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A Short History of the Second Nuclear Era American Nuclear Society Imbedded Topical on Reactor Safety (**)

On April 16, 1944, at a meeting of the New Piles Committee at the Chicago Metallurgical Laboratory Enrico Fermi expressed his doubts about the future of nuclear energy. To paraphrase, he argued that nuclear energy was encumbered by vast radioactivity, and by the danger of diversion of bomb material by hostile groups. And with remarkable prescience he pointed out that it was by no means clear that a new energy source so encumbered would be accepted by the public.

Fermi's warning was taken up by James Conant, President Roosevelt's personal representative to the wartime Manhattan Project. Speaking at the American Chemical Society's Diamond Anniversary in 1951 he predicted that "Fifteen or twenty years after the first atomic bomb was fired a sober appraisal of atomic fission had led people to decide the game was not worth the candle, the disposal of waste products have presented gigantic problems".

Until the accident at Three Mile Island, I don't think the nuclear community, by and large, took these warnings first expressed by Fermi and by Conant seriously. So to speak, we were so enchanted by our miraculous new source of energy that we tended to ignore the public's growing concern. Reactors were safe, and waste disposal was a technical issue that could yield to research and development. Nevertheless, even in those days designers proposed what we would call inherently safe systems: Edward Teller, the father of the field of Reactor Safety, with his plea for underground siting; Sam Untermyer with his inherently safe (but now forgotten) boiling water reactor, not to mention the first contaimment shell that housed the Submarine Intermediate Reactor near Schenectady. Containment shells at the time were regarded as the ultimate safety device — no matter what went on inside the containment, no radioactivity would escape.

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But TMI in 1979, and Chernobyl in 1986 brought us back to Fermi's warning — public acceptance of this new energy source was not to be taken for granted, indeed, engineering in this "Age of Anxiety" must meet criteria of public acceptability as well as the more traditional criteria of economic viability. This had already been promulgated by Prof. T. Kletz; following the cyclobexane accident at Flixborough he called for inherently safe chemical plants.

The first to call upon the *reactor* community to come up with a much safer reactor was David Lilienthal. He had been the first Chairman of the U.S. Atomic Energy Commission, but later became a nuclear skeptic. In his 1980 book, *Atomic Energy: A New Start*, he argued that nuclear energy could not survive unless it was based on reactors whose probability of catastrophic failure was essentially zero. In reviewing this book at the time I argued that a completely safe reactor was an oxymoron: that the road to acceptable safety was through organizational improvement, as well as technical improvement. At this time Peter Fortescue of General Atomics coined the expression "Forgiving Reactor" — and insisted that certain kinds of gas-cooled reactors were more forgiving, and therefore less likely to melt down than were the current line of water cooled reactors.

The Institute for Energy Analysis, which I directed at the time, brought together about a dozen old-time reactor engineers to ask: could Lilienthal be right after all? Could a new kind of reactor, or at least one based on today's technologies be designed to meet Lilienthal's criteria? Though skepticism pervaded the group, we decided the issue deserved attention — and with support from the Mellon Foundation, we embarked on a study of the Second Nuclear Era. The study was published in 1984.

In the meantime, although at first the necessity of increasing the safety of reactors was greeted with skepticism, the Chernobyl accident caused many reactor vendors and public bodies to re-examine the matter. And now, almost ten years later we find nuclear moratoria in many countries, and perhaps more important, ideas for reactors that are safer than the 400-odd power reactors of the First Nuclear Era.

I shall not try to list all of these ideas — ranging from back of the envelope designs to full scale proposals that are already in the various regulatory processes. Instead I shall speculate on what I judge are the technically necessary and publicly sufficient criteria that must be met by a new generation of nuclear reactors: if both these criteria are met there will be a Second Nuclear Era; if not there will be no Second Nuclear Era.

