Comparing Opportunities To Reduce Health Risks: Toxin Control, Medicine and Injury Prevention

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Executive Summary

The United States spends more than $1 trillion each year on medical services of all kinds, and serious questions are being raised about whether these health care dollars are well spent. Meanwhile, spending to regulate toxic substances such as chemicals and radiation is the subject of less public scrutiny. In fact, many federal laws discourage or even prohibit regulators from weighing the benefits and costs of toxin controls. This perverse outcome reflects the influence of advocacy groups that are demanding protection against all environmental toxins, regardless of how small the risks are or how great the costs of regulation might be. Recently, the annual rate of increase in toxin control spending has actually outstripped the annual rate of increase in health care spending.

The result? Billions of dollars are being spent to eliminate trivial risks to health and safety based largely on speculative fears that man-made sources of chemicals and radiation are important causes of human cancer. If this same money were spent effectively, it could save 60,000 lives each year and thereby add 600,000 life-years to the life expectancy of the American people. (A "life-year" saved is a statistical measure of how much a lifesaving program increases the life span of a target population.)

For example:

- Spending $100 million per year on control of benzene emissions at rubber tire manufacturing plants might save one life-year over a 200-year period (i.e., $20,000 billion per life-year saved). The same $100 million, if invested in automobile airbag technology, is expected to save 2,000 life-years every year (or $50,000 per life-year saved)!
- Spending $100 million per year on control of routine low-level releases of radiation from nuclear power plants might save one life-year each year. But the same amount of investment in cervical cancer screening and treatment is expected to save 2,000 life-years every year.

Overall:

- The median medical program costs $19,000 per year of life saved; the median injury prevention program costs $48,000 per year of life saved; and the median toxin control program costs $2.8 million per year of life saved.

- Put another way, the median toxin control program costs 58 times more than the median injury control program (per year of life saved), and 146 times more than the median medical program.

Some programs are so cost-effective the resource savings from fewer cases of disease (and associated downstream costs) are more than enough to outweigh the costs of the programs. Examples include smoking cessation advice by physicians for pregnant women who smoke, the accelerated phase-out of lead in gasoline and vaccinating children against mumps, measles and rubella. Yet many of these cost-saving programs are not fully implemented and may face resource cutbacks in the years ahead.

This perverse pattern of investment amounts to “statistical murder” of American citizens. Policy makers need to ask harder questions about whether our public health and environmental protection dollars are well spent. Legislators should pass broad-based legislation requiring use of risk analysis and cost-benefit analysis in governmental decisions. The president and Congress should reexamine annual appropriations to public health and environmental agencies to determine how reallocations of dollars could offer more health protection at no greater cost to the taxpayer or private sector. And communities faced with residual risks from exposures to toxins should be given greater flexibility to reduce risks through cost-effective measures.

Introduction: Health Care and Toxin Control[1]

The United States spends more than $1 trillion per year on medical services ranging from routine physician visits to outpatient drug therapy, hospitalization, surgery and institutional care of the chronically ill in nursing homes. Serious questions are being raised about whether these health care dollars are well spent. Is too much spent on the very old and frail? Should more health care dollars be allocated to promising preventive measures? Are exotic new technologies being evaluated to assure that their medical benefits are worth the added cost? Although there is no public consensus on answers, there is consensus that these questions need to be addressed.

Meanwhile, toxin control — the regulation of toxic substances such as chemicals and radiation — consumes about $200 billion per year, yet escapes the scrutiny health care spending receives. The public debate about environmental spending in general and toxin control in particular is far less sophisticated. Cost restrictions are fewer and public understanding of benefit issues is lower.

"Some groups demand that the government protect the public against all environmental toxins regardless of how small the risks or how great the costs."

Some influential advocacy groups demand that government protect the public against all environmental toxins regardless of how small the risks or how great the costs. Even some industry groups support legislation that would forbid regulators from weighing the benefits and costs of alternative regulatory actions. This "zero risk" or "negligible risk" perspective informs the U.S. approach to toxin control under federal laws including the Clean Air Act, the Clean Water Act, the Safe Drinking Water Act, the food additive provisions of the Delaney Clause to the Federal Food, Drug and Cosmetic Act,[2] and the statutes governing cleanup of hazardous wastes (Superfund and the Resource Conservation and Recovery Act).[3]

The public is only beginning to grasp the costs of such an idealistic approach to environmental policy. The annual rate of increase in toxin control spending recently outstripped the annual rate of increase in health care spending.[4] Policymakers need to ask harder questions about whether our environmental protection dollars are being well spent.[5] If the nation does not begin applying risk analysis principles to toxin regulation, we may face a fiscal crisis in environmental policy as severe as the one we face in health care policy.

The failure to compare the costs of toxin control rules to rules on health care and injury prevention and to allocate resources based on those comparisons is resulting in "statistical murder." In the United States, an additional 60,000 lives could be saved each year if we applied the same cost-effectiveness standards to all lifesaving programs and reallocated monies accordingly.

