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LETTERS

SDI:LEVERAGE AND COUNTERMEASURES

I am writing concerning the article on SDI by Peter Zimmerman in the January issue of P & S. It was a thought-provoking article, as many are in your publication. However, it serves as an example of how a few seemingly innocuous assumptions can mislead the reader. This is not to say that there are significant errors in the article; nevertheless, an initial casual reading left me with some impressions that are not warranted by the arguments presented.

The catastrophic failure of the defense, described by the author, is an artifact caused by the absence of any excess capacity in the first defensive layer. Although layers two through four have generous fractional excess capacities, the absolute amounts are small. For example, the terminal stage has a fourfold excess capacity, but this represents the ability to destroy only 40 warheads. A 10% increase in the capacity of all stages produces essentially the same result as the large increases assumed by the author. In other words, the apparently generous margins in stages two through four are equivalent to a slim one in the all stages.

Perhaps a more realistic model would take this into account and provide adequate margins for the whole system. The objection may be raised that this would require the deployment of an absurdly large number of defensive systems. Although this may be true at current levels of offensive deployments, the defensive system could be a reasonable alternative if offensive forces were reduced. In any case, a defense only makes sense if it is able to succeed in the presence of more than the expected number of warheads. I'm certain that Peter Zimmerman and I could agree on this.

Gabriel G. Lombardi, 615 Garnet Street, Redondo Beach, CA 90277.

Response:

Gabriel Lombardi suggests that the catastrophic failure of the prototypical ABM system I used in my article is an artifact caused by an absence of excess capacity in the first layer. He is wrong: by definition there can be no excess capacity against a countermeasure which takes the defense by surprise. In that case even a system with a significant excess capacity against the expected threat must fail.

Even without surprise countermeasures to contend with, it is unlikely that the first layer of a multi-layered defense can have significant excess capacity, since the offense can surely build up to and beyond the capacity of the boost phase system. The absolute excess capacity of the terminal defense layer is actually quite high in my system: it must be capable of taking those 40 warheads anywhere and everywhere — including all on the same target. In order to be able to handle 40 warheads anywhere, it must be capable of handling 40 warheads at each of dozens (or perhaps hundreds) of defense sites.

Actually, however, it doesn't matter much what numbers are put in for excess capacities, including at the front end. Catastrophic failure of the system can merely be postponed but not prevented. In a system where the offense is constrained by arms control agreements the situation may be quite different. I believe, however, that no such limitations will ever be achieved in an environment where the defense is allowed to run free.

Mr. Lombardi and I can probably agree that a defense is worthwhile only if it meets all of the Nitzze Criteria: effectiveness, survivability and cost-effectiveness at the margin. Unfortunately, the systems currently being proposed by the SDIO fail all three tests, in part because an unconstrained offense can always make a margin call.

Peter D. Zimmerman, Senior Associate, Carnegie Endowment for International Peace, 11 Dupont Circle, N.W., Washington, D.C. 20036.

ARTICLES

REDUCING THE HAZARDS OF NUCLEAR POWER: INSANITY IN ACTION

Bernard L. Cohen, University of Pittsburgh

How much money are we willing to spend to save a life? Some might say "Sky's the limit," but we don't act that way. We don't spend unlimited amounts on fire protection, highway and

motor vehicle safety, health care, etc., although it is a simple calculation to convert such expenditure into a cost per life saved. In this paper we consider the question of how much our society is

willing to spend to save a life in various contexts.

There are numerous opportunities for highly cost-effective life saving in under-developed countries. The World Health Organization (WHO) estimates¹ that over 5 million childhood deaths could be averted each year at a cost ranging from \$50 per life saved from measles in Gambia and Cameroon to \$210 per life saved by a combination of immunizations in Indonesia. These costs are for complete programs including providing qualified doctors and nurses, medical supplies, transportation, communication, etc. WHO also estimates¹ that about 3 million childhood deaths each year could be averted by oral rehydration therapy (ORT) for diarrhea. This consists of feeding a definite mixture of NaCl, KCl, NaHCO₃, and glucose with water on a definite schedule. The cost per life saved by complete programs range from \$150 in Honduras to \$500 in Egypt.

Other low cost approaches to life saving in the "Third World" include malaria control (\$550/life saved), improved health care (\$1930), improved water sanitation (\$4030) and nutrition supplements to basic diets (\$5300).

