tenance, and a sense of public responsibility—failed. For more than two hours on 28 March 1979, reserve coolant injection that could have saved the plant from a major catastrophe was manually throttled because the problem was misdiagnosed. And two of the technical failures leading to the accident—the stuck pressure relief valve and the clogged polisher—had occurred before and had not been properly addressed. Even with the redesign of the failed gadgets, TMI remains an icon of a profit-driven industry cutting corners.

One would expect that the decision to give unparalleled government subsidy to the nuclear power industry would be made after public discussion and input from the best scientific and technical authorities in the country. Instead, decisions have been made in a political setting. Even the possible future directions for nuclear power generation were chosen in a casual and cavalier way. As far as anyone not on the inside knows, no one was invited to the Vice President's Energy Task Force in 2002 who might have supported funding for development of Carlo Rubbia's thorium reactor.[4]

Walker recognizes in his book that the Nuclear Regulatory Commission has tried hard to improve its regulatory function. (See a review of Walker's book in PHYSICS TODAY, February 2005, page 63.) However, TMI continues to be discussed because we have not yet come to terms with the fact that it was allowed to happen.

Rather than disparage those who raise concerns about nuclear safety, physics educators might try to present students with facts not colored by free teaching materials paid for by those with a financial interest in biasing materials used in schools.

The lay public is not as stupid as some experts would have us believe. For one thing, there are out there in America some 2500 young adults who have an appreciation for the complexities of nuclear power, which they gained in a physics unit at Huron High School in Ann Arbor, Michigan.[5] In that unit they learned to think for themselves, to shy away from a decision to be simplistically for or against nuclear energy, and to apply knowledge about how a reactor works, from control rods, primary coolant, and emergency core cooling system, to pressurization, relief valves, and loss-of-coolant conditions.

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In light of Edwin Karlow's letter supporting nuclear power (PHYSICS TODAY, February 2006, page 11) and the article "Stronger Future for Nuclear Power" in that same issue (page 19), I would like to remind readers of the many reasons why nuclear power is a bad idea.

Nuclear power is not economically viable. Karlow explains the subsidies that the nuclear power industry needed in the past and pleads for continued subsidies in the future. Contrary to the early promise that nuclear power would be so cheap we would not need electric meters, nuclear power is very expensive. The main reason is that it is so dangerous; expensive safeguards must be attempted.

The risk of a catastrophic accident persists. Nuclear power plants are built and run by humans, who make mistakes and who can be pressured into making decisions that put profit above safety. And the same government that took care of us after Hurricane Katrina will assume responsibility for us after a nuclear accident.

Nuclear power plants are possible terrorist targets. A dedicated attack against a nuclear plant could not be prevented, and the highly radioactive spent fuel is poorly contained in many plants and is particularly open to attack.

The waste disposal problem is not solvable in the near future. The politically chosen Yucca Mountain disposal site is nowhere near opening, precisely because of its geological problems, and because of local opposition. So spent fuel will continue to pile up around the country, producing increasingly dangerous sources of radioactive materials vulnerable to human error, accident, and attack.

Current nuclear plants are being operated unsafely. The Nuclear Regulatory Commission is lax in its supervision of those plants. The NRC does not have workable evacuation plans for many power plants, including the Indian Point plant just upwind of New York City and the oldest plant in the country, in Oyster Creek, New Jersey. Fire safety problems have not been addressed. Routine operation of nuclear plants results in planned and unplanned releases of radioactivity, and there is no safe level of radiation exposure. The procedures for extending the life of unsafe reactors do not allow meaningful public input.

The most important reason why nuclear power is a bad idea is that it results in nuclear weapons proliferation. A fuel-processing plant for a standard 1000-MW reactor could produce enough uranium for between 10 and 30 uranium weapons per year. Its waste reprocessing plant could produce enough plutonium for 30 plutonium weapons per year. It is no accident that Iran and Venezuela, nations awash in oil, are pursuing nuclear power. India and Pakistan received nuclear fuel and technical help from other countries to develop nuclear power, and took advantage of this opportunity to make nuclear weapons. And the material can find its way into the hands of terrorists. Even a small nuclear attack or a small war between newly nuclear states would be devastating to humanity. Having invented nuclear weapons, we physicists have a moral responsibility to do everything we can to lower the probability of their use.