This study compares the cost and effectiveness of selected toxin control measures to the cost and effectiveness of selected medical procedures and injury prevention programs. The figures used are derived from the "Lifesaving Database," a computerized information system created and maintained by the Harvard Center for Risk Analysis (HCRA) under a grant from the National Science Foundation.[6] The study discusses the uncertainties in cost-effectiveness figures as well as quantitative and qualitative factors that complicate straightforward comparisons. It concludes with some steps that decision makers can take to reallocate resources from wasteful to worthwhile programs.

"Cost Per Life-Year Saved": A Yardstick for Comparison

When Hillary Rodham Clinton and her colleagues designed the administration's health care reform plan, they decided to cover a mammogram every two years and a Pap smear every three years. They rejected insurance coverage for more frequent screening because the incremental cost per year of life saved would have been very large, well over $100,000.[7] Is $100,000 the "right" standard? Different people would give different answers. But, as we shall see, the estimated cost per year of life saved by most toxin control regulations is far greater.

"Life-years saved" represents the impact of premature death on an average American's life span. For example, those who die of cancer at age 65 may lose 15 or so years of life expectancy.

Consumers have limited opportunities to directly purchase "life years" in the marketplace. However, based on answers to survey questions and inferences about routine on-the-job safety decisions, health economists have estimated the value of an average life-year, based on our willingness to pay, at somewhere between $10,000 and $500,000.[8] An underground coal miner or an ironworker on high-rise buildings, for example, would command higher wages than a clerk because of the higher risk involved in the job. The 50-fold range reflects variation in citizen preferences as well as genuine uncertainty about how much people care about life expectancy.

"Some toxin control regulations impose astronomical costs for a year of life saved."

There is little evidence that cost per life-year saved is a significant consideration in toxin control regulations, some of which impose astronomical costs relative to their benefits. For example:

- In a recent survey of 10 Environmental Protection Agency (EPA) rules aimed at curbing air emissions of benzene, a chemical known to cause leukemia at high doses, the estimated cost per year of life saved ranges from $200,000 to $50 million.[9]
- A proposed EPA standard for chloroform emissions at some pulp mills costs more than $99 billion per year of life saved.[10]

The numbers of worthy projects always exceed the numbers of dollars available to fund them. In the past, politicians and government regulators often failed to question whether spending for risk protection addressed the largest or most serious dangers. However, this is changing rapidly as the scientific community questions many of the assumptions on which environmental rules are based and raises concerns about the general direction of the federal government's toxin control programs.

There is both more reason and more opportunity than ever to subject toxin controls to some measurement of cost-effectiveness.

The Cost-Effectiveness Framework

The framework that is becoming the norm in medicine is used here.[11] It ranks "lifesaving" programs according to their cost-effectiveness ratio, and encourages decision makers to spend scarce resources on programs with the most favorable cost-effectiveness ratios.

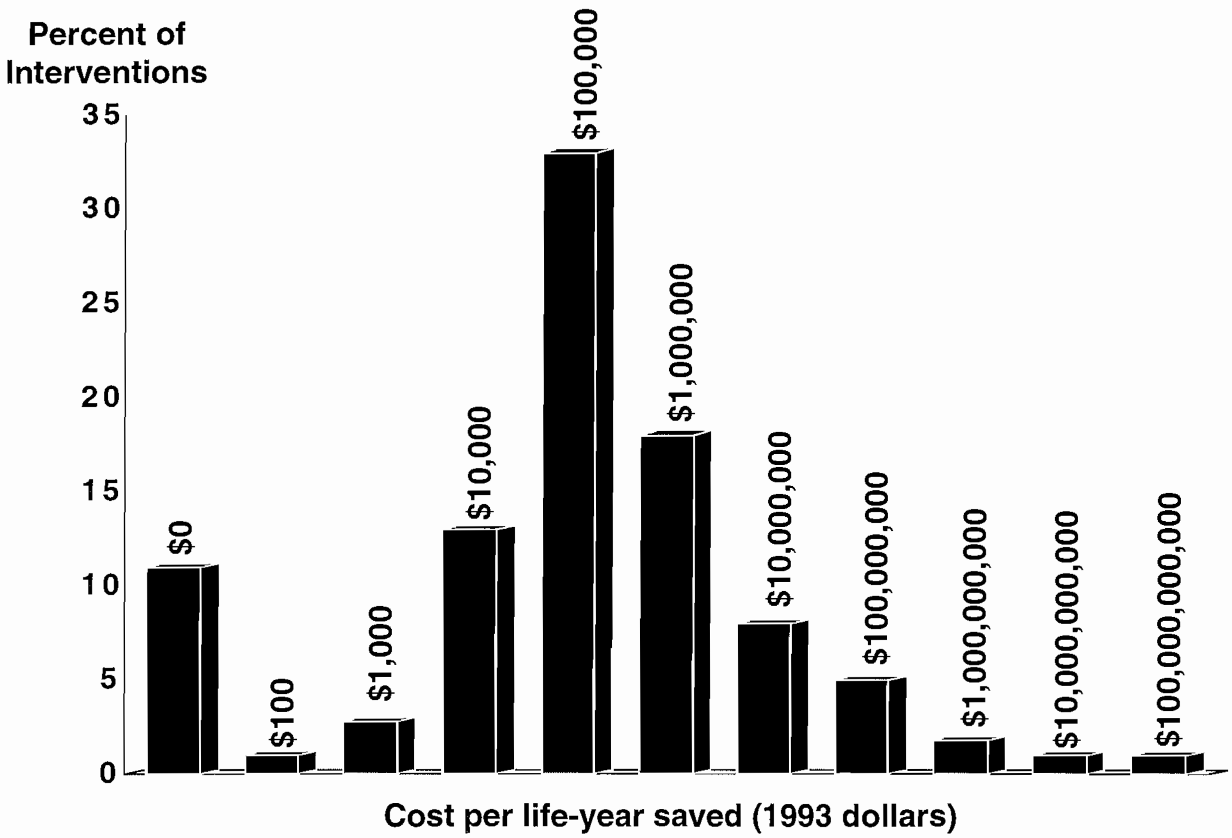
- Effectiveness is defined as the increase in life expectancy (i.e., years of life saved) resulting from a program.
- Cost is defined as the material and labor resources, measured in dollars, necessary to implement the program minus any resulting savings in resources (taking into account resource impacts in both the public and private sectors of the economy).[12]
- The cost-effectiveness ratio is the estimated net program cost divided by the estimated number of life-years saved (in comparison to a well-specified program alternative).

