

Letters to the Editor

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Revisiting Nuclear Power Plant Safety

THE ANGER OF D. M. CHAPIN ET AL. AT THOSE who describe spent nuclear fuel transport casks as “mobile Chernobyls” is understandable (“Nuclear power plants and their fuel as terrorist targets,” Policy Forum, 20 Sept., p. 1997). But that is no excuse for misquoting the work of others in support of the position that the consequences of a terrorist attack on a U.S. nuclear power plant would be “a minor event.”

Chapin *et al.* assert that “[n]o airplane, regardless of size, can fly through such a wall” [“the reinforced, steel-lined 1.5-m-thick concrete walls surrounding a nuclear reactor”]. Sandia National Laboratory, whose report Chapin *et al.* cite as evidence of this assertion, has already disputed the relevance of its report to this conclusion (1). Also relevant to the overall question of the risks from aircraft crashing into nuclear power plants is the conclusion of a recent Nuclear Regulatory Commission (NRC) report on the potential risks to the spent fuel pools that adjoin U.S. nuclear power reactors: “1 of 2 [large] aircrafts are large enough to penetrate a 5-foot-thick reinforced concrete wall” of a pressurized water reactor spent fuel storage pool, potentially causing it to be “so damaged that it rapidly drains and cannot be refilled from either onsite or offsite resources.” (2, p. 3-23, Appendix 2D). The NRC report concluded that, under these circumstances, the fuel in the “dense-pack” arrangement that is now virtually standard in U.S. spent fuel pools would heat up to the point where “the possibility of a zirconium fire leading to a large fission product release cannot be ruled out” (2, Executive Summary, p. xi). Elsewhere in the NRC report, it is estimated that such a fire could release about 10 times more cesium-137 than was released by the 1986 Chernobyl accident (2, Appendix 4A, Table 2, p. 5). That accident released 2 million curies of this 30-year half-life, gamma-ray-emitting fission product, contaminating 10,000 km² of land to the point

where mandatory evacuation and strict radiation controls were imposed (3, pp. 457, 472–475).

The authors cite the UN’s review of the consequences of the Chernobyl accident as the basis for their assertion that “no significant increase in mortality or cancer due to irradiation of the public have been observed.” However, that report shows an up to a 25-fold increase in the incidence of childhood thyroid cancers in cities in the most contaminated regions of Belarus and concludes that “there can be no doubt about the relationship between the radioactive materials released from the Chernobyl accident and the unusually high numbers of thyroid cancers observed in the contaminated areas during the past 14 years” (3, Table 57, p. 504). Similarly, the abstract of a review article cited by Chapin *et al.* as questioning whether Chernobyl caused a thyroid cancer epidemic states that “[t]hese thyroid tumours form the largest number of cancers of one type, caused by a single event on one date, ever recorded” (4). *Science*’s own news coverage of this thyroid cancer epidemic is similarly mis-cited (5).

The public fear of the risks from ionizing radiation may be disproportionate. However, this fear is reinforced by a learned distrust of reassurances from the

“The public fear of the risks from ionizing radiation may be disproportionate. However, this fear is reinforced by a learned distrust of reassurances from the nuclear industry.”
—VON HIPPEL

nuclear industry. This article by 19 mostly retired nuclear-industry leaders does nothing to remedy that situation. Contrary to the implied conclusion of their Policy Forum piece, the U.S. government should require strengthened protections against and preparations for emergency response to terrorist attacks on U.S. nuclear power reactors.

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3. UN Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), *Sources and Effects of Ionizing Radiation: UNSCEAR 2000 Report to the General Assembly* (United Nations, New York, 2000).
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D. M. CHAPIN AND COLLEAGUES GIVE A SURPRISINGLY UNBALANCED view of the issues relating to nuclear power plants as possible terrorist targets (“Nuclear power plants and their fuel as terrorist targets,” Policy Forum, 20 Sept., p. 1997) in terms of potential scenarios and the potential radiological risks.