I begin with technically *necessary* criteria: that is criteria which must be met, but even if met, by themselves do not assure a continuation of the nuclear age. I can identify two such necessary criteria: first, that nuclear reactors must be "safe"; and second, that the scientific community must withdraw its attachment to the linear, non-threshold hypothesis, and with it the obnoxious notion that wastes or even large accidents imply many additional phantom deaths among millions of people who are exposed to radiation levels that are small compared to background.

Let me expand first on what I mean by "reactors must be practically safe". This requires a definition of "practically safe". Clearly, as TMI and Chernobyl demonstrated, what the public regards as "safe" is not what the reactor community regarded as "safe". And as Sizewell B has demonstrated, with incremental improvements, one can reduce the estimated core-melt probability by one or two orders of magnitude.

Is this enough — or must one aim for "zero" probability of harm to the public. During our IEA study of 15 years ago, we claimed that PIUS and HTGR posed "zero" risk. But as things have turned out the definition of zero risk seems to be country-specific. Thus the German advanced PWR requires a core-catcher and therefore represents an inherently safe system in the spirit of the original containment shell of the SIR. By contrast the ALWR does not include a core-catcher, and instead provides a core-melt probability much lower than that of existing systems. But these proposals by no means exhaust the ideas for Advanced Reactors: I mention the MARS Reactor proposal of Prof. Cumo at the University of Rome; and the various proposals from Russia of lead-cooled systems (which really hark back to Leo Szilard's wartime proposal to use liquid bismuth to cool the reactor).

The definition of "practically" safe may be related to the probability of naturally occurring catastrophes — perhaps, in analogy to the "de minimis" radiation dose being the standard deviation of the natural background, I suggest a "de minimis" of reactor safety at the "standard deviation" of estimated bolide impacts. Thus John S. Lewis in his *Rain of Iron and Ice* estimates an impact like the Tunguska event (15 megatons energy released) to occur every 100 years; a 10-gigaton event every 250,000 years; a 100,000 gigaton impact every 100 million years. A 1,000 gigaton event would be a large catastrophe; a 100,000 gigaton impact would wipe out the human race. Thus one could make a case for setting the "practically" safe probability at between 10^{-6}/yr and 10^{-8}/yr — since in this range we are likely to be hit by an enormous meteor.

With respect to the LNT hypothesis, I plead simply that our radio-biological community, and the regulators concede that there is no direct epidemiological evidence for deleterious effects at background; and that therefore a strong case can be made for a "de minimis" radiation level, at, say, the standard deviation of the natural background. Instead of attributing human corpses to radiation at this level — from wastes or even from residual exposures at large distances from an accident — we as scientists should estimate consequences only at levels where consequences have been demonstrated, and deal with those exposed to "de minimis" without claiming that they have received any harm.

To summarize, I suggest that in a Second Nuclear Era, safety be related to natural background; the backgrounds being bolide impact in the case of safety and natural radiation background in the case of low levels.

I referred to these two developments — inherent safety and "de minimis" —

as technically necessary conditions for a rebirth of nuclear energy. Unfortunately, none of us can assert that these are publicly sufficient conditions for a rebirth — since in most countries, as Fermi said over 50 years ago, the public must decide. I have argued that the public is much influenced by the skeptical elite — knowledgeable opponents of nuclear energy who however can be convinced by technical arguments. Indeed, there have been prominent members of the skeptical elite who, on occasion have conceded that if we technicians come up with "practically zero" risk reactors, they would, albeit reluctantly, accept nuclear energy.

For it goes without saying that the quest for a publicly acceptable nuclear energy remains a central task for society. I needn't list the reasons why, eventually, we shall have to turn to an energy source that emits little CO_2 (the embodied energy of nuclear plants during their construction releases, only 10% as much CO_2 as does a coal fired plant), and that can produce energy that is competitive with other sources of energy.

As technicians, we have a responsibility to explore the possibilities for "practically" zero risk reactors. I believe the organizers of this Second Advanced Reactor Safety Meeting, George Flanagan, Mario Fontana and R. Taleyarkhan deserve our thanks for contributing so significantly to the world-wide search for acceptable nuclear energy.