Flawed or misused analytic techniques for assessing pollution risk can allow environmental injustice, disproportionate health harm to children and to poor or minority communities.

How Some Scientists and Engineers Contribute to Environmental Injustice

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As Danny Glover put it, environmental injustice (EIJ) is about the fact that South-Central Los Angeles children have only one-third of the lung capacity of Santa Monica children (van Gelder 2001). South-Central LA is mostly black and heavily polluted; Santa Monica is mostly white and pristine. Children bear the brunt of the difference.

In most nations poor people, minorities, and children bear EIJ—disproportionate pollution that causes poorer health and higher death rates. This article shows how scientists and engineers contribute to EIJ if they mask, thus encourage, EIJ by using flawed analytic techniques such as short-term studies or incomplete verification and validation. It illustrates EIJ effects of three such errors: using small or nonrepresentative samples, misrepresenting uncertainty, and misusing statistical significance.

Background

Each year US industry releases into the environment more than 4 billion pounds of toxic chemicals that contribute to the 40 percent of all global disease and premature death caused by environmental factors, especially pollutants (CEHC 2016; Pimentel et al. 2007). The World Health Organization (WHO 2014) says air pollution alone causes 7 million global, annual, premature, preventable deaths.

But pollution doesn't affect everyone equally. People of color are a majority of residents living within 3 km of US hazardous-waste sites, and they are 3–9 times more likely than whites to be exposed to toxin-releasing facilities such as waste incinerators (Bullard et al. 2008; Lougheed 2014). Of nearly 4 million residents living within the fenceline zones[1] of 3,433 US chemical facilities, the proportion of blacks is nearly 100 percent greater than their percentage of the US population, and the percentage of Latinos is 60 percent greater (Orum et al. 2014).

Poor and minority children are hurt worst by EIJ, partly because infants and children have unique biological vulnerabilities, proportionately heavier pollution exposures, and higher respiration rates and sensitivities. Rates of ADHD, asthma, autism, birth defects, cancer, and reduced IQ have all been rising, at least partly from increased environmental pollution, including exposure to 80,000 synthetic chemicals, most of which did not exist 50 years ago (Grandjean 2013; Grandjean and Landrigan 2014). Of the 20 US highest-volume toxic-chemical releases, physicians say 75 percent are known or suspected to be neurodevelopmentally toxic to children (CEHC 2016).

Why EIJ Continues

For two-thirds of the 3,000 high-production-volume chemicals (those with a production volume of at least 1 million pounds/year), the US government has no information on their child-harm potential. One reason is the failure of the 1976 Toxic Substances Control Act (TSCA), including its grandfathering 62,000 already-in-use chemicals without any testing.

The Industry-Government Funding Imbalance

Another reason for EIJ and poor pollutant information is chronic underfunding and understaffing of the US Environmental Protection Agency (EPA), responsible for enforcing TSCA. The result? Without overwhelming evidence to the contrary, regulators typically presume existing pollutants are safe (GAO 2015, pp. 280–287; Grandjean and Landrigan 2014).

A further reason for EIJ and poor pollutant information is the industry-versus-government science-funding imbalance. Industry's annual spending on environmental-health research is 100 times that of government, and its scientific results often are protected by trade-secrets laws (Shrader-Frechette 2007a, pp. 76–112). Coupled with financial conflicts of interest, this funding imbalance means that industry-funded research may use flawed science to generate pro-industry conclusions (Krimsky 2004). For instance, one false-negative bias—that masks EIJ—involves giving averages or point estimates instead of ranges or distributions of pollution levels. Yet pollution at the tail of the distribution, not average levels, typically hurts people.

Flawed Science about Product and Pollutant Harm

Still another reason for EIJ is weak regulations. Epidemiologist David Michaels (2008), President Obama's assistant secretary of labor, says the US health-regulatory system is broken because flawed science and engineering dominate it and encourage EIJ. He shows how unscrupulous product-defense, contract-research, and private consultants misuse analytic techniques, "manufacture" uncertainty about obvious product/pollutant harm, control the scientific literature, and thus derail needed regulations.

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Of course, most researchers never fall into research misconduct—that is, falsification, fabrication, or plagiarism (ORI 2011). Statistically, however, because biased methods can give funders the results they want, social scientists agree that knowing the funder generally predicts science and engineering results (Krimsky 2004).