But charity begins at home. We next consider two fertile areas for relatively cost-effective life saving in the U.S.. Table 1 lists the cost per life saved by cancer screening programs,² including many situations where it is under \$100,000. For example, only about 50% of sexually active American women get PAP tests for cervical cancer. In a few localities, there have been active programs, utilizing mail, telephone, and personal visits that have increased this fraction to over 90%. The cost of these programs² is about \$50,000 per life saved.

Table 1. Cost per life saved for cancer screening and medical care programs in the United States. Costs are from Ref.2, but since they are given there in 1975 dollars, they have been doubled.

Item	\$/life saved
Cervical cancer screening	\$ 50,000
Breast cancer screening	160,000
Lung cancer screening	140,000
Colo-rectal cancer	
Fecal blood tests	20,000
Proctoscopic exams	60,000
Multiple screening	52,000
Hypertension control	150,000
Kidney dialysis	400,000
Mobile intensive care units in smaller towns	120,000

As another example,² a textile mill in North Carolina started a program of multiple cancer screening tests for their employees. After several years, they added up the cost of the program and the number of lives saved by early detection; dividing these gave \$26,000 per life saved, or correcting for inflation, the \$52,000 per life saved in Table 1.

Another fertile area is highway safety. Table 2 lists some measures covered in the 1984 Annual Report of the U.S. Department of Transportation, including the number of lives saved per year and the cost per life saved. Since these measures typically have a service life of about 10 years, these measures taken in a single year will eventually save several thousand lives at a cost in the neighborhood of \$150,000 per life saved.

With this background, let us consider the price we are paying to save lives from radiation in the nuclear industry. Department of Energy documents give the cost per life saved in their radioactive waste management activities as \$300 million in the Savannah River Plant² and \$270 million at West Valley, New York.³ But more important is our commercial high level waste management program which is supported by a 0.1 cent/kw-hr tax on nuclear electricity, or \$8.8 million/GWe-yr (GWe=gigawatt-electric). It is estimated that random burial with simple precautions would eventually cause 0.02 deaths/GWe-yr.⁴ If half of the cost of the present program is to avert these deaths, the cost per life saved is ($\$4.4 \times 10^6 / 0.05 =$) \$220 million, similar to the Savannah River and West Valley expenditures.

Table 2. Evaluation of recent projects undertaken to improve highway safety. From U.S. Department of Transportation, "The 1984 Annual Report on Highway Safety Improvement Programs," April 1984. It gives cost/fatal accident; we assume 11 deaths per fatal accident.

Improvements	Lives saved per year	\$ per life saved
Improved traffic signs	79	\$ 31,000
Improved lighting	13	80,000
Upgrade guard rails	119	101,000
Breakaway sign supports	2	125,000
Obstacle removal	8	160,000
Median barrier	28	163,000
Impact attenuators	6	167,000
Median strip	11	181,000
Bridge-guard rail transition	3	260,000
Channels; turn lanes	75	290,000
New flashing lights at railroad	11	295,000
Permanent grooving	6	320,000

There are some strange aspects to these large waste management expenditures. In the first place, the lives saved are those of people living many thousands of years in the future, who bear no closer relationship to us than those now living in under-developed countries whose lives we disdain to save at one-millionth of these costs. In the second place, there is an excellent chance that a cure for cancer will be found in the next few thousand years, in which

case these deaths will never materialize and the money will be wasted. In the third place, if only a tiny fraction of this money were invested even at minimal interest, it could provide enormous benefits to these future potential victims, including the saving of tremendous numbers of lives. Equivalents of such an investment are spending the money on biomedical research, or simply using it to reduce the national debt and thereby making more money available to later generations to spend on themselves.

With any reasonable consideration of these matters, we are spending the equivalent of innumerable billions of dollars per life saved in our radioactive waste management programs.

As another example from the nuclear industry, consider reactor safety. Since the mid-1970s, the Nuclear Regulatory Commission (NRC) has been tightening regulations to reduce the risks of reactor accidents. This program of "regulatory ratcheting" has increased the cost of a nuclear power plant by a factor of 4-5 over and above inflation, an increased cost per plant of well over \$2 billion. How many lives does NRC hope to save at this cost? According to its own studies,⁵ plants built prior to this regulatory ratcheting could be expected to cause an average of 0.8 deaths over their operating life. Thus, according to their own calculations, NRC is knowingly spending (\$2 billion/0.8=)\$2.5 billion per life saved.

