship between mass and energy, $E=mc^2$. Over the next 30+ years, scientists worked toward proving Einstein’s theory. In 1934, Italian physicist Enrico Fermi conducted the first experiments that showed neutrons could split atoms.

Then in 1938, German scientists Otto Hahn and Fritz Strassman fired neutrons into uranium and were surprised to discover lighter elements, such as barium, in the leftover materials. They contacted their Austrian colleague Lise Meitner, who was working with her nephew Otto Frisch and Niels Bohr, to reveal their discovery. Initially, Meitner and Frisch thought the barium and other lighter elements produced resulted from splitting the uranium – or fissioning. However, upon adding the total masses of the fission products, they did not total the uranium’s mass. Meitner then used Einstein’s theory to show the lost mass was changed to energy, proving that fission occurred and confirming Einstein’s work.

THE FIRST SELF-SUSTAINING CHAIN REACTION

In 1939, Bohr came to the United States and shared with Einstein the Hahn-Strassman-Meitner discoveries. While at a theoretical physics conference in Washington, DC, Bohr also met Enrico Fermi. They discussed the possibility of a self-sustaining chain reaction in which atoms could be split to release large amounts of energy. The amount of uranium needed for a self-sustaining reaction is called critical mass.

In 1942, a group of scientists led by Fermi began developing their theories at the University of Chicago. On a squash court beneath the football field, they constructed the first nuclear reactor, Chicago Pile-1 (see Figure 1). The new reactor consisted of uranium and graphite with cadmium control rods. They discovered that since cadmium absorbs neutrons when inserted into the pile, fewer neutrons were available to fission uranium atoms. Once the control rods were removed, more neutrons were available to split atoms, and the chain reaction would speed up. On December 2, 1942, the world entered the nuclear age when the control rods were withdrawn, and at 3:25 pm (Chicago time), the nuclear reaction became self-sustaining.

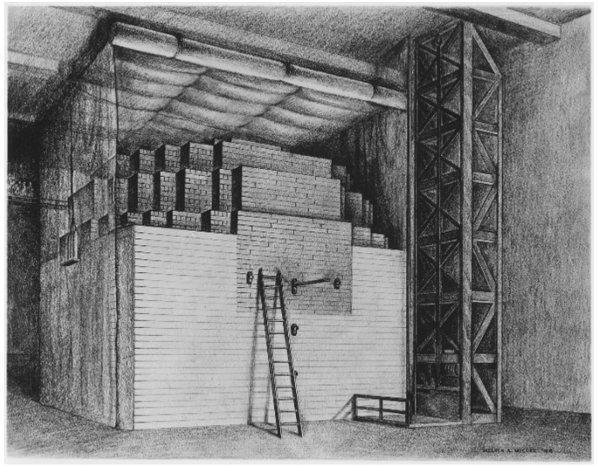

Figure 1 – Chicago Pile -1

Figure 2, First Electrical Power Generated from Nuclear Energy

However, given the world was in the beginning years of World War II much of the atomic research over the next several years would be dedicated to developing an effective weapon. This work would be code named the Manhattan Project here in the United States although other world powers at the time, particularly Germany and Japan, had intentions on producing a weapon as well. The new movie, Oppenheimer (July 2023), shows how the scientist that worked on the Chicago Pile-1 reactor would join this effort as well.

DEPLOYMENT OF NUCLEAR ENERGY FOR PEACEFUL APPLICATIONS

In 1946, after the war ended, the US government encouraged the peaceful development of nuclear energy for civilian uses, so Congress created the Atomic Energy Commission (AEC). During the war, some scientists had worked on breeder reactors that would produce the required fissionable material for chain reactions. The AEC authorized the Experimental Breeder Reactor I in Idaho, and on December 20, 1951, the reactor generated the first electricity from nuclear energy (see Figure 2).

At the same time, the US Navy was working toward nuclear-powered vessels. In 1952, they laid the keel for the first nuclear submarine, Nautilus. On March 30, 1952, the Nautilus started its nuclear power units for the first time and launched into service in 1954. On November 22, 1961, the world's largest ship, U.S.S. Enterprise, was commissioned with a nuclear reactor capable of operating up to 400,000 miles without refueling.

On August 30, 1954, President Eisenhower signed the Atomic Energy Act of 1954, which provided access to more nuclear technology for the civilian nuclear power program. The first commercial electricity-generating nuclear power plant was in Shipping Port, PA, and reached its full design power in 1957. This reactor was a light-water reactor that used ordinary water to cool the reactor during the chain reaction. Also, in 1957 the United Nations created the International Atomic Energy Agency (IAEA) to promote the peaceful use of nuclear energy while preventing the global spread of nuclear weapons.

The nuclear power industry in the US grew rapidly throughout the 1960s as utility companies came to see nuclear power as economical, environmentally clean, and safe. By 1971, 22 commercial power plants were in full operation throughout the US In 1973, utility companies ordered another 41 nuclear power plants. In 1974, the first 1,000-megawatt nuclear power plant, Commonwealth Edison's Zion I Plant, went online in Illinois.

