POLICY FORUM: NUCLEAR SAFETY

Nuclear Power Plants and Their Fuel as Terrorist Targets

Douglas M. Chapin, Karl P. Cohen, W. Kenneth Davis, Edwin E. Kintner, Leonard J. Koch, John W. Landis, Milton Levenson, I. Harry Mandil, Zack T. Pate, Theodore Rockwell,* Alan Schriesheim, John W. Simpson, Alexander Squire, Chauncey Starr, Henry E. Stone, John J. Taylor, Neil E. Todreas, Bertram Wolfe, Edwin L. Zebroski

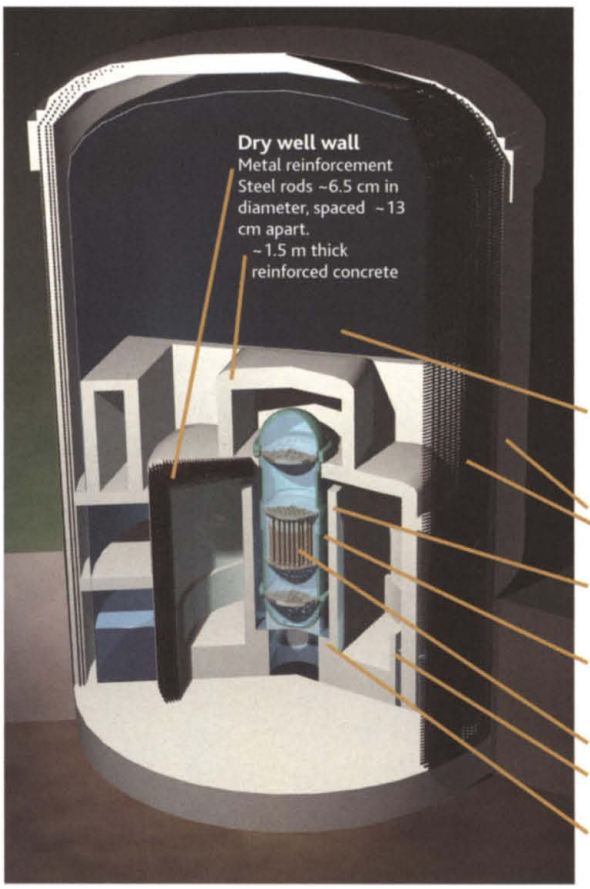
If you watch television or read repeated public statements of concern about nuclear power plants as terrorist targets, you would be justified in believing that spent nuclear fuel casks being shipped to Nevada for storage are each a nuclear catastrophe just waiting to be triggered. These casks have been called "mobile Chernobyls," and we are told they are capable of causing "tens of thousands of deaths" (*1*). What are the facts about the safety of nuclear shipments and power plants?

Since 11 September 2001, the U.S. nuclear industry and its regulators have been reevaluating plant and fuel shipment safety. These studies are being kept secret. But it is no secret that basic engineering facts and laws of nature limit the damage that can result. Extensive analysis, backed by full-scale field tests, show that there is virtually nothing one could do to these shipping casks that would cause a significant public hazard (*2, 3*). Before shipment, the fuel elements have been cooled for several years, so the decay heat and the short-lived radioactivity have died down. They cannot explode, and there is no liquid radioactivity to leak out. They are nearly indestructible, having been tested against collisions, explosives, fire, and water. Only the latest antitank artillery could breach them, and then, the result was to scatter a few chunks of spent fuel onto the ground. There seems to be no reason to expect harmful effects of the radiation any significant distance from the cask.

Similarly, we read that airplanes can fly through the reinforced, steel-lined 1.5-m-thick concrete walls surrounding a nuclear reactor and inevitably cause a meltdown resulting in "tens of thousands of deaths" and "make a huge area of the U.S. uninhabitable for centuries," to quote some recent stories (*4*). However, there seems to be no credible way to achieve that result (*5, 6*). No airplane, regardless of size, can fly through such a wall. This has been calculated in detail and tested in 1988 by flying an unmanned plane at 215 m/s (about 480 mph) into a test wall 3.6 m thick. The plane, including its fuel tanks, collapsed against the outside of the wall, penetrating a few centimeters. The engines were a better penetrator, but still dug in only 5 cm. Analyses show that larger planes fully offset their greater impact by absorbing more energy during their collapse. Higher speed increases the impact, but not enough to matter. And inside the containment wall are additional walls of concrete and steel protecting the reactor.

