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NUCLEAR WASTE ISSUES-A PERSPECTIVES DOCUMENT

Jerry J. Cohen
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February 1983

Lawrence
Livermore
Laboratory

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NUCLEAR WASTE ISSUES - A PERSPECTIVES DOCUMENT

**Prepared for
University of California
Lawrence Livermore National Laboratory
Subcontract 3622901**

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FEBRUARY 1983

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L INTRODUCTION

Background

The early years following the discovery of radioactivity were filled with optimism and promise. The medical uses of x-radiation and other radiation techniques in and out of the medical profession showed that there were numerous beneficial applications of this new field of technology.

With the wartime use of atomic weapons came the realization that radioactivity was a mixed blessing. Nevertheless, the post-war outlook for peaceful uses of atomic energy appeared bright. The prospect of a cheap and abundant long term source of energy was viewed with positive anticipation rather than apprehension.

It is perhaps ironic that in more recent years, as the cost of fossil fuels have skyrocketed, and the sources have become tenuous, there has been increasing opposition, in both the public and private sectors, to nuclear power.

That there is a necessity for a cheap, abundant, safe, and nonpolluting energy source is *something* that few will deny. The question is whether nuclear power can fill that bill. More specifically, the radioactive waste management problem has become somewhat of a focal point for discussion in opposition to nuclear power in general.

Purpose

Since the area of radioactive waste management has generated great interest and comment from diverse sources, a collection and review of these basic perceptions is in order to clarify the nature of the controversy. One observation that can be made from a review of the appropriate perspectives literature is that there are widely divergent

interpretations of the same basic technical information. This is somewhat unusual in a scientific area, and offers a focal point for further study into determination of the nature of the radioactive waste management problem.

There are some limitations to a study of this type, and they should be addressed at this point. Although it is sometimes difficult to separate the emotional from the technical arguments in the area of radioactivity, this report attempts to focus discussion on the technical aspects. The basic philosophy here is that technical solutions should be sought for technical problems, and that political, social, and/or emotional issues should be addressed using other appropriate methods.

Organization and Approach

This report contains the results of a systematic survey of perspectives on the question of radioactive waste management. Sources of information for this review include the scientific literature, regulatory and government documents, pro-nuclear and anti-nuclear publications, and news media articles.

In examining the sources of information, it has become evident that a major distinction can be made between the "optimistic" or "positive" viewpoints, and the "pessimistic" or "negative" ones. Consequently, these form the principal categories for presentation of the perspectives information.

Within these categories, perspectives on the radioactive waste management problem have been further classified as relating to the following issue areas: the physical aspects of radiation, longevity, radiotoxicity, the quantity of radioactive waste, perceptual factors,

radioactive waste management history, and the risk controversy. These issue areas form the basis for the report organization, a separate section being devoted to each.

The presentation of opposing viewpoints should be as objective as possible. This has been an implicit goal for the work represented by this report, and is specifically reflected in the broad categorization of perspectives into the optimistic and pessimistic classes. In some areas an additional category, that of neutral viewpoints, has been included.

The report is limited to the presentation of perspectives on the waste management problem and does not attempt resolution of any divergence in these viewpoints. Hopefully, this report will contribute to the eventual resolution of viewpoints through identification and collection in one document of a spectrum of views on the waste management problem. To highlight the divergent viewpoints, each section of the report contains an overview discussion where key questions that arise from the presented perspectives are identified.

In selecting the material presented, several diverse sources have been reviewed. It must be emphasized that the selection of any particular source does not imply either agreement, or disagreement with the material quoted. Selection was based upon interest and lucid presentation of the particular view presented. The general intent is to produce a document that will serve as a useful reference and provide food for thought.

II. THE LONGEVITY OF RADIOACTIVE WASTES

A. Introduction

To many scientists, laymen, and technical people the longevity issue constitutes the central problem of radioactive wastes. The concern is primarily related to the fact that certain radioactive components of nuclear waste have extremely long half-lives (Plutonium-239, for example, has a half-life of about 24,000 years). The predominant view is that the waste must therefore be isolated for extensive time periods and that such a requirement for assured isolation is unprecedented in the history of mankind. This section deals primarily with views that have been expressed about the longevity problem, sometimes characterized as the "thousand-year" or "million-year" problem, or even as the "Faustian bargain." The latter phrase implying that we are trading off a long range detriment to humanity in order to gain some near-term benefit.

B. Pessimistic Views

The United States' nuclear industry has produced 75 million gallons of high-level wastes which according to the Union of Concerned Scientists "will remain deadly for at least a quarter of a million years" [D. Ford].

A pessimistic view of the problem is well-defined in an article entitled "Perilous Legacy" [M.D. Magazine, April, 1979]. It states:

"Future generations may be saddled with a perilous legacy, the rapidly accumulating radioactive waste from nuclear weapons and power plants. At present 75 million gallons of high level radioactive waste from the production of atomic bombs, the operation of submarines and other military uses of nuclear energy, as well as 5200 tons of spent fuel from 72 civilian nuclear reactors are awaiting permanent disposal in the United States. Some elements in this vast stockpile will remain radioactive for more than 250,000 years, but the White House Office of Science and Technology has stated that available knowledge and technology is not yet sufficient to permit complete confidence in the safety of any particular repository design or the suitability of any particular site.

According to a task force composed of representatives of 14 federal agencies, it may take 17 more years of research to solve the problem of the safe disposal of nuclear waste. It is estimated that the military will have produced more than 450,000 tons of high-level waste in solid form and commercial sources almost that volume by the end of the century and that it will cost at least \$23 billion to isolate all this hazardous material."

The dangers of nuclear energy and its wastes are emphasized by Nader and Abbotts

[1979], who relate the problem to longevity of the wastes:

"Nuclear energy, in addition to generating power, also generates radioactive byproducts dangerous for thousands of years. Then there are the hazards of plutonium, which is weapons-grade material - and as such a target for saboteurs or terrorists - in addition to being extremely toxic and extremely long-lived." (p. 59)

The Interagency Review Group [1979] concluded that longevity of radioactive wastes is the basic issue in waste management:

"The central scientific fact about radioactive material is that there is no method of altering the period of time in which a particular species remains radioactive, and thereby potentially toxic and hazardous without changing that species. Only with time will the material decay to a stable (non-radioactive) element. The pertinent decay times vary from hundreds of years for the bulk of the fission products to millions of years for certain of the actinide elements and long-lived fission products. Thus if present and future generations are to be protected from potential biological damage, a way must be provided either to isolate waste from the biosphere for long periods of time, to remove it entirely from the earth, or to transform it into non-radioactive elements."

Concern for the long time period of radioactive hazards is expressed by Lipschutz [1979] of the Union of Concerned Scientists:

"Unlike many chemical toxins which can be neutralized, the hazard of radioactivity only disappears through natural decay, which may take hundreds, thousands, even millions of years."

Lipschutz [1979] extends the problem into a "billion year" one:

"A mass of a radionuclide with a long half-life will continue to produce radioactivity, in some cases, for billions of years."

One of the major concerns about the longevity of nuclear wastes is the danger posed to future generations. The Abalone Alliance [1979] contends that:

"The problem, actually, cannot be 'solved,' because there can be no way of knowing that the wastes have been permanently isolated from the biosphere. We can afford no mistakes, uncertainties, or sabotage with materials that must be kept isolated for hundreds of thousands of years. Do we have the right to endanger our children, and their children, by creating even more of these wastes?"

The longevity issue is addressed by Tamplin and Gofman [1970] who discuss wastes as a burden placed upon future generations and as a genetic threat to our offspring.

"One of the major legacies of the nuclear age is radioactive waste. Discussions concerning the disposal of radioactive waste are misleading because these wastes are not disposable. They must be kept isolated from the environment and, therefore 'guardianship of nuclear waste' is a more meaningful concept. We are producing waste products that must be maintained in isolation from the environment for a thousand years or more. Guarding this radioactive garbage is one of the prices that future generations will have to pay, in addition to the genetic consequences they will suffer from the radioactivity which we are presently introducing into the environment, either deliberately or under the guise of waste disposal." (p. 170)

The safety of future generations, and the assumption that future societies will be stable, is doubted by Lash [1977]:

"The toxicity of radioactive materials is much higher than other likely environmental pollutants. The long-lived nature of this radiotoxicity demands that we consider not only the environmental quality of our generation, but also that of generations a thousand or even a hundred thousand years hence. It appears untenable to assume that society will remain sufficiently stable to monitor and maintain our waste disposal sites for the requisite hundreds of thousand of years."

Nader and Abbotts [1979] also emphasize that stable human institutions will be required for safeguarding nuclear wastes:

"Storage of nuclear waste is much more than a problem of technology. Safe storage requires stable geological formations, a guarantee which is beyond the promise of technology. Safe storage also requires the development of

stable human institutions to exist for thousands of years to prevent the waste from leaking and contaminating the biosphere. It should be remembered that Neanderthal man appeared 'only' about 75,000 years ago." (p. 151)

The cumulative effects of radioactivity over many generations are brought into play in the longevity issue. Cochran et al. [1979] state this "intergenerational" problem as follows:

"Because many of the radionuclides have very long half-lives, they will be capable of irradiating populations for hundreds and thousands of years into the future. Thus, while the effects on one-generation might be small, the cumulative effects over many generations would be substantial. Thus, the fundamental criteria for radioactive waste disposal must include consideration of this intergenerational irradiation and effects."

Some scientists connect the longevity problem to the possibility of leakage of radioactive waste into the biosphere. Ringwood et al. [1979] state:

"Because of the intensely radioactive nature of the waste it is essential to prevent this material from reaching the biosphere for a period which may be as long as one million years."

A long period of isolation from the biosphere is also emphasized by the American Physical Society in its report on nuclear fuel cycles and waste management. A review of this report [Physics Today, 1977] points out:

"The issues in nuclear waste management arise either from the spent fuel itself or from waste created by fuel reprocessing and refabrication. Such waste contains fission products and long-lived transuranic elements created by the nuclear reaction; both must be isolated until the radioactive isotopes have decayed to insignificant levels. For fission products this requires less than a thousand years; however, for some of the transuranic elements hundreds of thousands of years may be required for adequate isolation from the biosphere. The long time scales have raised institutional as well as technical questions about the viability of nuclear waste management."

Leakage of long-term radioactive material into the biosphere is a concern of the Environmental Protection Agency (EPA), which states in a report by an Ad Hoc Panel of Earth Scientists [EPA, 1978]:

"Wastes of both kinds [those generated by the reprocessing of spent fuel rods, and the unprocessed spent fuel rods themselves] must be stored in such a manner that leakage from the deeply buried repository to the biosphere will be inconsequential to public health over the times during which the stored materials remain sufficiently radioactive to be hazardous. Thus we consider a maximum time scale of hundreds of thousands (10^5) to a few million (10^6) years, but pay special attention to the dangers of leakage over shorter terms up to a thousand years, when the levels of radioactivity are highest."