"The Lifesaving Database makes it possible to compare the cost-effectiveness of programs."

The HCRA's Lifesaving Database contains cost-effectiveness information on 587 "lifesaving" programs. A lifesaving program is any technological or behavioral intervention that has the potential to reduce the risk of premature death among people in a specified target population. Broadly speaking, the Lifesaving Database includes information on three types of programs: medicine (preventive and curative), injury prevention (i.e., safety programs aimed at preventing fatal cases of acute trauma from accidents) and toxin control (limitations on chronic exposures to toxic chemicals and radiation at work, in the home and in the general environment). Some examples of programs in the database are AZT therapy for people infected with the AIDS virus, coronary artery bypass surgery for heart patients, smoking cessation advice by physicians for pregnant women, installation of driver-side airbags in new cars, limitations on airborne benzene levels in the workplace, controls on airborne arsenic emissions at copper smelters and controls on radionuclide emissions at uranium fuel cycle facilities.[13]

FIGURE I

Cost Per Life-Year Saved Distribution



Source: Lifesaving Database, Harvard Center for Risk Analysis.

"Most of the programs cost between $10,000 and $1 million per life-year saved — but the cost ranges up to $100 billion."

Figure I is a frequency distribution of the cost-effectiveness ratios for all 587 lifesaving programs. The median program costs about $42,000 per year of life saved, although the ratios range over more than 10 orders of magnitude. Thus, the range is from approximately zero cost up to $100 billion per life-year saved. Most of the programs cost between $10,000 and $1 million per year of life saved.

Favorable Cost-Effectiveness. About 10 percent of the programs have net costs equal to or less than zero, which means that the program saves resources equal to or greater than the resources it consumes. For example [see Table I]:

- Immunizing children against mumps, measles and rubella is cost saving because the estimated reductions in subsequent treatment costs more than offset the costs of immunization.
- Requiring stricter flammability standards for children's sleepwear size 0-6x is another program that reduces estimated costs more than the costs of implementation.

Of course, a program may be desirable even if it is not cost saving.[14] Certainly, most people desire better health and longer lives; otherwise, families and governments would not expend resources to achieve these goals. For example, the estimated medical cost savings from installation of airbags in new cars are not large enough to cover the costs.[15] Even so, many informed consumers are willing to pay the costs. A full-blown cost-benefit analysis of airbags would seek to quantify the maximum willingness to pay.

The Lifesaving Database finds that medical programs and injury prevention programs typically cost far less per year of life saved than do toxin control programs:[16]

"The median toxin control program costs 58 times more per year of life saved than the median injury prevention program and 146 times more than the median medical program."

