UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

ATOMIC SAFETY AND LICENSING BOARD

Before Administrative Judges:
James P. Gleason, Chairman
Frederick J. Shon
Dr. Oscar H. Paris

In the Matter of	)	
CONSOLIDATED EDISON COMPANY OF NEW YORK, INC. (Indian Point, Unit No. 2)	)	Docket Nos. 50-247-SP 50-286-SP
POWER AUTHORITY OF THE STATE OF NEW YORK (Indian Point, Unit No. 3)	)	April 1, 1983

LICENSEES' MOTION FOR SUBMISSION UNDER COMMISSION QUESTION 5 OF "LICENSEES' TESTIMONY OF BERNARD L. COHEN ON COMMISSION QUESTION 1"

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Consolidated Edison Company of New York, Inc., licensee of Indian Point, Unit No. 2, and the Power Authority of the State of New York, licensee of Indian Point, Unit No. 3 ("the licensees") hereby move for an order permitting submission under Commission Question 5 of "Licensees' Testimony of Bernard L. Cohen on Commission Question 1," dated and served January 24, 1983 (Attachment A), in light of developments under Commission Question 5.

Dr. Cohen's testimony concerns comparative risk between nuclear and non-nuclear hazards by providing a frame of reference for the risks posed by the Indian Point plants. The Board refused to admit it under Commission Question 1 on the grounds that it was not applicable to that Question (tr. p. 8476). The testimony, however, is highly relevant to Commission Question 5.

Commission Question 1 addresses the risk posed by the Indian Point plants. Commission Question 5 asks about the comparative risk of Indian Point. A sub-issue under Commission Question 5 is NUREG-0880, containing preliminary safety goals for nuclear plants. One such goal sets a cost/benefit figure of $1,000 per person-rem averted.

This issue receives extended discussion in the Commission Staff's "Direct Testimony of Frank Rowsome and Roger Blond Concerning Commission Question 5," dated March 22, 1983. Indeed, in Appendix 1 to their testimony ("Economic Evaluation of Projected Severe Accident Losses"), at p. 3,

Rowsome and Blond explicitly reference an article by Dr. Cohen entitled "Society's Valuation of Life Saving in Radiation Protection and Other Contexts," printed in 38(1) Health Physics 33-51 (January 1980) (Attachment B). This is the same article upon which Dr. Cohen relies in Section V of his testimony, entitled "Spending Money to Reduce Risk." Because Staff addressed precisely the issue addressed in Dr. Cohen's testimony, his insights are highly relevant in addressing the legitimate concern under Commission Question 5 of monetization of health effect risk reduction.

Moreover, the intervenors themselves address the sufficiency of the levels of safety afforded by present NRC regulatory requirements in "UCS/NYPIRG Testimony of Steven C. Sholly on Commission Question Five," dated March 22, 1983, see, e.g., pp. 25-28 (Attachment C). In particular, the Sholly testimony states that NRC safety goal standards "reflect[] a hidden judgment that reactors in general are already adequately safe." (Id., p. 26) Dr. Cohen's testimony discusses just this topic.

The issues discussed in Dr. Cohen's testimony are thus relevant to Commission Question 5, and have been raised by both the Staff and the intervenors under Commission Question 5. Therefore, Dr. Cohen's testimony should be admitted in this proceeding. Licensees believe that Dr. Cohen's testimony can be received during the remaining three weeks of hearings without prejudice or inconvenience to any party, and without

affecting the Board's schedule for completion of this hearing.

Respectully submitted,

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Dated: April 1, 1983

ATTACHMENT A

DOCKETED

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NUCLEAR REGULATORY COMMISSION

ATOMIC SAFETY AND LICENSING BOARD

Before Administrative Judges:
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In the Matter of CONSOLIDATED EDISON COMPANY OF NEW YORK, INC. (Indian Point, Unit No. 2) POWER AUTHORITY OF THE STATE OF NEW YORK (Indian Point, Unit No. 3)	Docket Nos. 50-247 SP 50-286 SP January 24, 1983

LICENSEES' TESTIMONY
OF BERNARD L. COHEN ON COMMISSION QUESTION 1

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TESTIMONY ON RISK IN PERSPECTIVE

I. Introduction

My name is Bernard L. Cohen. I am a professor of physics at the University of Pittsburgh, and have done research in the areas of nuclear physics as well as societal risks and risk aversion. A statement of my professional qualifications is attached.

This testimony addresses Commission Question 1 in this proceeding which asks:

> What risk may be posed by serious accidents at Indian Point 2 and 3, including accidents not considered in the plants' design basis, pending and after any improvements described in [Commission Questions] (2) and (4) . . .?

Thus, a principal objective of this proceeding is to determine the level of risk posed by the continued operation of Indian Point. The licensees are simultaneously presenting testimony quantifying the risk using probabilistic risk assessment tools. The meaning of the numbers used to express risk probabilistically can be difficult for some people to understand. The purpose of my testimony is to provide a frame of reference for the estimates of risk posed by Indian Point, as well as to assess the reasonableness, desirability and necessity of pursuing certain further efforts to reduce the already low risk of Indian Point as determined in companion testimony.

One of the major reasons for public misunderstanding of the risk of Indian Point and other nuclear power plants is that the great majority of people do not understand and quantify the risks we face. Most of us think and act as though life should be largely free of risk. We view taking risks as foolhardy, irrational, and assiduously to be avoided. Training children to avoid risk is an all-important duty of parenthood. Risks imposed on us by others are generally considered to be entirely unacceptable.

Unfortunately, everything we do involves risk (Ref. 1). There are dangers in every type of travel, but there are dangers in staying home -- 40 percent of all fatal accidents occur there (Ref. 2). There are dangers in eating -- food is probably the most important cause of cancer and of several other diseases -- but most people eat more than necessary. There are dangers in breathing -- air pollution probably kills many tens of thousands of Americans each year, and many diseases are contracted by inhaling germs -- but hardly anyone uses filters to avoid them. There are dangers in working -- 12,000 Americans are killed each year in job-related accidents (Ref. 2), and probably 10 times that number die from job-related illnesses (Ref. 3) -- but most alternatives to working are even more dangerous. There are dangers in exercising and dangers in not getting enough exercise. Risk is an unavoidable part of our everyday lives.

This does not mean that we should not try to minimize our risks. We cannot minimize our risks by simply avoiding those we happen to think about. For example, if one thinks about the risk of airplane travel, one might decide to go by automobile instead -- an alternative which would be many times more dangerous. The logical procedure for minimizing risks is to quantify all risks and then choose those which are smaller in preference to those which are larger. The main object of this testimony is to provide a framework for that process and to apply it to nuclear power risks.

There are many ways of expressing quantified risk, but here I will use just one: the loss of life expectancy (LLE), *i.e.*, the average amount by which one's life is shortened by the risk under consideration. For example, statistics indicate (Ref. 4) that an average 40-year-old will live another 34.8 years, so if he takes a risk having a 1 percent chance of immediate fatality (and a 99 percent chance of doing no harm), it causes an LLE of .348 years.[1] The methods for calculating LLE are discussed in the Appendix. Of course, most risks are with us to varying extents at all ages, and the effects of these risks must be added up over a lifetime, which makes the calculations somewhat complex. A computer program was developed to perform the calculations and to study extensively a wide variety of risks

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1. .348 years = (.01 x 34.8) + (.99 x 0).

(Ref. 1). Some of the results of this study are summarized in the next section, a listing of them is given in Table 1, and a graphical representation is shown in Figure 1.

II. A Catalog of Risks (Ref. 1)

A widely recognized risk is that of smoking cigarettes (Ref. 5). A person who smokes one pack per day incurs an LLE of 6.4 years if a male and 2.3 years if female; in the former case this figure corresponds to an LLE of 10 minutes for each cigarette smoked. For non-inhalers the lifetime risk from one pack per day is 4.5 years for men and 0.6 years for women, while for those who inhale deeply it is 8.6 years for men and 4.6 years for women. Giving up smoking reduces these risks; after 5 years the LLE is reduced by 1/3, and after 10 years it is more than cut in half. Cigar and pipe smoking do little harm if there is no inhalation, but with inhalation the LLE is 1.4 years for pipes and 3.2 years for cigars for men.

Another major risk over which we have some personal control is being overweight (Ref. 6) -- we lose about one month of life expectancy for each pound our weight is above average.[1] For example, the LLE for 30 pounds overweight is 30 months or 2-1/2 years. An assessment of the effect of

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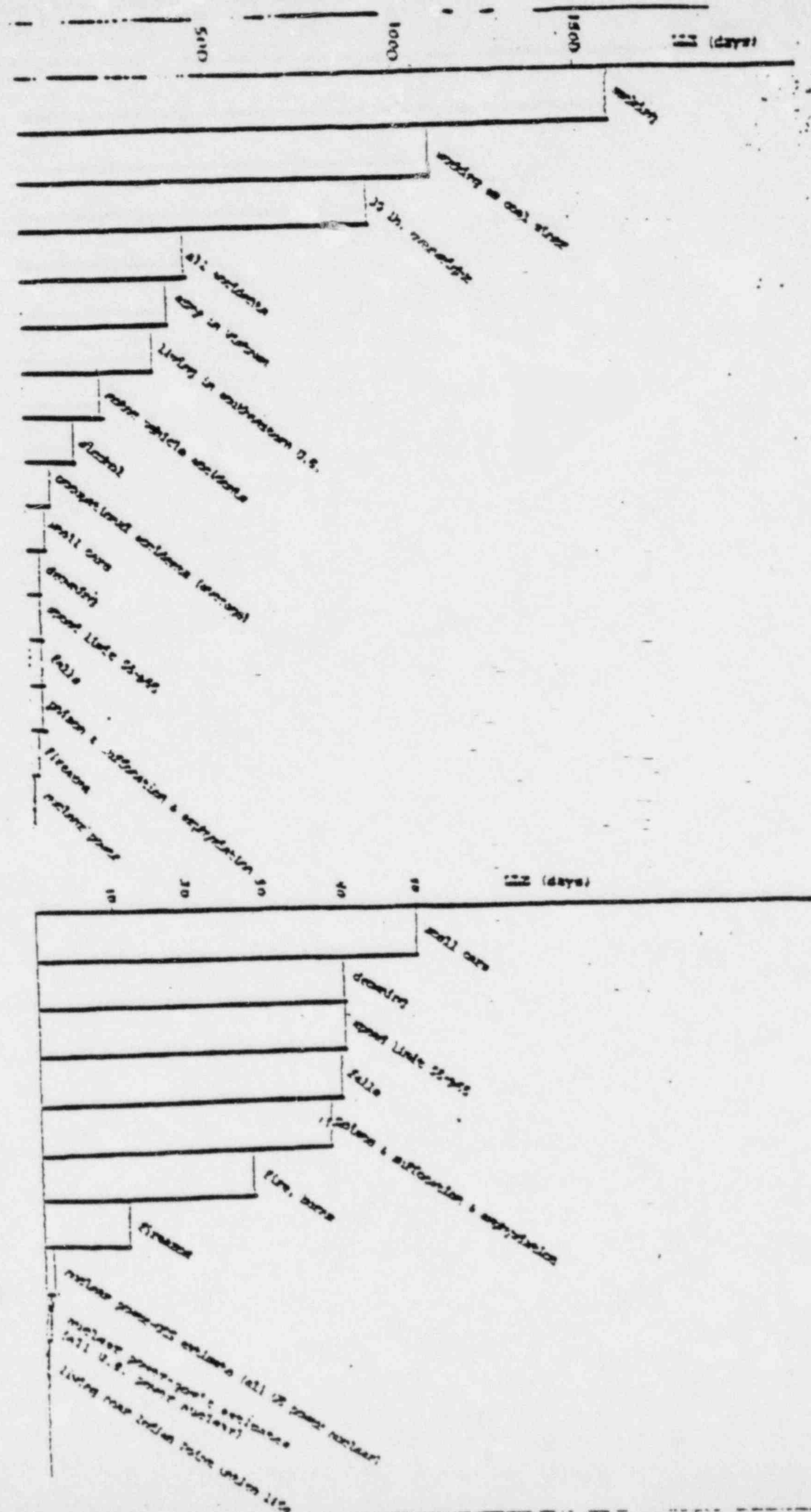
1. Note that the average weight is <u>not</u> necessarily the optimum.