In an EPA public forum, laymen were given the opportunity to express their views on the longevity issue. One of those commenting on biosphere pollution over geologic time scale periods was Ycung [1978] who said:

"One of the most fearful uncertainty factors is the likelihood of future geological upheaval or other basic changes on the face of the earth (Ice Age, etc.); changes which increase in likelihood of occurrence as we get into the thousands and tens of thousands of years, and any one of which could cause a major release of stored radioactive waste materials into the biosphere."

Potential hazards for future generations are mentioned by Carlone [1978] of the U. S. General Accounting Office:

"Some wastes will remain potentially hazardous for hundreds of thousands of years. Decisions on what we do with our radioactive wastes in our lifetime will affect the lives of countless generations to come."

Rapoport [1970] cites the effect on future generations of the long half-life of plutonium:

"Plutonium's half-life of 24,000 years is a good deal longer than the full-life of asphalt [used to temporarily solve a spillage problem], and many years from now when the roadbed wears away, the hot plutonium will be exposed, to contaminate unborn generations."

The Sierra Club raises the basic moral issue of nuclear wastes which has often been categorized as the "Faustian Bargain." In "Nuclear Power and the Sierra Club" [Sierra Club, 1977] they raise the question:

"In exchange for relatively short-term gains, to what extent may one generation jeopardize the safety and well-being of future generations and the environment?"

The rule of decay periods of 10 or 20 half-lives also comes into play when considering long-lived transuranics such as plutonium. The Sierra Club [1977] reasons as follows:

"The half-life of plutonium is 24,000 years. Given the rule of thumb that a toxic radioactive substance must be contained for 20 half-lives, the most minute fraction of the 10 million pounds of plutonium which will be produced must not be allowed to escape for 500,000 years, when radiation will have been reduced to 'background levels.' But in human terms, 500,000 years is essentially forever. There is little evidence that human-maintained surface storage of plutonium for a half-million years is possible."

The Clergy and Laity Concerned [CALC] address the longevity issue by stating in a recent pamphlet:

"There is no known way to dispose of radioactive wastes safely. Because they last so long (Pu-239 alone remains dangerous for 250,000 years - longer than the existence of all civilization), the dangers don't diminish, they persist and grow."

A. Weinberg [1972] describes the problem in the following terms:

"We nuclear people have made a Faustian Bargain with society. On the one hand we offer - in the catalytic nuclear burner [breeder] - an inexhaustible source of energy ... But the price we demand of society for this magical energy source is both a vigilance and a longevity of our social institutions that we are quite unaccustomed to."

According to Gofman [1978]:

"What is really at issue is a moral question - the right of one generation of humans to take upon itself the arrogance of possibly compromising the earth an habitable place for this and essentially all future generations."

C. Optimistic Views

The view that nuclear waste management presents a problem of unprecedented duration is not universally held. Thus the "million-year problem" can also be viewed from an optimistic perspective.

Whipple [1977] directly addresses the legacy of radioactive wastes:

"Let us recognize that the criteria of infinite storage of radioactive wastes under conditions that guarantee zero release cannot be attained. Let us also recognize that there is no justification for either criterion. A reasonable expenditure of care and effort will assure that releases and any effects that they may cause will be entirely insignificant. Under these conditions, the legacy of radioactive wastes we leave to our descendants is a trivial problem, either in absolute terms, or in comparison to other burdens we are likely to leave them."

Williams [1978] suggests that the legacy problem is overstated since most wastes decay within 30 years. Williams states:

... "over 99.9 percent of the initial ingestion hazard potential of the wastes decays with an effective half-life of 30 years or less. This means that most of the hazard potential of wastes on hand in the future will have been produced by the generations living then, not past generations, if waste production continues at current rates or increases. In this case, it is not very meaningful to speak of the legacy of the present generation's wastes."

According to Angino [1977] reprocessing would reduce the long-term activity of wastes:

"Present waste extraction processes provide for 99.5% removal of plutonium and uranium. If we were to require 99.9% removal for Pu, U, and Np, and 99% for Am and Cm, the long-term activity would be reduced by a factor of 100. The waste problem would then become of concern for only 700 to 1000 years - a time period much more tractable from man's frame of reference."

Another approach to viewing the longevity problem has been proposed by Lieberman and Forbes [1977] in an EPA workshop:

"However, pragmatically one might just as well consider the very long-lived radioactive materials, the transuranics, as stable (like arsenic or mercury)."

The following two quotations compare radioactive wastes (which decay) to toxic chemical wastes which have infinite half-lives.

"The much used rhetoric about wastes remaining 'radioactive for thousands of years,' while perfectly true (the half-life of plutonium 239 is 24,400 years), is quite misleading and largely meaningless - because you must bear in mind the fact that the longer the half-life of an isotope, the less intense its radiation. Arsenic, which is not radioactive at all, has an infinite half-life, and indeed, while plutonium will be around for a long time, arsenic will be around forever." [Beckman, 1977]

"In some ways the whole hullabaloo over waste disposal seems to have been distorted way out of proportion. The actual task does not look forbidding when it is viewed in perspective. To be sure, it takes centuries for the most dangerous radioactive wastes from reactors to decay to safe levels, but at least they do decay. The industrial world routinely uses hundreds of other dangerous substances whose toxicity, far larger in aggregate, stays at full strength forever - for example, mercury, arsenic, and some poisonous compounds. [Faltermayer, 1979]

Healy [1977] also comments on the disposal of chemical vs. radioactive wastes in response to the longevity problem:

"Once again we are faced with the problem of defining 'safe,' however this time in the context of the long time periods for which many of the radioactive species will survive. I would note in passing that this problem is not unique to radioactive materials but must also be considered for the stable chemical wastes, particularly the toxic metals which cannot be degraded to less toxic or non-toxic forms."

Cohen et al. [1980] point out that special concern related to the persistence of long-lived radionuclides may be unwarranted. They make the following observations:

"It should be recognized that there is an inverse relationship between the specific activity of a radionuclide and its half-life. In other words the longer its half-life, the less radioactive it is. Carried to its extreme, the concern over the longevity of a radioactive material would demand an infinite degree of concern over the toxic stable elements. However, considering that the proton itself decays with a half-life of 10^{30} years even these so-called stable elements are to some extent radioactive. The fact that this radioactivity is unobservable is attributable to their extremely long half-life."

D. Overview

Undoubtedly, concern over the persistence of the long-lived components accounts for much of the apprehension which has been expressed regarding nuclear waste. That such concern is not manifested toward stable (non decaying) material appears to be somewhat inconsistent. Nonetheless, the idea that nuclear waste presents a hazard of unprecedented duration seems well embedded, and policies for its management appear to incorporate the concept that isolation must be assured into the far distant future.

Some key questions regarding the longevity issue that arise from the opposing viewpoints are the following:

- Are the long lifetimes of certain constituents of radioactive waste unique or unprecedented, or can they be legitimately compared with the essentially infinite lifetimes of stable toxic materials?
- What is an appropriate measure of decay to innocuous levels?
- Can we afford mistakes in the management of radioactive wastes? Is "zero release" over long time periods necessary to adequately protect the public health of future generations, or is there some acceptable level of contamination?

THE LONGEVITY OF RADIOACTIVE WASTES

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III. THE TOXICITY OF NUCLEAR WASTES

A. Introduction

In addition to the problem of longevity, the overall toxicity of nuclear wastes has become a major issue in waste management. The purpose of this section is to cite references dealing with this issue and to categorize the viewpoints. General issues are discussed first, followed by the sub-issues. These sub-issues are: the genetic effects of radiation, the cumulative nature of the effects, the latent nature of the effects, and the special issue of plutonium toxicity. Some optimistic viewpoints on toxicity are also given to balance the perspectives.

B. Pessimistic Views

Dr. H. Alfen, Nobel Prize physics winner in 1970, was quoted in The Washington Spectator [Coffin, T., ed., 1979], as saying:

"In a full-scale fission program, the radioactive waste will soon become so enormous that a total poisoning of the planet is possible."

Gofman and Tamplin [1971] assert the poisonous nature of radwastes:

"Radioactivity represents one of the worst, maybe the worst of all poisons. And it is manufactured in astronomical quantities as an inevitable by-product of nuclear electricity generation. One year of operation of a single, large nuclear power plant, generates as much of long-persisting radioactive poisons as one thousand Hiroshima-type bombs. There is no way that electric power can be generated in nuclear plants without generating the radioactive poisons. Once any of these radioactive poisons are released to the environment, and this we believe is likely to occur, the pollution of our environment is irreversible." (p. 22).

In New York State's West Valley, according to the Sierra Club[1979]:

"The amount of radioactivity is truly prodigious (assuming a 5 year decay period, 11 to 18 billion curies of Cs and Sr), corresponding to the cancer potential of trillions of bone, muscle and thyroid cancers and genetic effects to future generations. These wastes will stay toxic and pose a threat to New York State for millions of years."

The General Accounting Office [1977] speaks to the toxicity of radioactive wastes. In this report the Comptroller General states:

"Radioactive wastes being highly toxic can damage or destroy living cells, causing cancer and possibly death depending on the quantity and length of time individuals are exposed to them."

Furthermore, the General Accounting Office relates the measure of radioactivity (curies) to degree of hazard of wastes as follows:

"This (radioactive) waste contains many fission products and small amounts of transuranics, such as plutonium, which are not recovered during reprocessing operations. Its radioactivity is measured in thousands of curies per gallon (as much as 10,000 curies per gallon). This waste is considered one of the most hazardous and complex of all radioactive wastes to manage." (p. 2)

A perspective on toxicity vs. volume of the wastes is attempted by Ehrlich et al. [1977]:

"It is not uncommon to hear from the public relations arm of the nuclear industry that the radioactive wastes from nuclear power are equivalent in size to only an aspirin tablet per year for every person whose electricity is provided by nuclear plants. Probably the most misleading aspect of this analogy is that toxicity, not volume, is the important characteristic of those wastes. If a tablet were to be an apt comparison, it would have to be a cyanide tablet -- and even that would not do justice to the actual toxicity of the fission products."

Radioactive additions to natural background are often claimed to be a threat to the health of the nation. According to the Abalone Alliance [1979]:

"Geneticists believe that a constant stream of background radiation from natural sources such as cosmic rays causes some of the present-day cancers and genetic disorders. But human-made radiation is increasing, especially from medical x-rays and nuclear sources, such as the five metric tons of plutonium now dispersed over the entire earth from above ground weapons testing. And cancer continues to increase faster than other causes of death in the U. S."

When asked what sources of man-made radiation were most dangerous, Dr. W.