- The median medical program costs $19,000 per year of life saved.
- The median injury prevention program costs $48,000 per year of life saved.
- The median toxin control program costs $2.782 million per year of life saved.
- Put another way, *the median toxin control program costs 58 times more per year of life saved than the median injury prevention program and 146 times more than the median medical program.*

TABLE I

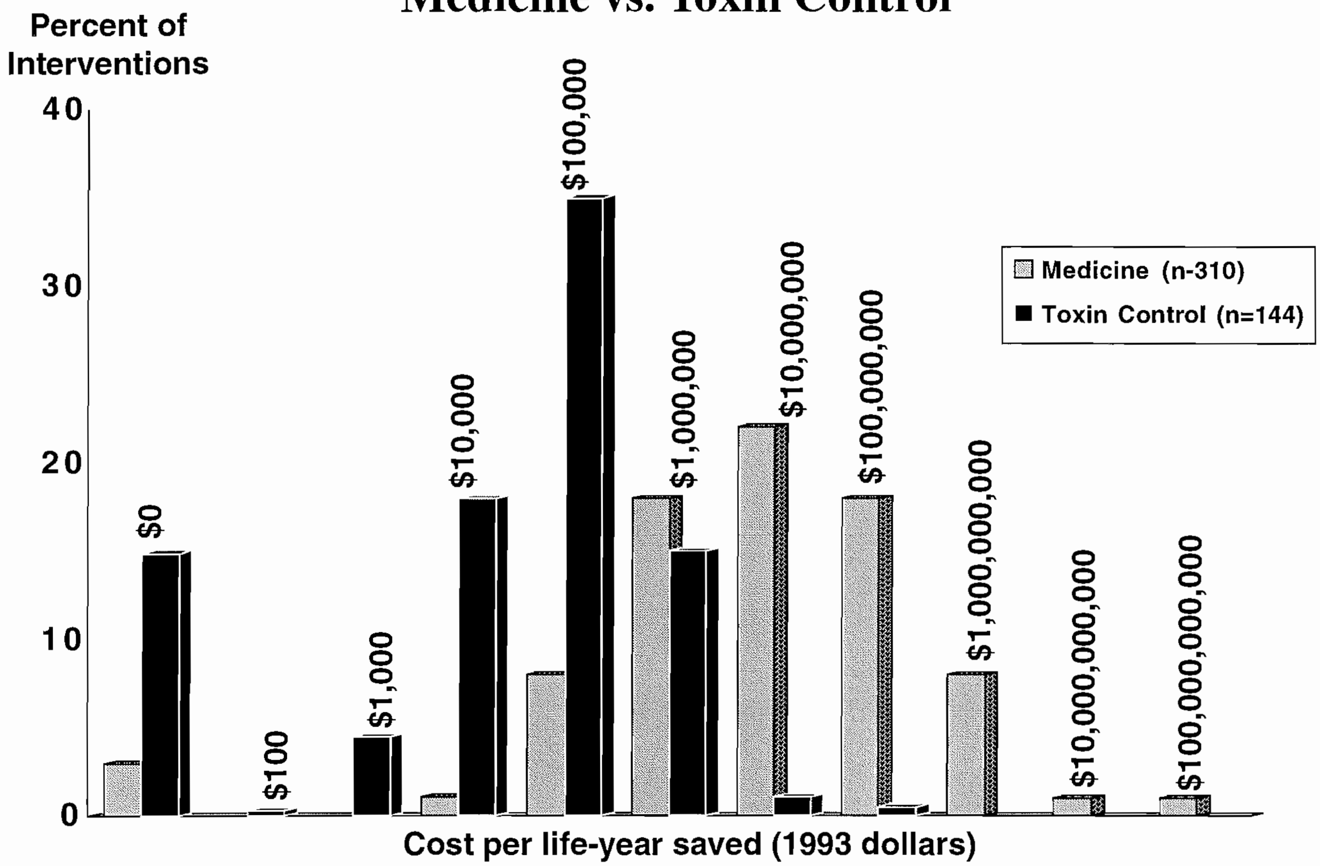
Ten Cost-Saving Interventions

	Cost/Life Year
Smoking cessation advice for pregnant women who smoke	**at or below $0**
Ban residential growth in tsunami-prone areas	**at or below $0**
Chloroform emission standard at 17 low-cost pulp mills	**at or below $0**
Truss (vs. elective inguinal herniorrhaphy) for inguinal hernia in elderly	**at or below $0**
Install windshields with adhesive bonding (vs. rubber gaskets) in cars	**at or below $0**
Flammability standard for children's sleepwear size 0-6X	**at or below $0**
Measles, mumps & rubella immunization for children	**at or below $0**
1988 (vs. 1971) safety standard for concrete construction	**at or below $0**
Terminate sale of three-wheeled all-terrain vehicles	**at or below $0**
Ban amitraz pesticide on apples	**at or below $0**

Source: Tammy O. Tengs et al., "Five-Hundred Life-saving Interventions and Their Cost-Effectiveness," *Risk Analysis*, Vol. 15, No. 3, 1995, pp. 369-390.

FIGURE II

Cost Per Life-Year Saved Distributions: Medicine vs. Toxin Control



Source: Lifesaving Database, Harvard Center for Risk Analysis.

"Some toxin control programs save more resources than they cost, but the average program costs much more than the average medical or injury prevention program."