Is it possible to cause a nuclear reactor to melt down some other way? Yes, it happened at Three Mile Island (TMI) in 1979. Reactors are much improved since then, and the probability of such an accident is now much less. But suppose it happens, through terrorist action or other; what then? Well, the TMI meltdown caused no significant environmental degradation or increased injury to any person (*7–10*), not even to the plant operators who stayed on duty. It has been said that this lack of public impact was due primarily to the containment structure. But studies after the accident showed that nearly all of the harmful fission products dissolved in the water and condensed out on the inside containment surfaces. Even if containment had been severely breached, little radioactivity would have escaped. Few, if any, persons would have been harmed.

To test how far the 10 to 20 metric tons of molten reactor penetrated the 13-cm-thick bottom of the reactor vessel on which it rested, samples were machined out of the vessel and examined. The molten mass did



Multiple layers of safety at nuclear power plants.

Boiling water reactor

Containment vessel
~4 cm thick steel cylinder
~55 m tall

Shield building wall
~1-meter-thick reinforced concrete. Steel rods ~6.5 cm in diameter, spaced ~13 cm apart

Bio shield
Leaded concrete ~1.2 m thick with steel lining ~2.5 cm thick inside and out

Reactor vessel
~21.3 m tall. ~6.4 m in diameter. High tensile steel 10 to 20 cm thick

Reactor fuel

Weir wall
Concrete 46 cm thick. ~7.3 m tall

Pedestal
Concrete ~1.6 m thick with steel lining ~2.5 cm thick inside and out

CREDIT: NUCLEAR ENERGY INSTITUTE

D. M. Chapin, Principal Officer, I. H. Mandil, and T. Rockwell, Founders and Board Members, MPR Associates, Inc., Alexandria, VA 22314–3230, USA. K. P. Cohen, Chief Scientist, Nuclear Energy Group, General Electric Co., Retired. W. K. Davis, Vice President, Bechtel Corporation, Retired. E. E. Kintner, Executive Vice President, GPU Nuclear Corporation, Retired. L. J. Koch, Vice President, Illinois Power Company, Retired. J. W. Landis, Chairman, Public Safety Standards Group, Weston, MA 02493, USA. M. Levenson, Vice President, Bechtel International, Retired. Z. T. Pate, Chairman Emeritus, World Association of Nuclear Operators (WANO), Atlanta, GA 30339, USA. A. Schriesheim, Director Emeritus, Argonne National Laboratory, Argonne, IL, USA. J. W. Simpson, Executive Vice President, Westinghouse Electric Corp. and Westinghouse Power Systems, Retired. A. Squire, Consultant, Durham, NC 27704, USA. C. Starr, President Emeritus, Electric Power Research Institute, Inc. H. E. Stone, Vice President and Chief Engineer—Nuclear Energy, General Electric Company, Retired. J. J. Taylor, Vice President, Nuclear Power, Electric Power Research Institute, Palo Alto, CA 94303, USA, Retired. N. E. Todreas, Professor of Nuclear and Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139, USA. Bertram Wolfe, Vice President and General Manager, General Electric Co., Retired. E. L. Zebroski, Consultant, Los Altos, CA 94024, USA.

*To whom correspondence should be addressed. E-mail: tedrock@cpcug.org

not even fully penetrate the 0.5-cm cladding, confirming tests in Karlsruhe, Germany, and in Idaho, that the "China syndrome" is not a credible possibility (*8–10*).

The accident at Chernobyl in 1986 is simply not applicable to American reactors. The burning graphite dispersed most of the fission products directly into the atmosphere. Even in that situation, with no evacuation for several days, the United Nations' carefully documented investigation UNSCEAR-2000 (*11*) reported that there were 30 deaths to plant operators and firefighters, but no significant increase in mortality or cancer due to irradiation of the public have been observed (*12*, *13*). A possible link between exposure and thyroid cancer is still under study (*14*). The terrible and widespread consequences of that accident—increased suicide, alcoholism, depression, and unemployment (*15*), plus 100,000 unnecessary abortions (*16*)—were caused primarily by fear of radiation and by poor planning based on that fear. The evacuated lands are generally now no more radioactive than the natural background levels where many people have lived healthily for generations.

Three Mile Island nuclear power plant.

CREDIT: DOE

It's not surprising that some people overstate the concern about radiation, for whatever reason. But it is surprising that most nuclear advocates are reluctant to challenge such claims. They say they just want to be cautious. But striving for maximum caution leads to the assertion that we should act as if even the tiniest amount of radiation might be harmful, despite the large body of good scientific evidence that it is not (*17–22*). This policy has scared people away from mammograms and other life-saving treatments and has caused many Americans to die each year from pathogens that could have been killed by food irradiation (*23*). It has piled regulations on nuclear medicine facilities that caused many of them to shut down. And now, "permissible doses" have been pushed below those found in natural radiation backgrounds (*24–26*).

