does not make for probity in scientists working there. Scientific research is no more a mildly pleasurable pursuit. It has become self-centered and competetive. Damn fairplay. I was recently discussing some data with a European scientist friend of mine, once a model of caution. We interpreted the data on hand this way, that way and every which way. He finally said 'Put it down as demonstrating this and not that. Our interpretation is most probably wrong all over anyway'. That reflected the changing times and the slackening rigour. Perhaps it also portended advancing age and the dawning of cynicism.

To compound matters, scientists do not relish writing about themselves or even being written about, an exception seems to be the remarkable Stephen Hawking. Most scientists live in constant dread of being interviewed by media persons and of the ignominy of making it to the pages of popular weeklies. A German scientist—a biologist—who was mentioned once too often in *Der Spiegel* in the sixties had to face peer opprobrium even though his science, by all accounts, was judged as having been good.

One of the eternal dilemmas of a scientist is to know when he has indeed 'arrived'. In science you are not seeded as in Wimbledon. You do not know your number in the hierarchy, your rank in the pecking order. But with the kind of exhilaration good science can generate, even the travel is well worth one's while as the arrival, if there is indeed any. Peer appreciation is the only ultimate reward a scientist awaits. In concluding may I state that a good young scientist must view every hurdle in his way as a challenge. Hurdles are there to be surmounted. After all, kites rise against the wind and not with it.

Acknowledgements. This is the slightly altered text of a lecture delivered on this topic to DST Young Scientists Awardees at the Indian Science Congress, 1989 Madurai. I am grateful to the DST for having invited me to deliver this lecture and for supporting my science over the years.

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Enrico Fermi and the nuclear age

In November 1954 I had occasion to attend the fall meeting of the American Physical Society held in Chicago. Thousands of physicists had assembled. There were many plenary lectures, invited lectures; there was one by Subrahmanyan Chandrasekhar. I felt that the usual exuberance and boisterousness associated with the young of America were missing. Something seemed to be wrong. When I expressed this to my neighbour he asked, 'In what way' and, I replied the atmosphere suggested an impending doom. He said 'yes it does; do you not know that Fermi is seriously ill and is dying?' (Fermi died two weeks later.)

In Chicago, I visited the Squash Court under the Stagg football stadium where Fermi and his colleagues had assembled the 'atomic pile' and performed one of the most significant experiments which affected science and technology of the twentieth century. I also met and talked to Arthur Compton who was in charge of the project.

It all started in 1934. Fermi's group, at the University of Rome, established that many elements, if bombarded with neutrons, would be transmuted into new radioactive elements. Later that year, they found that neutrons filtered through paraffin were much more effective in producing nuclear reactions than those emerging directly from a radon plus beryllium source. Fermi gave the explanation that neutrons were slowed down by elastic collisions in passing through paraffin and these spent more time in the vicinity of the nucleus and so were more likely to be captured by the nucleus. Fermi and his group also irradiated uranium with neutrons the same year but did not detect nuclear fission because they had covered the sample with an aluminium foil to stop lower energy alpha rays, which uranium spontaneously emitted even without any bombardment.

Bohr at a lecture in Princeton in 1939 leaked out the great news of the discovery of Hahn and Strassmann and the interpretation of Lise Meitner and Otto Frisch that the uranium nucleus split into two equal parts when bombarded by slow neutrons—a phenomenon which they called fission. The same year Fermi discovered in the Pupin laboratory of Columbia University that the number of neutrons released in fission was between 2 and 3, enough to initiate a chain reaction.

The rest is history. A team of scientists was assembled in Chicago. It was Fermi's advice to build the 'pile' in the Squash Court and not in the Argonne Forests. The 'pile' was constructed with 340 tonnes of the purest graphite (moderator), 37 tonnes of uranium oxide, 5 tonnes of pure uranium metal and a few control rods of cadmium (which is voracious in absorbing neutrons). Fermi with his proverbial slide-rule calculated the exact position of the cadmium rod at which chain reaction would occur. The operation began on December 2nd. The pile was operated with a single control rod. There were many safety precautions—the most peculiar was the one rod being held by a rope outside the pile where a team member stood with an axe! At 3.41 p.m. the reactor became self-sustaining (1/2 watt). It was worked for 12 minutes when the safety rod was lowered. The operations were shifted then to Los Alamos; the bomb made and dropped on Hiroshima (on 6th of August 1945), and on Nagasaki—the latter, some say, was just to prove that a plutonium bomb also works.

When Rudolph Peierls (who played a major role in all these and who later was listed as a security risk) came to India, I asked him for a brief story.

He remarked how great men could be utterly wrong. Rutherford in his 1937 British Association speech had said, 'Anyone who looked for a source of power in the transformation of atoms was talking moonshine'. In 1939 Niels Bohr published a paper (even after fission had been discovered) that there was no possibility of making a weapon using uranium. Bohr had considered uranium in its natural form and not the separate isotopes. Because of a discussion with Otto Frisch in Birmingham, Peierls considered ^{235}U and calculated that 1 kg of this material was sufficient to produce an explosion corresponding to a TNT bomb of 20,000 tonnes. They also worked out how to separate the isotopes and wrote their famous 3-page note. In it they wrote 'Because of the big power and because of the radioactive fall out it will not be possible to use this weapon without killing a large number of civilians. The weapon will never be suitable to use by the British.' I asked him, 'Were you thinking only of Europe? Did not this consideration come up when it was dropped on Japan?' He shrugged his shoulder and said: In the old days it was considered that bombing cities and civilians was immoral. All this changed later. People got used to the killing of civilians in war. When Hitler bombed Guernica in Spain, 1600 people died and the world was outraged. It prompted Picasso to paint his famous painting condemning war. In London due to air raids 3000 died. In Dresden about 120,000 and in Hiroshima about 200,000 died. Now people and governments do not care. Unfortunately scientists at that time were caught up with the sheer excitement of their work and they did not think how the weapon would be used!