Information on the medians does not tell the whole story. Figure II compares the frequency distributions for medical and toxin control programs, illustrating that the range of cost-effectiveness ratios is large for both. Some toxin control programs save more resources than they cost. For example, the accelerated phase-out of lead in gasoline has been estimated to save more in automobile maintenance expenses than it costs in extra refining investments.[17] But note also that the frequency distribution for the toxin control programs is shifted to the right in Figure II, suggesting that the average toxin control program costs much more per life-year saved than the average medical program. As Figure III shows, the frequency distributions of injury prevention and medicine are similar.

How To Save 60,000 Lives

In a 1994 doctoral dissertation, Tammy Tengs analyzed a subset of 287 U.S. toxin control, medical and injury prevention programs for which information on the current implementation levels was available.[18] Dr. Tengs found that some potentially valuable and very inexpensive programs were not being implemented while more costly programs were. She estimated that:

- If resources were reallocated to more cost-effective programs, an additional 60,000 lives (or about 600,000 years of life) could be saved each year in the United States at no increased cost to the public or private sectors.
- Looked at another way, an efficient reallocation of resources could save $31 billion per year without reducing the number of lives (and life-years) saved.

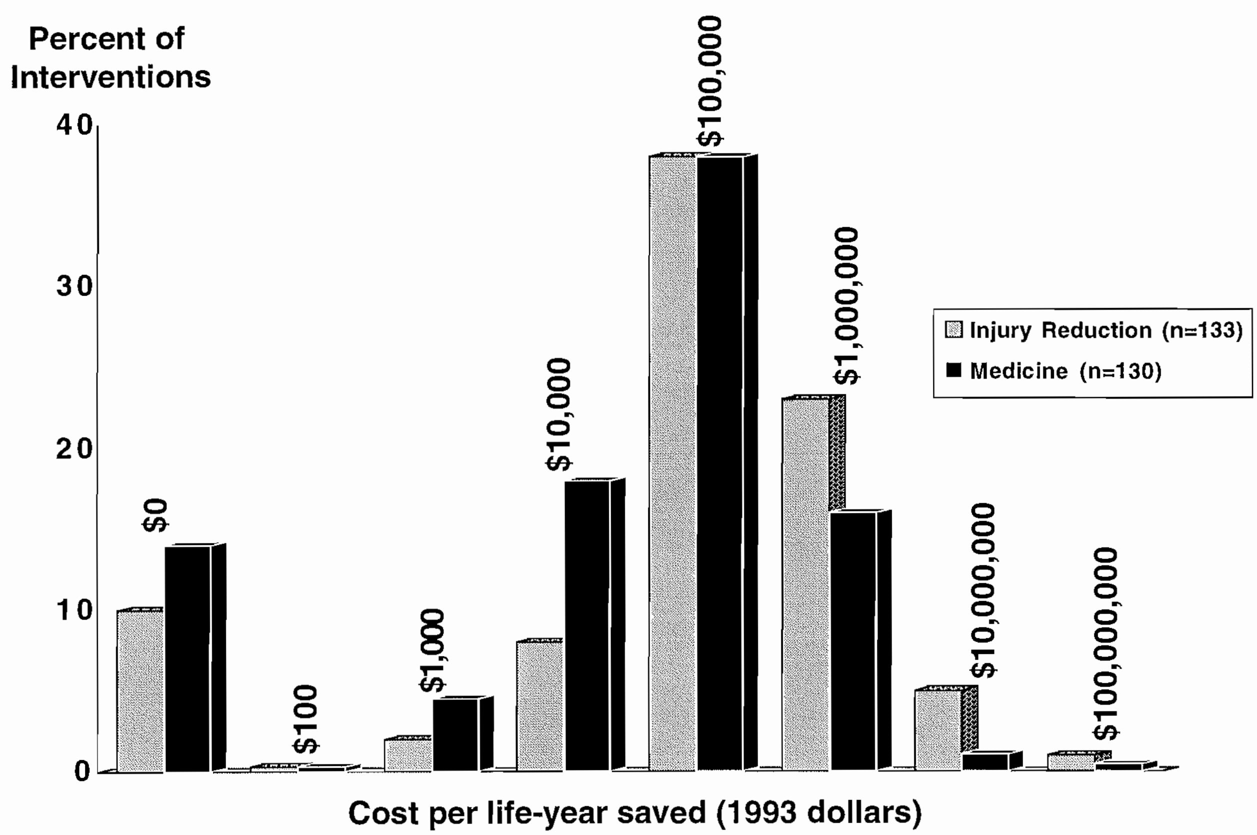
"By reallocating resources, we could save an additonal 60,000 lives per year at no increased cost."

To demonstrate why the allocation of resources is so important:

- We spend $115.6 million per year on benzene emission control during waste operations to save five life-years.
- Spending the same amount on collapsible steering columns in cars saves 1,684 life-years.

FIGURE III

Cost Per Life-Year Saved Distributions: Medicine vs. Injury Fatality Reduction



Source: Lifesaving Database, Harvard Center for Risk Analysis.