Investigating flawed scientific techniques in the chemical industry, a prominent US National Research Council report warned that "a study cannot be ethically acceptable if it is scientifically invalid," for example, if it lacks "adequate statistical power" or is not "reported comprehensively" (NRC 2004, p. 7).

Besides being unethical, invalid science and engineering also can cause EIJ. Three of many flawed analytic

[1] The fenceline zone is an "area designated as one-tenth the distance of the vulnerability zone, in which those affected are least likely to be able to escape from a toxic or flammable chemical emergency" (Orum et al. 2014, p. 1).

techniques that encourage EIJ include employing small or nonrepresentative samples, misrepresenting uncertainty, and misusing statistical significance.

Employing Small or Nonrepresentative Samples

When scientists or engineers test samples that are nonrepresentative or include only a few of many instances or subjects, they risk false negatives, false conclusions of no harm. A typical case in which scientists appear to have drawn false conclusions of no harm, at least partly because of their small, nonrepresentative samples, is the 2015 joint EPA and auto-industry *Advanced Collaborative Emissions Study* (ACES).

> *Early environmental pollution exposures often "program" children for different diseases later in life.*

The Controversial "Clean-Diesel" Research

ACES assessed the health effects of "clean diesel" (as defined by 2007 US air-pollution standards). After using several questionable methods, such as employing no positive controls, inaccurate state variables, and small, nonrepresentative samples (Shrader-Frechette 2015), ACES concluded that "clean diesel" is neither carcinogenic nor genotoxic (Greenbaum et al. 2015).

Despite its denial of carcinogenicity and genotoxicity, ACES admits that "clean diesel" (which removes only some diesel-particulate matter [DPM] from regular diesel exhaust) still contains 200,000–800,000 DPM particles per cubic centimeter (Greenbaum et al. 2015; McDonald et al. 2015). Yet DPM has no safe dose. Each particle can move directly and immediately into the brain and lungs, then to the blood and all organs, where it causes inflammation, oxidative stress, blockage, disease, or death (APHA 2014; CalEPA 2007; IARC 2012; Pope and Dockery 2006; Pope et al. 2009; Shrader-Frechette 2015; US EPA 2013).

No wonder the WHO, International Agency for Research on Cancer, American Public Health Association, and most scientific and medical groups say that any amount of diesel exhaust is carcinogenic. They say "strong evidence" shows that diesel, especially DPM, induces cancer in humans through genotoxic mechanisms. Decades-long, controlled, 600,000-person studies, across the US, have shown that any nonzero DPM or PM exposure increases risks such as Alzheimer's, autism, birth defects, cancer, cardiovascular disease, Parkinson's, and respiratory disease (e.g., Costa et al. 2014; Krivoshoto et al. 2008; Oudin et al. 2016; Pope and Dockery 2006; Pope et al. 2009; Raz et al. 2015; Shrader-Frechette 2015; Terzano et al. 2010).

ACES Tested Only the Healthiest, Least-Sensitive Individuals

One reason ACES rejected scientific consensus about diesel risks appears to be that it used only short-term studies. ACES claimed to have done "lifetime" exposure studies of "clean diesel," but instead tested only rats at the middle, healthiest parts of life. This is equivalent to testing only humans older than age 6—far beyond the period when children can be up to 40 times more sensitive than adults. This sensitivity explains why many prominent scientists have documented higher rates of child autism and IQ losses that are proportional to higher PM and DPM traffic exposures (e.g., Becerra et al. 2013; Harris et al. 2015; Makhijani et al. 2008; Raz et al. 2015).

Using such nonrepresentative samples (McDonald et al. 2015), ACES ignores the way that early environmental pollution exposures typically "program" children for various diseases later in life (e.g., Grandjean 2013; Grandjean and Landrigan 2014). By preselecting subjects that had no typical infant or juvenile exposure, ACES was less likely to detect diesel harm.

ACES Tested Only Small Samples, 3–5 Rats

In addition, ACES' samples of only 3–5 rats, at each of 4 exposure levels (McDonald et al. 2015), are too small by a factor of 1000 to detect most harm (Shrader-Frechette 2015). ACES' small samples are puzzling because using thousands-of-rats samples would have been easy and inexpensive, compared to human testing (e.g., Hamra et al. 2015).