With regard to potential terrorist scenarios involving a nuclear power plant, the authors are correct to point out that the very thick walls of the containment vessel make the nuclear core an unlikely target. They do not, however, address the more pertinent issue of the spent fuel-rod storage pools, which are located adjacent to most commercial reactors (1). These spent fuel storage facilities typically contain amounts of radioactivity comparable to that in the reactor core itself. Typically, the fuel rods are stored underwater and in nonhardened buildings; often, they are on upper floors. The issues relating to the possibility of a plane- or missile-based attack on a spent fuel pool or the possible theft of a spent fuel rod for use in a “dirty bomb” seem much more relevant than the unlikely scenario of an attack on a nuclear reactor core.

In terms of the radiological risks from the low levels of radiation that might be produced in a radiological terrorism incident, the authors present a one-sided perspective. Indeed, the biological effect of low levels of radiation are hard to quantify because the individual risks are small, but there is little evidence that low doses of radiation are actually beneficial, as the authors suggest. The most recent consensus report on the risks of low doses of ionizing radiation, from the National Council on Radiation Protection (2, p. 7), concluded that “although other dose-response relationships for the mutagenic and carcinogenic effects of low-level radiation cannot be excluded, no alternate dose-response relationship appears to be more plausible than the linear-nonthreshold model, on the basis of present scientific knowledge.” In other words, as the dose goes down, the risk probably goes down proportionately, but is unlikely to actually reach zero.

Chapin *et al.* suggest that no significant increase in mortality or cancer has been observed from the radiation from the 1986 Chernobyl accident. The study of thyroid can-

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cer in the exposed children is ongoing, but the evidence that radiation from the accident has increased thyroid cancer rates in this population seems unequivocal (3). Of course, thyroid cancer is comparatively rare and has a high survival rate, but extensive studies of the A-bomb survivors (4) suggest that increases in thyroid cancer and leukemia are early indicators of a bigger wave of solid cancers yet to come (5). It is only 16 years since the Chernobyl accident, which, based on the A-bomb survivor experience (4), is still too early to expect significant radiation-related increases in solid cancers. Most of any potential increase in cancer rates in individuals exposed in 1986 would not be expected to appear until 25 to 50 years after the accident (4).

Yes, the cancer risks from very low doses of radiation are probably very small. But nuclear terrorism could result in large numbers of people being subject to these very small risks. That's why it may represent a significant public health concern.

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2. Evaluation of the Linear-Nonthreshold Dose-Response Model for Ionizing Radiation (Report 136, National Council on Radiation Protection and Measurements, Bethesda, MD, 2001).
3. L. N. Astakhova *et al.*, *Radiat. Res.* **150**, 349 (1998).
4. D. A. Pierce, Y. Shimizu, D. L. Preston, M. Vaeth, K. Mabuchi, *Radiat. Res.* **146**, 1 (1996).
5. Risk estimates for radiation-induced leukemia due to the Chernobyl accident are rather variable, as uncertain dosimetry has necessitated primarily descriptive studies (6), although there are indications of a small increase in risk in exposed children (7, 8).
6. L. E. Peterson *et al.*, *Stem Cells* **15** (suppl. 2), 211 (1997).
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AS PRESIDENT OF AN ORGANIZATION CRITICIZED

for exaggerating the danger of a terrorist attack on a nuclear power plant ("Nuclear power plants and their fuel as terrorist targets," D. M. Chapin *et al.*, Policy Forum, 20 Sept., p. 1997), I would like to outline the technical basis for our concern. Chapin *et al.* selectively invoke "a few simple scientific and engineering truths" to assert that nuclear plants are essentially invulnerable to attack. In fact, the issues they raise are far from simple and cannot be so neatly resolved.

Today's nuclear plants are vulnerable to common-mode failures, such as station black-out events, that could result in core damage in as little as 2 hours (1). Terrorists could exploit these weaknesses to maximize the severity of an attack. During a series of security exercises between 1991 and 2001, mock attackers were able to simulate the destruction of enough equipment to cause a meltdown at nearly 50% of U.S. nuclear plants. In many of those exercises, the attackers were also able to

breach the containment (2).