TABLE II

Ten Most Expensive Interventions

	Cost Per Life-Year
Benzene emission control at chemical manufacturing process vents	$526,323,000
Arsenic emission control at low-emitting Copper Range/White Pine copper smelter	$890,822,000
Radionuclide emission control at coal-fired industrial boilers	$925,403,000
Ban asbestos in diaphragms	$1,434,478,000
Radionuclide emission control at coal-fired utility boilers	$2,395,161,000
Radionuclide emission control at NRC-licensed & non-DOE facilities	$2,612,903,000
Benzene emission control at rubber tire manufacturing plants	$19,865,323,000
Radionuclide emission control at uranium fuel cycle facilities	$33,750,000,000
Sickle cell screening for nonblack low-risk newborns	$34,239,773,000
Chloroform private well emission standard at 48 pulp mills	$99,351,684,000

Source: Lifesaving Database, Harvard Center for Risk Analysis.

Table I shows 10 programs that save both money and life-years. By contrast, Table II shows the 10 most expensive programs relative to each year of life added. As the tables show, the EPA standard for chloroform emissions at 48 pulp mills imposes over $99 billion in costs for each year of life added, while the standard at 17 low-cost pulp mills actually saves resources. This information, while neither definitive nor exhaustive, suggests that decision makers should scrutinize how lifesaving resources are being allocated.

Is It Fair To Compare Toxin Control to Other Health Programs?

Numerous objections have been raised to comparing the cost-effectiveness of toxin control programs to other public health programs. Since the comparisons call into question the relative cost-effectiveness of toxin control, it is not surprising that advocates of environmental regulation have raised strenuous objections. Some of the objections have more merit than others, so it is useful to discuss them specifically.

Objection No. 1: The lifesaving effectiveness estimates for toxin control programs are less certain than those for medical services.

This statement is generally correct because medical effectiveness estimates usually are based on higher-quality information.

- Medical effectiveness estimates tend to be based on randomized trials of treatments or direct epidemiological observations.
- Toxin control effectiveness estimates are often based on results extrapolated to humans from high-dose rodent tests of chemicals.

It is important to consider the potential implications of these uncertainties when comparing the two kinds of programs. The effectiveness estimate is equal to the baseline risk (life-years lost prior to adoption of a program) multiplied by the program's risk-reduction factor (i.e., a factor of 0.8 means that the program eliminates 80 percent of the baseline risk). The true yet unknown number of life-years saved could prove to be higher or lower than current estimates.

"There are no indications that risk-reduction predictions for medicine are more optimistic than for toxin control."

Despite this uncertainty, there are no indications that the risk-reduction predictions for medicine are systematically more optimistic than those for toxin control programs. Rather, there are indications that the baseline estimates of risk from toxin exposures are often more pessimistic than those for medical technologies. For example:

- The baseline estimates of cancer risk from exposure to toxins are based on the assumption that any exposure to a carcinogen, however small, increases one's cancer risk.
- Recent scientific evidence on chemicals such as chloroform, formaldehyde and benzene suggests that this assumption is incorrect and that low levels of exposure are associated with little or no incremental risk of cancer.[19]

A potentially serious concern — not often included quantitatively in estimates of baseline risk — is that toxins can cause diseases other than cancers. As scientists and risk assessors learn more about noncancer effects (e.g., neurological effects and immune system dysfunction), their findings should be incorporated into baseline risk estimates. However, many scientists believe that cancer is the most or the only sensitive endpoint for low-level exposures to toxins— which suggests that omitting noncancer effects may not always be important .[20]

Objection No. 2: The focus on saving lives ignores health effects that are serious but not fatal.

This observation is correct but not necessarily relevant. There is no reason to believe that the ratio of nonfatal to fatal health benefits is larger for toxin control than for medicine or injury prevention. Just as less exposure to toxins may prevent nonfatal as well as fatal cases of cancer, so hypertensive therapy may prevent nonfatal as well as fatal heart attacks and strokes. And airbags may prevent many nonfatal skull fractures and brain injuries as well as some that would be fatal.

In general, programs that save lives may also reduce nonfatal cases of disease or trauma that range in severity from several days of discomfort per year (e.g., from mild bronchitis) to chronic pain and discomfort (e.g., chest pain from angina) to extended periods of disability and/or illness requiring hospitalization. The next generation of studies likely will include these "morbidity effects" in a new measure of effectiveness called "quality-adjusted life years" (QALYs) saved. This measure, which is increasingly used in medicine, combines information on life expectancy and on quality of life.[21]

Objection No. 3: The focus on human lifesaving ignores the possible impacts of toxins on nonhuman species.

This statement is correct and reflects the immature state of ecological risk assessment. Until more resources are devoted to the scientific study of ecology (including human values about ecological health), this unknown will persist and decision makers will have to consider potential ecological effects as a qualitative or intangible factor.

Objection No. 4: The cost estimates for toxin control programs are more uncertain than those for medical programs.

"No systematic evidence supports the contention that cost estimates are more uncertain for medicine than for toxin control."