Such cautiousness has drawbacks when applied to design and operation of nuclear facilities. But it is particularly dangerous when applied to terrorism. To tell people that they and the Earth are in mortal danger from events that cannot cause significant public harm is to play into the hands of terrorists by making a minor event a cause for life-endangering panic. Now is the time to clear the air and speak a few simple scientific and engineering truths.

References and Notes

1. "[A] major fire is possible which could release 25 times more radioactive material than Chernobyl... such a fire could render 29,000 square miles uninhabitable...cause 28,000 cancer deaths and $59 billion in damage." B. C. Smith, *The Tech*, 1 May 2002. Available at: www-tech.mit.edu/V122/N22/col22brice.22c.html.
2. The shipping casks and the spent fuel are described in the 207-page Appendix J of the *Yucca Mountain Environmental Impact Statement* (DOE/EIS-0250, Government Printing Office, Washington, DC, 2002); available at: www.ymp.gov/documents/feis_a/vol_2/eis_j_bm.pdf
3. For an independent analysis, see J. L. Sprung *et al.*, *Re-examination of Spent Fuel Shipment Risk Estimates* (NUREG/CR-6672, Sandia National Laboratory, Albuquerque, NM, 2000); available at http://ttd.sandia.gov/nrc/nuregcr6672/chap1.pdf
4. "You could have tens of thousands to hundreds of thousands of fatalities from cancer ... the downwind path from these types of casualties could extend for hundreds of miles." P. Leventhal, Director of Nuclear Control Institute, on the Cable News Network, 1 February 2002; "Nuclear specialist Mark Gaffney said that an attack on a plant could make a huge area of the US uninhabitable for centuries." D. Nelson, in OneWorld UK, 2 November 2001 (www.oneworld.net/uk). To which the Government reportedly responded, "Of course it would be a big mess. Would it lead to multiple tens of thousands of deaths? That's much less certain." B. Henderson, Nuclear Regulatory Commission (NRC) representative, in K. Davidson, *San Francisco Chronicle*, 5 October 2001, p. A6. NRC Commissioner Nils Diaz recognized the need to correct this situation in his plenary talk at the American Nuclear Society Conference, Hollywood, FL, 10 June 2002: "I do not believe nuclear power is being portrayed in a balanced manner.... This is probably the fault of all of us who know better ... public health and safety consequences might very well be nuclear power and radiation technology's strongest and most favorable arguments when comparing risks and benefits." But on 5 August 2002, the Associated Press reported that NRC declared that "the best available way" to prevent a public health hazard is "controlling the airspace over atomic power plants."
5. "A hijacked commercial airliner loaded with explosive jet fuel like the one that hit the Pentagon on September 11 could not penetrate a U.S. nuclear power reactor and release deadly radiation," from a Reuters report, 17 June 2002, of a National Press Foundation Seminar. The report, commissioned by the Nuclear Energy Institute of independent contractors, is being reviewed by industry experts and will be completed this fall. The study reports detailed computer modeling, confirmed by large-scale tests.
6. Videotapes of tests of an unmanned airplane impacting a mockup of a section of containment wall can be seen at www.sandia.gov/media/NRgallery00-03.htm.
7. J. G. Kemeny, Chairman, *The Need for Change: The Legacy of TMI*, Report of the President's Commission on the accident at Three Mile Island, October 1979 (Government Printing Office, Washington, DC, 1979), 179 pp.
8. Organization for Economic Cooperation and Development (OECD), *Three Mile Island Reactor Pressure Vessel Investigation Project: Achievements and Significant Results*, Proceedings of an open forum sponsored by the OECD Nuclear Energy Agency and the U.S. Nuclear Regulatory Commission, Boston, MA, 20 to 23 October 1993.
9. See especially N. Cole, T. Friderichs, B. Lipford, pp. 81–91 of (*8*), "Specimens Removed from the Damaged TMI Reactor Vessel."
10. N. Cole, "TMI-2, A learning experience: Assessing the damage" (MPR-889, MPR Associates, Alexandria, VA, 1985).
11. *Sources and Effects of Ionizing Radiation: UNSCEAR 2000 Report to the General Assembly, with Scientific Annexes* (U.N. Scientific Committee on the Effects of Atomic Radiation, U.N. Publications, New York, 2000); available at www.unscear.org/reports.htm. See especially "The Chernobyl accident," vol. 1, p. 13 and the extensive scientific annexes, specifically vol. 2, Annex J, "Exposures and effects of the Chernobyl accident."