The 1979 Three Mile Island (TMI) accident has little bearing on this scenario because operators were able to restore core cooling before the core became fully molten. With time, a molten core will indeed cause rupture of the reactor vessel, an event that was observed in a dramatic test at Sandia National Laboratories in 2000 (3). In contrast to the sequence of events at TMI, if terrorists were able to seize the control room and remote shutdown panels during an attack, they could prevent operators from taking timely corrective action.

We have assessed the consequences of a large radiological release resulting from a meltdown and containment breach using the SNL code MACCS2 and standard code parameters (4). We find that children hundreds of miles downwind are at risk of thyroid exposures high enough to warrant potassium iodide prophylaxis under FDA guidelines. The number of all radiation-induced cancer fatalities predicted by the code is site and scenario dependent but could exceed 10,000 for a typical U.S. plant.

The level of security at nuclear power plants is not commensurate with the consequences of a terrorist attack. The cost of additional protective measures is small compared with the benefits of risk reduction. To ignore the dangerous potential of such events, as Chapin *et al.* would do, can only lead to uninformed and irresponsible policy decisions.

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4. D. I. Chanin, M. L. Young, *Code Manual for MACCS2: Volume 1, User's Guide*, SAND97-0594 (Sandia National Laboratories, Albuquerque, NM, 1997).

Response

OUR POLICY FORUM PAPER DOCUMENTS THAT engineering tests and analyses of radioactivity from molten nuclear fuels, with failed containment, under realistic worst-case assumptions, would produce few, if any, casualties. Commenters have made no attempt to answer

the referenced reports that support this conclusion and refute their position.

Commenters have questioned the use of Sandia tests that rocketed an aircraft into a concrete block. These tests were not intended to prove containment invulnerability, but to confirm calculations that impact energy disintegrates large aircraft, with little penetration. Containment damage itself cannot lead to reactor damage. But we examined worse acci-

dents or terrorist events that destroy redundant plant systems inside or outside containment, rupturing containment penetrations, producing ground-level, unfiltered releases. Even in this extreme situation, the radioactivity remains largely bound in the fuel. Condensing water and the physical-chemical properties of fuel retains most radioactivity in water and structures (as at Three Mile Island). Condensing water limits releases, which are

not in readily dispersible forms, nor do they remain in respirable forms. This minimizes inhalation hazards (1).

Spent fuel pool radioactivity has lost the short-lived and most volatile products and has insufficient energy to disperse in hazardous forms. Even hypothesized zirconium fires would only burn cladding and structures, external to the fuel, adding little to the radioactivity release.

In the worst case scenario, near-plant contamination would warrant evacuation, but not urgently; there would be time for evacuation without significant public health risk. Radioactivity dispersed widely has lower concentrations, in low-hazard forms. Our Policy Forum documented [in notes (11-15)] that even ejecting Chernobyl radioactivity directly to the environment, burning for 10 days, without evacuation or interdicting contaminated food, caused few, if any, deaths or injuries among the public. (Most evacuated area dose rates remained below those of high natural radiation areas.) The average effective dose (8.2 mSv in 5 million people) is small compared with doses from hundreds of millions of relevant medical exposures showing no adverse effects at much higher doses (2, 3).

Brenner and von Hippel correctly note increased thyroid cancer rates from the Chernobyl accident (about 2000 cases) but do not acknowledge that the references we cited document that these cases are readily

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—CHAPIN ET AL.

treated, producing few if any (none confirmed) fatalities, with expected normal health and life-span, with patients taking thyroid hormones. No other cancer increases have been identified.

Analyses that predict many deaths use invalid release quantities, materials characteristics, dispersion, dose estimates, and dose consequences. For example, the Department of Energy spent fuel cask missile damage study assumes no cleanup and exposes "victims" for 1 year. Even so, the highest dose is tolerable, and if the "victims" walked away, it would be negligible. Similarly, a Nuclear Regulatory Commission report falsely "predicts" radiation deaths 500 miles from spent fuel fires (4).

Brenner concedes that the issues of nuclear terrorism relate to a very small individual lifetime risk, but he claims that multiplied by a very large number of people, it presents a significant public health concern using linear no-threshold (LNT) assumptions. Lyman similarly "predicts" thousands of deaths. But there is no scientific basis for such predictions.