D. Rowe [1976] of the Environmental Protection Agency replied:

"All sources of radiation are essentially equally dangerous in terms of the relation seen between exposure and dose. Alpha particles from heavy radioactive elements are much more damaging to human tissue than gamma rays. We feel that some of the long-lived alpha-particle

materials, such as plutonium and radium, can indeed be very dangerous because of their long half-lives and ability to enter the body and remain there for long times."

There is currently a controversy on what constitutes a safe level of radiation. Dr. H. Caldicott [1978] insists that no level is safe:

"Government agencies similarly permit a certain amount of radiation to be 'routinely' emitted from a reactor stack... To claim that the radioactivity in these discharges is diluted to safe levels is fallacious; it in fact adds to the existing levels of background radiation, increasing the risk of disease." (p. 61)

A similar opinion was stated by Gofman and Tamplin [1971]:

"The only possible way to set a truly safe standard, - a definite number of rads or millirads assigned to a particular tissue or organ - would be to know beyond any reasonable doubt that within that amount no biological effect will occur. We can state unequivocally, and without fear of contradiction, that no one has ever produced evidence that any specific amount of radiation will be without harm. Indeed, quite the opposite appears to be the case." (p. 92)

The following pessimistic quotations deal with genetic effects from radiation. A frequently expressed concern about radiotoxicity or radiation in general is its effect on the gene pool. The National Council on Radiation Protection [1971] emphasizes this concern:

"In man, it has been estimated that about one person in ten either fails to reproduce or dies before maturity because of genetic defects, but further studies may modify this figure. Concern over radiation exposure arises from the fact that radiation is a mutagenic agent. Each new mutant added may result in harm to some descendant, and any additional number of defective individuals, of course, constitutes a greater burden to society." (p. 33)

Because the effects of radiation are the same whether natural or man-made, Gofman and Tamplin [1971] condemn any additions to present natural sources. In their words:

... "Natural radiation and the genetic and chromosomal mutations caused thereby are doing a great deal of harm. The genetic disorders and deaths caused by natural radiations are no different at all from those caused by man-made radiation ... all these radiations act similarly and the injuries are no different from one source of radiation than from another. All we can say is that, at this moment, we know of no way to turn off the various natural sources of radiation. We, therefore, suffer

an enormous toll of disease, debility and death as a result of natural radiation. As a minimum element of common sense, we should refrain, except under the most dire circumstances, from adding to this enormous burden of suffering by adding the injury of man-made radiation. The benefits to society should be required to be enormous and obviously so before permitting any amount of increase in radiation mutations due to man-made sources." (p. 79)

Another effect of radiation from wastes stems from its cumulative nature in the environment and in man. This is recognized by Edwards [1972], biologist from the University of British Columbia:

"Since many of the radionuclides released from nuclear plants have long half-lives, their presence in the environment will be essentially cumulative. It is therefore most important to ask what the long-term effects of small doses of radiation may be."

A third sub-issue of the toxicity of nuclear wastes concerns the delayed effects. The following pessimistic arguments pertain to the characteristic of latency periods.

Gofman and Tamplin are most concerned about delayed genetic defects, since radioactive poisons can act after a latency period. From the same reference cited above:

"For most of the serious environmental poisons, cancer at 5 to 25 years after the poisoning is precisely the kind of effect we must worry about. Genetic effects, occurring in subsequent generations, can be many times more serious than cancer! The folly of looking for 'immediate' effects, and thereby exonerating a poison, must be strongly condemned if disaster is to be prevented." (p. 114)

Similarly, Edwards [1972] criticizes physicists who neglect this latency period:

"Time-lag factors are something which physicists are just not used to taking into account, and - quite frankly - they have very little experience to draw on in their particular field of study. It may take twenty years or more before the biological effects of exposure to radiation become known. Studies of the survivors of Hiroshima and Nagasaki showed that all kinds of cancer had a very much higher incidence among those who had been exposed to radiation, but that these cancers did not develop until 5, 10, 15, or 20 years after the event. There is a 'latency period' during which no increase in the incidence of

cancer is observed - and then comes a whopping big increase. For leukemia, the latency period is about 5 years, whereas for other types of cancer it can be much longer - for thyroid cancer (as hinted above) the latency period is about 13-15 years. Studies of uranium miners as well as silver and cobalt miners (all of whom were exposed to radon gas in the mines) confirm these latency periods."

Plutonium toxicity is perhaps one of the largest sub-issues in the radioactive waste controversy. Many differences of opinion exist on the real dangers of this substance; this section demonstrates the "negative" side of plutonium.

According to Metzger, author of The Atomic Establishment [1972], a comparison can be made:

"Plutonium is perhaps the most toxic element known, and represents a chronic biological hazard on a weight basis comparable to the acute hazard from botulinus toxin, i.e. it is hazardous to 10^{-6} g, if appropriately deposited in lungs or bone."

Physicist A. M. Weinberg [1972] compares the hazard of plutonium to that of natural uranium:

"Plutonium-239 in equilibrium with its daughters has a direct radiological hazard about 10,000 times that of natural uranium in equilibrium with its daughters."

The dangers of plutonium are further expounded by J. D. Watson, [1979] Harvard biology professor:

"I am increasingly worried that the current blossoming of the nuclear power industry will be an irreversible calamity for the human race. Particularly scary is the thought that we shall senselessly march into wide-scale employment of breeder produced plutonium, the most dangerous atom man has yet tried to assimilate into his industrial life. Only the tiniest of traces of plutonium are needed to induce cancer and if its use becomes widespread, the possibility must be faced, of awful incidents, either accidental or deliberate, that will cause wide regions of our earth to become forever uninhabitable."

Plutonium cancer potential is further explained by Gofman and Tamplin [1971]:

"The cancer producing potential of plutonium is well known. An amount as small as one ten-millionth of an ounce injected under the skin of mice has caused cancer. A similar amount injected into the blood streams of dogs has produced bone cancers. However, it is the lung that is the most vulnerable to plutonium.

The vulnerability of the lung to plutonium exists because plutonium exposed to air ignites spontaneously. As it burns, it forms numerous tiny particles of plutonium dioxide. These particles are intensely radioactive. If inhaled, they are deposited in the deepest portions of the lung. There they remain, immobilized for hundreds of days, and during this time their radiation is able to affect the cancer-sensitive cells of the lung. The tissue around the particle is exposed to a very intense dose of radiation." (p. 197)

The uncertainty involved with plutonium toxicity as viewed by Hohenemser et al. [1977] leads to a controversy as they note:

"Plutonium toxicity is based on its alpha activity and, like fission product toxicity, at low doses manifests itself through cancers with a latent period of 15 to 45 years. However, while fission product effects are fairly well defined, numerical estimates of plutonium toxicity vary and are controversial."

C. Optimistic Views

To balance the perspectives on toxicity, the following section gives some optimistic viewpoints.

Bruns [1977] relates hazard to availability as follows:

"From the beginning of time very toxic substances have existed (e.g., in plants, snakes) with varying degrees of impact on man. The hazard from such substances lies not so much in the degree of their toxicity as in their availability to man."

Similarly, Lapp [1977] uses arsenic as an example of a toxic substance that is less hazardous due to its lack of availability:

"No matter how toxic a substance is or how much there is of it, it cannot be of high risk unless the public has access to it. For example, every year the United States imports enough arsenic to constitute one billion lethal doses. But this chemical is controlled strictly in industry and is treated as a poisonous substance when made available in the marketplace. In the same way, 200 tons of plutonium have been produced, processed and transported in the United States. But, with the noted exception of nuclear weapons testing, it has been isolated from man's environment. Thus, for the American public the plutonium hazard in the postwar period is essentially non-existent."

The radiotoxicity of high-level waste has been compared to that of naturally occurring radioactive minerals. This comparison is noted by the World Health Organization (WHO) [1978]:

"An illustration of the radiotoxicity of vitrified highly active waste can be gained from comparing it with the toxicity of naturally radioactive materials. Such a comparison is shown in Figure 1 indicating the relative radiotoxicity of fission products and transuranic elements in the glass and naturally occurring pitchblende. All toxicities are evaluated on the basis of data from ICRF and are derived from ICRP recommendations on maximum permissible nuclide concentrations in drinking water. It is important to note that after some 1000-3000 years the toxicity of the waste material will become (gram for gram) less than that of typical radioactive minerals. Several of the highly radiotoxic isotopes of the transuranic elements contained in the waste have half-lives of thousands of years, and after a few hundred years they become the dominant hazard." (p. 27-31)

The basic difference between toxicity and hazard is pointed out by Comar (1976):

"The public has been told, 'Plutonium is the most toxic substance known to man.' Toxicity is a medical term defined as the inherent capability of a substance to produce injury once it reaches a particular tissue within the body. In this sense, plutonium is certainly highly toxic. However, of greater importance of human beings is not toxicity but, rather, a more inclusive property called hazard. The hazard of a substance takes into account not only its toxicity but its availability - the extent to which the substance can actually reach individuals and have its toxicity take effect. For plutonium, the factors that determine its hazard are the amount that is handled, the effectiveness in preventing its release from the time of production through waste storage, the degree to which environmental and biological processes tend to determine the exposure of human beings to that which may be released, and finally, its toxicity."

In the following citation by Bishop [1978] another comparison is made between the toxicity of non-radioactive wastes, and radioactive wastes. He points out the lack of perspective as follows:

"Substances other than radioactive wastes are just as toxic and just as available in our society. This is true, and it is a statement made by the industry to argue for less strict or at least consistent regulation. But experience with other industries (e.g., the chemical industry) indicates that releases do occur, and harm results (e.g., the Kepone spill, arsenic, mercury, nerve gas, etc.). The hope, of course, is to keep the nuclear industry from committing similar errors.

Nonetheless, the argument is correctly made that the hazards from nuclear power production should be kept in some sort of perspective with respect to comparable hazards. One survey indicated that only nuclear technicians believe that the risks of nuclear power plants are less than those of coal fired plants. In the long run, coal plants may involve risks as high as or even higher than those of nuclear plants. But perspective

Assumptions: pressurized water reactor fuel uranium fuel cycle, 1% plutonium in waste, 15% waste in solidified (glass) material, typical pitchblende toxicity normalized to unit weight.

Fig. 1.
Relative ingestion radiotoxicity of components of highly active waste and naturally occurring radioactive pitchblende.
(From World Health Organization, 1978.)

seemingly does not exist. It is not clear that such a perspective gives any rationale for easing requirements on the nuclear industry. It may, in fact, argue for stricter requirements on other industries." (p. 54)

This lack of perspective is also pointed out by Reissland and Harries [1979]:

"In particular, the possibility of radiation inducing cancer creates a highly emotive issue. The existence of sources of ionizing radiation other than those connected with nuclear power and the existence of many cancer-causing chemicals in the environment which can produce the same malignancies as radiation (often in much larger numbers) are often overlooked in the debate."