Table 1. Loss of Life Expectancies (LLE)
(From selected sources)

Activity or risk	Days LLE
heart disease	2100
cigarettes (1 pack/day; male-female average)	1600
working as a coal miner	1100
cancer	980
30 lbs. overweight	900
stroke	520
15 lbs. overweight	450
all accidents	435
Vietnam army duty	400
living in southeastern U.S. (SC,GA,AL,MS,LA)	350
mining or construction work (due to accidents only)	320
motor vehicle accidents	200
pneumonia, influenza	130
alcohol	130
homicide	90
occupational accidents (average)	74
small cars (vs. standard size)	50
drowning	40
speed limit 55 -> 65 mph	40
falls	39
poison + suffocation + asphyxiation	37
fire, burns	27
radiation worker, age 18-65	12
firearms	11
diet drinks (one/day throughout life)	2
all electric power in U.S. (nuclear) (UCS)	1
hurricanes, tornadoes	1
airline crashes	1
dam failures	0.5
all electric power in U.S. (nuclear)(Govt. estimates)	0.03*
spending lifetime near Indian Point	0.006

* This number includes all Americans, even those who do not live near a nuclear power plant.



500
1000
1500
(days)
living in southeastern U.S.
motor vehicle accidents
alcohol
occupational accidents (average)
small cars
drowning
speed limit 55 mph
falls
firearms
(days)
small cars
drowning
speed limit 55 mph
falls
fire, burns
firearms

FIGURE 1

over-eating shows that our weight increases by 7 pounds for every 100 calorie increase in average daily food intake (Ref. 7). That is, if an overweight person changes nothing about his eating and exercise habits except for eating one extra slice of bread and butter (100 calories) each day, he will gain 7 pounds (gradually over a period of about one year) and his life expectancy will be reduced by 7 months. This works out to a 15 minute LLE for each 100 extra calories eaten.

Any discussion of major risks must include the traditional leader, disease, (Ref. 8) which caused life expectancy early in this century to be 20 years less than at present. Among individual maladies, heart disease with LLE-5.8 years, cancer with LLE-2.7 years, and stroke with LLE-1.1 years for men and 1.7 years for women are rated one, two, and three, respectively, followed by pneumonia and influenza with LLE-4-1/2 months, and cirrhosis of the liver and diabetes with LLEs slightly over 3 months each, the former occurring more in men and the latter occurring more in women by approximately 3 to 2 ratios.

The most highly publicized risks are those of being killed in accidents (Ref. 2), although the actual danger is well below that of the risks discussed above. The LLE from all accidents combined is 435 days (1.2 years). Almost 1/2 involve motor vehicles which render an LLE of 207 days, 170 days while riding and 37 days as pedestrians. Using small

cars rather than standard size cars increases one's LLE by 50 days, and changing from standard size to large cars reduces it by an equal amount. Before the national speed limit was reduced from 65 to 55 miles per hour, the total LLE was 40 days higher. On the average, riding one mile in an automobile and crossing a street each have an LLE of 0.4 minutes, making them as dangerous as one puff on a cigarette (assuming 25 puffs to a cigarette), or an overweight person eating 3 extra calories.

Accidental death rates vary greatly with geography (Ref. 9); they are 4 times higher in Wyoming than in New York State, the two extremes; the Northeast is generally the safest area while the Rocky Mountain region is generally the most dangerous.

We spend most of our time at home and at work, so that is where most of our non-travel-connected accidents occur (Ref. 2). The LLE for accidents in the home is 95 days, and for occupational accidents it is 74 days. The latter number varies considerably from industry to industry, from about 300 days in mining, quarrying and construction to 30 days in trade. Nearly 1/2 of all workers are in manufacturing and service industries for which the LLE is 45 days.

Some showmanship activities are widely advertised as having very high accident potential, but judging from statistical experience, these dangers are exaggerated in the public mind. For example, (Ref. 10) professional aerialists

(tight-rope walkers, trapeze artists, aerial acrobats, and high pole balancers) receive an LLE of 5 days per year of participation, or 100 days from a 20-year career. The risk is similar for automobile and motorcycle racers of various sorts, so the risk of accidental death in these professions is less than in ordinary mining and construction work. The most dangerous profession involving thousands of participants is deep-sea diving with an LLE of 40 days per year of participation.

In addition to accidents, occupational exposure causes many diseases which affect a worker's life span, and in most cases these are much more important than accidents. Coal miners generally live three 3 years less than the average man with the same socioeconomic status, and statistics are similarly unfavorable for truckers, fishermen, ship workers, steel erectors, riggers, actors and musicians (perhaps due to irregular hours), policemen, and firemen. On the other hand, there are occupational groups in which men live 1 year or more longer than average for their socioeconomic standing, like postal workers, government officials, university professors, and gardeners. Clearly one's choice of occupation can have a large effect on one's life expectancy, extending it several years.

The media have publicized the dangers of various individual substances. Coffee is believed to cause bladder cancer, with an LLE of 6 days for regular users (Ref. 11).

There is some evidence that saccharin may cause bladder cancer (Ref. 12); the LLE from one diet soft drink every day of one's life is 2 days, but the weight gain from one extra non-diet soft drink per day causes an LLE of 200 days. Birth control pills can cause phlebitis (Ref. 11) which gives their users an LLE of 5 days.

Even very tiny risks often receive extensive publicity. Perhaps the best example was the impending fall of the orbiting Sky-Lab, which gave us an LLE of .002 seconds (Ref. 13). The Three Mile Island nuclear power plant accident gave the average Harrisburg area resident an LLE of 1.5 minutes (.001 days).[1] The risk of being struck by lightning (Ref. 15) gives us an LLE of 20 hours.

Mass Scale (Catastrophe) Risks

One may think that large catastrophes pose an important threat to us, but this is hardly the case (Ref. 15). Hurricanes and tornadoes combined give the average American an LLE of 1 day, as do airline crashes. Major fires and explosions (those with 8 or more fatalities) give us an LLE of 0.7 days, and our LLE from massive chemical releases is only 0.1 day. The LLE from being sent to Vietnam during the war

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1. The average exposure to people in that area was 1.2 mrem (Ref. 14). The LLE for 1 mrem of radiation exposure is 1.2 minutes (see Appendix). Thus, the LLE for 1.2 mrem is (1.2 x 1.2) $\cong$ 1.5 minutes.

was 2.0 years in the Marines, 1.1 years in the Army, 0.5 years in the Navy, and 0.28 years in the Air Force.

Some people say that risks which kill one person or a few people are not important, but only large catastrophes are worthy of consideration and must be avoided at all costs. Media coverage is certainly focused upon catastrophes or "potential" catastrophes. Therefore, some people attribute great importance to the possibility of a reactor meltdown accident. This argument is highly distorted. The cancers from a hypothetical severe meltdown accident at Indian Point would increase the cancer rate of those exposed by .02 percent whereas the national average cancer rate is approximately 20 percent. Testimony presented in this proceeding by licensees demonstrates that the risk of an accident at Indian Point increasing this cancer rate is very small.

III. Risks of Nuclear Energy -- In Perspective

With the benefit of the perspective provided by quantifying the risk of day-to-day life, I now turn to Indian Point and other nuclear steam electric power plants and will evaluate them under the assumption that all the electricity now used in the United States were to be generated from nuclear power. The calculations are simple and are explained in the Appendix, but here I will only quote the results.

The mortality risk of living near the Indian Point plants has recently been calculated to be 1.2×10^{-8}/year.[1] This is equivalent to an LLE of 0.006 days (9 minutes) from spending a lifetime in that area.[2]

According to the Reactor Safety (Rasmussen) Study (WASH 1400) (NUREG-75/014), the risk of nuclear reactor accidents would reduce the life expectancy for the average American by .012 days or 18 minutes,[3] whereas the estimate based upon the Union of Concerned Scientists' (UCS') assessed risk is 1.5 days (Ref. 16). Because our LLE from being killed in accidents is now 435 days, it would be increased by .003 percent according to Rasmussen, or by 0.3 percent according to UCS. If the risks of a meltdown are 20 times those given in the Rasmussen Study, the LLE is (20 x 18 minutes) = 6 hours, and the LLE from accidents is increased by 0.6 percent. This makes nuclear accidents thousands of times less dangerous than moving from the Northeast to the West (where accident rates are much higher), an action taken in the last few decades by millions of Americans with little considerat-

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1. Draft testimony to be submitted by licensees under Commission Question 5; subject to confirmation.

2. The lifetime risk is 1.2×10^{-8}/yr x 72 years = 8.6×10^{-7}. The average victim loses about 20 years of life expectancy (7300 days), so the average person loses ($8.6 \times 10^{-7} \times 7300$) = 0.006 days or 9 minutes.

3. See Appendix for an explanation of the derivation of these numbers.

ion given to the added risk. Yet nuclear accidents are what a great many people are worrying about.

If we compare these risks with some of those listed in Table 1, we see that were all electricity in this country generated by nuclear power plants, under the assumption that meltdown risks are <u>20 times</u> higher than those given by Rasmussen, nuclear power would present the same added health risk (UCS estimates in brackets) as a regular smoker indulging in 1 extra cigarette every 9 months [every 3 months], or as an overweight person increasing his weight by .24 ounces [.8 ounces], or as raising the U.S. highway speed limit from 55 miles per hour to 55.1 [55.4] miles per hour, and it is 100 times [30 times] less of a danger than switching from standard size to small cars.

Indian Point and nuclear power generally are being opposed because they are viewed as being too risky, but the best way for the parties to this proceeding to understand a risk is to compare it with other risks with which they are familiar. These comparisons are also the best way for members of the general public to understand the risks of nuclear power. The comparisons set forth in this testimony are the all-important bottom line in evaluating Commission Question 1 relating to the risk posed by the Indian Point plants. These comparisons show that the risk of nuclear power plants in general, and Indian Point in particular, is

extremely small compared to the everyday risks to which the public is exposed.

IV. Acceptability of Risks Posed by Indian Point

The purpose of the discussion presented above is to make the risks of the Indian Point nuclear power plants understandable. Risks are best understood when compared to other risks with which we are familiar. But, what is not generally discussed is the question of whether they are acceptable. Acceptability includes factors other than the magnitude of risks.

For example, many people are more willing to accept voluntary risks like skiing, auto racing, and mountain climbing than involuntary risks, and anti-nuclear activists are quick to point out that nuclear power presents an involuntary risk to the public. On the other hand, many other risks are involuntary, or at least have an important involuntary component. In many if not most cases, a person's occupation is determined more by circumstances than by voluntary choice. Riding in automobiles is hardly voluntary for most people, as they have no other way to get to work, to purchase food, and to participate in other normal activities of life; even if you avoid riding in automobiles, you are still subject to accidents to pedestrians which account for 20 percent of deaths from motor vehicle accidents. Most other accidents are largely due to involuntary activities.

Most drownings occur to children, but a parent cannot prevent his child from going swimming without risking psychological damage. An appreciable fraction of drownings result from taking baths. Deaths from fires, burns, falls, poisonings, suffocation, and asphyxiation are also not usually due to voluntary risk taking.

Some people are more willing to accept natural risks than man-made risks, but nearly all of the risks considered in this testimony are man-made. Living with man-made risks is the price we pay for the benefits of civilization and, in my opinion, these benefits grossly outweigh the risks.

An appreciable number of early fatalities is expected in less than 1 percent of all meltdowns (Ref. 15). A comparable disaster has already occurred from air pollution -- an episode in London in 1952 in which there were 3500 extra deaths within a few days. There are dam failure accidents (Ref. 15) which could kill 200,000 people within a few hours, and they are estimated to be far more probable than a severe nuclear meltdown accident.

There are many potential causes of large loss of life anywhere large numbers of people congregate. A collapse of the upper tier of a sports stadium, a fire in a crowded theater, and a poison gas entering the ventilation system of a large building (some buildings house 50,000 people) are a few examples. The idea that a potential reactor meltdown

accident is uniquely or even unusually catastrophic is grossly erroneous.

I have a deeper objection to the idea that a catastrophic accident is more important than a larger number of people dying unnoticeably. In choosing between technologies on the basis of health impacts, the total number of deaths should be the overriding consideration. Anyone who does not agree should attempt to explain to the survivors of the victims that their loved ones had to die because people consider only large catastrophes important. I am certain that their explanation would gain little acceptance.