An ironic aspect of these NRC reactor safety upgrading activities is that the cost increases they have caused have forced utilities to build coal burning power plants instead of nuclear plants. A typical estimate⁶ is that the air pollution from 1 GWe of coal burning plants kills 25 people per year, or about 1000 people over its operating lifetime. Considering the fact that the nuclear plant is expected to kill 0.8 according to NRC⁵ (or 100 according to the anti-nuclear activist organization, Union of Concerned Scientists⁷), that means that every time a coal burning plant is built instead of a nuclear plant, something like 1000 extra Americans are condemned to an early death.

As a result of this NRC program of regulatory ratcheting, about 100 GWe of coal burning plants will eventually be built instead of nuclear plants, causing about 100,000 needless deaths. The 60+ nuclear plants that will eventually be completed have cost an average of at least \$1.6 billion extra, for a total cost of \$100 billion in an effort to save these (60X0.8=)50 lives. If this money were spent, instead, on cancer screening and highway safety measures, it could have saved something approaching a million lives.

There are additional indirect consequences of this NRC regulatory ratcheting. Essentially the same nuclear power plant costs about 2 1/2 times as much in the United States as in France and since projected costs for coal-burning electricity and nuclear electricity in the United States are about equal, this means that electricity will probably be twice as expensive in the United States as in Western Europe and Japan. This puts a direct bite on our standard of living. But more important, many economists believe that a large part of the reason for past U.S. economic success has been our relatively low cost of energy, so it is not unlikely that the reversal of that advantage will contribute substantially to our unemployment problems. It is estimated⁸ that a 1% increase in unemployment in the United States causes an extra 37,000 deaths per year, including about 20,000 from cardiovascular failures, 900 suicides, 650 homicides, and 500 deaths from alcohol-related cirrhosis of the liver. In addition to the deaths, it causes 4200 admissions to mental hospitals, and 3300 admissions to state prisons.

Returning to our principal theme, we see that our society is spending \$2X10⁹/life saved from nuclear hazards while it could save a life for each \$2X10⁸ spent on cancer screening or highway safety. This policy is clearly causing the needless loss of thousands of lives and the waste of billions of dollars every year. Why is this insanity taking place? It's easy to find out. Just ask the government officials who make these decisions. They tell you that the primary responsibility of a government official is to be responsive to public concern. In a democracy, that is the way it should be - we want our government to be responsive to our concerns. The problem is that public concern is driven by media coverage rather than by rational scientific analysis. The media have driven the public insane over the fear of radiation and of nuclear power accidents.

Why do the media do this? They are basically in the entertainment business. One point in the Nielsen rating for network evening news brings \$11 million per year in increased advertising revenue. They must therefore do everything possible to attract an audience, and discussing hazards is much more useful for that purpose than discussing good, smooth, routine operation.

The entire problem can be viewed as one of natural selection, survival of those who adapt best to their environment. A TV producer who valued presenting problems in the proper perspective over emphasizing dangers to attract an audience would not survive, and a government official who valued doing what is right over being responsive to public concern would not survive. Laws of natural selection are hard to beat. But when the results lead to the needless deaths of many thousands of Americans every year, and to the impoverishment of our nation, we must do everything we can to try to beat them.

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THE NRDC/SOVIET ACADEMY OF SCIENCES JOINT NUCLEAR TEST BAN VERIFICATION PROJECT

Thomas B. Cochran, Natural Resources Defense Council, Inc.

[Thomas B. Cochran received the Forum's 1987 Leo Szilard Award for his role in the project described here. This article is the author's talk given at the Forum's Awards Session, 20 April 1987, at the Crystal City, VA, APS meeting. For more about the history and personnel of the project, and for the official text of the agreement, see *Physics and Society*, September 1987, pp.6-7.]

I am deeply honored to have been chosen to be the recipient of the 1987 Leo Szilard Award for my negotiation and implementation of a May 1986 Agreement with the Soviet Academy of Sciences for demonstration of in-country seismic verification of a nuclear test ban. I am, of course, very pleased to be now added to the list of great individual physicists who have received this award, but the credit for the NRDC/Soviet Academy project must be shared among the number of individuals who have played an important role in this historic initiative - the largest privately funded scientific exchange ever between the U.S. and the U.S.S.R..

On the Soviet side, Academician Evgeny P. Velikhov, Vice President of the Soviet Academy of Sciences and Academician M.A. Sadovsky, Director of the Institute of Physics of the Earth (IPE) agreed to the project in Moscow last May when I first formally presented the concept at an Academy-sponsored Workshop on Verification of a Comprehensive Test Ban. At what must have been considerable political risk, they showed great political courage in seeking and obtaining Soviet government approval for this unprecedented project. Professor Mikhail Gokhberg, Deputy Director of IPE, is responsible for the overall management of the Soviet component of the project and Dr. Igor Nersesov, Chief of Seismology at IPE, oversees the Soviet field team.