Because plutonium has been widely recognized and studied, it is believed to be less of a hazard according to some organizations. For example, the Electrical Power Engineers Association [1978] states:

"When considering the particular problems of plutonium, it is recognized that they are considerable and consequently, its physical and biological effects have been studied more intensively than for any other radioactive substance ... The professional experience accumulated in relevant fields concerning plutonium is now so extensive, that the EPEA concludes there is no justification for alarm in this area."

Similarly, the U.S. Labor Party (op. cit.) recognizes our knowledge of plutonium and its relative safety:

"... it (plutonium) is potentially hazardous as are many other materials; it is currently treated with overwhelming precautions in its handling and use. Because of its well recognized potential danger—it is a long lived, low energy, alpha-particle emitter which if ingested into the human body, has the potential of causing cancer—more is known today about plutonium and its effects than is known about most other substances that we face routinely."

Plutonium is compared to radium by Wilson [1979]:

"Plutonium is often called the most highly toxic material known to society. But radium, which is present in coal, bricks and stone, is 100 times more toxic and a little can be found in the bones of every one of us."

Beckman [1977] compares plutonium toxicity to coal-fired plants and heavy metals:

"... the poisons produced by nuclear plants will be with us for centuries; but the poisons produced by fossil-burning plants will be with us forever ... Of course, plutonium is toxic. But its danger has been exaggerated beyond all reasonable bounds. There are radioactive substances reproduced not by the Pentagon, but by Mother Nature which are far more toxic than plutonium. All the heavy metals are toxic and several of them are more toxic than plutonium."

Beckman continues:

"It is far from being the most toxic substance known to man. When eaten or absorbed into the bloodstream, it is ten times less toxic than lead arsenate and hundreds of times less toxic than some biological poisons such as diphtheria, or botulism toxin. Caffeine, some of which you probably had this morning in your coffee, is only ten times less toxic than plutonium. (Relative toxicity is measured by comparing the weights of 50% lethal doses given to the same type of animal. The '50% lethal dose' is the amount that will kill half of the experimental animals)."

Table 1, compiled by B. Cohen [1976], presents the number of annual lethal doses of some commonly used materials compared to the number of lethal doses of nuclear waste. These figures indicate that the hazards of 10 yr. and 500 yr. nuclear waste are not extraordinarily high in comparison to some common non-radioactive chemicals.

D. Overview

Several contrasting views of both optimistic and pessimistic nature related to radioactive waste toxicity have been presented. The contrast between these opposing views is great and leads to several key questions regarding the toxicity issue:

- What is the more important characteristic: toxicity or volume? Where does specific toxicity (i.e., toxicity per unit volume) fit in? What are the advantages or disadvantages of a toxic waste that has at the same time a small volume and a high level of toxicity?
- Can safe levels of exposure be defined? Is it valid to suggest that the release of any amount of radioactivity, no matter how small, is unacceptable?

TABLE 1
ANNUAL U.S.A. PRODUCTION OF SOME TOXIC MATERIALS

<u>Material</u>	<u>Number of Lethal Doses</u>
● <u>Via Inhalation</u>	
Chlorine	4×10^{14}
Phosgene	2×10^{13}
Ammonia	6×10^{12}
Hydrogen Cyanide	6×10^{12}
Nuclear Waste	2×10^{11}
{ 10 yr. old	
{ 500 yr. old	5×10^{10}
● <u>Via Ingestion</u>	
Barium	9×10^{10}
Copper	8×10^{10}
Arsenic	1×10^{10}
Lead	4×10^9
Nuclear Waste	3×10^{10}
{ 10 yr. old	
{ 500 yr. old	1×10^7

From Cohen [1976]

- Are the effects of radioactivity so unique as to require absolute isolation, or can these effects be related to natural radioactive or nonradioactive environmental contaminants?
- What is the extent and nature of effects due to natural background radiation? How would these background effects relate to effects that might result from radioactive waste operations?
- Is plutonium the most toxic material known to man, or is it of comparable toxicity to many other familiar materials?
- Is it valid to consider toxicity alone without including the influences of environmental availability and time decay?

THE TOXICITY OF RADIOACTIVE WASTES

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IV. THE QUANTITY OF NUCLEAR WASTES

A. Introduction

Even though good quantitative estimates of the amount of nuclear wastes are known, two questions remain. First, do the known volumes constitute a relatively large or a relatively small amount compared to other types of waste. Second, how will this amount change as the nuclear industry proceeds. No simple answers exist, but the following remarks are intended to give some perspective on the quantity of waste and its impact on waste management.

The Environmental Protection Agency offers estimates on the volume of high-level defense wastes, uranium mill tailings, and phosphate wastes for comparison [EPA, 1977]:

"The total volume of the high-level defense wastes is approximately 74.2×10^6 gallons, which is roughly equivalent to the capacity of an oil supertanker."

"The total current volume of tailings, at both active and inactive mill sites, is assumed to be equal to the total volume of ore mined to date (1977), or approximately 2.1×10^{10} gallons. This is approximately the volume of the Empire State Building."

"The total volume of all wastes from the phosphate industry is nearly as large as the initial volume of the phosphate ore mined and is estimated to be approximately 4.4×10^{11} gallons. This volume would cover Washington, D.C. to a depth of 35 ft."

Figure 1 shows these same quantities in a more striking way. All volumes are expressed in gallons, even though all wastes are not in the liquid form.

Fig. 1

Volumes of radioactive wastes

*All numerical values contained in this summary represent the best approximation that could be derived from the referenced materials. The uncertainty associated with some of the values, however, may be as large as $\pm 25\%$.
(Taken from U.S. EPA, 1977)

B. Pessimistic Views

Lipschutz [1979] states that the quantities that have accumulated are large and will increase:

"The nuclear power and weapons programs of the United States have generated immense quantities of radioactive waste, and these in the prospect, in a continuing program, of much more ... They have already piled up in considerable quantities: 10 million cubic feet of highly radioactive liquids, 4000 tons of uranium fuel discharged from power reactors, 140 million tons of uranium mill tailings, 65 million cubic feet of contaminated garbage."

The following forecast for spent fuel was given by Calkicott [1978]:

"... the end of 1976, 3000 metric tons of spent fuel lay in nuclear pools across the United States. By 1983, an estimated 13,000 tons will be dangerously straining the capacity of present storage pool facilities." (p. 58)

The large amount of wastes is seen by some to pose a dangerous hazard.

Hansen [1979] commented at a DOE public hearing:

"Even if we could turn off every nuclear power plant and every military reactor this very instant, we still have a hideous problem glowering balefully at us -- the storage of more than 75 million gallons of high level liquid waste and 15 million cubic feet of low level solid waste, now residing mostly at the Hanford Military Reservation in Washington and the Savannah River Facility in South Carolina, plus about 5000 metric tons of spent fuel rods piling up in cooling pools next to each nuclear reactor..."

Because of the large quantity of wastes, some people suggest that there can never be a safe solution for its disposal. According to Newby [1979]:

"There is no safe place in the U.S. for the expected 1 billion cu. ft. of lethal radioactive waste by the year 2000 (if present plans for reactors are implemented) -- enough to cover a 4-lane highway coast to coast 1 foot deep."

C. Optimistic Views

Nuclear advocates often do not consider the volume of wastes to be a problem. Beckman [1977] gives the aspirin tablet analogy:

"It is, in fact, one of the reasons that makes nuclear power far more preferable to, say, coal-fired power. If all of the U.S. power capacity were nuclear, the total amount of wastes per person per year would amount to one aspirin tablet, and that can easily be disposed of deep in the earth, where it came from in the first place. On the other hand, the amount of wastes generated per person per year by coal fired plants amounts to 320 lb. of ash and other poisons, of which as much as 10% is spewed into the atmosphere.

Eisenbud [1978] reports that the volume of radioactive wastes will be relatively small. He gives the following perspective:

"The advantage of conversion [of high level wastes] to solid form is that the volume is reduced enormously and the wastes can be managed more readily ... The total volume of the solidified wastes will be very small. It is estimated that by the year 2000, the volume of total national inventory will be about 600,000 cubic feet which, if stored in one place, would constitute an 85-foot cube."

Nuclear wastes are often compared to coal wastes, and in terms of volume, Voss [1979] gives the following:

"... the total volume of nuclear waste, both low-level and spent fuel, generated in producing a persons total electrical needs is slightly more than one gallon per year ... Assuming one's total electrical needs were supplied by coal, then the solid waste generated is more than 250 gallons per year ... the volume of garbage produced per person is over 1300 gallons per year.

D. Overview

In considering the views on the quantity of nuclear waste, we note discrepancies in estimates of waste to be generated. For example, Eisenbud [1978] estimates a high level waste inventory of 600,000 cubic feet by the year 2000, while Newby [1978] claims that there will be one billion cubic feet. Perhaps more important than the exact numerical values is the underlying meaning in terms of manageability of the radioactive waste. Some questions that result from considering the opposing views on waste quantities are the following:

- How can waste volumes be related to the question of manageability of the waste? In what way is volume related to hazard?
- Are per capita or total volume figures more useful in evaluating the scope of the waste management problem?

THE QUANTITY OF NUCLEAR WASTES

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V. PERCEPTUAL FACTORS IN THE NUCLEAR WASTE ISSUE

A. Introduction

In this section, we shall consider those aspects of radioactive waste management concerns that are of a perceptual nature. These are problems that are perceived by the public to be of paramount importance and urgency. W. P. Bishop [1978] divides the nature of radioactive waste problems into the following five categories:

- 1) Perceptions of the waste management problem.
- 2) Hazards of radioactive wastes.
- 3) Methodology for assessment of radioactive waste management.
- 4) Decision processes in waste management.
- 5) Problems of implementation of a waste management system."

Bishop defines perception of the problem as follows:

- "Among the issues regarding nuclear power, waste management may be pivotal, and is certainly one of the most important and urgent.
- Radioactive wastes do not rank as highly (as a problem) as overpopulation, economic conditions, and other similar concerns.
- No one wants radioactive wastes in his backyard.
- The government must be responsible for radioactive waste management.
- No system has, in fact, been implemented for disposing of high level wastes.
- The public does not distinguish between wastes from past and ongoing military activities and those coming from nuclear production.
- "There are 3 time horizons of particular importance in dealing with radioactive wastes.
 - 5-10 yrs: urgent need for some solution to problem.
 - A few centuries in which there is little trust of social institutions stability.
 - Few thousands of years - distrust of predictions for geologic disposal.
- "There are two possible scales for the generation of wastes.
 - Fission power as an essentially perpetual source, with perpetual generation of waste.
 - Fission power eventually displaced by other sources, resulting in a limited quantity of radioactive wastes."

B. Neutral Views

The following citations are neutral in position but serve to further describe perceptions of the waste issue. We later present arguments that can be characterized as pessimistic followed by comments that take the optimistic view.