After the war came the dream of nuclear energy. This is a highly controversial field and the common man and the scientists are completely confused. They say that economics is the Achilles heel of nuclear power. Much 'creative accounting', i.e. cooking up, was essential to give Britain its first atomic power station, a semblance of economic respectability. It is often said that nuclear power would compete with other fuels. It is also said that its proponents had to put forward tortuous argument to suggest such a claim. Yet Nuclear Electric of UK is now making big profits. Then there is the question of danger of explosion and the problems of disposing radioactive waste. As John Collier, the Head, Britain's Nuclear Electric Co., says: 'The past fifty years were all about *technology push* with technologists dreaming up all types of nuclear power stations (PWR, FTBR, etc.). The next fifty years will be governed by *customer pull.* Nuclear power will only survive if the public actually believes and is convinced that nuclear energy is *economical, safe and environmentally clean.*

While touching on all these controversies, let us not forget one of the greatest figures of science that the century has produced—Enrico Fermi. From the age of 13 to 17 his 'teacher' Amadei fed young Enrico with some of the best treatises on very advanced mathematics each one of which he mastered without difficulty. When Amadei asked him whether he would dedicate himself to mathematics or physics, the 17-year-old Fermi replied, 'I studied mathematics with passion because I considered it necessary to the study of physics to which I want to dedicate myself exclusively'. When asked whether his knowledge of physics was as vast and profound as his mathematics he replied: 'It is much wider and I think equally profound because I have read *all the best-known books in physics*'. One is astonished how between the ages of 13 and 17 he could do all this. Yes, he dedicated himself exclusively to physics. 'He gave to science all that he had and with him disappeared the last universal physicists in the tradition of the great men of the 19th century when it was still possible for a single person to reach the highest summits both in theory and experiment and to dominate all fields of physics.'

—*Editor*

We publish below the statement made by 'the pioneers' at the 50th anniversary celebration of nuclear power development on 16 November 1992.

Perspectives of nuclear pioneers

On this commemoration of the half-century anniversary of nuclear power development, a few of us who nurtured its early germination and flowering have gathered to look back and ahead to speculate on its role. While we are unlikely to be around a half-century from now to verify our speculations, many of you will be and presumably will make appropriate mid-course adjustments.

Prior to the nuclear age, the source of nearly all life-supporting energy was solar radiation. It has taken many millennia for mankind to learn to use the stored solar energy in coal, oil, gas, and biomass as a supplement to the direct warmth of sunlight. In this century we have found the photovoltaic cell to be a conversion device from sunlight to electricity. Biomass is potentially a source of transportation fuel. In the mythical temple of energy gods, the sun will reign supreme for a long time to come and deserves our continued worship.

However, the temple now makes space for a lesser god, nuclear power, brought forth from nature's secret archives by the nuclear pioneers that we represent here. It is the only addition to mankind's primary energy resources in recorded history, and we are confident that it will increasingly contribute to global energy supply. It appears on the global scene at a most timely period, when it has become apparent that fossil fuels, especially oil and gas, may be limited, and when the global environmental consequences of their use are being recognized. We have the rare lifetime satisfaction of having been principals in a most fundamental contribution to the future of mankind.

In the past 50 years much has been contributed to nuclear power development. The first half of this period provided exploratory demonstrations of several reactor concepts, and the second half gave use the first commercialized versions of a few. As with all new technologies, it will take many cycles of improvements, new system concepts, and operational learning to reach its full potential. To many of us it is most satisfying to see nuclear electricity providing such a large fraction of the needs of industrial countries at such an early stage of its development.

A most significant contribution to human progress is the medical and research use of the radioisotopes made abundantly available as a by-product of these nuclear processes. It far exceeds the initial vision of the nuclear pioneers. Daily shipments of radioisotopes produced by nuclear reactors are utilized by thousands of hospitals and clinics globally in the broad span of medical specialities ranging from pediatrics to cardiovascular disease to dementia. The therapeutic use for targeting malignant disease is expanding greatly. The research applications in all the scientific fields have become part of the common tools of scientists everywhere.

And, as with all new technological developments, these experiences have disclosed problems whose resolution will contribute to the long-time growth of nuclear power.

Again, we should observe that the history of fossil fuel use is replete with difficulties that required centuries to overcome. Even today fossil fuels pose hazards that need societal management and accommodation. Concentrated energy forms will always have the inherent potential to be hazardous, and their acceptable use requires meticulous design, construction and operation. So we should not be surprised that nuclear power brings a new category of issues, arising from the possibility of accidents and consequent radioactivity exposures. Important for reactor safety is providing continued removal of the residual shutdown heat of the reactor, a special engineering objective. Another issue, which has concerned the public, is the radioactivity from spent fuel and the back end of the fuel cycle. Fortunately the science of containing radioactivity is well-understood and we have no doubt that its engineering application will be successful.

Although the growth of the world nuclear industry is slowed at present by the state of the world economy and public opinion, nuclear power will come to be seen as a less polluting and more desirable choice than fossil fuels. We have great confidence in foreseeing a major global role for nuclear power in the future.