I am a climatology professor doing research on global warming. In my opinion, we must reduce our greenhouse gas emissions to mitigate future negative consequences to the climate. But nuclear power is not the answer.

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Atoms and quarks, two 20th-century revolutions

One aspect of Albert Einstein's heritage seems to have been overlooked in the many centenary celebrations of his annus mirabilis. The 20th century began with the confirmation of the revolutionary finding that matter was not continuous but made of atoms and molecules. It ended with a second revolutionary finding that matter is made of even tinier objects called quarks. The similarity between the two revolutions has been missed. Einstein played a crucial role in the first. A number of physicists were crucial to the second.

By 1966 Richard Dalitz and I were both already convinced that matter was made of quarks[1] as we led the discussion on this topic at the International "Rochester" Conference on High Energy Physics in Berkeley, California. We could not understand why quarks were not generally accepted until well into the 1970s. Unexplained regularities in the hadron spectrum, simple surprising relations in hadron reactions, the preponderance of three-meson final states in proton–antiproton annihilation at rest, relations between the electromagnetic properties of mesons and baryons, and the $^3/_2$ ratio of the magnetic moments of the neutron and proton—all converged on the same conclusion: Mesons and baryons were built from the same elementary building blocks.

The answer for the delayed acceptance of quarks seems to be that people who do not understand history are condemned to repeat it. The missed history lesson was that Nature always reveals to us a new level of the structure of matter—new smaller building blocks—long before we have any theory of why those particular building blocks exist and what the elementary forces and interactions are that hold them together.

In describing the first revolution, Abraham Pais points out that the debate on the reality of molecules was finally settled because of the extraordinary agreement in the values of Avogadro's number, N, obtained by many different methods.[2] Matters were clinched not by a determination of N but by an overdetermination of it. From subjects as diverse as radioactivity, Brownian motion, and the blue in the sky, it was possible by 1909 to state that a dozen independent ways of measuring N yielded results that lay between 6×10^{23} and 9×10^{23}.

Of course, there was no indication of what these molecules were, or their masses and interactions. No one had ever seen a single molecule, and an understanding of molecular physics had to wait for many new experiments and a completely new theory.

The parallel is striking between the development of our understanding of the structure of matter at two different levels—its molecular structure and its quark structure. Quarks were just as real in 1966 as molecules were in 1910 after Einstein's remarkable demonstrations of their reality in his work on Brownian motion and critical opalescence—the blueness of the sky. *Three* is the Avogadro's number of hadron physics; it might be called the Goldberg–Ne'eman number since Haim Goldberg and Yuval Ne'eman were the first to suggest the revolutionary proposal that the proton and neutron could be constructed from elementary building blocks with baryon number $^1/_3$. (See Ne'eman's obituary in PHYSICS TODAY, August 2006, page 72.)

But none are so blind as those who do not want to see. Members of the physics establishment refused to look at the clear message that Nature was sending in experiments that confirmed the value of the Goldberg–Ne'eman number. Instead they followed the path of those who refused in 1910 to abandon the continuity of matter. They followed a similar path based on wrong theoretical ideas and looked for a "final theory of hadron interactions" before they understood that smaller building blocks were already evident.

The analogue of Einstein here was first and foremost Dalitz, who has never received the credit he deserves for showing the reality of quarks in hadron spectroscopy (see his obituary in PHYSICS TODAY, July 2006, page 65). Evgeni M. Levin and Leonid L. Frankfurt showed quarks' reality in reaction cross sections; Hector Rubinstein showed their reality in nucleon–nucleon annihilation, and he also led the work that pointed the way to dual resonance models and later to string theory.