On the American side, Dr. Charles Archambeau of the University of Colorado has overall technical responsibility for seismic research and is Chairman of the NRDC Seismic Monitoring Advisory Committee. Dr. Jonathan Berger of Scripps Institution of Oceanography, University of California, San Diego and Professor Jim Brune of Scripps and who is also Director of the Seismological Laboratory at the University of Nevada, Reno are co-investigators responsible for the American field teams and the installation and operation of the seismic equipment.

The project represents the largest single program NRDC has ever undertaken in its 17-year history. Adrian DeWind, chairman of NRDC, participated in the Moscow Workshop, signed the agreement with the Soviet Academy on behalf of NRDC, and has played an active role in its implementation. John Adams, Executive Director of NRDC, has made a major contribution, including his tireless efforts to raise the funds for NRDC's participation in this exchange. My colleague S. Jacob Scherr, NRDC Staff Attorney, has worked closely with me on a day-to-day basis in the management of the project.

There are numerous other Americans and Soviets on what we think of as our Test Ban Verification Team, making this project a success. And finally, this effort would never have gotten off the ground without the very generous support from American foundations, individual funders, and the public.

The United States has sought a Comprehensive Test Ban Treaty (CTBT) since the mid-1950s - through every Administration from Eisenhower to Carter. From a U.S. perspective, at least up until the Reagan Administration, achieving adequate verification was the principal obstacle. Ultimately, negotiations toward a CTBT were broken off by the Carter Administration following the Soviet invasion of Afghanistan. Negotiations were not resumed during the Reagan Administration. Reagan is the only President to actively oppose a CTB.

General Secretary Gorbachev made clear his interest in a test ban when he unilaterally suspended Soviet testing in July 1985. He also announced that verification would not be an obstacle to a test ban. It is in this setting on May 22 of last year that NRDC proposed to the Soviet Academy of Sciences to establish and jointly staff seismic monitoring stations adjacent to each of the principal nuclear weapons testing sites in the two countries: in eastern Kazakhstan in the Soviet Union and the Nevada Test Site in the United States. As you know, seismology provides the main tools for detecting and discriminating underground nuclear tests and for accurate estimates of their yields. The objectives of the project as originally envisioned are:

- . to demonstrate that in-country nuclear weapons test verification is not an obstacle to a comprehensive test ban (CTB) or a moratorium on testing;
- . to demonstrate that scientists of the United States and the Soviet Union are prepared to cooperate to work toward a common goal of a CTB; and
- . to obtain baseline seismic data that would be useful in designing and operating a seismic verification network.

We agreed that we need not wait until a treaty was negotiated but could place equipment in the field to demonstrate verification procedures and find out what problems might arise. By May 28, Velikhov had obtained Soviet government approval for the basic idea and the historic agreement was signed by Evgeny P. Velikhov on behalf of the Academy and by Adrian DeWind on behalf of NRDC.

In the past ten months, NRDC and the Academy have made substantial progress in implementing the NRDC/Academy agreement.

Under the Agreement, we had a single month in which to launch the project. In just three weeks, NRDC raised about \$1 million. Dr. Archambeau persuaded Drs. Berger and Brune at Scripps to agree on extremely short notice to equip and send a team

seismologists to the Soviet Union. In a little more than a week, we were able to obtain the necessary export license.

The U.S. team of seismologists arrived in Moscow on July 4. With IPE, we established the first station at Karkaralinsk on July 9 of last year. By the end of August the U.S. and Soviet teams had established three stations around the Kazakh test site about 200 kilometers distant. The stations were located at Karkaralinsk, Bayanaul and Karasu in the Kazakh Republic.

It was decided to equip the stations in two phases. The stations were initially equipped (Phase I) with short period (Teledyne Geotech S-13) and intermediate period (Kinometrics S-1) surface seismometers and battery operated portable digital recorders. Most of this equipment was loaned by Scripps. Over the last ten months rotating teams of two seismologists from Scripps and the University of Nevada have joined with their IPE counterparts in operating this Phase I equipment.

In late July, Scripps also began the procurement of over \$600,000 worth of state-of-the-art seismic and computer data recording equipment for Phase II. This included high frequency down-hole seismometers which had to be custom manufactured by Teledyne Geotech.