Brooks [1976] speaks out on public concern in radwaste management:

"... If the average person, otherwise vaguely favorable to nuclear energy, is asked what he thinks about the future of this source, he is most likely to mention waste disposal as the big unsolved problem. The other issues ... reactor accidents, diversion or theft of fissionable materials, routine radioactive emissions, thermal pollution ... have tended to come and go ... I would predict that, should nuclear energy ultimately prove to be socially unacceptable, it will be primarily because of the public's perception of the waste disposal problem."

And in agreement with Bishop, Marshal [1979] states:

"Most people do not distinguish between low-level wastes of the kind generated at hospitals and research laboratories which pose negligible health hazards, and high-level wastes of the kind that must be removed from the crippled reactor in Pennsylvania. The public has become more worried about all forms of radiation this year (1979), and radioactive garbage of whatever sort has become a political liability for any official who allows it to be shipped into his jurisdiction."

Shoup [1977] discusses the polarity that has developed between the technical community and the general public:

"An issue that is probably the most important in waste management is public acceptance. No matter how technologically sound a solution may be, a system that is socially unacceptable will not be given an opportunity to be deployed ... Waste disposal is the area where the largest gap exists between the perceptions of the technical community and those of the general public."

Perkins [1978] calls for a moderating voice to clear up issues put forth by opposite extremes, and to give a perspective which is lacking. In his words:

"That is exactly what is missing from the current debate over radioactive waste: the credible source and the perspective. Like most of the nuclear controversy, this issue is presented in the terms of the two extremes - absolutely dangerous or absolute safe - because all parties have become so completely polarized. Even independent scientists and professors find it nearly impossible to avoid being labeled 100% for nuclear power, or 100% against it. A moderating voice must be found to sort out the overstatements on both sides, and especially in the area of waste management, that voice must be the federal government."

Another perceptual argument is that of the "Faustian bargain," mentioned in the longevity section of this report and here by Shoup [1977]:

"An argument regarding nuclear waste disposal that has had a great deal of appeal to laymen is the 'Faustian bargain,' which refers to the problems bequeathed to future generations as a result of our contemporary 'fing' with nuclear power ... This fear ... has often been expressed."

In January of 1977, the EPA conducted a poll to rank problems that posed a threat to future generations. The number one problem (cited by 49% of the public) was "more and more nations developing the capability to conduct atomic warfare." In fourth place was "the radiation problems that will be caused by the increasing amounts of atomic wastes that must be disposed of from atomic plants". It was cited by 41% of the public. Other responses included 17% of the public who cited "the increasingly widening gap between developed and undeveloped nations"; and 16% who cited "increasing numbers of devastating earthquakes". [Roper, 1977]

C. Pessimistic Views

The seriousness of nuclear waste disposal as a national issue was stated by Senator Gary Hart [1978]:

"Nuclear waste disposal is one of the most serious environmental and public health issues facing our country today. Some say it is the Achilles heel of nuclear energy. This matter is so serious that, if an acceptable solution is not found, we may be forced to look seriously at halting further development of nuclear power as an energy resource.

... we have failed to come to terms with this problem ... failed to find permanent, safe, and acceptable solutions ... failed to confront the frightening long-range implications of having created a substance that will last thousands of years longer than all recorded human history."

The development of nuclear power proceeded rapidly without regard to the future problems posed by nuclear wastes, according to Tom Wicker [Washington Spectator, 1979]:

"In its three decades of existence, the American Nuclear power program - pushed with too much zeal and too little concern for the consequences - may have created a Frankenstein's monster that threatens to slip out of control."

Another pessimistic argument of a perceptual nature often taken by some people is that nuclear power is unnecessary. The Abalone Alliance [1979] states:

"Nuclear power is unnecessary. Our energy needs for the future can be met through conservation and other energy sources, such as solar. These alternatives are much less harmful to our society and the environment."

With the following statement, nuclear power appears to be unnecessary, or at least inefficient [Lipschitz, 1979]:

"It takes about 25 billion fissions to produce the energy equivalent to the combustion of one gallon of oil." (p. 11)

Lack of trust in science and technology is an issue related to nuclear waste management. Dr. H. Caldicott raises these doubts in her book Nuclear Madness [1978] in which she says:

"Nor can technology alone ever provide the answers we seek. For even if unbreakable, corrosion-resistant containers could be designed, any storage site on earth would have to be kept under constant surveillance by incorruptible guards, administered by moral politicians living in a stable, warless society, and left undisturbed by earthquakes, natural disasters or other acts of God for no less than half a million years - a tall order which science cannot fill." (p. 64)

Waste management becomes a moral issue according to Nader and Abbots [1979].

"If no technical solution to the waste problem is developed, the federal government will be forced to store and guard the waste for as long as it is hazardous. This means that stable human institutions, as well as stable geological formations, must be found for managing the waste. For many people, this makes the waste problem a moral one: the electricity consumed today leaves radioactive garbage for thousands of generations to come." (p. 62)

The fear that nuclear wastes will someday result in a catastrophic "reaction" has often been expressed. According to Caldicott [1978]:

"In an attempt to minimize the corrosive properties of West Valley's high-level waste, scientists have used sodium hydroxide to neutralize the acid solution in which spent fuel rods were dissolved. Unfortunately, this procedure ... doubles the waste volume ... precipitates a radioactive sludge consisting of Sr^{90} , Cs^{137} , other fission products and Pu to the bottom of the tanks ... some experts fear that it may go "critical," initiating a reaction similar to a meltdown and releasing tons of deadly radioactive materials into the biosphere. If the 600,000 gallons of high-level waste stored at West Valley were to be dispersed in this way, the resulting radiation could devastate Buffalo and surrounding towns." (p. 58)

Pessimistic arguments concerning nuclear wastes are most often given in a qualitative sense, and in an attempt to simplify the ideas for the public, witty slogans or poems are often used. One example is by Knight [1977]:

"Waste is easy to deal with. All you need is a stable geologic formation. But to find the stable formation you have to drill, and after you drill it's not stable (and may contaminate the water table) since its integrity has been pierced. Of course, there is a solution. All you do is fill the hole you made with the drill. But, if you don't have the hole, how do you know it is stable? Give it up while you are able."

And the same author offers the following on background radioactivity:

"Background radioactivity is considered all right and totals much more than has been deposited by man. But man started depositing before he started measuring. So how much is background, huh?"

Some laymen are less negative, yet, in a qualitative way, they demand absolute safety assurances from nuclear waste contamination. Scherf [1978] in an EPA public forum is quoted as follows:

"In addition to urging you to take as expedient action in developing your solution as possible, as a layman, I would offer a solution of storage within underground areas that would be safe from groundwater flows. I'm sure the containers you would choose would be safe, but I personally would like this extra protection, knowing that if there was any leakage, it would not be distributed by the way of any fluid flows such as water, air, etc."

Placing the blame on high technology and demanding absolute safety for mankind has also been expressed in regard to plutonium [Wafer, 1977]:

"One of the great dangers of plutonium lies with its quality of oxidizing quickly, thereby being a serious fire threat ... So little as one-millionth of a gram inhaled or embedded in the skin can be deadly. Plutonium with a radioactive half-life of over 24,000 years, is an example of the product of an unforgiving technology which allows humankind little, if any, room for error."

Another perceptual factor is the mystique of radiation, which often translates as "fear of the unknown." This is described by Lipschutz [1979]:

"The radioactive emissions from this waste are invisible, odorless, tasteless. They cannot be felt or heard. Yet minute amounts of radioactivity are capable of inducing cancer in the living, birth defects in the unborn, and mutagenic effects in the descendants of those exposed."

Transportation accidents are another factor that contributes to perceptual fears. According to an article in The Progressive [Schwab, 1979]:

"From 1974 through 1978, according to federal records, 328 accidents occurred on American highways involving shipments of radioactive substances. Of these, 118 resulted in spillages. These shipments are increasing yearly, and spillages now occur on an average of once every ten days."

A major issue of the waste problem has to do with the safety aspects of transportation or disposal. It is often assumed that since safeguards are established, then the health dangers of nuclear waste must exist. F.H. Burmeister [1978] states this in another way:

"There are always health dangers in areas of nuclear energy; if that were not so, why are so many attempts made to safeguard the transportation and disposal of nuclear wastes?...Would anyone be willing to handle nuclear material if he suddenly became aware that it had been placed in the wrong facility?"

D. Optimistic Views

We offer some counter-arguments to those given above. These take the opposite stand, a more optimistic view, with more faith in science and technology to solve the waste problem.

Soviet scientist A. Sakharov [1978] explains the reason for anti-nuclear feelings:

"The basic reason for anti-nuclear feelings among people is probably the fact that they do not have sufficient information about the complex and very specialized problems involved. Due to this lack of information, the natural and legitimate concern of contemporary man for preservation of his environment is misdirected ... The basic peculiarity that distinguishes nuclear technology from that using chemical fuels is the high concentration and small volume of the dangerous by-products and the small size of the process as a whole."

And according to an article in Changing Times [1979]:

"Opponents of nuclear power are a loose alliance of people who believe that such alternative sources as wind and solar energy can supply our needs; scientists and others worried about radiation hazards and theft of nuclear materials by terrorists; and people who have a deep fear of nuclear power or somehow imagining that a power plant can explode like an A-bomb."

Kubo and Rose [1973] indicate that the problems of waste disposal are largely perceptual:

"Do the perceived difficulties of the waste disposal problem arise from severe scientific or technological limitations, or from lack of understanding and institutional restrictions? Both contribute, but we think that the latter are dominant: we find several attractive technological options that have been given little consideration, and institutional arrangements that have contributed to premature narrowness of thought."

Not only are these problems largely perceptual but they are compounded by public fears. According to Bodansky and Schmidt [1979]:

"... the antinuclear movement gains its popular strength primarily from the fact that people can be readily frightened by horror tales about nuclear risks. The unreasonableness of these fears does not lessen their potency. It will be unfortunate for our society and for the integrity of the democratic decision-making process if these fears prevail, and if nuclear power is rejected by an apprehensive public."

But according to Hammond [1979], the developers of nuclear power misread the problem:

"Part of the public's reaction came from past failure of nuclear proponents to make clear the distinction between the short-lived and long-lived parts of the waste. Antinuclear zealots were quick to claim, since no one refuted them, that the wastes were lethal for millions of years, when, in fact, after a few hundred years one would have to eat them by the pound to ingest enough for any radiation effect. But eating almost any rocks by the pound is neither healthy nor likely."

A rebuttal to the radiation mystique concept is put forth by McCracken [1979]:

"Because radiation is invisible, intangible, tasteless, odorless, and silent, and because it is measured in unfamiliar units that are themselves not always easy to understand, many people see it as mysterious, something to avoid at all costs, like evil ... But as a matter of fact, radiation is not really mysterious: we know a good deal more about it than, say, the carcinogens in coal smoke, because we have studied it longer and more intensively. And we can measure it with great precision and extraordinary sensitivity. We can, for example, detect radioiodine in milk at a concentration of 10 trillionths of a curie per liter, which is 1/20 of the concentration the FDA treats as worth taking precautions about."