This small-sample bias thus masks diesel's EIJ harm, not only to sensitive populations such as children and sick or elderly people, but also to minority and poor people who tend to live near highways where DPM is highest. In Los Angeles County, for instance, mobile pollution sources like vehicles generally cause 90 percent of the total cancer risk from air pollution, but DPM alone causes 80 percent of this risk (South Coast AQMD 2015).

How Small, Nonrepresentative Samples Mask Harm and Help Cause EIJ

Because nearly all US freight trucks and trains use diesel fuel, intermodal-freight-transport hubs and highways have especially high DPM levels. Yet because hub neighborhoods are mostly African-American or Latino, they bear diesel EIJ (Hricko et al. 2014; US EPA 2014).

The mostly Latino residents of the Los Angeles neighborhood surrounding the East Yards intermodal-freight-transport facility, for instance, have cancer rates up to 19 times higher than average-US rates, and 11 times higher than Los Angeles County rates (CalEPA 2007; US EPA 2013).

Chemical-Industry Small Samples

Why has government not prevented the higher cancer rates in areas like East LA? One reason is that small-sample, nonrepresentative pollution testing, like what ACES did, allows many polluters to tell both government and EIJ victims that their air, water, or food is safe when it is not. Polluters have used small samples for a long time, and they usually get away with doing so.

For instance, in 1993 the US National Research Council (NRC 1993) warned about likely child-neurodevelopmental harm from then-current pesticide regulations. As a result, Congress directed EPA to reassess possible harm and imposed stricter pesticide regulations during the 10 years of reassessment.

Yet EPA found no neurodevelopmental harm, and it rejected the stricter pesticide regulations. Why? Part of the reason is that it relied on pesticide studies presented by the chemical industry. All 22 chemical-industry studies—submitted to EPA in response to the stricter pesticide regulations—had small samples, averaging only 25 subjects. Yet only sample sizes hundreds of times larger could avoid most false-negative conclusions that current pesticide regulations were safe. In addition, all chemical-industry studies had further false-negative biases because they were only hours or days long, far too short a time to detect neurodevelopmental harm (Shrader-Frechette 2007b).

Misrepresenting Uncertainty

Researchers also can bias their results and contribute to EIJ when they misrepresent uncertainty or fail to do uncertainty analysis, a statistical assessment of the reliability of scientific or engineering judgments about the values attributable to estimates, models, or measures. Whenever such values are untestable, rely on unknowns, or reflect cumulative effects of data variability, uncertainty analysis can assess both random error and bias (Jordaan 2005; Shrader-Frechette 2007a, pp. 76–112).

Uncertainty analysis is especially needed when scientists or engineers estimate long-term, inaccessible, or difficult-to-predict harm, such as 10,000-year effects of climate change—or the timing, route, and volume of pollutants that may escape from a hazardous-waste site. Otherwise, experts' well-documented overconfidence, representativeness, anchoring, and other cognitive biases could compromise sound science and promote EIJ (Bullard et al. 2008; Kahneman et al. 1982).

Small-sample pollution testing can allow polluters to tell government and EIJ victims that their air, water, or food is safe when it is not.

The Flawed MIT Study

Yet even well-known engineering analyses, like the classic MIT study of commercial-nuclear-accident probabilities, misrepresent uncertainty either through subjective assumptions or failure to do uncertainty analysis. The MIT engineers relied on purely theoretical calculations, assumed that control-rod and other failure probabilities were independent, then concluded that nuclear-accident risks were only 1/17,000 per reactor-year, about 1 in 5 for all US reactors during their lifetimes. Unsurprisingly, the American Physical Society and US Nuclear Regulatory Commission said they do "not regard as reliable" the MIT "numerical estimate of the overall risk of reactor accidents" (Shrader-Frechette 2014; US NRC 1975, 1979).

Even worse, US, Dutch, and other engineers showed that the MIT study ignores empirical data, exhibits overconfidence biases, thus overestimates nuclear safety. When they compared actual US reactor-accident frequencies from Oak Ridge data, with the MIT predictions for the same 7 events, the actual occurrence rates for all 7 accident types were outside MIT's 90-percent-confidence bands. The MIT authors said these accidents had only a 10 percent probability. Simply checking available empirical data could have avoided this misrepresentation of uncertainty (e.g., Cooke 1982; Shrader-Frechette 1991, 2007a; US NRC 1975).