Construction of facilities to house the Phase II equipment were completed by the Soviets by early November 1986. The sites at Karkaralinsk, Bayanaul and Karasu, are all located in granite massifs that rise several hundred meters above the surrounding Kazakh steppe. In order to reduce the surface noise, boreholes with 20 cm diameters, which would eventually house the high frequency seismometers, were drilled to depths of 70 to 100 meters, cased, and sealed. Wellhead vaults were set in the surrounding rock, just below the earth's surface. The interiors of these vaults measure approximately 3X4 meters with a 1X2 meter pier situated next to the borehole. At each site a large trailer was situated approximately 300 meters from the vault to house recording instruments. One or two additional trailers at each site provide accommodations for Soviet and American personnel. High-voltage power lines were installed

at each site along with backup diesel generators.

During the past two months the two teams have been installing and calibrating the instruments at the three Kazakh stations. At each station there are three component high-frequency accelerometers (Teledyne Geotech 54100) in the borehole, augmented by six surface seismometers on the pier, three component short period instruments (Teledyne GS-13) and three component intermediate period instruments (Kinometrics S-1). There are also plans to install three broadband seismometers (Streckeison STS-VBB). When fully equipped these stations will each cover a frequency band from 100 Hertz down to a period of about 3000 seconds. The seismic signals are to be recorded locally on magnetic tape. The data recording system (designed and assembled by Scripps) at each station includes signal digitizers and a PDP 11/73 computer.

The Soviet Union ended its nineteen-month unilateral testing moratorium on February 26, 1987. At the insistence of the Soviet Government, the Kazakh stations are required to be turned off for a short period surrounding each of their tests. A military official flies into each station a few days prior to a test, and a protocol is followed to shut down and seal the instruments. The day after the test an official returns and the stations can be turned on. During the first few tests thus far, this procedure has not worked well due to the difficulty of transporting our team to each of the stations to turn them

back on. Since February 26, the stations have been down about 50 percent of the time. Provided we can reduce the delay in restarting our stations, the scientific objectives of the project should not be compromised by the inability to record Soviet tests. The primary purpose of the project is to demonstrate technology to verify the absence of clandestine, or unannounced, tests. In the past Soviet tests were not announced, either before or after the shot. NRDC is now in the unprecedented position of receiving formal advanced notice of Soviet tests.

While operating, the Kazakh stations will continue to collect seismic data from U.S. nuclear tests in Nevada, teleseismic and regional earthquakes, and industrial explosions in the region, as well as background noise. Our best scientific results, associated with verification of test limitations or bans, will come from the analyses of these data.

The ambient ground noise level is being recorded and its frequency dependence measured. The noise levels obviously control the magnitude of events that can be detected and the accuracy with which signals can be characterized by any given station configuration.

Analysis of regional earthquakes and explosions (out to 2000 km) can be used to study the source properties and transmission efficiencies of various seismic wave types, which are usually termed seismic "phases," in the Kazakh area and thereby reduce uncertainties in the quantitative description of seismic wave propagation characteristics. Numerous studies of this kind have been conducted in Nevada, but this provides the first opportunity for U.S. seismologists to study the Kazakh test site area. These studies will be particularly useful in reducing the uncertainties of important parameters of models used to estimate the capability of in-country seismic stations to verify a low threshold test ban treaty.

Evernden, Archaibeau and Cranswic (*Review of Geophysics* 24, May 1986, pp. 143-215), for example, argue that 40 high-frequency stations, including 25 in-country stations in the Soviet Union of the type being operated under the NRDC/Soviet Academy project, would be sufficient to verify a 1 kiloton threshold test ban. A similar number would be required to monitor the U.S. They assume the possibility of evasion by fully decoupling the underground explosion, that is, they assume attempts might be made to muffle the seismic signal from the explosion by exploding the nuclear device in a large underground cavity. Their model assumes sufficiently quiet sites can be found in the Soviet Union and efficient transmission of high-frequency (30 to 40 Hz) seismic compression and shear waves at regional distances in stable continental shield areas. Preliminary analysis of the data from our Kazakh stations is consistent with these assumptions.

The velocity and attenuation of compression and shear waves depend on the temperature and composition of the medium. It is now well known that the upper mantle attenuation below the Kazakh test site is low compared to the attenuation below the Nevada test site. Thus, for the same yield, the amplitude of the compression body wave (the so-called P-wave) recorded at a distant station from a nuclear test in Nevada is smaller than for a test in Kazakh. Consequently, if no correction is made for these differences, the explosion in Kazakh will appear larger than the equivalent explosion in Nevada.

Failure to properly correct for the m_b bias for P-waves leaving the Nevada and Kazakh test sites, in years past, has led to over-