What risks are acceptable is not a scientific question; therefore, I as a scientist cannot claim expertise in this area. I have merely presented the risks as they are, hopefully in understandable terms. If any citizen feels that the tens of billions of dollars worth of electricity produced by nuclear power plants is not worth the risk of a regular smoker smoking 1 extra cigarette every 9 months, or of an overweight person adding 1/4 ounce to his weight, or of raising the national speed limit from 55 to 55.1 miles per hour, he is entitled to that opinion. I do not share it.

V. <u>Spending Money to Reduce Risk</u> (Ref. 17)

Another aspect of understanding risk is to consider what society is doing -- or deciding not to do -- to reduce

our risks. It is unreasonable to spend a lot of money to reduce one risk, such as attempting to reduce the risk at Indian Point through the retrofitting of a filtered vented containment system (FVCS) or some other device, if we can reduce a greater risk much more cheaply but do not. I respectfully submit that it would be inappropriate for this Board to recommend Indian Point retrofits unless the cost per fatality averted data (see below) available to the Board fully justifies such a course.

It may seem immoral and inhumane even to consider the monetary cost of saving lives, but the fact is that a great many of our risks can be reduced by spending money. A few years ago, air bags were offered as optional safety equipment on several types of automobiles, but they are no longer offered because not enough people were willing to buy them. They were proven to be effective and safe -- an estimated 15,000 lives per year would be saved and the average American's life expectancy would be increased by 15 days if they were installed in all cars (Ref. 18). There is no discomfort or inconvenience associated with them. They have only one drawback -- they cost money. Apparently Americans did not feel that it was worth the money to reduce their risk of being killed or injured in an automobile accident.

There is a long list of other automobile safety features we can buy -- premium tires, improved lights, and rear window de-icers, to name a few. We can spend money on fre-

quent medical examinations, we can use only the best and most experienced doctors, we can buy elaborate fire protection equipment for our homes, we can fly and rent a car at our destination rather than drive on long trips, we can move to safer neighborhoods; the list is endless. Each of these alternatives also costs money. In this section we consider how much it costs to save a life by spending money in various ways. In some cases, when personal effort and time are also required, a reasonable monetary compensation will be added to the cost.

For example, obtaining a Pap smear to test for cervical cancer requires making an appointment and spending a few minutes at the doctor's office, but most women would be willing to do equivalent chores for a payment of 5 dollars. A Pap test costs about 10 dollars, so we add the 5 dollars for time and effort and arrive at a total cost of 15 dollars. Each annual Pap test has one chance in 3,000 of saving a woman's life (Ref. 19) so for every 3,000 tests, costing (3000 x 15 dollars) = 45,000 dollars, a life is saved. The average cost per life saved is then 45,000 dollars.

The above example is taken from a study (Ref. 17) completed a few years ago in which all costs are given in 1975 dollars. Other details of calculation are given in the Appendix, but here I will quote some of the other results of that study.

There is in fact a compelling reason for risk-reducing decisionmaking to be guided by "cost of saving lives" thinking: society's resources are only finite. Because unlimited sums cannot be spent on reducing risks in all areas, were we to spend money on risk-reducing measures unwisely from the standpoint of how effective they would be, other more needy and deserving alternatives will be passed over.

If there were a smoke alarm in every home, it is estimated that 2,000 fewer people would die each year in fires (Ref. 20). Even with a generous allowance for costs of installation and maintenance, this works out to a life saved for every 60,000 dollars spent, but only 20 percent of American homes now have smoke alarms.

On the other hand, a great many Americans purchase premium tires to avert the danger of blowouts. If everyone did, this would cost an aggregate of about 5 billion dollars per year and could avert nearly all of the 1,800 fatalities per year which result from blowouts, a cost of nearly 3 million dollars per life saved. Many Americans buy larger cars than they need in order to achieve greater safety, although this decision costs approximately 6 million dollars per life saved (Ref. 17).

There are millions of Americans who purchased premium tires with their new cars but did not order air bags, even though the air bags are 10 times more cost-effective. The problem is that the American consumer does not calculate

cost-effectiveness. His actions are governed by advertising campaigns, salesmanship, peer group pressures, and a host of other psychological and sociological factors.

Measures could be taken to increase the percentages of women who receive annual Pap smears; this has been done in a few cities including Louisville, Toledo, Ostfold (Norway), Aberdeen (Scotland), and Manchester (England), and approximately 90 percent participation in these cities was achieved by such measures as sending personal letters of reminder or visits by public health nurses. These measures involve added costs, but tests are cheaper when done in a large-scale program (Ref. 19) -- a Mayo Clinic program conducted them for $3.50 in the 1960s and a British program conducted them for $2 in 1970 -- so thousands of lives could be saved each year at a cost below 50,000 dollars each.

There are several other cancer-screening programs which could be implemented. Fecal blood tests can detect cancer of the colon or rectum for as little as 10,000 dollars per life saved (Ref. 21). Many more of these cancers could be detected in men aged 50 to 65 by annual proctoscopic examinations (Ref. 22), saving a life for every 30,000 dollars spent, but only one in 8 men this age now receive such examinations.

Testing for high blood pressure has almost become a fad in this country, but the problem goes beyond detection. Treatment is quite effective but because the condition is

not immediately life threatening, many people ignore it. A well-organized treatment program would save a life for every 75,000 dollars invested (Ref. 23), with 1/2 of that cost compensating patients for their inconvenience, but such programs have not been developed.

An especially effective approach to saving lives with medical care is the use of mobile intensive care units (MICU) (Ref. 24), well-equipped ambulances carrying trained paramedics ready to respond rapidly to a call for help. Experience in large cities has shown that MICUs save lives at an average cost of approximately 12,000 dollars, and consequently every large city has them. However, for smaller towns the cost increases, and when it reaches 30,000 dollars per life saved, the cost for a town with a population of 40,000, it is often considered too expensive (Ref. 25). Effectively, it is decided that saving a life is not worth more than 30,000 dollars.

To summarize these medical examples, there are several available programs which could save large numbers of lives for costs below 50,000 dollars each, and many more for costs up to 100,000 dollars per life saved. These are, of course, American lives which may be our own. Saving lives overseas is much cheaper. Sending food to underdeveloped countries (Ref. 26) like India could effectively save one life for every 5,000 dollars spent, and there is an immunization program in Indonesia which can save 300,000 lives at a cost

of 30 million dollars, or 100 dollars per life saved (Ref. 27).

Health care is not our only means of spending money to save lives. Over 35,000 Americans die inside automobiles each year as a result of collisions, and over one million are seriously injured even though there are many ways in which this toll could be reduced by investing money in highway or automobile safety devices.

To some extent these improvements have been made. A number of new safety devices in automobiles were mandated by law between 1966 and 1974, and a study by the U.S. General Accounting Office (Ref. 28) indicates that they have saved one life for every 140,000 dollars spent. Unfortunately the program has ended. In 1970-73 alone, 16 new safety measures in automobiles were mandated, but hardly any have been added since that time. As noted previously, an air bag requirement which would cost 300,000 dollars per life saved has not been implemented.

There are many highway construction measures which could save lives. For example, about 6,000 Americans die each year in collisions with guardrails, and there are guardrail construction techniques which could save most of them (Ref. 29). The "National Highway Safety Needs Report" (Ref. 30), published in 1976, represented a federal government effort to estimate the cost-effectiveness of various highway safety measures. It found that guardrail improve-

ments in selected locations could save over 300 lives per year at a cost of 34,000 dollars each. Improvements in speed limit and hazard warning signs would save even more lives at a similar unit cost. Other measures which would each save hundreds of lives per year at costs below 50,000 dollars per life include construction techniques to improve skid resistance and better designed bridge rails and parapets. The use of standard techniques to avoid wrong way entrance onto freeways would save about 80 lives per year at that cost.

If we were willing to pay 100,000 dollars per life, we could save 680 lives per year with impact-absorbing devices at critical roadside points, and 325 lives per year by useing breakaway sign and lighting supports rather than rigid supports on high-speed roadways.

It is estimated (Ref. 31) that high school courses in driver education avert approximately 6,000 fatalities per year and they cost less than 100,000 dollars per life saved, even if we include a 50 dollar payment to each student for his time and trouble. Yet, there are recent indications that these programs are being cut to save costs.

Before leaving the area of traffic safety it should be pointed out that there are 40 serious injuries for every fatality in traffic accidents (Ref. 2), and the measures discussed would reduce the former as well as the latter. I have erred on the high side in charging all of the costs to

lifesaving, so the costs per life saved are lower than given in the above discussion.

We have seen that some of our governmental agencies are forgoing opportunities for saving lives at costs below 50,000 dollars, and they are rarely willing to spend over 200,000 dollars. But when radiation is involved, they hasten to spend much more. The Environmental Protection Agency is now requiring that in cases in which the radium content is abnormally high in drinking water, special measures must be taken to remove a portion of it. This measure, it estimates, corresponds to spending 2.5 million dollars per life saved (Ref. 32).

UCS/NYPIRG has suggested that a FVCS be installed at both Indian Point units. They estimate the cost of such a device to be "tens of millions of dollars," which they acknowledge does not include research and development, downtime or other related costs, and thus is an understatement of the true full cost. UCS/NYPIRG Testimony of Gordon R. Thompson and Steven C. Sholly on Commission Question Two, Contentions 2.1(a) and 2.1(d) at 19 (Dec. 28, 1982). For purposes of my analysis here, I have assumed the total cost of designing and installing a FVCS at Indian Point would be 50 million dollars for each unit. The UCS/NYPIRG witnesses further estimate that the reduction in cancer deaths from this device would be approximately .90. Id. at 16.

Using the above estimates and the expected latent fatalities of 1.7×10^{-1}/reactor-year for Indian Point Unit 2 and 3.3×10^{-2}/reactor-year for Indian Point Unit 3 as determined in the Indian Point Probabilistic Safety Study (Ref. 33), I have calculated a cost per fatality averted associated with the installation of a FVCS. For Indian Point Unit 2, the cost per fatality averted is 10.9 million dollars, and for Indian Point Unit 3, the cost per fatality averted is 56.1 million dollars.

A summary of the costs per life saved developed here, plus others from Ref. 17, is shown in Table 2. Clearly, there are enormous wastes of money and of lives resulting from the illogical inconsistency in our spending for life-saving. Thousands of Americans die needlessly each year for lack of money spent on medical programs and traffic safety, while the money which could save them is spent to save a single life from radiation hazards.

VI. Conclusions

Based upon the foregoing, I have shown that the risk from nuclear power, specifically Indian Point, is small compared to the everyday risks with which people are faced. I have also shown that many more lives could be saved by taking the money which would be spent on nuclear power plant modifications such as proposed by UCS/NYPIRG to this Licensing Board and using it to upgrade other areas,

such as traffic safety and medical care, when the same expenditures would unquestionably result in a much greater saving of American lives.

Table 2. Cost per fatality averted (1975 dollars) implied by various societal activities (Ref. 17)

Item	$ per fatality averted
Further medical screening and care for	
Cervical cancer	25,000
Breast cancer	80,000
Lung cancer	70,000
Colorectal cancer	
Fecal blood tests	10,000
Proctoscopy	30,000
Multiple screening	26,000
Hypertension control	75,000
Kidney dialysis	200,000
Mobile intensive care units	30,000
Traffic safety	
Auto safety equipment — 1966-70	130,000
Steering column improvement	100,000
Air bags (driver only)	320,000
Tire inspection	400,000
Rescue helicopters	65,000
Passive 3-point harness	250,000
Passive torso belt-knee bar	110,000
Driver education	90,000
Highway construc.-maint. practice	20,000
Regulatory and warning signs	34,000
Guardrail improvements	34,000
Skid resistance	42,000
Bridge rails and parapets	46,000
Wrong way entry avoidance	50,000
Impact absorbing roadside dev.	108,000
Breakaway sign, lighting posts	116,000
Median barrier improvement	228,000
Clear roadside recovery area	284,000
Miscellaneous non-radiation: further expenditures for	
Immunization in Indonesia	100
Food for overseas relief	5300
Smoke alarms in homes	60,000
Higher pay for risky jobs	260,000
Coal mine safety	22,000,000
Other mine safety	34,000,000
Coke fume standards	4,500,000
Air Force pilot safety	2,000,000
Civilian aircraft (France)	1,200,000
Radiation-related activities	
Efforts to reduce radium in drinking water	2,500,000
Improved medical X-ray equipment	3600
ICRP recommendations (Ref. 34)	320,000
Better radwaste practice--general	10,000,000
FVCS (at IP-2)	10,900,000
FVCS (at IP-3)	56,100,000

Appendix

For those persons who are interested, I demonstrate here how to calculate some of the results quoted in this testimony.