On October 11, 1974, the Energy Reorganization Act divided the A.E.C. into two new agencies, the Energy Research and Development Administration (ERDA) and the Nuclear Regulatory Commission (N.R.C.). The ERDA carried out research and development, while the N.R.C. regulated nuclear power. One last change would happen in 1977 when the ERDA transferred its functions to the newly established Department of Energy (D.O.E.).

COMMERCIAL REACTOR ACCIDENTS THAT CHANGED EVERYTHING

The demand for nuclear-powered electricity began to slow in the mid-1970s due primarily to a decrease in electricity demands plus rising concerns over waste disposal and reactor safety. However, construction of nuclear power plants continued. On March 28, 1979, the worst accident in US commercial reactor history occurred when a loss of coolant from the reactor core occurred at Three Mile Island, Unit 2 (TMI-2) nuclear power station in Harrisburg, PA. The investigation revealed that mechanical issues and human error led to the accident. The accident released some radioactive gas, but not enough to cause any dose above background levels to residents. In addition, there were no injuries or adverse health effects from the accident.

Nearly seven years later, on April 26, 1986, the worst-ever civilian reactor accident occurred at the Chernobyl Nuclear Power Plant, Reactor #4, in the north of the Ukrainian SSR in the Soviet Union. In 1987, after investigation, the accident was determined to have resulted mainly from the operator's actions during a test. However, after the dissolution of the Soviet Union in 1991 resulted in the declassification of several KGB documents, a new investigation determined while the operators were inadequate, the RBMK reactor's design led to the accident. The Chernobyl accident released at least 5% of the radioactive reactor core into the environment, which spread into many areas of Europe. It resulted in the evacuation of 350,000 people, an eventual death toll of 4,000 – 27,000, and the creation of a 19-mile exclusion zone around the reactor.

As a result, in 1990, the International Atomic Energy Agency (IAEA) produced the International Nuclear and Radiological Event Scale (INES) to prompt communication of safety information in case of nuclear accidents (see Figure 3). The scale rates events from 0 to 7 based on the significance of the accident.

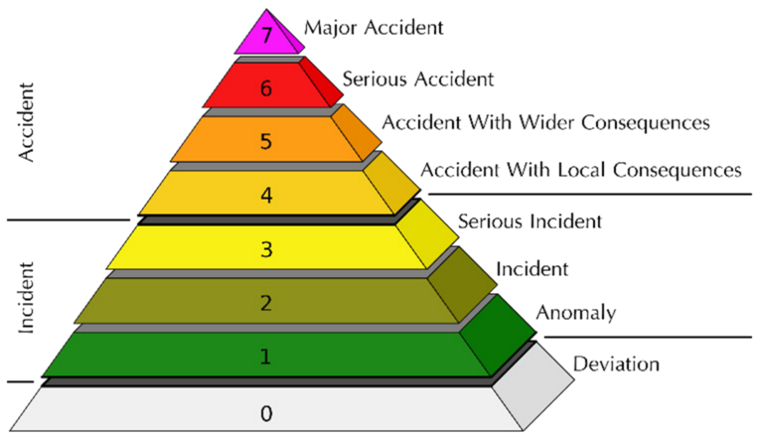

Figure 3 – International Nuclear Event Scale

The Three Mile Island event in Harrisburg, PA was classified at a Level 5, Accident with Wider Consequences, while Chernobyl was classified as a Level 7, Major Accident. The Chernobyl accident would remain the only Level 7 event for 25 years. On March 11, 2011, a series of events beginning with a magnitude 9.0 earthquake centered 80 miles off the eastern coast of Japan led to a major tsunami impacting the Fukushima Daiichi Nuclear Power Plant in Okuma, Fukushima, Japan.

The major earthquake did not damage the facility's six reactors (in fact the three active reactors (1-3) were automatically shut down per established protocols). However, 41 minutes after the earthquake, the initial tsunami wave (40-45' in height) hit the plant, followed eight minutes later by a second wave. These waves submerged and damaged seawater pumps for primary and auxiliary cooling circuits. The wave also submerged the diesel generators and inundated the electrical switchgear and batteries located in the basement of the turbine building, resulting in a station blackout and the reactors being isolated from their cooling sources. As workers struggled to restore power and cooling to the facility, the production of hydrogen steam eventually led to explosions in Units 1, 3, and 4 and core meltdowns in Units 1, 2, and 3.

Like Chernobyl, the Fukushima event was classified as a Level 7, Major Accident on the INES scale. As a result, all four reactors were irreparable and shutdown, resulting in a loss of 2,719 megawatts of power, the release of high levels of radioactive gas and water over four to six days, the evacuation of 100,000 people, approximately 2,313 disaster-related deaths among evacuees (not including the 19,500 that killed by the earthquake and tsunami) and the creation of a 12-mile exclusion zone around the reactors.

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