In December 1942, seventy-five years ago, Enrico Fermi succeeded in designing the first working elementary nuclear reactor. Since then hundreds of nuclear reactors have been made and today 448 power reactors produce nuclear electricity with 390 GW of installed capacity the world over.

He along with 40 others was working on an experiment to find whether a chain reaction of nuclear fission could be established in a mass of uranium, using neutrons. That evening, 75 years ago, they indeed established such a chain reaction and kept it going for about four minutes.

The event was significant in many ways. Scientifically, this was the first demonstration of the technique to tap the energy locked up in the atom; this energy was postulated by Einstein three decades earlier by his celebrated equation $E = mc^2$.

The other significance was on the war front. The Second World War was already three years old with no sign of Germany yielding. A possibility of a sustained chain reaction was a pre-requisite for a Super Bomb and making that bomb before Germany was an absolute must to end the war.

The weapon project was already taken over by the US army since August that year. That is the reason the coded message was sent to James Conant who was the chairman of the Defense Committee. Conant asked Compton, "How were the natives?" perhaps meaning the behaviour of neutron, to which Compton replied, "Very friendly."

Neutrons – The Old Friends
For Enrico Fermi, working with neutrons was an old habit. Shortly after neutron was discovered by the British scientist James Chadwick in 1932, Fermi began working with it. In fact, his Nobel Prize was for creating artificial radioactivity using neutrons. Radioactivity, whether natural or artificial,
occurs because the unstable nucleus is searching for stability. By giving away a particle and/or some amount of energy in the form of gamma photon, it rearranges its stock of nucleons at the lowest possible energy level.

Before 1933, when artificial activity was obtained by Irene and Joliot Curie by using alpha particle bombardment, natural radioactivity was known to exist in the chain of daughter products of uranium and thorium decay series (like radium etc.). In artificial radioactivity you deliberately disturb the balance inside the nucleus by sending in a particle.

Fermi planned to do this using neutrons, when at the University of Rome. His team used as many as 63 of the 92 elements of the periodic table as the target nuclei. They employed fast as well as slow neutrons (technically known as ‘thermal’ neutrons). The extensive experiments, though using very primitive instrumentation, proved immensely useful. The nature of new radioactivity helped in understanding the structure of nucleus.

One of the findings was that excess neutrons in the nucleus resulted in an emission of a beta particle. Fermi studied this phenomenon and gave a theory of beta decay, now known by his name. In the process, he also confirmed the concept of the new particle neutrino, with zero charge and negligible mass, earlier proposed by a theoretician Wolfgang Pauli. In a simplified way, he said that a neutron decays into a proton, giving out an electron.

As the atomic number of the product nucleus is higher by one, it is the next element in the periodic table. For example, 77-Iridium becomes 78-Platinum by this process. When he sent his paper on neutron irradiation to Lord Rutherford, who himself was an ace experimental physicist, he wrote back, “I compliment you on your successful escape from the sphere of theoretical physics!”

The nature of this process made him think that the uranium, which is the heaviest element (Z = 92) in the periodic table, can be transformed into a new element beyond the periodic table and not available in nature. He with his team pursued the idea very actively. They once thought they had acquired element no. 93 and announced so in a local academic circle. When the result was proved wrong, Fermi suffered embarrassment. He had unknowingly broken the uranium atom!

It was a year or so later that Hahn and Strassman also did the same thing but Lise Meitner found out that the phenomenon was nuclear fission (See SR, December 2010). It is a spectacular twist of destiny that Fermi who missed out on fission while in Italy, became the one to harness it using the chain reacting pile later in USA.

Migration and the Nobel Prize
Fermi was born in Italy in 1901, when it was under Austrian rule. In 1931, a decree came from the Fascists that government employees including professors would have to take an oath of allegiance to Fascism.

Amidst this gloom came the Nobel Prize in 1938. It was given to him for “his discovery of new radioactive elements produced by neutron irradiation & for the discovery of nuclear reactions brought about by slow neutrons”. This provided them an opportunity to escape from Italy. The family left Rome on 6 December 1938 on the pretext of collecting the Nobel Prize but with the clear intention of not returning.

Fission Follows Fermi
After collecting the Nobel Prize at Stockholm he arranged for travel papers and the family reached New York in the first week of January 1939. He had already secured a job with the Columbia University. Neils Bohr also reached USA in the same week on a lecture tour and brought with him the news of uranium fission from Copenhagen. Meitner and her nephew Otto Frisch had proposed the idea of uranium fission. They also predicted an energy of 200 MeV being available with each fission.