First, calculate the LLE from reactor accidents according to the Rasmussen Study (Ref. 9), which estimates one meltdown per 20,000 reactor-years of operation, and an average of 400 fatalities per meltdown. If all United States electricity were derived from nuclear power plants, approximately 250 such plants would be required and we would have 250 reactor-years of operation each year. We would expect an average of one meltdown every (20,000/250) = 80 years. The average fatality rate is then (400/80) = 5 per year. If the U.S. were to maintain its present population for a long time there would be a total of approximately 3 million deaths from all causes each year, and (5/3 million) = 1.7 of every million deaths would be due to nuclear accidents. Victims of nuclear accidents lose an average of 20 years of life expectancy (cancers from radiation usually develop 15 to 50 years after exposure), giving the average American an LLE = $1.7 \times 10^{-6} \times 20 = 34 \times 10^{-6}$ years; multiplying this by 365 days/yr x 24 hrs/day x 60 minutes/hour gives LLE = 18 minutes as quoted previously for the Rasmussen Study.

The UCS estimates (Ref. 16) are one meltdown every 2000 reactor-years, with an average of 5000 deaths per meltdown. These numbers are 10 and 12.5 times higher, respec-

tively, than the Rasmussen estimates, so the LLE is larger by a factor of 10 x 12.5 = 125. Multiplying this number by 18 minutes yields 2250 minutes or 1.5 days. Alternatively, one could perform the entire calculation explained in the previous paragraph.

For major risks such as disease, smoking, and motor vehicle accidents, a "life table" calculation must be performed. (A computer program prepared for that purpose was used in all calculations from Ref. 1.) The correct way to calculate life expectancy is to devise a table with one line for each year of age. Starting with a cohort of 1000 people at age 0, and introducing the average risk of death between age 0 and 1, the number dying in that age range and the number surviving to age 1 is calculated. From the risk of death between ages 1 and 2, the number of these dying in that age range and the number surviving to age 2 is calculated. This procedure is followed for all ages until all of the cohort has died. The number dying at each age is multiplied by the number of years lived (e.g., those dying between ages 35 and 36 are construed as having lived 35.5 years), and the results are added to yield the total number of years lived by the original cohort of 1000 people. Their life expectancy is this total divided by 1000.

To calculate the LLE from cancer, for example, the risk of death from cancer at each age is subtracted from the total risk of death at that age, and the above life table

calculation is repeated with these decreased risks. This yields a life expectancy if there were no deaths from cancer. The difference between this result and the previous one is the LLE from cancer.

The comparisons of risks are based upon the ratio of LLE. For example, if one pound of added weight gives an overweight person an LLE of 30 days while the UCS estimate gives an LLE from reactor accidents of 1.5 days, gaining one pound is $30 \div 1.5 = 20$ times more dangerous, or gaining 1/20 of one pound must be equally dangerous. Multiplying by 16 ounces per pound gives 0.8 ounces as the weight gain resulting in an equivalent risk.

As an example of calculating the cost per life saved, consider the use of air bags. According to Allstate Insurance Co. (Ref. 18) an air bag reduces the drivers' mortality rate by 1.4 deaths per hundred million miles driven. A car driven 50,000 miles has a probability of saving a life of $1.4 \times (50{,}000/100{,}000{,}000) = 1/1500$, one chance in 1500. This air bag would cost approximately 200 dollars, so the cost per life saved is 200 dollars divided by 1/1500, or 300,000 dollars. For every 1500 cars equipped with an air bag, an average of one life would be saved; the cost would then be 1500×200 dollars = 300,000 dollars to save one life.

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Employment:

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1950-58: Oak Ridge National Laboratory
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1959-60	General Atomic Co., La Jolla, CA
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1965	Brookhaven National Laboratory
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Chairman, Am. Physical Society Div. of Nuclear Physics, 1974-75
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SOCIETY'S VALUATION OF LIFE SAVING IN RADIATION PROTECTION AND OTHER CONTEXTS

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Abstract—Various situations are described in which societal action may be interpreted as a dollar value placed on averting a human fatality, and numerical values are derived in each case. Situations included are a variety of medical screening and medical care programs and of automobile and highway safety measures, food for overseas relief, air pollution control, fire prevention, industrial safety, and several radiation-related activities including standards for radium in drinking water, radwaste systems in nuclear plants, and defense and civilian high-level waste management. Values varying from a few thousand dollars to hundreds of millions of dollars per fatality averted are obtained. An attempt to derive data of this type from polling is described. The problem of discounting when money is spent now to save lives far in the future (as with nuclear waste) is discussed.

It is concluded that nearly all of the vast variation in the results is unjustified and represents a need for educating the public, especially in the area of radiation protection.

INTRODUCTION

THE PRINCIPAL purpose of radiation protection is to save lives, and the principal limitations on its capability of doing so derive from the costs involved. Almost any operation can be done by remote control, and the shielding can almost always be increased to reduce radiation exposure. Where do we stop? The traditional answer to this question lies in application of the concept of maximum permissible dose, but that is, in many ways, a "cop-out". The only logical answer is to stop where the *costs* exceed the *benefits*.

This introduces a very difficult element into the decision-making. The costs are usually in dollars, while the benefits are principally in lives saved, whence the comparison between costs and benefits can only be made quantitatively if we are willing to assign a dollar value to saving a human life. This is the problem addressed in this paper.

Assigning a dollar value to life saving appears intuitively to be an immoral and repugnant subject, but actually we all do it frequently. For example, when we buy low-priced tires rather than the type that cannot blow out, or when we decide not to have frequent medical check-ups, we are placing a dollar value on saving our own lives and even on saving the lives of our loved ones. The value of life saving is also an implicit element in public decision-making. It is well recognized that divided highways bordered with gently sloping terrain free of obstacles that may provide targets for hard collisions are much safer than typical roads and hence can save lives, but we build only a small fraction of our highways with those features, only to save money. There are many ways in which medical care could be improved by expenditure of public funds, and surely these would save lives.

Perhaps the moral position in considering a dollar valuation on saving of human lives is improved if we recognize the monetary costs

largely represent human labor, both directly and indirectly in that the costs of materials largely represent the cost of labor to derive them—when we mine a mineral we do not pay the earth for it. The question we are really addressing, then, is how many man-hours or life-times of labor should be devoted to extending one person's life.

It would clearly be inappropriate for a scientific paper to recommend a value to be placed on life saving in radiation protection contexts. However, it does appear relevant to decisions in that area to recognize the value adopted by society in other contexts. In this paper we therefore attempt to assemble the available information on that question and to develop further estimates wherever possible.

The valuation of life saving as an element in cost-benefit analysis is not a new subject; in fact there is a rather large body of literature on that topic (Fr65; Sc68; Mi72; Ze75; Li75; Li76; Co76; Ze76; Fi77; Kr77; Li78; Rh78; to cite a few examples) largely developed by economists and sociologists. In fact this literature often does not stop short of making recommendations on the valuation. Some of the criteria they have used for this purpose are expected future earnings (complete with discounting as for interest, and in one case even a correction for funeral expenses), court judgements, and insurance coverage. In a few cases this literature is aimed at pointing out specific "bargains" or "over-payments" in the enterprise of spending money to save lives. The National Safety Council (Na75) even provides a dollar cost of a death—$43,000 in 1968, $97,000 in 1974, $110,000 in 1975—which is widely used in decision making on highway modifications. Other values used (Ge76) are $140,000 and $201,000 in 1970–71. In this paper, we refrain from such activities and confine our attention to collecting and deriving information. We do this by identifying situations in which money can be spent to save lives but in which the decision of Society is to do so to a significant extent, but not in a massive way.

In some cases, saving lives requires human time and effort as well as money, as for example in medical screening programs where subjects must appear for examinations or tests. In such cases we attempt to add the cost of this inconvenience, based on a subjective estimate of how much you would expect to pay a person for expending an equivalent amount of time and effort for some other purpose. In the above case we apply an "inconvenience cost" of $5 to appear for an examination taking only a few minutes. In many cases throughout our treatment it is necessary to make estimates of this general type, but they are always presented in such a way that the reader can substitute his own estimates to derive his own results.

There are also many cases where it is necessary for us to make judgements. For example in the early 1970s it became clearly recognized that lives could be saved at a cost in the range $5000 each by introducing in cities an advanced ambulance service with well-trained paramedics and elaborate equipment. Within a few years, this was implemented in all large cities. It is our judgement that the fact that it was not implemented earlier does not indicate that life saving was valued at less than $5000, but rather that the cost-benefit relationship was not recognized. As a counter example the fact that after more than two decades of experience with PAP tests for cervical cancer, with data available on several local successful programs, the fact that only 50% of those at risk receive annual tests is, in our judgement, an indication that society is not willing to spend the money to greatly increase the coverage. In borderline cases of this type, the facts are presented and the reader is, of course, free to substitute his own judgements for ours.

Since the data we present are from different time periods, we have made at least a crude effort to correct costs for inflation. These corrections are minimized if we use 1975 dollars so, for convenience, we have converted all costs to those terms.

Because of the many estimates involved, few

of our results can be assigned high accuracy. We feel that most of them are accurate to within 50%, although this may be over-optimistic in many cases. Where there are uncertainties, we have tended to accept higher valuations in medical areas where the valuations seem to be relatively low.

With this introduction, we now embark on a series of case studies in which we judge that a dollar value of life saving is implicit. The results are summarized in Table 1 as both the cost per fatality averted, and the cost per 20 years of life expectancy gained. In many cases, the conversion from the former to the latter involves a crude estimate, but this is not an important source of error.

CASE STUDIES

(A) *Medical areas*

Perhaps the most obvious area in which money can be spent to save lives is in medical care. Large increases in life expectancy have been achieved during this century as a result of improved medical care, and there is abundant evidence that nations with poor medical care have lower life expectancy.

We present evidence here on several medical care programs that could save lives but which are not being widely implemented largely because of cost considerations. For cancer screening programs we have ignored treatment costs because they would probably be at least as great if the cancer were later discovered from symptoms as if it is detected early by screening.

(1) *Cervical cancer screening.* Cervical cancer afflicts mature women, bringing death to one U.S. female in 10,000 each year. It is readily detected by a test developed by Papanicolaou (PAP smear) and, if detected at an early stage, can almost always be cured. PAP tests became widely available in the 1950s, but by 1968 there was no state in which as many as 20% of all women of the susceptible age were tested (Cr74), although by 1977 the percentage screened rose to about 50% (Ga77). Local screening programs were set up in many places throughout the world, and these are useful for cost–benefit analysis. They also demonstrate the feasibility of achieving at least 90% coverage of the population at risk (Wa76).

In a study of a Mayo Clinic program in Olmstead County, Minnesota, during 1960–67, Dickinson (Di72) reported that the program cost $182,000 for 51,700 PAP smears, and detected 184 cases; among these the cure rate was 91% vs 74% for cases detected without a screening program, which corresponds to saving $(0.91-0.74) \times 184 = 31$ lives. The cost was thus $182,000/31 = $5800 per life saved. The average life expectancy of those cured was 40 years. If we apply an inflation factor of 1.5, and assume that the inconvenience to the person taking the test is worth $5, the corrected cost per life saved becomes $17,000.

In a study of screening programs in Aberdeen, Scotland, during 1971, Thorn *et al.* (Th75) reported that 16,500 smears at $2 apiece identified 56 cases. If we apply an inflation factor of 1.3, add $5 per smear inconvenience cost, and assume that 17% of the detected cases resulted in lives saved (from the Mayo Clinic Study), the cost becomes [(1.3 × $2) + $5] × 16,500 = $125,000 to save $0.17 \times 56 = 9.5$ lives, or $13,000/life saved.

The Walton Report (Wa76) on cervical cancer in Canada principally between 1961 and 1972 found that the mortality rate which was initially 20×10^{-5}/year among women aged 30–64 decreases roughly in proportion to the percentage of women screened. Thus a 50% screening of 100,000 women would save 10 lives, one life saved per 5000 screenings. If the inflation corrected cost of screening, plus the inconvenience cost is $10 (as in the Mayo Clinic case), the cost per life saved is $50,000. This is completely non-selective screening.

Grosse (Gr72; JEC69) estimated that a government program of screening 9.4×10^6 women at a cost of $10.44 each would find 107,000 cases and avert death in 44,000 of these. With corrections for inflation and inconvenience, the cost approaches $20 per

Table 1. Cost per fatality averted (1975 dollars) implied by various societal activities (left column) and cost per 20 yr of added life expectancy (right column).