Perkins [1978] addresses the unique risks involved with radioactive wastes in a speech delivered to the Atomic Industrial Forum, Inc.:

"A discussion of the risks of waste management can be complete only with a consideration of alternatives -- the risks of other sources of power, or of the alternative of no nuclear power. Any context but the broad one of relative risks and benefits is an incomplete one and overemphasizes what has been called the unique risks associated with radioactive wastes. In fact, the uniqueness is the public's perception."

A similar opinion has been expressed from an ethical viewpoint by Maxey [1977] in an EPA workshop:

"... I suggest that the problem of radioactive wastes is neither unique and unprecedented, nor has it been properly formulated from an ethical perspective. We have always lived with toxic elements in our environment, and they have not been registered with the skill, forethought, and planning applied to radwastes. From an ethical perspective, public concern has not only been inflated for political purposes, but it has been aimed in the wrong direction."

In another article [Maxey, 1978] Maxey concludes:

"To recover and maintain a balanced perspective on this particular biohazard and to introduce some corrective perception in the public mind becomes an ethical imperative."

Voss [1979] makes the comparison to other wastes and gives the following opinion:

"Nuclear wastes are derived from a particularly beneficial endeavor of man, the generation of electricity with nuclear power. These wastes pose no unique hazard in comparison to many of man's other industrial and residential wastes."

The Commonwealth of Pennsylvania [1978] made the following comparison in an EPA public forum:

"It is perceived by many technical people in the waste disposal field that the environmentally acceptable disposal of hazardous waste is more of a problem than the disposal of radioactive waste."

The proliferation issue is countered by Weinberg [1979] who states:

"Those who wish to extirpate nuclear energy base their position on an unquestioning acceptance of human fallibility and a cynical denial of human ingenuity ... Proliferation is an issue far from most people's perception; more than that, it faults nuclear power by association, not by intrinsic connection."

E. Overview

The perceptual (i.e. social and political as opposed to technical) aspect of waste management concern is thought by many to be a very significant impediment to the long term viability of the nuclear power option. Although concerns of a perceptual nature permeate the comments presented in other sections of this report, they have been separately included in this section due to their overall importance in the waste management area.

Some key questions that result from considering the opposing views on perceptual factors include:

- Is it true that no adequate method for waste disposal exists, or would any of several that have been studied be acceptable?
- For those concerns based on perceptual rather than technical factors, how could criteria for acceptability be established?
- Are the dangers of waste management so unique and unprecedented as to require an extraordinary burden on future institutions, or would foreseeable lapses in institutional control be tolerable?
- Is nuclear power unnecessary so that the waste management question need not be addressed?
- Are questions concerning criticality legitimate, or are they overstated?
- Is the invisible, odorless, tasteless nature of radioactivity sufficient to cause legitimate concern, or, conversely, is it true that radioactivity is one of the best understood of all toxic agents.

In addition to these questions, another important point should be considered. To what extent is the large scale conspicuous effort to develop solutions to waste problems a response to public concern; and to what extent does this effort contribute to the level of concern?

PERCEPTUAL FACTORS IN THE NUCLEAR WASTE ISSUE

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VI. WASTE MANAGEMENT HISTORY--UNRESOLVED ISSUES

A. Introduction

In this section we address waste management history and unresolved issues. These issues, both technical and non-technical, have resulted in criticisms which tend to create a credibility problem between nuclear experts and their critics. Some decisions and practices have been labelled as "failures" according to certain critics. Other critics see "no solution" to the waste problem. We also address issues that question decisions that have been made in the past, point out the public demand for a demonstrated facility, consider uncertainty factors in waste disposal, and discuss the nature of technical vs. political decisions. In contrast we offer some views which tend to illustrate a more optimistic view of past experiences in waste management.

B. Pessimistic Views

Senator Hart (Colorado) defined the problem in an EPA Forum [1978] when he said:

"All of this adds up to our having created a monster with no cage to keep it in. Building that cage is a problem which must be solved and solved soon ... One problem we have identified is the regulatory jungle surrounding our nuclear waste efforts. Federal authority to regulate nuclear waste is confused and inadequate ... To date, we have avoided disaster. Despite the lack of a clear and concrete nuclear waste program, there have been no immediate casualties and there has been no wholesale contamination of large parts of our environment. But short of that, we have compiled a complete catalogue of errors."

An unresolved issue of a non-technical nature is the belief in a technological fix. Metlay [1978] analyzes this problem as it applies to waste management:

"The persistent faith in a technological fix has produced a myopic vision of the waste management problem. In theory, as well as in reality, the boundaries of the waste management 'system' have been severely circumscribed. This constrained view of what must be considered in designing a waste management system has resulted in a number of significant distortions ... another consequence of the belief in a technological fix is that it reinforced factors that reduced the incentive to devote scarce organizational resources to solving the waste problem."

One of Metlay's conclusions is that "compared to the analysis of the technological issues involved, little attention has been paid to the non-technological aspects of the problem."

The General Accounting Office [1977] has recognized the following obstacles in the previous ERDA program:

- "The most serious and critical obstacle is public and political opposition to waste disposal sites.
- Geological uncertainties and natural resources tradeoffs.
- Questionable demonstration time period estimates.
- Undemonstrated technology for preparing radioactive waste.
- Lacking NRC criteria for orderly waste management operation."

An important unresolved issue is lack of communication between the nuclear scientific community and the public. According to Franklin [1979]:

"The message I try to get across is that the nuclear scientific community cannot say on the one hand that nuclear power is safe and on the other hand contend that waste must be buried. That community has over the years not communicated with the public, and as a result a large number of people are suspicious of what went on. And they are still suspicious."

Abbotts [1979] blames the federal government for the non-technological problems in waste management:

"So management of nuclear waste is much more than a problem of technology. Responsible management would require stable geologic formations and stable human institutions to guard the waste for many thousands of years. But the federal government's performance in trying to establish a waste storage policy has been characterized for over a decade by a series of false starts, shifts in direction, mistakes, and suppression of critical material ..."

Similar pessimism has been expressed by Nader and Abbotts [1979]:

"The back-end of the fuel cycle is presently in disarray. There are presently no reprocessing plants in operation, and it is likely to be several months before one begins to process spent fuel. While there are many speculative "solutions" to the ultimate problem of nuclear waste, none has been demonstrated, and the history of attempted solutions is full of failures and false starts, raising serious questions about the ability of human institutions to manage nuclear waste for the centuries which may be required." (p. 143)

Technical failure has occurred at the military waste site at Hanford, WA., as noted by Caldicott [1978]:

"From 1958 to 1975, twenty of Hanford's older, single-walled carbon steel tanks developed cracks through which 430,000 gallons of high-level waste leaked into the soil. In 1973 alone, an oversight on the part of a tank operator caused the escape of 115,000 gallons ... the escaped waste is migrating through the soil toward the water table ..." (p. 59)

Nuclear waste management is often viewed as such a troublesome problem that many critics contend that there are no solutions. One group [Friends of the Earth, 1978] says that:

"... presently there is no waste management solution. For now the best solution would be no more nuclear waste. Let's have the talented nuclear industry devote its efforts to cleaning up the mess it has already made."

Caldicott [1978] also says that no one else has any solutions to the waste problem:

"... as a physician, I have no answers for the problem posed by the 'back end' of the nuclear fuel cycle: the disposal of the lethal radioactive wastes produced each year by America's commercial and military nuclear programs. Nor, unfortunately, does anyone else—including the nation's nuclear engineer..." (p. 56)

Based on the assumption that there are no solutions, some groups propose that nuclear power should be dispensed with completely. According to the Abalone Alliance [1979]:

"The longer-lived materials are produced in vast quantities in nuclear power plants, and will continue to be produced until we insist that nuclear power facilities, and the whole nuclear fuel cycle, are shut down."

According to Nader and Abbotts [1979] no acceptable solutions are in sight. Their pessimism is expressed in the following paragraph:

"Nuclear waste represents a serious unresolved hazard which the industry, despite public relations efforts to proclaim it a non-problem, cannot banish. There are presently 600,000 gallons of high-level

"commercial" nuclear waste in storage at Nuclear Fuel Services, and the total will grow rapidly. Although the industry promises all types of solutions to waste storage, the solutions are at best speculative. When the proposed solutions have been tested, even on a small scale, they have been fraught with practical problems. The AEC's mismanagement raises questions about any waste storage program. Moreover, it is unlikely that any method can be developed which can realistically guarantee the stability of geological formations as well as human institutions for the quarter-million years or more which may be necessary. The waste problem is so serious that many scientists and citizens believe a nuclear moratorium is dictated by that problem alone. Nuclear electricity generated now could burden thousands of future generations with its lethal by-products."
(p. 158)

Credibility is another issue that further complicates an already complex problem, and leads to confusion of the public. In her essay Hoos [1978] comments on the "credibility issue":

"A phenomenon which can be called an intellectual passing-of-the-buck is widespread in the matter of radioactive waste handling. Not only has there been evidence of relying on technologies not yet devised but also of relegating the problem to others' spheres of responsibility ... To the technically minded, getting public approval is recognized as important, but the process by which this is to be achieved turns out to be one not of creditable performance in waste management but rather of convincing the public through smart tactics that its concerns are groundless! Thus, we find plans for public opinion surveys, media campaigns, and other manipulative tactics to persuade Nervous Nellies that risk-taking is an old American Custom, that radiological exposure may be benign; in short, that there need be no concern about wastes. To some engineers, technical matters pose few problems. Left out of their formula are two vital ingredients: (a) technology is not self-implementing; (b) technology is not self-evaluating."

Disagreement among nuclear experts also tends to aggravate the credibility issue [Holdren, 1975]:

"If you laid them all end to end, they'd never reach a conclusion. The fact is that the experts -- individuals with appropriate specialized training who have devoted a significant amount of time to aspects of nuclear issue -- do not agree about the answers to many of the important questions. They do not agree, for example, about just how toxic plutonium is, nor about the probability of certain kinds of reactor accidents, nor about the adequacy of various proposals for the management of radioactive wastes."

The waste management problem is compounded by uncertainty in the matter, as illustrated in the following by Dixon [1978]:

"I refer to the real waste storage problem: what to do with highly radioactive spent fuel from reactors is precisely a result of the growing uncertainty that either reprocessing or any permanent waste disposal method will be developed or approved in the foreseeable future."

Uncertainty associated with geologic disposal of wastes has been expressed by Bredehoeft [1978]:

"We are not saying that it is not feasible to store hot wastes in a deep geologic repository. We are saying, however, that given the current state of our knowledge, the uncertainties associated with hot wastes that interact chemically and mechanically with the rock and fluid system appear very high."