Biased DOE Studies

Similar misrepresentations occurred when US Department of Energy (DOE 2000) engineers assessed the million-year safety of the proposed Yucca Mountain, Nevada, nuclear-waste repository. After DOE failed to do uncertainty analysis, then made optimistic predictions about repository safety, scientists from the International Atomic Energy Agency used DOE's own data to do uncertainty analysis. The results were damning. DOE's overconfident estimates of low radiation doses were uncertain by 9–12 orders of magnitude. Yet if they erred by only 2 orders of magnitude, catastrophic numbers of deaths could occur (IAEA 2001; Shrader-Frechette 1993, 2007a).

Both the MIT and DOE misrepresentations of uncertainty arguably have contributed to false-negative biases, thus EIJ risks, as US commercial reactors are disproportionately sited in predominantly poor, southeastern US communities. Yucca Mountain was sited near predominantly Native American and Latino communities (Shrader-Frechette 2011).

Misrepresentation of uncertainty has been a key cause of disproportionate siting of US commercial reactors in poor communities in the Southeast.

Misusing Statistical Significance

Researchers also contribute to false-negative conclusions and EIJ by invalidly rejecting observational/epidemiological evidence of pollution harm if it is not statistically significant. However, statistical-significance tests are valid only with randomized, representative samples, randomized assignment to experimental-versus-control groups, and randomized dosing and treatment. Without randomization (that typically ensures parent- and sample-population homogeneity), reliable inferences are impossible (Greenland 1990; Shrader-Frechette 2014).

Yet scientists and engineers frequently demand statistically significant results from nonrandomized data, or they invalidly deny health damage from pollutants, e.g., near toxic-waste dumps. With hundreds of thousands of such US dumps, disproportionately sited in poor or minority communities, invalid statistical analyses can promote EIJ (Bullard et al. 2008; Rushton 2003; Shrader-Frechette 2012, 2015; Triassi et al. 2015.).

Flawed Statistics about Three Mile Island

Consider what happened at Three Mile Island (TMI), Pennsylvania. The US government and nuclear industry claim that "no member of the public died" because of the 1979 nuclear accident (e.g., WNA 2016), partly because they reject key epidemiological evidence of harm, as not statistically significant (Hatch et al. 1991, 1990; Shrader-Frechette 2014; Talbott et al. 2003).

Yet by definition, after-the-fact accident data cannot be randomized, thus validly assessed for statistical significance. No wonder most university epidemiologists who study TMI disagree with the industry-government, no-deaths claim. Only four years after the accident, already there was a 64 percent increase in cancer incidence within 10 miles of TMI. This represents about 126,000 cancers that otherwise would not have occurred (Hatch et al. 1990; Shrader-Frechette 2014; Wing 2003).

These observational, nonrandomized data are especially damning to the no-deaths claim because the increased cancers were disproportionately radiosensitive, exactly what a nuclear accident would cause. They also were disproportionately respiratory, predictable because TMI released mostly radioactive noble gases (Shrader-Frechette 2014; Wing 2003).

UN documents report that TMI radiation doses were 100,000 times higher per hour than industry and government claim. They say TMI released 10 times more radiation than Hiroshima-Nagasaki, while the Chernobyl accident released 200 times more radiation than Hiroshima-Nagasaki (Shrader-Frechette 2011, 2014; WHO 1995).

But if scientists and engineers do not dismiss Hiroshima-Nagasaki harm, why should they dismiss TMI harm?

Even after the highest TMI releases ended, the US NRC admitted that additive, *hourly* TMI-offsite doses were higher than *yearly* average-background-radiation doses that annually cause 3–6 percent of all cancers.

Under oath, the TMI utility also admitted in court that *hourly* TMI doses were *more than double the yearly* background doses and 6 times greater than the many-months TMI-maximum dose that the US NRC claimed (Shrader-Frechette 2014; Walker 2006).

Who was hurt most because of the industry-government demand for statistically significant results and the resulting denial of TMI harm? Children. They're up to 40 times more sensitive than adults to the same radiation doses (Makhijani et al. 2006).

TMI insurers quietly spent $80 million to require gag orders in exchange for paying off the worst TMI-accident victims of cancer, infant retardation, and infant mortality, all of which can be caused by high radiation doses. The insurers then rejected thousands of other claims, mostly on behalf of children, partly by claiming that the increased numbers of cancers, to date, were not statistically significant (Epstein 2011; Shrader-Frechette 2014; Wing 2003).