Item	$ per fatality averted	$/20-yr life expectancy
Medical screening and care		
Cervical cancer	25,000	13,000
Breast cancer	80,000	60,000
Lung cancer	70,000	70,000
Colorectal cancer:		
Fecal blood tests	10,000	10,000
Proctoscopy	30,000	30,000
Multiple screening	26,000	20,000
Hypertension control	75,000	75,000
Kidney dialysis	200,000	440,000
Mobile intensive care units	30,000	75,000
Traffic safety		
Auto safety equipment—1966–70	130,000	65,000
Steering column improvement	100,000	50,000
Air bags (driver only)	320,000	160,000
Tire inspection	400,000	200,000
Rescue helicopters	65,000	33,000
Passive 3-point harness	250,000	125,000
Passive torso belt–knee bar	110,000	55,000
Driver education	90,000	45,000
Highway construc.–maint. practice	20,000	10,000
Regulatory and warning signs	34,000	17,000
Guardrail improvements	34,000	17,000
Skid resistance	42,000	21,000
Bridge rails and parapets	46,000	23,000
Wrong way entry avoidance	50,000	25,000
Impact absorbing roadside dev.	108,000	54,000
Breakaway sign, lighting posts	116,000	58,000
Median barrier improvement	228,000	114,000
Clear roadside recovery area	284,000	142,000
Miscellaneous non-radiation		
Expanded immunization in Indonesia	100	50
Food for overseas relief	5300	2500
Sulfur scrubbers in power plants	500,000	1,000,000
Smoke alarms in homes	250,000	170,000
Higher pay for risky jobs	260,000	150,000
Coal mine safety	22,000,000	13,000,000
Other mine safety	34,000,000	20,000,000
Coke fume standards	4,500,000	2,500,000
Air Force pilot safety	2,000,000	1,000,000
Civilian aircraft (France)	1,200,000	600,000
Radiation related activities		
Radium in drinking water	2,500,000	2,500,000
Medical X-ray equipment	3600	3600
ICRP recommendations	320,000	320,000
OMB guidelines	7,000,000	7,000,000
Radwaste practice—general	10,000,000	10,000,000
Radwaste practice—^{131}I	100,000,000	100,000,000
Defense high level waste	200,000,000	200,000,000
Civilian high level waste		
No discounting	18,000,000	18,000,000
Discounting (1% year)	> 1,000,000,000	> 1,000,000,000

examination, giving a cost/life saved of $(9.4 \times 10^6 \times 20)/44 \times 10^3 = \$4300$.

Rhodes (Rh78) gives a cost of $3500/life saved without detail.

In view of the above, it seems conservative to estimate that cervical cancer screening programs can save one life for every $25,000 spent. Since an average life saved corresponds to a gain of 40 years of life expectancy, the cost per 20 years of life expectancy gained is $12,500.

(2) *Breast cancer screening*. Breast cancer is the leading cause of cancer death among U.S. females, with an overall mortality rate of 23×10^{-5}/year, and several times higher for ages beyond 50. When detected early, it is frequently curable, and early detection is reasonably efficient with X-ray and clinical examination.

Shapiro *et al.* (Sh72) reported on a clinical trial in New York City involving 31,000 women aged 40–64 invited for screening of whom 20,000 responded, and 31,000 unscreened controls. In a 5-yr period, there were 40 deaths from breast cancer among those invited vs 63 among the controls, which may be interpreted as saving 23 lives. The cost was $40/examination, which with our inflation and inconvenience factor becomes $60, or $20{,}000 \times \$60/23 = \$52{,}000$/life saved. This price could have been substantially reduced by limiting the service to those above age 50.

Kristein (Kr77) gives breast cancer incidence among females of age 55–64 as 2×10^{-3}, so among 1 million women there would be 2000 cases/year of whom 42% would normally die and 20% of these (169) would be saved (this is half the save rate in Sh72). He gives the cost as $40/examination which remains approximately unchanged when corrected for inflation and inconvenience. The cost per life saved is then $40 \times 10^6/169 = \$240{,}000$. However, he estimates that the radiation from the X-rays would cause 67 deaths (this seems high for women of that age) which increases the cost/life saved to $40 \times 10^6/102 = \$400{,}000$. He considers this to be obviously cost ineffective.

Irwig (Ir74) reports on British experience as $3300/cancer detected with these cases having a one-third increase in 5-yr survival over cases developing without screening. This represents about a 20% increase in 5-yr survival, or perhaps a 12% increase in long-term survival. The cost/life saved is then $\$3300/0.12 = \$28{,}000$. With inflation and inconvenience included this might be increased to $40,000. Irwig calls this price "costly" and concludes "it would seem wise to await [improved] developments before considering the introduction of mass screening for breast cancer".

Grosse (Gr72; JEC69) estimates that a government screening program covering 2.3×10^6 women would cost $7.79 per examination and eventually avert 2936 deaths. With inflation and inconvenience corrections, the cost becomes $17 per examination, giving a cost/life saved $= 17 \times 2.3 \times 10^6/2936 = \$13{,}300$.

It is difficult to reconcile the wide variations we have found here, but the actual cost is not the important point for our purpose; we are interested in the cost as perceived by those in a position to institute screening programs. Since the Kristein analysis is rather recent, we must conclude that screening programs were not widely instituted when the perceived cost was in the range below $80,000/life saved. In a 1977 Gallup poll (Ga77), 51% of women above age 18 said that they had had some type of breast examination during the previous year.

(3) *Lung cancer screening*. Lung cancer is the largest cancer killer by far among U.S. males, with a rate approaching 50×10^{-5}/year among all males and several times higher than this for heavy cigarette smokers. Early detection is facilitated by X-ray and sputum cytology studies, and early detection is the key to survival, although even at best the chance of survival is small.

The most optimistic screening information comes from two studies in London (Na68; Br69) involving about 30,000 subjects each, plus an equal number of controls. They report costs as low as $350/cancer found and cured

among heavy smokers, but Boucot and Weiss (Bo73a) estimate that their costs for X-ray film alone should have been \$12,500/survivor, and with inconvenience and other costs and a correction for inflation, the cost would be increased to perhaps \$30,000/life saved.

Colley (Co74) estimates the costs of the London projects as \$1300 per case found and cured and concludes that the programs should be phased out! With our inflation and inconvenience factors, the cost would be raised to about \$20,000/life saved.

Boucot and Weiss (Bo73), working in Philadelphia, examined 10,000 men at 6-month intervals for 3 yr, for a total cost of \$250,000 and found and cured three lung cancers, a cost of \$83,000/life saved. They conclude "It is questionable whether the community could afford the price". With our inflation and inconvenience factors, the cost would be increased to about \$200,000/life saved.

The Mayo Lung Project (Fo75) detected 25 lung cancers (plus two cancers of the upper respiratory tract and one cancer of the tongue) in their first examinations of 3900 participants. Following pulmonary resections, the prognosis was good in 12 of these cases. If *three* of these prove to be cured, and the cost of an examination is taken to be \$50 (including inconvenience), a single examination will have saved three lives at a cost of \$195,000 or \$65,000/life saved. This takes no credit for the three other cancers found and cured.

Actually, the Mayo project was designed to provide examinations at 4-month intervals in order to detect newly developing cancers which they estimate to be 50% curable. In the early work they found (Fo75) six cases in 3000 follow-up examinations, which hopefully corresponds to one cure/1000 examinations or \$50,000/life saved. Recent experience (Fo78) has detected 4.5 cancers/yr–1000 people, which, with three examinations/year at \$50 each and a 50% cure rate correspond to $150/2.3 \times 10^{-3}$ = \$65,000 per life saved.

In view of the above, it seems reasonably conservative to conclude that, at least in the perception of those in a position to institute programs, lives could be saved by lung cancer screening at a cost of \$70,000 each. The 1977 Gallup poll (Ga77) indicated that 26% of adult men and women have lung X-rays each year.

(4) *Screening for cancer of colon and rectum.* Cancer of the colon and rectum causes an annual mortality rate in the U.S. of 20×10^{-5} for males and 15×10^{-5} for females; the rates are much higher for ages above 45. A simple screening technique involves fecal blood tests, and a more elaborate procedure is visual examination by proctosigmoidoscopy.

Kristein (Kr77) gives the mortality rate for all people over 55 as 3×10^{-3}/year and estimates that 20% of these could be saved by early detection with fecal blood tests at a cost of \$2 each. We add another \$2 as an inconvenience cost as this requires only turning in a fecal sample with no office time. For a program involving 10^6 people, there would then be 3000 cases of which 600 would be saved at a cost of \$4 × 10^6. The cost per life saved would then be \$6700.

Bolt (Bo71) estimates that by screening 9000 people above age 45 by proctosigmoidoscopy, one can expect to find 20 colorectal cancers and cure 17 of them whereas only 10 of them would be cured without screening, a net saving of seven lives. He estimates the cost to be \$12/scan, which gives a cost/life saved = \$12 × 9000/7 = \$16,000. He argues that this price is too high to be practical! With our corrections for inflation and inconvenience, the cost per life saved is raised to \$27,000.

Gilbertson (Gi74) estimates that screening of 400,000 people would detect 1300 cases of which 88% would survive vs 50% without this early detection, a saving of (0.88–0.50) × 1300 = 494 lives. He estimates the cost at \$11.73/examination, but adding our inflation factor and inconvenience charge this becomes \$20. The cost/life saved is then 20 × 400,000/494 = \$16,000.

Grosse (Gr72; JEC69) estimates the cost of an examination at \$20.10 which, corrected for inflation and the inconvenience, becomes \$35.

He estimates one case found per 496 examinations, with an additional 22% cured as a result of the early detection. The cost per life saved is then $35 × 496/0.22 = $79,000.

Since Grosse's work is rather old, we give it less weight and conclude that lives can be saved by proctosigmoidoscopy screening at a cost of $30,000 each, and a screening program in fecal blood tests could save lives at a cost of perhaps $10,000 each. According to the 1977 Gallup poll (Ga77), only 8% of all men and 12% of those aged 50 and above had proctoscopic examinations in the previous year.

(5) *Miscellaneous cancer screening and comments.* Grosse (Gr72; JEC69) estimates that screening for cancers of the head and neck could save lives at a cost of $44,000 each. With corrections for inflation and inconvenience charge, this becomes $75,000.

Cannon Mills, a large textile manufacturing corporation, runs a program of medical screening of its employees for colorectal (fecal blood); cervical, and breast cancer, blood pressure, and diabetes. The examinations cost $8 for men and $12 for women, or an average of about $9, but it would seem that only about $7 of this should be charged to cancer screening. In 11,000 examinations, 23 cancers were found (He77). If three additional cures are obtained as a result of this early detection, the cost would be 7 × 11,000/3 = $26,000. This item is entered as "multiple cancer screening" in Table 1.

The *Lancet* ran an extensive series on cancer screening and, in summary papers on the series, Randall (Ra74) favored screening for cervical cancer but recommended caution on all others, while Holland (Ho74a) concluded that no type of cancer screening is worth the cost!

(6) *Hypertension screening and control.* Hypertension (high blood pressure) is a contributory factor in about one-third of all fatalities from heart-disease and stroke. It is also a fairly common condition; in one large screening activity involving 1 million Americans, 25% had diastolic pressure above 90 and 12% were above 95 (St76). In this study, 28% of these cases had been previously undetected, 11% had been detected but untreated, and 17% had been treated but uncontrolled, so fully 55% of the 25%, or 13% of those screened, obtained important information. Since blood pressure measurement is an extremely simple and cheap procedure, this suggests that the cost–benefit ratio would be very favorable, although it is not easy to quantify because hypertension is not ordinarily a direct cause of death. However, an analysis by Kristein (Kr77) indicates that such screening is cost effective even from the standpoint of money loss from missing work.

We derive an estimate of cost/life saved from finding *and controlling* blood pressure as follows (St75): for males 55–64 years old, the annual mortality risk can be reduced from 219×10^{-4} to 179×10^{-4} by reducing diastolic blood pressure from 97 to 87 mm-Hg, a reduction of 40×10^{-4}/year, at a cost of $150/year for medicine and care plus perhaps an equal amount for inconvenience. This corresponds to $\$300/40 \times 10^{-4} = \$75,000$/life saved. Similarly male mortality rates in this age range can be reduced by 60×10^{-4} by reducing blood pressure from 102 to 87 mm-Hg, which costs about $240/year for medicine and treatment plus a somewhat lesser amount for inconvenience, which corresponds to about $\$450/60 \times 10^{-4} = \$75,000$/fatality averted. For females and males in adjacent age ranges, the reduced mortality is 3–5 times smaller so the cost per fatality averted would go up to $300,000, but this does not change the above value for 55–64-year-old males which is listed in Table 1.