Lash [1979] has blamed the federal government for irresponsible decisions:

"No fully acceptable disposal means is currently available for handling any of these [wastes]. Beyond the significant obstacles to devising acceptable disposal methods, major barriers to implementation of adequate waste management programs come from institutional and human failings. A brief review of America's nuclear development reveals frequently ill-advised and, at least in hindsight, irresponsible decisions by the federal government which have caused unnecessary delay and expense as well as unwarranted health hazards."

The lack of a demonstrated long-term storage or disposal facility has been criticized by the General Accounting Office [1978] in which they raise the following questions:

- "Does DOE have the technological capacity to extract high level waste from its current storage tanks?
- Can DOE demonstrate, outside the laboratory, a waste form that is suitable for disposal?
- Can suitable disposal facilities be engineered and/or located to safely store this waste for the thousands of years required?
- ... and technology to transform neutralized waste into a suitable stable form for long-term storage and disposal has yet to be demonstrated on full-scale."

C. Optimistic Views

The following optimistic views are from Voss [1979]:

"... nuclear wastes are not alone in being hazardous industrial effluents. However, they are one of the few for which highly engineered management practices have been developed and are in use."

"Technology in nuclear waste management is advanced, experienced, and reliable. The radioactive wastes from nuclear power are of a manageable size and character, and should be viewed as no more than the waste by-product of one of man's beneficial activities."

"A good deal of experience has been acquired in the management of nuclear power plant wastes. The safety precautions taken by nuclear power plant operators and enforced by the U.S. Nuclear Regulatory Commission has resulted in a public and occupational safety record virtually unmatched in industrial operations. No radiation related fatalities in the public and occupational sectors have occurred as a result of commercial nuclear power plant or waste management operations."

An optimistic outlook for nuclear technology is given by J. Hill [1978] in a lecture on nuclear waste disposal.

"Our technology is improving all the time, largely as a result of the practical experience we are getting in operating our power stations and plants. I am certain that nuclear power is going to be the mainstay of the electrical industry in the future, leaving coal for the manufacture of substitute natural gas and the production of liquid fuels for transport. Moreover, the nuclear industry can do this with less damage to the environment than any of the alternative ways of getting the energy we require."

Nuclear experts insist that the technology for waste disposal already exists. Such an opinion is that of Soule [1978]:

"... all technologies needed to manage radioactive wastes from the back end of the commercial LWR fuel cycle are commercialized, available, or under development; there are no gaps ... Technologies for managing wastes from LWR reactors are fully commercialized. Technologies for treatment, interim storage, and transportation of wastes from fuel cycle operations such as fuel processing are commercialized, or ready for commercial-scale design and proof-testing, or can readily be implemented by adaptation of commercial practice for management of nonradioactive wastes ... The available technologies for final disposition of wastes are burial grounds and provisional storage in deep continental geologic formations. Stable geologies expected to be suitable for deep geologic isolation are known, technologies for site exploration and site selection are available, and design principles for waste repositories are known. Repository designs and qualification procedures will be specific to the site being considered; they can be developed as necessary when candidate sites are identified."

With regard to waste disposal, Dallaire [1979] defends the utility industry:

"Many in the electrical industry believe the nuclear waste issue has been blown out of proportion. They believe anti-nuclear and anti-growth groups are using it as a weapon to stop nuclear power. Many utility people feel the industry has been singled out as a scapegoat ... When a state says no more nuclear power until there's a solution to ultimate disposal of nuclear wastes, then the federal government has to act ... The utility industry is eager to prove ... that a solution to the long-term disposal of highly radioactive wastes is at hand."

And, finally, Jackimo and Bupp [1978] try to reconcile the conflict over waste disposal:

"The critics of nuclear power will have to resist putting government and the nuclear industry in the impossible position of demonstrating something which by definition would take centuries or longer. And the nuclear industry must resist the temptation to rush ahead with a hardware and construction program in order to claim that the problem has been solved."

D. Overview

This section has considered viewpoints related to waste management history and unresolved issues. Some questions resulting from the opposing viewpoints are as follows:

- Is the history of waste management one of a continuous series of errors and failures, or is it characterized by the successful protection of the public health?
- Are there no viable solutions to the disposal of radioactive waste, or are several acceptable methods at hand?
- Given that uncertainties exist in waste management technology, are they sufficient to invalidate proposed methods? How certain do we need to be?
- Does a significant amount of expert disagreement on waste management exist, or does the major expert disagreement represent the fringes of expert thought?
- Do we have the means at hand to even characterize an "acceptable solution?"

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VII. RISK - THE CONTROVERSY

A. Introduction

The question of risk as it applies to nuclear wastes has caused a great deal of controversy. We cite views which illustrate the nature of this controversy and the problems involved in resolving this conflict. The first section includes some neutral views about risk as applied to nuclear waste. Pessimistic viewpoints are then followed by optimistic viewpoints.

B. Neutral Views

D. Okrent and researchers at UCLA studied types of risks and those that the public are willing to accept. According to Sage [1979] these researchers found that:

"The public seems to be willing to accept a risk which is of low consequence but high frequency. One of the most prominent examples is automobile mishaps, in which small numbers of people die very often, tallying up half a million deaths each decade. In contrast, one dam failure in ten years that killed 50,000 people all at once would be seen as a far more horrifying, and unacceptable disaster."

Public acceptance of nuclear risks has been studied by Otway et al. [1978] by means of an attitude model. Comparisons of nuclear vs. non-nuclear risks were made, but according to Otway et al. other processes may be involved in the public attitude besides theoretical and statistical estimates. They summarize as follows:

"The argument in favor of nuclear energy often presents comparisons of theoretical estimates of the risk from nuclear energy with statistical data on other, more familiar risks. Nuclear risks are invariably shown to be orders of magnitude lower than those familiar risks, thus implying a rational basis for the acceptance of the former. Even if the public were to accept the conceptual validity of such comparisons, the attitude model we have discussed shows that they are unlikely to be the only informational input to the overall attitude. To expect people's attitudes toward a new technology to be primarily determined by statistical estimates of physical safety is a highly simplified, and incorrect, model of human thought processes - it implies such a degree of 'rationality' as to be itself irrational."

This additional input to attitudes on nuclear risks has been studied by Niehaus and Swaton [1978]. Their conclusion concerning pro and con nuclear attitudes is

"An analysis of attitudes of groups PRO and CON nuclear power reveals the different structure of beliefs of both groups. Attitudes towards nuclear of the CON group are mainly determined by factors which include beliefs about risks with psychological and socio-political implications. Attitudes towards nuclear of the PRO group are mainly determined by beliefs about technical and economic benefits and positive environmental aspects."

C. Pessimistic Views

A Nuclear Regulatory Commission Task Group [1976] comments on statistical models vs. the real world:

"It is easy to say that each of us loses a few minutes of his life as a consequence of some radioactive waste hazard but, in fact, no one will lose only a few minutes; instead, a few people die tens of years early. Unlike our statistical model, the real world consists of real people, not of statistical people averaged over time and space. The public may not know exactly what statistical trickery goes into assurance that radioactive hazards mean the loss of only a few minutes of life, but they do know that when someone gets cancer, he loses more than a few minutes."

Criticism of risk/consequence modeling is given by Cochran and others [1979]:

"... the basic uncertainty common to all predictions of what will occur in the future is bound to infect any waste disposal plan aimed at meeting a given standard; however, of the two alternative approaches for managing this problem, one (risk/consequence modeling) is likely to increase the doubt that a waste plan will meet desired goals, while the other (defense-in-depth) diminishes uncertainty."

A basic problem is that quantitative risk assessment is often distrusted by a qualitative, subjective public, as noted by Bartlett [1974]:

"In broadest terms, our current problem is to determine if and how the illusions of certainty created by the analytic methods of risk assessment can be accommodated in a society that distrusts computers and perceives risk subjectively. For this problem especially, there are no easy answers."

Many people will accept only a risk of zero or absolute safety. One such opinion is held by Ballen [1978]:

"In the face of increasing scientifically based knowledge on the effects of low-level radiation the only adequate risk assessment is zero release ... The fact that the nuclear industry has been and is producing bombs, weapons, and power plants without public accountability and has imposed a radioactive waste problem on future generations robs the nuclear industry of its credibility. At the very least, a moratorium on the production of radioactive waste needs to take place. I accept no standards of acceptable risks from radioactivity and I resent standards that are 'benevolently' determined by others."

The Rocky Flats Action Group contends that lack of technical solutions to the waste problem increases risk; in their words:

"To ignore the building pressure of a continuously expanding radioactive inventory while technological solutions are not yet in hand, is to encourage a greater risk of error or accident, or to encourage the hasty, less than acceptable disposal of those accumulating wastes."

Others say that taking risks for technological advancement may be a sin (Shinn, 1978):

"To put others at risk, without their consent, for our benefit is sinful."

D. Optimistic Views

Many take a more optimistic view towards nuclear waste management, especially when risks are compared. Beckman [1977] speaks of risks of nuclear energy compared to risks associated with alternate forms of energy:

"The problems of nuclear power are sharply defined, quantifiable, measurable, and well understood. There are viable solutions to all of them. When the experts debate a problem - such as nuclear waste disposal - the reason for the debate is not the absence of a solution, but the large number of satisfactory alternatives ... Given these hard numbers of the risks to human health and to the environment associated with nuclear power, and comparing them to the somewhat fuzzier, but still unambiguously high, numbers of the risks associated with other forms of energy, nuclear power emerges convincingly as the safest."

Similarly, the Electrical Power Engineers Association confirms the safety of nuclear power facilities in relation to their risks as compared to other hazards [EPEA, 1978]:

"As a result of this wide-ranging and thorough review, it is concluded that, although there are risks of damage to health for workers in the industry and for members of the public in the vicinity of nuclear establishments, the care taken in the design and operation of all relevant facilities is such as to render these risks significantly lower than those accepted by workers in many other industries and by the general population due to other man-made hazards."

The Inhaber Report, Risk of Energy Production, [Inhaber, 1978], compares the risks of non-nuclear technology with risks of nuclear energy production. In this report Inhaber concludes:

"In spite of their possible advantages, nonconventional energy technologies appear to have high risk to human health when their entire energy production cycle is evaluated. In particular, they have much higher risk than either nuclear power or natural gas used to generate electricity."

Cohen has studied the risks from the disposal of high-level wastes and has come to the following conclusions [Cohen, 1977]:

- "Assuming deep burial, there are important time delays which prevent the waste from reaching the biosphere in the first few hundred years, while its toxicity is decreasing by several orders of magnitude.
- The most important pathway to man is through groundwater into food and water supplies, resulting in 0.4 fatalities in 10^6 years.
- Other less important pathways are meteorites, volcanism, release through groundwater to airborne particulate, human intrusion (drilling and mining).
- Nuclear power can reduce man's exposure to radiation by consuming uranium.
- Buried high-level waste is environmentally much less dangerous than uranium mill tailings."