NCRP-121 states, "Few experimental studies, and essentially no human data, can be said to prove, or even provide direct support for the concept... It is conceptually possible, but with a vanishingly small probability, that any of these effects could result from the passage of a single charged particle... It is a result of this type of reasoning that a linear non-threshold dose response relationship cannot be excluded." (5, p. 45).

NCRP-136, cited by Brenner, states, "It is important to note that the rates of cancer in most populations exposed to low-level radiation have not been found to be detectably increased, and that in most cases the rates have appeared to be decreased." (6, p. 6) The LNT fails at every level—molecular, cellular, microorganism, animal, and human. Organisms' responses produce beneficial, nonlinear health effects (7). Natural radiation varies from below 1 mSv/year to 10 mSv/year, with local areas exceeding 100 mSv/year. Inhabitants of high radiation areas show average or better health and cancer rates (8).

Following Roentgen's 1895 x-ray discovery, low-dose radiation (LDR) was found to produce immunological stimulation, curing infections and inflammatory diseases and enhancing physiological conditions (9); by the 1920s, it was found to prevent and cure some cancers (10). We referenced [notes (21, 22) in our Policy Forum] information that relevant mechanisms are being elucidated. Radiation produces consistent biphasic responses in vivo: on immune cells and molecules; transcription factors; and enzymes, genes, and intercellular communications; etc. LDR responses are consistent with medical

and health benefits (7). Antibiotics have largely replaced LDR therapies (11), but positive LDR effects on biology and health remain. Oak Ridge hospital facilities successfully exposed patients at moderate dose rates for hours and low dose rates for days (12). LDR, including radon therapies, is applied worldwide, with physicians' prescriptions, and is covered by medical insurance.

Commenters objected to our asserting that LDR is essential to life. But relevant, confirmed, uncontroverted data show detrimental health effects and biological functions when organisms are "protected" from background radiation (13) and in experiments using potassium with potassium-40 removed, e.g., in the Oak Ridge calutrons (14).

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- LDR is still sometimes used when antibiotics and anti-inflammatories fail, e.g., in some arthritic conditions, and radon therapies are used extensively and successfully by medical direction in Europe, Russia, and elsewhere. LDR had 95% success treating gas gangrene, largely eliminating any amputation, whereas current practice is to amputate and use antibiotics, with 30 to 70% mortality (15).
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- The authors are all members of the National Academy of Engineering, but this statement does not constitute an official statement of the academy. James Muckerheide, Director of the Center for Nuclear Technology and Society at Worcester Polytechnic Institute, and Massachusetts State Nuclear Engineer, contributed to authoring this response.

TECHNICAL COMMENT ABSTRACTS

COMMENT ON "Otolith $\delta^{18}\text{O}$ Record of Mid-Holocene Sea Surface Temperatures in Peru"

Philippe Béarez, Thomas J. DeVries, Luc Ortlieb

Andrus *et al.* (Reports, 22 Feb. 2002, p. 1508) used oxygen isotope profiles and zoogeographic data of fish remains from modern and archeological samples to infer Holocene oceanographic conditions off Peru. We contend that the study relied on ecologically inappropriate proxies and oceanographically mischaracterized sites. Conclusions regarding faunal and climatic changes were supported by misinterpreted diversity data.

Full text at

www.sciencemag.org/cgi/content/full/299/5604/203a

RESPONSE TO COMMENT ON "Otolith $\delta^{18}\text{O}$ Record of Mid-Holocene Sea Surface Temperatures in Peru"

C. Fred T. Andrus, Douglas E. Crowe, Daniel H. Sandweiss, Elizabeth J. Reitz, Christopher S. Romanek, Kirk A. Maasch

Close examination of the comment strengthens rather than undermines our original interpretations. We present new independent proxy data supporting our conclusions. Peruvian mollusk $\delta^{18}\text{O}$ profiles and reanalysis of published radiocarbon dates of molluscan assemblages corroborate the interpretation of enhanced seasonality and warm sea surface temperatures prior to 5800 cal. B.P.

Full text at

www.sciencemag.org/cgi/content/full/299/5604/203b