It may be noted that we have not mentioned the costs of *screening* here; actually they are included but they contribute a small amount to the above costs.

(7) *Kidney dialysis.* About 6000 Americans need kidney dialysis treatment on a regular basis, but only 850 were receiving it in 1968 while the rest were condemned to early death. (Government in Sweden was committed to

provide treatment for all.) A person on dialysis has a life expectancy of about 9 yr (Kl68) and the cost is about $10,000/year, whence the average cost to avert early death is about $90,000. A recent cost estimate (Rh78) is $30,000/year which gives a cost per death averted of $270,000. In Table 1 we list an interpolated value for 1975 of about $200,000. If we standardize to 20 years of life expectancy, this is increased to $440,000.

It may be noted that the costs here are much higher than those of other medical items. This seems reasonable in view of the fact that the person at risk is readily identifiable in advance, and it is much more difficult to condemn a particular person to certain death than to condemn large numbers of people to a slightly increased risk. The kidney dialysis item is therefore less applicable to effects of radiation than are the other items.

(8) *Mobile intensive care units.* About one-third of all deaths in the United States are from heart attacks, and 30% of these are in people less than 65 years old. Two-thirds of the deaths occur before the patient reaches a hospital, so many lives could be saved by providing more prompt care.

Zeckhauser and Shepard (Ze76) estimated that a mobile coronary care unit (MCCU) which involves an ambulance with a trained paramedic and coronary monitoring and defibrillation equipment could save a life in 8% of all heart attacks (reducing "dead on arrival" at hospitals from 22% to 14%) at a cost of $400/attack. This represents a cost of 400/0.08 = $5000/life saved. Additional treatment at the hospital costs $3500 and follow up care costs $400/year for the 8 yr of remaining life expectancy, which adds up to $12,000/life saved.

Acton (Ac73) estimated that for a community of 100,000 a special ambulance program would save 11 lives/year at a cost of $24,000 plus spill-over costs of about $68,000 for subsequent hospital care (including ruling out heart attack as the diagnosis in most cases) for a total of $92,000, or $8400/life saved. Alternatively, an MCCU could save 15 lives at a cost of $42,000 plus $78,000 in spill-over costs or $8000/life saved.

When the effectiveness of this type of service was recognized, programs were implemented in all large cities (Br79; Ri79). It was soon found that efficiency could be improved if the paramedic was trained and the ambulance was equipped for handling severe burns, trauma, and other injuries, and these units are now known as Mobile Intensive Care Units (MICU). In areas served by them, there is typically one unit for each 100,000 people, handling an average of about 10 calls per day. We assume that the costs are those from the above discussion, about $12,000 per life saved.

In order to determine an implicit valuation of life saving, one can observe how small a community does *not* have such a service. It is estimated (Ri79) that the great majority of communities with more than 75,000 population either have, or are considering obtaining, this service. On the other extreme it is estimated that such a service would be highly unusual in a community of less than 25,000. We assume then that it is not generally considered cost effective in communities of less than 40,000, and we further assume that the cost per life saved is inversely proportional to the population serviced below 100,000. This yields a cost at which the service is only partially implemented to be $12,000 × (100,000/40,000) = $30,000 per life saved. This estimate is conservative in that it ignores benefits from servicing conditions other than heart attacks.

(B) *Traffic safety measures*

Over 35,000 Americans die from accidents inside automobiles each year, so it seems reasonable to seek technological methods for protecting them. Congress passed the National Traffic and Motor Vehicle Safety Act of 1966, setting up a National Highway Traffic Safety Administration to attack the problem and since that time there has been a great deal of activity in this area. We review some of the

cost–benefit information that has developed from it.

Most of the items to be discussed have benefits in averting injuries as well as deaths. For every traffic fatality there are 40 injuries (Na75) resulting in disability extending beyond the day of the accident and many of them have lifelong serious effects. As a general average it would probably be reasonable to assign only half of the costs to averting fatalities. Since we do not do this, there is approximately a factor of 2 conservatism in all figures. Traffic fatalities differ from most medical problems in preferentially affecting the younger segment of the population, so about 40 yr of life expectancy are lost in an average traffic fatality. This is reflected in the right-hand column of Table 1.

Many of the measures taken require an appreciable effort by the people protected so the dollar cost is not the entire cost. For example, seat belts are tremendously cost effective, but are generally not used because of the effort involved. Rather than trying to assign dollar values to this effort, we will ignore measures of this type and confine our attention to passive measures.

(1) *Auto safety improvements, 1966–70.* According to an analysis by the General Accounting Office (Ge76), the effects up through 1974 of safety improvements introduced in 1966–70 model cars were: amortized costs, \$3 billion; lives saved, 28,200. This gives a cost/life saved = \$106,000. Correction for inflation increases this to \$130,000. The GAO Report found little benefit up to 1974 from items introduced in 1971–74 models. Their amortized cost was \$205 million; if this is included the above number is raised to \$140,000.

One item introduced during this period was the energy-absorbing steering column. It is estimated (Ge76) that it cost \$153 million and would avoid 1800 fatalities (plus an equal number of injuries). This corresponds to \$83,000 per life saved; corrected for inflation it becomes \$100,000.

(2) *Air bags.* Air bags are an especially clean example of society's evaluation of life saving since they save lives and cost nothing but money, but they are not being used because of their cost (there have been allegations that they do not function as expected, but these have been proven to be false (In76)).

According to Allstate Insurance Company, an air bag reduces a driver's mortality risk from 2.7×10^{-8} to 1.3×10^{-8} per mile (Ka76). The cost of an air bag as an option was \$315 in 1976, although this would be greatly reduced to perhaps \$100 if it were standard equipment (Ka76). We take the cost to be \$200 and assume that it gives protection at this cost for 50,000 miles. The cost/life saved is then $200/1.4 \times 10^{-8} \times 50{,}000$ = \$290,000.

Patrick (Pa75) estimates that equipping essentially all automobiles with airbags to protect the driver over a 10-yr period would cost \$18.5 billion and would save 46,400 lives. This corresponds to \$400,000 per life saved.

Stork (St73) estimates that using four air bags in a car would cost \$77/year, and that if all cars were equipped, fatalities would be cut in half. This corresponds to a cost of $\$77 \times 10^8$ to equip all U.S. automobiles and it would save 17,000 lives, a cost/life saved of \$450 000. Protecting four passengers is only about half as cost-effective as protecting the driver (the average car carries 1.5 people); with a correction for inflation, this gives \$250,000/life saved by protecting the driver only.

Averaging our three estimates gives \$320,000 per life saved.

(3) *Automobile tire inspection.* Most states have inspection requirements on automobile tires, and in many places it is illegal to drive on worn tires. The rationale for this is that worn tires have a better chance of a blow-out which can cause an accident.

About 4% of all fatal traffic accidents in the U.S. are caused by blow-outs, which amounts to 1800 fatalities per year. Roughly we assume that this number would be doubled without the inspection and legal requirements. There are 180 million passenger car tires sold each year in the U.S., and we crudely estimate that

30 million of these would not be purchased without the above requirements. If an average tire costs $25, this is $\$25 \times 30 \times 10^6/1800 =$ $400,000 per life saved. It is evident from the quality of these inputs that this estimate is particularly crude.

It is interesting here to consider the costs some people are willing to pay to protect their own lives and those of their loved ones by buying tires that will not blow out. These cost at least an additional $30, so if all automobiles were so equipped this would represent a cost of $\$30 \times 180 \times 10^6/1800 = \$3$ million per life saved.

(4) *Use of small cars vs standard size.* The risk of being killed while riding in a small car is about 25% higher per mile of travel than in a standard size car (Co76). The average American's risk of being killed in an automobile is 1.6×10^{-4}/year, whence use of the heavier car averts a risk of 4×10^{-5} per year. The added cost of a heavier car, including operating and maintenance costs, is perhaps $500/year. Since an average car carries two people, the cost per fatality averted is then $\$500/2 \times 4 \times 10^{-5} = \$6$ million. Of course this applies only if added safety is the sole reason for purchase of the larger car. This item is not included in Table 1 because society has made no move to ban the use of small cars.

(5) *Miscellaneous auto safety devices and comments.* Stork (St73) estimates that in West Germany, a fleet of 50 rescue helicopters could save 400 lives per year at a cost of $24.4 million which, with a small correction for inflation, is $65,000/life saved. He also estimates that a fleet of 150 rescue cars in urban areas could save 350 lives/year at a cost of $73.5 million which, with an inflation correction, is $230,000/life saved. The helicopters are the more cost-effective option so only it is included in Table 1.

Patrick (Pa75) estimates that a $135 passive three-point harness, a seat belt–shoulder harness that closes over the driver without his intervention, would avert 30% of all fatalities. Equipping all U.S. cars over a 10-yr period would cost $13.5 billion and save 55,000 lives, a cost of $250,000/life saved.

He similarly estimates that a passive torso belt–knee bar restraint combination would cost $5 billion and would save 46,000 lives, a cost of $110,000/life saved.

From the entries on auto safety in Table 1, it is apparent that many lives can be saved at costs in the $300,000 range or less. However, the auto safety program has all but ground to a halt (In76a); in 1970–73, 16 new standards were issued, but only one new standard was issued in 1974–75.

(6) *Driver education.* Kaywood (Ka76) has estimated that a high-school course in Driver Education for all students would reduce traffic fatalities by 10–15%. It would therefore presumably save about 5800 lives per year. Such courses involve time and effort expenditure by the students, so a dollar cost must include compensation for these. A brief opinion survey indicated that a payment of $50 would be ample inducement for the great majority of students. Instruction costs average about $75 per student (Na78), but there are probably hidden costs (e.g. automobiles are often donated) to bring the total cost to $150/student. For 3.5×10^6 students/year, the cost/life saved is $\$150 \times 3.5 \times 10^6/5800 = \$90,000$.

Driver education courses are now taken by 81% of all high-school students (Na78), so it is perhaps unfair to include this option as not fully implemented. However, 20% of all high schools, including many large ones, do not offer courses, and there have been many recent indications that programs are being cut back (Ka76a).

(7) *Highway construction improvements.* There are many practices in highway construction and operation that could be improved to save lives at a cost of money alone. For example, it is estimated (Ta76) that moving light posts 30 ft back from the edge of highways would save 500 lives per year. About 6000 people per year are killed in collisions with guardrails, and there are guardrail construction techniques that could save most of them. A

recent paper (Sp77) stated that there are many local highway improvements that could be implemented in Oklahoma that would save a life for every $43,000 spent.

The National Highway Safety Needs Report (US76) conducted a study by polling knowledgeable people to determine the cost per fatality forestalled of various measures. The most cost-effective measures which involve no personal effort or inconvenience are listed in Table 1 and explained below:

Highway construction and maintenance practices refer to following the Manual on Uniform Traffic Control Devices including inspection and maintenance: this would save 46 lives/year at a cost of $20,000/life. Regulatory and Warning Signs refers to upgrading and installation of signs in accordance with the aforementioned manual; this would save 367 lives/year at a cost of $34,000 each. Guardrail includes using improved designs in a program to replace substandard and damaged units; this would save 316 lives/year at a similar cost. Skid resistance refers to locating places where slippery conditions are contributing to highway accidents and implementing construction techniques to improve their skid resistance; this would save 374 lives/year at a cost of $42,200/life saved. Bridge rails and parapets includes design and installation of these so as to redirect vehicles which would otherwise have collisions with objects or other vehicles; this would save 152 lives/year at a cost of $46,000 per fatality averted. Wrong-way entry avoidance involves use of standard techniques to avoid wrong-way entrance on to freeways; this would save 78 lives/year at a cost of $49,400 each. Impact-absorbing devices means using these at critical roadside points where removal of fixed object hazards and yield-on-impact techniques are not feasible; this would save 678 lives/year at a cost of $108,000 per life saved. Breakaway sign and lighting supports involves using these rather than rigid supports along high-speed highways, with a program for systematic replacement; this would save 325 lives/year at a cost of $116,000 each. Median barriers includes use of improved design on these to reduce consequences of collisions, and includes programs for replacing substandard and damaged sections; this would save 53 lives/year at a cost of $228,000 each. Clear roadside recovery areas includes areas that enable vehicles which leave the travel lanes to return without injury; this includes construction of gradual side slopes and removal of hazardous drainage features, trees, and rocks for a minimum of 30 ft from the edge of freeways. This would save 53 lives/year and would cost $284,000 per fatality averted.