Cohen also considers the results from possible meteorite impact on an HLW repository [Cohen, 1977]:

"If there are worries about release through meteorite impact, it should be noted that the maximum number of fatalities ... is 30,000, whereas a direct impact on a city could easily kill millions, and an impact on water would form a tsunami that could easily kill hundreds of thousands."

Acceptable risk constitutes an on-going controversy. What determines acceptable risk and how can nuclear risks be compared to everyday risks? Lapp [1977] provides an answer which gives some perspective:

"All of us, without exception, live in a risk-filled world from cradle to grave. The average household contains toxic substances sufficient to poison its inhabitants a hundred times beyond the lethal level. Yet we accept the risk and live with it. Meanwhile, the foes of nuclear power isolate the nuclear risk as being unique to man and find it totally unacceptable. In so doing, they overlook other hazards that have confronted people living in the Industrial Age, especially the widespread chemical risks ... Our society has in effect established a double standard of risk." (p. 92)

Public perception of the radioactive waste disposal problem has become distorted because of the lack of reasonable comparisons to other disposal problems. When compared to hazardous chemical wastes, the radioactive waste problem diminishes. This comparison has been made by Dornsife [1979] who summarized as follows:

"In the past radioactive waste disposal has been viewed by a majority of the public in a complete vacuum because it was felt that the problems involved were not comparable to any other environmental insult. However, when considering some of the problems which are inherent in the safe disposal of hazardous waste, it must be concluded that radioactive waste disposal is not a unique problem for this country to solve. In fact, when directly comparing the two problems, radioactive waste seems to be the more manageable and therefore the easier to implement successfully."

Langner [1978] calls for consistent risk criteria:

"Zero risk and complete safety are impossible to achieve in society. There should be consistent risk criteria applied to radioactive material and nonradioactive material based on scientific data, not prejudices of a few uninformed."

Many risk comparisons have been made between coal-fired and nuclear power. Cuddihy et al. [1977] speaks to the greater safety of nuclear power.

"Radionuclides, especially elements of the uranium and thorium series, occur in coal. When coal is burned in large power plants many of the trace elements become concentrated in the effluents. The more volatile

elements can vaporize ... and then recondense at lower temperatures further down the effluent streams to be released to the atmosphere.

... the projection for lung tumors was 400 times greater for operation of a coal-fired plant compared to that of an equivalent size LMFBFR."

Many standards have been proposed for waste disposal in order to minimize risks to the populace and the environment. One of these is Maxey's bioethical principle for choosing among current options for waste disposal facilities:

"Any involuntary risks imposed by social policies for radiation protection must be congruent with, must not be in excess of, and may be reasonably less than, those involuntary risks imposed by the wide variations in naturally occurring toxic elements and harmful effects from our natural environment." (Maxey, 1980).

A final perspective on risk is that provided by Wilson [1979] in the Christian Science Monitor:

"The assertion that no one has an answer to the permanent waste disposal problem is true only in the sense that no one can foretell the future precisely. A meteorite might hit Boston tomorrow, and being killed by a meteorite is more likely than being killed in a nuclear power accident."

E. Overview

The overriding concern related to nuclear waste management is the potential risk it may present to present and future generations. Yet, the concept of risk itself is one upon which there does not appear to be common understanding or agreement. Among the questions that arise regarding the risk controversy are the following:

- Should risk be viewed in absolute terms (i.e. either present or absent), or in relative terms (varying degrees of risk)?
- If, as the majority of opinion seems to hold, risk is relative, what guidelines can be applied to judge acceptable levels?
- Should risk levels accepted for nuclear waste operations be commensurate with those applied to other societal activities or are more restrictive levels indicated?
- What is the most rational method of determining risk and what measures of risk are most meaningful?

RISK - THE CONTROVERSY

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VIII. SUMMARY AND CONCLUSIONS

A spectrum of viewpoints on issues related to radioactive waste management has been presented. Clearly, there exists a wide diversity of opinion on the subject. In each section of the report, key questions representing major aspects of viewpoint divergence have been noted. This section offers a summary of the observed disparity of views, discusses the characteristics of viewpoint divergence, and suggests approaches toward reconciliation of the differing views.

A. Viewpoints on Waste Management Issues

The public literature regarding waste management contains a variety of issues that have been the subject of extensive discussion.

One of the basic issues appears to be the question of whether artificial radioactivity presents hazards of a fundamentally different form than other dangers which are naturally occurring and/or non-radioactive in nature. This issue involves the effects of low-level radiation exposure, and the basic nature of radioactivity and its effects on human beings. Concerns over the effects of radiation exposure are aggravated by its specter of invisibility, cumulative and delayed effects, carcinogenicity, mutagenicity, and deleterious effects to the population gene pool.

In any event, there appears to be a general impression that the overall toxicity and hazard of radioactive waste is such that any mistakes, if made, would result in a catastrophe of unprecedented dimensions to present and future generations.

On the other hand, data and calculations have appeared in the literature which indicate the toxicity of nuclear waste is significantly less than that of many non-radioactive materials routinely produced and accepted in our society. Also, the relative hazard of a typical radioactive waste repository would be less than that of many naturally occurring mineral formations, according to some analyses. Other analyses have shown the toxicity of radioactive waste decreases relatively rapidly so that, in a few centuries, it is lower than that of the ore from which the reactor fuel originally came.

The time behavior of radioactive materials is another area that has generated a considerable amount of comment. Some have expressed the opinion that the hazard of radioactive material is related to its half-life. The long half-lives of some radionuclides has led to description of radioactive waste disposal as a problem on a 250,000 year time scale, with the implication that toxicity persistence on this time scale is unprecedented in the history of human activities.

On the other hand, it has been pointed out that the difficulty with equating potential hazard to half-life is that, if carried to its extreme, the stable toxic elements with essentially infinite half-lives would be considered to be the most hazardous substances. In this regard, it should be noted that specific activity is inversely proportional to half-life. In other words, the longer the half-life of any radionuclide, the less radioactive it is.

Another area of divergent opinion is on the questions of the predicted quantity of radioactive wastes, and the costs of their management. Opinions on these issues run the complete spectrum between the extremes with a surprisingly large amount of opinion at the extremes.

Other issues of importance include the general area of risk characterization, the potential for catastrophe, uncertainty, waste form, the capability of government to regulate with credibility, the history of waste management operations, and various other non-technical issues. On each of these issues there exists a wide divergence of attitudes.

B. Characteristics of Viewpoint Divergence

It is interesting to attempt to characterize the opposing attitudes on waste management issues. To some extent, these attitudes can be classified as either optimistic or pessimistic, depending on how individuals view the severity of the problem.

One of the first generalizations that can be observed is that the pessimistic statements tend to be qualitative and colorful, while the optimistic statements tend to be of a more quantitative nature. At the extremes, the pessimistic statements can revert to unsubstantiated assertions and emotionalism, while the optimistic statements can become clouded by oversimplification and the expression of quantitative values with much higher precision than is justifiable.

Another characteristic that can be observed is that the optimistic statements tend to address individual issues while the pessimistic approach frequently relates to a combination of issues.

The divergence of conclusions drawn from the same basic data is a particularly interesting characteristic of some of the statements on specific issues. For example, based on the actual volume of radioactive waste to be produced, one statement might conclude that this presents a serious problem, while another statement will conclude that this presents a situation which is quite manageable.

In some cases, statements are made which are demonstrably false, or at least technically incorrect, but nevertheless are effective in stimulating public opinion. For example, the statement is made that plutonium is the most toxic material known to man. Yet, it has been shown that, on a toxicity per unit mass basis, many materials are more lethal than plutonium, particularly via ingestion pathways. In other cases, statements that are technically correct are phrased in such a way as to infer conclusions which may be misleading. For example, one author implies that nuclear power is basically inefficient in stating that it takes 25 billion fissions to produce the energy equivalent to the combustion of only one gallon of oil.

In compiling perspectives on the radioactive waste problem, it becomes apparent that the preponderance of the popular literature tends to support the pessimistic view. Whether this fact supports the conclusion that the problem is particularly serious and intractable, or simply that people with negative views tend to express them more readily, is conjectural.

C. Reconciliation of Viewpoints

The reconciliation of divergent viewpoints presents some difficult challenges to those charged with decision-making on behalf of the public. Some issues may be amenable to reconciliation while others are not. Fears and issues which are philosophical in nature do not have a definable technical base and therefore may defy resolution through technology. Political problems might find their best solutions in the political arena.

Within the scientific community, a certain degree of reconciliation should be achievable. In particular, unfounded assertions and improper numerical manipulation ought to be easily detected and revealed as such, through the standard procedures of scientific study. The elimination of these forms of "expert opinion" would simplify the effort toward consensus of the remaining body of opinion.

Another problem related to the public perception of scientific activities is that when a high priority is given to a particular technical research program, it can be inferred that the results of the program are critically needed in order to shape defensible public policy. For example, from the efforts to develop increasingly stable waste forms, it might be inferred that failure to do so could result in dire consequences. Similarly, the efforts to assure complete isolation of waste might imply that complete isolation is really necessary. Yet, the results of several assessments indicate that neither of these implications is valid. Such assessments indicate that even using pessimistic assumptions, containment failure would likely result in radiation exposures considerably lower than natural background.

It is interesting to note that the Reactor Safety (Rasmussen) Study, did not result in widespread acceptance of the relative safety of nuclear reactors despite the fact that the quantitative results of the study indicated a high degree of relative safety. Perhaps this is indicative of the difficulty of providing technical solutions to political or emotional problems.

Where widely divergent conclusions result from commonly accepted basic data, further study of the accepted data would not appear to be of use in generating consensus. For this type of opinion divergence, a broader view of the issue may be required so that attention can be better focused on points where disagreement exists. There can be no reconciliation until individual issues in contention are identified and dealt with.

Where negative public opinion exists as a result of unfamiliarity with technical areas, it would appear that public education could be useful toward gaining acceptance. Where the negative feelings are philosophical in nature, such efforts may be futile.

D. Conclusions

Divergence of opinion within the scientific community, as well as within the public at large, is a characteristic of issues related to nuclear power. The divergent opinions can largely be characterized as either optimistic or pessimistic in nature. They run the complete spectrum from qualitative to quantitative and from emotional to detached. The divergence of conclusions drawn from the same basic data is a particularly interesting characteristic of some of the statements on specific issues.

Reconciliation of divergent viewpoints presents some difficult challenges. It is doubtful that issues which have an emotional or philosophical basis can be resolved through technical efforts.

Public education on the technical issues might prove helpful. Although, in itself, this education may not lead to reconciliation of divergent public views, a general understanding of the issues might provide a sound basis for their eventual resolution.