If one has to tap this energy at the
practical level, a large number of fission reactions have to happen in a short time. The question was, ‘could a chain of fissions be established to proceed in a sustained manner?’ It appeared feasible because each fission gave out two or more neutrons as a by-product.

Leo Szilard had arrived in the USA on his second migration from UK. He joined Fermi in the pursuit of chain reaction and they began to think about the design of the first pile.

The word ‘pile’ is used to mean an elementary nuclear reactor without a formal cooling arrangement. Heat produced during experiments is dissipated by convection of air. The modern word for this kind of arrangement is the ‘critical assembly’. Its purpose is to carry out experiments to determine physical parameters related to neutron multiplication and absorption.

The first pile was built at the Columbia University but it never became ‘critical’, meaning that no sustained chain reaction could be established. Meanwhile the project fell in the hands of the army and the experiments were shifted to the Chicago University. The pile Fermi erected there was named CP-1 (Chicago Pile 1).

Modern reactors have scores of types of materials; in contrast the first pile had just three materials: Graphite, Uranium and Cadmium. Cadmium is a strong absorber of neutrons; its use is in controlling the reactor and if need be to shut it down in emergency.

On 2 December 1942, Fermi and his team gathered at 09.45 a.m. for the final operation. All control rods of cadmium were fully inside the graphite. There were 43 persons included the lone lady scientist Leona Woods and one representative of the chemical company DuPont, which was supposed to replicate the future piles.

Fermi ordered to pull out the control bars gradually and the neutron counters were monitored. He was ready with his slide-rule to make calculations and decide the speed of withdrawal of control rods. To appreciate the mood of the day, here is the eyewitness account of H.L. Anderson, the American physicist who assisted Fermi:

*When the cadmium rod was pulled out to the position, Fermi asked for next, the increase in neutron intensity was noticeably quickened. At first you could hear the sound of the neutron counter, clickety-clack, clickety-clack. Then the clicks came more and more rapidly, and after a while they began to merge into a roar; the Geiger counter couldn’t follow any more. That was the moment to switch to a chart recorder. But when the switch was made, everyone watched in the sudden silence the mounting deflection of the recorder’s pen. It was an awesome silence. Everyone realized the significance of that switch; we were in the high [neutron] intensity regime and the counters were unable to cope with the situation any more. Again and again, the scale of the recorder had to be changed to accommodate the neutron intensity which was increasing more and more rapidly. Suddenly Fermi raised his hand: “The pile has gone critical,” he announced. No one present had any doubt about it. Then everyone began to wonder why he didn’t shut the pile off. But Fermi was completely calm. He waited another minute, then another, and then when it seemed that the anxiety was too much to bear, he ordered, “Zip in!” Zinn released his rope [dropping a control rod], and there was a sigh of relief when the neutron count dropped abruptly and obediently…."

The Second World War was already three years old with no sign of Germany yielding. A possibility of a sustained chain reaction was a pre-requisite for a Super Bomb and making that bomb before Germany was an absolute must to end the war.
It was sometime around 3.45 p.m., there was excitement but no cheers. Those present were aware of the importance and seriousness of the event. It was the first baby step that mankind had taken to unplug the energy locked up in the atom. Though the journey began with a destructive use, ultimately after a decade USSR and Britain produced electricity using nuclear energy.

In the next 75 years, 768 research reactors were made (including many critical piles) and 552 dismantled and closed down after serving their purpose. Today 448 power reactors produce nuclear electricity with 390 GW of installed capacity the world over. All these research and power reactors also produce radio-isotopes used in the service of mankind. Undoubtedly, Fermi’s is the most important influence behind all these.

The pile worked at Chicago for three months and was moved to Hanford for modifications and further work. Fermi rose in position in the Manhattan project and became Associate Director of Research at the Los Alamos Lab and took US citizenship in 1944.

After the war, Fermi moved to the Institute of Nuclear Studies of the Chicago University and worked on pi-mesons, their interaction with nucleons and other topics in nuclear physics. He began as a theoretical physicist and transformed into an experimentalist of the first order. In view of the substantial contribution Fermi made to the different branches of science it would not be out of place to call him the Newton of the 20th Century.

Due to his very long association with nuclear radiation during the period when the hazards were not known well and precautions were minimal, Fermi fell prey to stomach cancer. The disease took his life on 29 November 1954, at a premature age of 53. In this short life span, he received much from life and returned even more to science.

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