If these numbers are credible, there are many ways that lives can be saved for less than $50,000 spent on highway improvements, and this general category has one of the most favorable cost–benefit ratios. However, there has been strong criticism that the program is floundering (Ge76a).

(C) *Miscellaneous categories**

(1) *Food for overseas relief.* Starvation is a common experience in many underdeveloped nations of the world and its effects are especially important in children. About 60 million children are born each year in these countries, and 25–30% of them will die before reaching age 5 from malnutrition and related diseases, a total of 15–18 million deaths/year that could be averted by food relief. Moreover, those that survive the first 5 yr suffer throughout life from the effects of this early starvation.

Ward (Wa74) has estimated that most of these children could be saved by $20/year worth of food, but most estimates are higher. One estimate (Eg77) is that $120/year would do the job in Brazil. In the Rice Bowl of Asia,

**Note added in proof.* A much more cost-effective program than any listed here has recently come to light (Ba78). Expanding the present smallpox and BCG immunization program in Indonesia to cover a larger population and to include immunization for diphtheria, whooping cough, and tetanus would avert 313,000 deaths (in a 5 year program) at a cost of $33 million, or $106 per life saved. It would also avert 5.5 million non-fatal cases of these diseases.

\$10/year would supply the needed milk and \$50/year would provide the needed extra protein for adequate nutrition.

To derive an estimate, we conservatively assume that \$150 per year through the first 5 yr of life would avert half of the deaths. This corresponds to a \$750 expenditure per child to increase the probability of survival by 14%, or \$5300/life saved. This is probably an overestimate for saving the young children, but it may be compensated by the need for some additional food for older children.*

(2) *Air pollution control.* Typical estimates are that sulfur dioxide (SO_2) air pollution causes about 10,000 fatalities/year in the United States (Co76). About half of the SO_2 comes from coal-burning power plants, and it is hoped that 85% of this contribution can be eliminated by installation of scrubbers, at least on newly constructed plants. This would save 4300 lives per year.

Our current coal-generated electricity could be produced by about 150 of these plants. According to EPA estimates (Sc78) the cost of SO_2 scrubbers is 0.3c/kW-hr which works out to be \$15 million per year for each plant. This therefore represents an expenditure of \$2.3 × 10^9 to save 4300 lives, or \$500,000/life saved.

(3) *Smoke alarms in homes.* It is estimated (Ru78) that smoke alarms in homes would save 2000 lives/year. We estimate that such protection could be supplied by the production and distribution of 10 million units/year at a cost, including installation, maintenance over a 10-yr average lifetime, and inconvenience, of about \$50 each. This corresponds to a cost per life saved of $50 \times 10^7/2 \times 10^3$ = \$250,000.

There are currently 10 million smoke alarms in use in the United States (Gr79) which means that something less than 15% of all homes are protected.

(4) *Higher pay for risky jobs.* Thaler and Rosen (Th75a) carried out a correlation analysis of salaries vs risk in various jobs, and concluded that the higher pay for an 0.001 increase in mortality risk is \$260/year. This corresponds to an evaluation of a life at \$260,000.

Carlson (Ca63) calculated that the flight pay for a U.S. Air Force captain implies an evaluation of his life at between \$135,000 and \$980,000, depending on the type of plane flown. If we take the mean of these and apply an inflation factor, the result is about \$600,000.

(5) *Industrial safety.* A study of the effects of the Coal Mine Health and Safety Act of 1969 (De78) indicated that compliance requires the addition of 118,000 miners in U.S. coal mines. The average salary of a coal miner is \$14,000/year (Co77), and we assume an additional 50% for overhead and fringe benefits, which brings the total annual cost to \$14,000 × 1.5 × 118,000 = \$2.5 × 10^9. The new safety measures have reduced the annual average fatality toll in coal mines from 260 in 1965–70 to 145 in 1972–75 (Co77), a saving of 115 lives/year. The cost per life saved is then \$2.5 × 10^9/115 = \$22 million.

A similar study of the effects of the Federal Metal and Non-metal Mine Safety Act of 1966 indicated (De78) that compliance requires employment of 42,000 additional miners at \$12,000/year (Co77) which, if we assume 50% overhead, amounts to \$750 million/year. This has reduced accident fatality rates (Co77) by no more than 22 per year (93/year in 1965–70 vs 71/year in 1973–75, but 152 in 1972), which corresponds to \$34 million per life saved.

Rhoads (Rh78) reports that occupational safety standards for coke fumes corresponds to expenditure of \$4.5 million/life saved. He questions the wisdom of this practice, but says that it is strongly supported by the Union.

(6) *Aircraft.* Carlson (Ca63) estimated that the cost of the ejection system on a B-58 bomber implies a cost per life saved between \$1.7 million and \$9 million. If we take an

**Note added in proof.* Another potential overseas aid program is one of malaria control in Indonesia (Barnum H., "An Economic Analysis of a Malaria Control Program in the Outer Islands of Indonesia", unpublished). It would save 13,300 lives at a cost of \$64 million, or \$4800 per fatality averted.

average of these and apply a correction for inflation, we get a cost of \$8 million/life saved.

Carlson also estimates that the emergency procedures for pilots flying jet fighter planes imply a life saving cost (for recommending ejection) in excess of \$270,000. With an inflation correction this becomes \$450,000. In Table 1 we list the mean proportion between the costs for bomber and fighter pilots at \$2 million.

Morlat (Mo70) estimated that in France about \$900,000/life saved is spent on additional civilian aircraft safety measures. Corrected for inflation this becomes \$1.2 million.

(D) *Radiation-related activities*

The field of radiation protection involves a great many health protection regulations and standards, and in many situations these can be translated into a value placed on fatalities averted. In this section we make this translation for several cases. In general, radiation-induced cancers reduce life expectancy by about 20 yr, so the listings in the two columns of Table 1 are identical.

(1) *Radium in drinking water*. The Environmental Protection Agency requires that the radium content in drinking water be no larger than 5 pCi/liter and that remedial action be taken where necessary to meet this standard (EP76). They estimate that compliance with this standard will require expenditure of \$2.5 million per fatality averted.

(2) *Medical X-rays*. A 1970 study by the U.S. Public Health Service (Ro71) indicates that unnecessary exposures in medical X-rays can be substantially reduced at a cost averaging \$1000 per machine by attaching more sophisticated collimation devices. Terrill (Te72) estimated that this would reduce gonad exposures by 330 man-rem/year for each machine. If we assume that this advantage is maintained for 6 yr, this represents an exposure reduction of 2000 man-rem for \$1000, or 50¢/man-rem.

According to the BEIR Report (NA72), 1 man-rem of exposure to the whole body induces 1.8×10^{-4} fatal cancers. If we make the reasonable assumption that, on an average, gonadal and whole-body doses are equal, improving X-ray machines can save lives at a cost of $0.5/1.8 \times 10^{-4}$ = \$2800 each or, after a correction for inflation, for \$3600/life saved.

(3) *ICRP recommendations*. The International Commission on Radiological Protection (IC73) recommends values for cost/man-rem in the range \$10–\$250 to be used in cost–benefit analysis. The mean proportion of these is \$50/man-rem, which, with the BEIR risk estimator of 1.8×10^{-4}/man-rem, corresponds to a cost per life saved of \$280,000. With a correction for inflation this becomes \$320,000/fatality averted.

(4) *OMB guidelines*. The Office of Management and Budget, in OMB Circular A-94 (1972) recommends a value of \$1000/man-rem averted to be used as the justifiable costs in analysis of reactor safety systems. With the 1.8×10^{-4} deaths/man-rem estimator and a correction for inflation, this corresponds to \$7 million per fatality averted.

(5) *Nuclear industry radwaste practice*. In seeking guidance for application of the ALARA principle, the Nuclear Regulatory Commission imposed interim standards (10 CFR 50, Appendix I) of \$1000/man-rem to the whole body and to the thyroid as the incremental cost that must be spent for equipment to avert an incremental population dose. It was found that equipment already in place at all reactors easily conformed to these standards, and therefore this was made permanent in Regulatory Guides 1.109-1.113 (1976).

The fact that industry practice was already conforming to these standards implies that the money being spent for radwaste equipment exceeds \$1000/man-rem. For whole-body radiation this implies expenditures of more than \$1000/1.8×10^{-4} = \$5.5 million per fatality averted. If this is easily exceeded in all plants it is safe to conclude that the average expenditures are at least \$10 million/fatality averted.

The mortality risk from thyroid exposure is very much lower than from whole-body exposure. The UNSCEAR Report (UNSCEAR77)

estimates $5\text{–}15 \times 10^{-6}$/rem. If we take 10×10^{-6}/rem, the expenditures for ^{131}I emission control must be in excess of $\$1000/10 \times 10^{-6}$ = $100 million per fatality averted.

(6) *Defense high-level waste.* The U.S. Department of Energy is proposing a $2.7 billion program to convert high-level radioactive waste from the Savannah River Plant to a glass and store it in a deep geologic repository (Oe78). One alternative plan is to leave the waste in its present liquid form and set up a trust fund to maintain it, at a cost of $500 million. It is estimated (En77) that this would cause an additional 500 man-rem of radiation exposure. The more elaborate program therefore represents an additional expenditure of $\$2.2 \times 10^9/500 = \$4.4 \times 10^6$/man-rem averted. Dividing this by 1.8×10^{-4} fatalities/man-rem gives $25 billion/fatality averted.

To some extent the decision not to maintain the present system is based on the fact that it relies on future generations maintaining responsibility, although the costs for this are provided. An alternative plan which does not depend on such reliance would be to simply pump the unprocessed waste as a slurry into local bedrock. This involves an integrated exposure of 61,000 man-rem above the option chosen, and would cost $500 million. Thus the option chosen represents a straight trade-off of $\$2.2 \times 10^9$ for 61,000 man-rem, or $36,000/man-rem which corresponds to $200 million/life saved. This is the number entered in Table 1. Similar projects are planned for the Hanford and Idaho Falls Waste.

(7) *Civilian high-level radioactive waste.* It is estimated (Co79) that dumping high-level radioactive waste in the ocean will eventually cause 0.17 eventual fatality/GWe-yr without doing harm to ocean life, but this is considered too dangerous. The present plans are to spend about $3 million/GWe-yr for geologic disposal as a safer option. This represents a cost of $\$3 \times 10^6/0.17 = \$18$ million per fatality averted.

It should be noted here that the fatalities being averted are several thousand years in the future, which introduces the question of the relative value of averting a fatality now and in the distant future. This will be discussed in the next section.

TIME-DELAY CONSIDERATIONS

It is conventional in cost–benefit analyses to discount money that will be spent or needed in the future at rates varying between 5% and 10% per year. For example if 5% discounting is used in the estimates of the economic value of a life from the standpoint of earnings (discussed in the Introduction), $10,000 earned 20 yr from now is counted as having a present value of $5000. This discounting is in addition to inflation.

Considerations of this type have a tremendous importance when considering the cost effectiveness of managing radioactive waste which may cause fatalities far in the future. One dollar now at even 1% annual real interest (i.e. discounting inflation) becomes $20,000 after 1000 yr, $400 million after 2000 yr, $8 trillion after 3000 yr, etc. At 5 or 10% interest the time before these values are reached is reduced by a factor of 5 or 10. Based on this reasoning it is completely cost ineffective to spend any money now to save lives a thousand or perhaps even a few hundred years in the future. It would be far better for those living then if we would instead set up a modest trust fund which will give them copious supplies of money to save lives by methods whose value they will be in a better position to judge than we are now. For example, a simple cure may be found for cancer, or it may be determined that low-level radiation is harmless, in either of which case our money would be wasted.

This line of reasoning would not be applicable if our actions now could cause large-scale killing in the distant future, but this is clearly not the case. It would be extremely difficult to construct a credible scenario in which a release of deeply buried radioactive waste could cause a detectable number of excess cancers at any future date.