In 1966 we had no idea what quarks really were or how they interacted. We had to wait until experiments had shown individual "partons" in elastic scattering, just as Jean Baptiste Perrin had to wait until 1926 to receive the Nobel Prize for his work on Brownian motion. We had to wait for the theoretical developments of asymptotic freedom and quantum chromodynamics. But it was already clear in 1966 that quarks were the real basic constituents of hadrons and not simply mathematical objects.

This letter was written when Dalitz and Ne'eman were still with us, and I had anticipated their reactions. Today I think it is appropriate to dedicate this letter to their memory.

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A long history of peristaltic perturbations

Yves Pomeau and Emmanuel Villermaux, in their article "Two Hundred Years of Capillarity Research" (PHYSICS TODAY, March 2006, page 39), give a comprehensive overview. It is noteworthy, however, that the stability condition mentioned in the section on breakup and fragmentation was known decades before Joseph Antoine Ferdinand Plateau's 1873 publication cited it. The condition that peristaltic perturbations are naturally unstable if their longitudinal wavelength is larger than the cylinder's circumference was known to Plateau as early as 1850.[1] His analytical result was quoted by August Beer in 1855.[2] In correspondence with William Thomson (later Lord Kelvin), James Clerk Maxwell referred to this limiting condition in 1857.[3] Maxwell's phrase "it is easy to show" suggests he had derived the result, though it is plausible he also read the earlier discussion by Plateau. Some of these references have been noted much more recently, in conjunction with an investigation of the nonlinear capillary response of liquid cylinders.[4]

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Footnote on slippery ice

Here is an interesting footnote to the article "Why Is Ice Slippery?" by Robert Rosenberg (PHYSICS TODAY, December 2005, page 50). A wonderful out-of-print biography of Robert W. Wood,[1] who is especially famous for his research on physical optics and spectroscopy, relates that as an undergraduate at Harvard University in 1891, he heard of the "pressure-molten" theory of glacier sliding, and "totally disbelieved this."

Wood had access to a powerful hydraulic press at a blower plant and decided to use it to disprove the theory. Water was frozen inside a cylindrical iron block, with a bullet accurately placed in the center of the ice cylinder. "The mighty ram of the hydraulic press" then pressed so strongly on the ice via a steel cylinder that ice needles "forced [their] way through imperfections in the casting" of the iron walls. And yet, when pressure was released and the ice removed, "the bullet was found at the center where it had originally been placed, thus clearly demonstrating that the ice within the cylinder had at no moment existed as *pressure-molten water*" (italics in the original). Wood, the inventive undergraduate student, published the results.[2] His experimental creativity later became legendary, and that early contribution to the "slippery ice" story looks like a harbinger of his future reputation.

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Refuting evolution's Cambrian controversy

In an item in the January 2006 issue of PHYSICS TODAY (page 32), Jim Dawson quoted National Academy of Sciences president Ralph J. Cicerone on " 'controversies' (e.g. the Cambrian explosion) that evolutionary scientists have refuted many times using the available evidence." I thought PHYSICS TODAY readers might like to know what some of the refutations are. How privileged we are today to know with more certainty than did Charles Darwin himself!

A true follower of Darwin knows that "the sudden appearance of animal fossils at the beginning of the Cambrian [period] was of particular concern to him."[1] Darwin argued that the animals should have diverged gradually during a long prior period—"as long as, or probably far longer than, the whole interval from the Silurian [that is, the Cambrian period] to the present day."[2] Because the required fossils were not found, he confessed, "The case at present must remain inexplicable; and may be truly urged as a valid argument against the views here entertained."[3]

Only in 1954 were very early pre-Cambrian fossils convincingly found: bacteria and one-celled fungi, abundantly frozen in 2-billion-year-old black chert from North America.[4] This discovery quadrupled the known age of life on Earth. An investigative explosion into pre-Cambrian paleobiology was then inevitable. Since the 1960s, fossilized microbes up to 4 billion years old have been found in some of the oldest rocks on Earth.

We do not know the whole answer to Darwin's concern, regarding the sudden appearance of animal fossils, with developed body plans in all the phyla. Nevertheless, that living things (at least one-celled microbes) flourished long before the Cambrian, just as claimed, is today indisputable.

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