Denying EIJ

In response to apparent EIJ, critics typically either deny or excuse the harm. Those who deny EIJ say health risks near hazardous facilities need not be higher than elsewhere, just because pollution releases are higher (Boerner and Lambert 1997; Hayward 2009).

These EIJ deniers are partly right; emissions do not equal exposures. However, studies on thousands of airborne pollutants show clear dose-response curves that correctly predict dose-related harm. Unequivocal data show that the closer one gets to noxious facilities, the higher the health risks and the lower the resulting property values (Anstine 2003; APHA 2007; Muehlenbachs et al. 2015).

Deniers also say that EIJ disappears when supposedly victimized areas are redefined. EIJ can vanish when victims are defined as living within 50, rather than 5, miles from a hazardous site (Boerner and Lambert 1997).

Deniers are right that dilution sometimes can be a partial solution to pollution, getting farther away from hazards. Yet those who deny EIJ don't dilute near-facility pollution, only their methods of detecting pollution. By including less- and non-exposed people over a larger area, they reduce average-pollution doses. Thus the appropriate response to apparent EIJ is not gerrymandering that masks spatially related effects, but scientific analysis that can discover any disproportionate pollution burdens anywhere (Gracia and Koh 2011).

EIJ deniers likewise claim that the correlation between hazardous sites and poor/minority residents does not prove that polluters caused EIJ. They say poor people/minorities may have moved to risky areas after facility siting (Hayward 2009; Mohai and Saha 2015).

Yet here again, EIJ deniers partly err. The issue is not only whether siting decisions deliberately victimize or target poor people and minorities, given that lower-socioeconomic-status neighborhoods are less able to force costly pollution controls. Instead, the issue is also that even when there is no deliberate discrimination, government should guarantee everyone rights to life, to equal opportunity, to breathe clean air, to drink clean water, and to be protected from environmental toxins (Shrader-Frechette 2004).

The main EIJ victims of TMI, hurt by invalid demands for "statistically significant" results, were children.

Excusing EIJ

Still, those who excuse EIJ often claim that because polluting facilities must be located somewhere, different pollution levels are unavoidable. Or they say that because of factors like cheaper housing, EIJ victims benefit overall by living near noxious facilities.

The unavoidability excuse for EIJ begs at least two questions. Should pollution burdens be distributed unequally, all other things being equal? Should people's rights to breathe clean air depend on their race or socioeconomic status?

This excuse also ignores the fact that a more equal distribution of pollution burdens likely would force the US to bring all pollution standards at least up to those of Europe, which often has better protections. For instance, US per-capita CO_2 emissions are about 20 tons/year, but 10 in the UK, 8 in Italy, 7 in France, and 6 in Denmark—countries where there is much more public transport, recycling, green energy, and pollution-control expenditures per dollar of GDP. The United States has up to 300 percent more CO_2 emissions per dollar of GDP than EU nations like Germany, Italy, Sweden, and the UK (Rosenthal 2009; Shrader-Frechette 2007a; World Bank 2011).[2]

Likewise the overall-benefits excuse for EIJ begs the question that cheaper housing near polluting sites is worth killing or sickening innocent people. It also ignores the fact that people have legal and moral rights to equal treatment—long-standing common-law rights not to be harmed by others. If US equality means anything, Americans should bear mostly equal pollution burdens (Shrader-Frechette 2004).

But do overall economic benefits excuse EIJ?

Those who think so always ignore the massive economic costs of pollution-induced poor health. Just the current IQ losses and their resulting lifetime-earnings losses, just from lead pollutants (mostly from incinerators and factories, not lead paint), just for the one-year cohort of US children under age 5, are $51 billion/year. Child-IQ and resulting economic losses attributable to lead, pesticides, and other neurotoxic pollutants are each roughly the same as those for preterm birth, traumatic brain injury, brain tumors, and congenital heart disease. Why does the US try to prevent the four preceding medical problems, while it allows EIJ (Attina and Trasande 2013; Grandjean and Landrigan 2014)?

Conclusion

Scientists and engineers ought not use or misuse analytic techniques that mask, thus encourage, EIJ. Sound science promotes sound ethics, including environmental justice.

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[2] Country-specific data are available online from the World Bank, CO2 emissions (metric tons per capita), at http://data.worldbank.org/indicator/EN.ATM.CO2E.PC.

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