Perhaps the concept of a trust fund extending over many hundreds of years is unrealistic since it assumes that capital will continue to attract real interest, or that capital can be invested to generate more wealth than its original value. But there are more subtle ways in which we can invest money for the benefit of our progeny even more effectively. For example, money invested in research now benefits all future generations, paying a high rate of compound interest if we can judge by past performance. The high standard of living we enjoy today is largely the product of small amounts of money and effort invested in research over the past two centuries.

Another way of arriving at a similar conclusion is to recognize that our attempts to spend money now to save lives in the distant future represents what some consider our moral obligation to leave each segment of the environment to our progeny in at least as good a condition as we found it. This is an intuitively appealing goal, but it is wholly unrealistic. Anything we can do in this regard is completely overshadowed by the horrible legacy we leave our progeny when we consume all of the earth's rich mineral resources. What we *can* do is make enough positive contributions to turn the world over to our progeny in better *overall* condition that we found it. It seems obvious that with this goal in mind, it would be better to spend money on research than to spend millions of dollars to save the life of some person living in the distant future.

But since this paper deals with society's valuations, we must point out that society does *not* value future lives equivalently with lives of those now living. For example, with such a philosophy we would spend nearly all our money on medical research rather than on medical care. According to Table 1 we can save a life now for every $50,000 or so that we spend on medical care, and let us say that with medical research we can save one life/year for every $5 million dollars spent; if our concerns extend to 1000 yr, we save 10 times as many lives with the research. It is obvious that this argument does not depend on the particulars of the costs we assume—with any assumed costs we will eventually save more lives with medical research than with medical care expenditures. But our society does not behave that way—we spend far more money on medical care, and even our research expenditures are targeted at short-term pay-offs. Congress was willing to spend vast sums on cancer research when it believed that it would develop a cure for cancer in our lifetime. If it were informed that the cure would not come for 500 yr, the money would all but dry up instantly, although the number of lives that would be saved over the next several thousand years would be essentially the same.

If we accept the idea that the value of lives saved far in the future should be discounted at 1%/year, the final entry of Table 1 represents a rough estimate of the cost/life saved by not dumping nuclear waste in the oceans.

POLLING

Another approach to determining public attitudes toward the value of saving a life is by polling samples of the public on questions whose answers depend only on that evaluation. Acton (Ac73) used this approach to determine how much people were willing to spend for service by a mobile coronary care unit, and depending on how the question was phrased the equivalent value of life saving was $28,000 or $43,000. This is in reasonable agreement with the value in Table 1.

We presented the same set of questions to classes of about 100 students in a course on Energy and Environment at the University of Pittsburgh in two successive years, and essentially the same average results were obtained. We present a few examples, all of which the class was told are realistic:

(1) If control equipment could be added in a nearby nuclear power plant to reduce your mortality risk from 1 in a million to 1 in 2 million, how much extra would you be willing to pay for electricity in order to add them? The average answer was $25 which gives a

value of life saving at $25/5 × 10⁻⁷ = $50 million.

(2) If control equipment could be added in a nearby coal-fired power plant to reduce your mortality risk from 1 in 1000 to 1 in 2000, how much extra would you be willing to pay for electricity in order to add them? The average answer was $60, which gives a value of life saving at $60/5 × 10⁻⁴ = $120,000.

(3) How much money would you be willing to have the government spend on a health program that would save 1000 lives? The average answer was $2.5 billion, which corresponds to $2.5 million per life saved.

(4) If having an air bag in your car does no harm other than adding to the cost, and if it reduces your mortality risk from 1 in 1500 to 1 in 3000, how much would you be willing to pay for the air bag? The average answer was $170 which corresponds to $110/(1/3000) = $500,000 value for life saving.

(5) (For cigarette smokers only). If a new-type cigarette came out that was in every way the same as your present brand except that it was guaranteed to avoid bad health effects, how much extra would you be willing to pay for it? The average answer was 50c/pack. A 1-pack/day smoker buys 20,000 packs in a lifetime, so at 50c/pack he pays $10,000. A man loses 6.5 yr of life expectancy and a woman loses 2.6 years from this habit (Co79a), and since boys were a majority the average is 5 yr. If we assume that an average early death involves 20 yr loss of life expectancy, a 1-pack/day smoker has one chance in four of being such a victim. This gives a valuation of life saving at $10,000 (1/4) = $40,000.

(6) If you were going on a 500-mile trip and had your choice between a bus and an automobile, and if all aspects of the two choices were equal except for the added safety of the bus, how much extra would you be willing to pay to go by bus. Many answers were zero, but the average was $13. The risk is about 1×10^{-8}/mile (for thruway travel) × 500 = 5×10^{-6}, so the valuation implicit is $13/5 × 10⁻⁶ = $2.6 million.

It is clear from the discrepancies in valuation implied by the various answers that these values are not calculated even subconsciously, at least by an average university student. This seems especially clear from No. (1) and No. (2) where the wording was almost identical and the numerical probabilities were given explicitly. The best interpretation we could devise is that a few tens of dollars sounds like a reasonable amount to spend for a risk reduction or a little less on a single day trip, $170 is a reasonable extra cost when buying a car, 50c extra seems reasonable for a pack of cigarettes, and a few billion dollars is about right for a government program; in each case, the expenditure is enough to be meaningful, but not enough to make a big difference.

DISCUSSION

The wide variations in the values in Table 1 would seem to be worthy of extensive discussion. Some of them can be justified. The low value on food for overseas relief represents a common human attitude that charity begins at home, and the high expenditures for protecting miners and coke workers may be justifiable as the price they demand of us for their services (although they should perhaps be offered the alternative of having some of the costs now spent in protecting them added to their wages instead).

But aside from these few cases, it seems difficult to justify the differences morally. Indeed, one could argue that it is highly immoral for $100 million in funds obtained from the general citizenry to be spent in saving one life from ^{131}I emissions when that same money could save 2000 lives if it were spent on medical or traffic safety programs which are being held back for lack of money.

Sociologists and economists usually try to explain rather than to justify discrepancies like those in Table 1 (Fi76; Li78a; Sl78). Human fears are not necessarily correlated with actual dangers, and government agencies are more concerned with allaying fears then with averting dangers. This could be interpreted as a

cynical disregard for human welfare, but on the other hand it could be viewed as participatory democracy functioning properly by being responsive to the desires of the citizenry. In any case, it explains the large values in Table 1 for radiation-related activities—with the exception of medical X-rays which the public does not view as radiation, and the ICRP recommendations which are not made (or used) by government agencies. The only solution to this dilemma would seem to be education, and it is clear from Table 1 that the radiation protection community has done a particularly poor job of educating the public.

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the PRAs for the plants being compared must be carefully examined to ascertain the sources of the uncertainties and their impact on the validity of the comparisons being attempted.

Q.25 Is a comparison of the Indian Point results with the Commission's Safety Goals germane to answering Commission Question Five?

A.25 Not in my view. The principal reason for this view is that what the Commission ultimately seeks to assess through this proceeding is the acceptability of the risks posed by operation of Indian Point Units 2 and 3. Comparisons of risk estimates with the safety goals does not accomplish this goal for two principal reasons.

First, the safety goals are incomplete estimators of risk. As noted by the Risk Assessment Review Group report [NUREG/CR-0400, page ix], there are many accident consequences associated with risk. The safety goals focus on early fatality, latent cancer, and core melt risks. Other consequences which can be important risk considerations are land contamination, financial impacts, and non-fatal injuries and disease. Second, the safety goals are intended as assessment tools, not as "speed limits" [Bernero, page 7]. A given plant may exceed a safety goal and still not represent an unacceptable risk; by the same token, a given plant might meet all of the safety goals, and still represent an unaccaptable risk. Moreover, the safety goals are subject to change after the two-year evaluation period which the Commission has adopted [Safety Goal Policy Statement, pages 2, 4, and 8].

It should also be noted that during the two-year evaluation period, the Commission has stated that the safety goals and quantitative design objectives should not be used in the licensing process, and are not to be litigated in NRC hearings. The Commission has explicitly limited the use of the safety goals during the evaluation period to: (a) examination of proposed and existing regulatory requirements; (b) establishment of research priorities; (c) resolution of generic safety issues; and (d) definition of the relative importance of issues as they arise [Safety Goal Policy Statement, page 7].

Q.26 Are there any conclusions regarding the risk of Indian Point relative to the "range of risks" that can be drawn on the basis of information now available?

Q.26 Yes. On a site basis, and considering the actual power level of the Indian Point reactors, it is clear that the Indian Point site is an outlier with respect to other plants. The only sites which approach the conditional mean consequences (based on an SST-1 release) for Indian Point are Zion and Limerick. These two sites are also outliers.

Considering design/operation risk characteristics, valid comparisons are not feasible at present. There are a limited number of PRA studies available, the typicality of the reactors upon which the studies have been performed has yet to be established. Furthermore, the existing PRA studies vary significantly with regards to completeness, assumptions, methodology, data base, and degree of conservatism employed in the analyses. It would be premature to attempt to rank reactors according to absolute risk because of these factors.

Q.27 What implications do these conclusions have regarding the desirability of accident mitigation systems?

A.27 Serious consideration of such mitigation systems for Indian Point should be undertaken. It will be a period of several years (at best) before it will be reasonable to attempt relative risk rankings based on abcslute risk projections. Waiting for such results, if they are indeed available in a few years, poses an uncertain risk to the population surrounding Indian Point. It is clear that the risk associated with site risk characteristics is high compared to other sites. The risk associated with design/operation risk characteristics is highly uncertain, but provides no firm basis for delaying in-depth consideration of accident mitigative measures.

Q.28 Does consideration of mitigative measures using a value of $1,000 per person-rem averted provide a reasonably complete view of the value of mitigation systems?

A.28 No. Use of the $1,000 per person-rem averted standard reflects a hidden judgment that reactors in general are already adequately safe. It would

require a very high core melt probability combined with a large conditional probability of a large release to make even the most modest add-on mitigation system "cost-effective" under the $1,000 per person-rem averted standard.

Moreover, the standard does not reflect the degree to which fatalities, injuries, and offsite property damage is caused by the person-rem exposure. This is especially true with respect to consequences whose magnitude is determined on a threshold basis, since the number of persons suffering the early consequences is strongly determined by population magnitude and distribution near the plant site. Using the CRAC2 results from the Sandia siting study, D.R. Strip of Sandia National Laboratories has examined this issue by ranking the number of sites versus the number of early fatalities, early injuries, latent cancer fatalities, and offsite property damage per thousand person-rem of exposure for an SST-1 release. The results for early fatalities per thousand person-rem span more than a factor of 1,000. The results for early injuries span a factor of about 70. The results for offsite property damage span about a factor of 10. The results for latent cancer fatalities span a range of less than a factor of 2 [NUREG/CR-2899, page 6]. Thus, the results of applying the 1,000 per person-rem averted will not be consistent from site-to-site.

In addition, with regard to latent cancers, the present use of the $1,000 per person-rem standard involves two problems. First, the reevaluation of the atomic bomb casualty data is ongoing; Radford asserts that this reevaluation will support the linear hypothesis for cancer risk coefficients, rather than the present model which is based on a liner-quadratic formulation [Radford, page 14]. Second, the present consequences model calculates only fatal cancers; there would also be a large number of non-fatal cancers whose costs would not be assessed under the $1,000 per person-rem standard. In addition, the costs associated with treatment of early injuries would not be assessed as the standard is presently designed.

The value of a mitigation system for Indian Point should also be

considered in conjunction with cost estimates for an early shutdown of the reactors. The costs of an early shutdown of Indian Point Units 2 and 3 will be addressed in testimony by Vince Taylor, to be filed under Commission Question Six in this proceeding.

Q.29 Does this conclude your testimony?

A.29 Yes.

UNITED STATED OF AMERICA
NUCLEAR REGULATORY COMMISSION

ATOMIC SAFETY AND LICENSING BOARD

Before Administrative Judges:
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Dr. Oscar H. Paris
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CONSOLIDATED EDISON COMPANY OF NEW YORK, INC. (Indian Point, Unit No. 2)	Docket Nos. 50-247-SP 50-286-SP
POWER AUTHORITY OF THE STATE OF NEW YORK, (Indian Point, Unit No. 3)	
	April 1, 1983

CERTIFICATE OF SERVICE

I certify that I have served copies of Licensees' Motion for Submission Under Commission Question 5 of "Licensees' Testimony of Bernard L. Cohen on Commission Question 1" by deposit in the United States mail, first class postage prepaid this first day of April, 1983

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