12. This report (*11*) was reviewed and the conclusions on Chernobyl reaffirmed in the 3rd International Conference, Health Effects of the Chernobyl Accident: Results of 15 Years of Follow-Up Studies, Kiev, Ukraine, 4 to 8 June 2001, sponsored by UNSCEAR; the World Health Organization; other U.N. agencies; and Ukraine, Belarus, and Russia; available at www.unscear.org/chernobyl.htm. Z. Jaworowski, member and former chairman of UNSCEAR, discusses the significance of these findings in *Phys. Today* **52**, 24 (1999).
13. Z. Jaworowski, *Science* **293**, 605 (2002).
14. See D. Williams, *Nature Rev. Cancer* **2**, 543 (2002) and recent news coverage [R. Service, *Science* **292**, 420 (20 April 2001)].
15. *The Human Consequences of the Chernobyl Nuclear Accident: A Strategy for Recovery, A Report Commissioned by UNDP and UNICEF, with the support of UN-OCHA and WHO* (25 January 2002). The report (356KB) is summarized in a U.N. news release at www.undp.org/dpa/frontpagearchive/2002/february/7feb02/ and is available for download at that URL.
16. G. Walinder, "Has radiation protection become a health hazard?" (Swedish Nuclear Training and Safety Center, Nykoping, 1995).
17. H. F. Henry, *JAMA* **176**, 671 (1961).
18. A.M. Brues, *Science* **128**, 693 (1958).
19. L. Gerber *et al.*, *Q. Rev. Biol.* **74** (no. 3), 273 (1999).
20. R. S. Yalow, *The Scientist* **2** (13 June), 11 (1988).
21. L. E. Feinendegen, M. Pollycove, *J. Nucl. Med.* **42** (no. 7), 17N (2001).
22. M. Pollycove, L. E. Feinendegen, *J. Nucl. Med.* **42** (no. 9), 26N (2001).
23. The FDA site on Food Irradiation, www.fda.gov/fdac/features/1998/398_rad.html states, "A May 1997 presidential report, 'Food Safety from Farm to Table,' estimates that 'millions' of Americans are stricken by food-borne illness each year and some 9,000, mostly the very young and elderly, die as a result." There is general agreement that this number could be reduced markedly by food irradiation, but reliable estimates will not be available until irradiation is in widespread use.
24. The U.S. Environmental Protection Agency set an annual limit on radioactivity in primary drinking water, based on a permissible annual dose of 0.04 mSv/year [65 Fed. Reg. 76708 (7 December 2000), with technical justification in the Notice of Data Availability, 65 Fed. Reg. 21576 (21 April 2000) and its Technical Support Document]. Natural radiation background typically varies from less than 1 mSv/year to about 10 mSv/year. The U.S. average is about 3 mSv/year. (NCRP Report no. 94, available from the National Council on Radiation Protection and Measurements, 7910 Woodmont Avenue, Bethesda, MD 20814, USA.) In high-background regions, doses to populations range up to several hundred mSv/year, with no indications of adverse health effects. [UNSCEAR 2000, cited in (*11*), vol. 1, Annex B.]
25. *Low Level Radiation Health Effects: Compiling the Data*, J. Muckerheide, Ed. [Radiation, Science, and Health (RSH), Needham, MA, ed. 2, 1998]; with revisions and preliminary contents for the 3rd ed.; available at http://cnts.wpi.edu/rsh/docs, with access to UN reports on the Chernobyl accident health effects provided by the Center for Nuclear Technology and Society (CNTS) at Worcester Polytechnic Institute. James Muckerheide, Director of CNTS and Massachusetts State Nuclear Engineer, contributed to authoring this statement. RSH, along with the Nuclear Energy Institute, the National Mining Association, and several municipal water districts are currently suing the U.S. Environmental Protection Agency, charging that by basing its rules on the premise that low-dose radiation is harmful at any level, EPA is arbitrarily and capriciously failing to follow the best peer-reviewed science as required by law.
26. The most comprehensive compilation and evaluations of the biology and health effects of low-dose ionizing radiation from 1898 to 1988 are T. D. Luckey, *Hormesis with Ionizing Radiation* (CRC Press, Boca Raton, FL, 1980) and *Radiation Hormesis* (CRC Press, Boca Raton, FL, 1991).
27. The authors are all members of the National Academy of Engineering, but this statement does not constitute an official statement of the academy.