This statement may be true, but no systematic evidence supports it. In general, the real (inflation-adjusted) marginal costs of new technologies tend to decline rapidly due to learning effects and economies of scale in production. This pattern should be true for both medical technologies and toxin control technologies. On the other hand, the cost savings resulting from programs are not always as large as projected and the operating and maintenance expenses of some new technologies are sometimes higher than anticipated.

Objection No. 5: The risks from exposure to toxins may be ethically and/or psychologically more compelling because these risks are unfamiliar, invisible, unfair, frightening and imposed on citizens without their knowledge or consent.

This statement is well grounded in risk-perception research and may also have ethical significance.[22] Policymakers should not ignore such qualitative considerations.[23] Yet no one should use qualitative factors as trump cards in public debates about resource allocation.[24] Those who would give primacy to qualitative concerns may not represent the values of most citizens. For example, recent surveys found that Americans, when asked to recommend allocations of scarce lifesaving resources, took psychic and ethical concerns into account but did not give them great weight.[25] Such information suggests that psychic and ethical considerations do not explain how or why we have implemented programs with vast discrepancies in incremental expenditures per year of life saved. Giving these qualitative factors too much weight may lead to a misallocation of resources and hence to the "statistical murder" of people whom cost-benefit analysis could have saved.[26]

Practical Steps for Advocates and Policymakers

Broad comparisons of the three types of lifesaving programs offer both insights and frustrations. Why compare toxin control to medicine when more resources should be available for both worthy pursuits? Why not, for example, cut "waste" in the defense budget to pay for both?

"Some rationing of resources is inevitable."

The answer is that no matter how strong the case for public health and environmental protection may be, the voting public will limit the resources available for risk reduction. They will do so precisely because they also care about other things — public safety, crime prevention, housing quality, education quality, access to recreational opportunities and so forth. Further, what some regard as "waste" in the defense budget is regarded by others as essential to preparedness.

In the end, some rationing of resources is inevitable.

If public health professionals attempt to protect inefficient investments, they undermine the long-term credibility of public health policy. Most inefficiencies are exposed eventually, and their exposure tends to reduce public confidence — and the budgets the public is willing to support.[27]

The failure to terminate inefficient public health policies also leads to "statistical murder," as mentioned above. Skeptics will challenge this claim. If the nation decides against a tightening of benzene emission standards at oil refineries, they will argue, this will not result in more prenatal care or fewer cases of AIDS. They are right, unless policymakers assure the desired transfers of resources. There are three concrete reforms policymakers can begin to make now.

Reform No. 1: Reallocate tax dollars to those programs that pay the greatest health returns.

Congress should examine annual appropriations to public health and environmental agencies and determine whether marginal tax dollars are being devoted to the agencies and programs that are likely to make the most efficient investments in risk reduction. The data presented here call for reconsideration of the toxin-control budgets of agencies such as EPA and OSHA. The same data suggest a possible reallocation of budgetary resources from toxin control to selected medical services in the Department of Health and Human Services and injury control programs in agencies such as the Centers for Disease Control, the National Highway Traffic Safety Administration, the

Consumer Product Safety Commission and the Occupational Safety and Health Administration. Congressional appropriations committees and the Office of Management and Budget need to work more aggressively and cooperatively to institutionalize this kind of "risk-based" budgeting.[28]

Reform No. 2: Void and avoid mandates that would force the private sector to spend money where the public sector should not.

"If an expenditure is inappropriate for the federal government, it is no more appropriate for the private sector."

Obviously, expenditures that are inappropriate for the federal government are not more appropriately imposed on the private sector. All public policies, regardless of who pays for their implementation, should be carefully examined for cost-effectiveness.

Reform No. 3: Give local communities flexibility.

Communities faced with residual risks from toxin exposures should be free to propose and carry out alternative risk-reduction plans.[29] For example, urban communities near abandoned hazardous waste sites should be able to substitute violence prevention programs and/or smoking cessation programs for expensive groundwater treatment programs. Residents living near coke plants and chemical factories should be allowed to choose prenatal care, smoking cessation or breast cancer screening and treatment over costly industrial pollution control programs. Reforming federal environmental laws to allow such flexibility promises both greater public health protection and greater credibility for the public health movement.

Conclusion

Public policymakers should heed the information being generated by this and other cost-effectiveness studies. While such studies alone cannot answer all of the difficult questions in public health policy, they can provide valuable information to decision makers.

Notes

1 The author wishes to thank Janice Wright for providing helpful information for this study.

2 The Delaney Clause prohibits the use of any amount of any food additive found to cause tumors in laboratory animals. This law does not recognize any margin of safety for extremely small doses.

3 Alon Rosenthal, George M. Gray and John D. Graham, "Legislating Acceptable Cancer Risk From Exposure to Toxic Chemicals," *Ecology Law Quarterly*, Vol. 19, 1992, pp. 269-362.

4 Ron Winslow, "Medical Costs Are Increasing at a Low Rate," *Wall Street Journal*, July 14, 1994, p. A2; "Environmental Spending Set at $142.1 Billion in 1993; Yearly Growth in 1994-97 Seen at 9%," *Air/Water Pollution Report*, June 13, 1994, p.195.

5 Senator Daniel Patrick Moynihan (D-NY), "Environmental Risk Reduction Act," *Congressional Record*, January 21, 1993, p. S550.

6 Tammy O. Tengs, Miriam Adams, Joseph S. Pliskin, Dana G. Safran, Joanna E. Siegel, Milton C. Weinstein and John D. Graham, "Five Hundred Lifesaving Interventions and Their Cost-Effectiveness," *Risk Analysis*, June 1995, in press.

7 See, for example, David M. Eddy, "Screening for Cervical Cancer," *Annals of Internal Medicine*, Vol. 113, 1990, pp. 214-26.

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9 U. S. Environmental Protection Agency, "National Emission Standards for Hazardous Air Pollutants: Benzene; Rule and Proposed Rule," *Federal Register*, Vol. 54, September 14, 1989, pp. 38044-72; Timothy J. Considine, Graham A. Davis and Donita Marakovits, "Costs and Benefits of Coke Oven Emission Control," Final Report to U. S. EPA, Washington, DC, December 17, 1992.

10 Tengs et al., "Five Hundred Lifesaving Interventions and Their Cost-Effectiveness."

11 Michael F. Drummond, Greg L. Stoddart and George W. Torrance, *Methods for the Economic Evaluation of Health Care Programmes* (New York: Oxford Medical Publications, 1987); and Milton C. Weinstein and William B. Stason, "Foundations of Cost-Effectiveness Analysis for Health and Medical Practices," *New England Journal of Medicine*, Vol. 296, 1977, pp. 716-21.

12 All costs are expressed in 1993 dollars, with future costs and effectiveness discounted to present value at an annual rate of 5 percent. The same assumptions are applied (to the extent possible) to all programs in order to allow comparison of multiple programs.

13 Readers interested in learning more about the database can obtain a program summary by contacting the Harvard Center for Risk Analysis.

14 P. Doubilet, M.C. Weinstein and B. J. McNeil, "Use and Misuse of the Term 'Cost-Effective' in Medicine," *New England Journal of Medicine*, Vol. 314, 1986, pp. 253-56.

15 R. Crandall, H. Gruenspecht, T. Keeler and L. Lave, *Regulating the Automobile* (Washington, DC: Brookings Institution, 1986).

16 The Lifesaving Database considered 310 medical programs, 133 injury prevention programs and 144 toxin control programs. Since the degree of uncertainty in these estimates is substantial, differences that are less than a factor of two should be ignored.

17 U. S. Environmental Protection Agency, *The Costs and Benefits of Reducing Lead in Gasoline*, Final Regulatory Impact Analysis, Washington, D. C., 1985.

18 Tammy O. Tengs, "Optimizing Societal Investments in Preventing Premature Death," doctoral dissertation, Harvard School of Public Health, Boston, June 1994.

19 Center for Risk Analysis, *A Historical Perspective on Risk Assessment in the Federal Government* (Boston: Harvard School of Public Health, 1994).

20 Ibid., pp. 49-50.

[21] G. W. Torrance, "Measurement of Health State Utilities for Economic Appraisal," *Journal of Health Economics*, Vol. 5, 1986, pp. 1-30.

[22] Baruch Fischhoff et al, "How Safe Is Safe Enough? A Psychometric Study of Attitudes Toward Technological Risks and Benefits," *Policy Sciences*, Vol. 8, 1978, p.127.

[23] Center for Risk Analysis, *Reform of Risk Regulation: Achieving More Protection at Less Cost* (Boston: Harvard School of Public Health, 1995); R. Pildes and C. Sunstein, "Reinventing the Regulatory State," *University of Chicago Law Review*, Vol. 62, 1995, p.1.

[24] F. Cross, "The Public Role In Risk Control," *Environmental Law*, Vol. 24, 1994, pp. 888-969.

[25] John Mendeloff and Robert M. Kaplan, "Are Large Differences in 'Lifesaving' Costs Justified? A Psychometric Study of the Relative Value Placed on Preventing Deaths," *Risk Analysis*, Vol. 9, 1989, pp. 349-63; Maureen L. Cropper and Uma Subramanian, "Public Choices Between Lifesaving Programs: How Important Are Qualitative Factors Versus Lives Saved?" draft report, Resources for the Future, Washington, DC, March 1994.

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[28] Report of the Harvard Group on Risk Management Reform, *Reform of Risk Regulation: Achieving More Protection at Less Cost* (Boston: Harvard Center for Risk Analysis, 1995).

[29] J. D. Graham and M. Sadowitz, "Superfund Reform: Reducing Risk Through Community Choice," *Issues in Science and Technology*, Summer 1994, pp. 35-40.

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