COMMITTEE VII
Global 2000 Revisited: Re-assessing Man's Impact on Spaceship Earth

DRAFT - 9/15/86
For Conference Distribution Only

NUCLEAR WASTE DISPOSAL: THE NATURE OF THE PROBLEM

by

Jerry J. Cohen
Lawrence Livermore National Laboratory
Livermore, California

The Fifteenth International Conference on the Unity of the Sciences
Washington, D.C. November 27-30, 1986

NUCLEAR WASTE DISPOSAL: THE NATURE OF THE PROBLEM*

Jerry J. Cohen
735 Wimbledon
Livermore, California 94550

1. INTRODUCTION

In ancient times, myths (beliefs not necessarily based upon fact) became embedded in the folklore of a culture over long periods of time by passing from generation to generation. Often such myths were embellished and amplified with each passage. Laws and rules governing society, such as the witchcraft laws in colonial America, were sometimes predicated on myths since they came to be regarded as fundamental truths. Today, in the age of mass communication, myths can become established far more quickly. The advent of science during the last few centuries may have had a mitigating effect on adherence to mythology, particularly in modern societies, but this is by no means always the case. The folklore regarding nuclear waste presents a particular case in point where beliefs, not supported by science and logic, have played a major role in the development of our laws and policies.

The two major beliefs implicit in deriving our nuclear waste policies are:

(1) Nuclear waste is extremely toxic. Its disposal poses a danger of immense magnitude. The requirements for its complete isolation from the biosphere suggests that escape of the most minute quantity from isolation would pose an extremely serious threat to the environment and the health and safety of anyone who might become exposed to it.

---

*Paper prepared for presentation at the Fifteenth International Conference on the Unity of the Sciences, Washington, DC, November 27-30, 1986.

(2) Because of the long half-lives of many component radionuclides, the disposal of nuclear waste presents mankind with a threat of unprecedented duration. For example, nuclear waste disposal has been characterized as a 250,000 year problem (ten times the half-life of plutonium-239). Such a problem is considered unique since human institutions are simply not capable of coping with problems that persist for unimaginably long time periods.

The Nuclear Waste Policy Act (NWPA) of 1982 embodied both of these concerns in defining high level waste (HLW) as "highly radioactive material resulting from the reprocessing of spent nuclear fuel" and "other highly radioactive material that ... requires permanent isolation." An understanding of the general character of concern related to nuclear waste can be gained from sampling views on the subject expressed in the literature. For example, Nader and Abbotts (1979) state:

> "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."

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. As summarized in <u>Physics Today</u> (1977), this report points out:

> "Nuclear waste contains fission products and long-lived 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."

The Clergy and Laity Concerned in a pamphlet (CALC, 1980) stated:

> "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."

Finally, Alvin Weinberg [1972], former director of the Oak Ridge National Laboratory, described the problem in the following terms:

> "We nuclear people have made a Faustian Bargain with society. On the one hand we offer ... 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."

The above quotations are but a small sampling of a ponderous amount of literature supporting the perception that nuclear waste management presents us with a problem of unprecedented dimensions. A comprehensive summary of viewpoints on the nuclear waste problem may be found in a review document [UCRL-15530, February 1983] compiled by the Lawrence Livermore National Laboratory (LLNL). From this review, it is apparent that the negative views toward nuclear waste management are long on rhetoric and short on quantification. Although it is clear that such views are deeply felt, they are generally not based on scientific rationale.

It can be conservatively estimated that to date, hundreds of millions of dollars have been spent in this country alone, in an attempt to develop an acceptable solution to the nuclear waste disposal problem. Current plans call for the expenditure of billions more. Yet in the minds of the vast majority of the public, the problem is perceived as intractable and evokes great apprehension. The suggestion for the siting of a nuclear waste repository at any specific location stimulates fierce opposition. The so-called NIMBY (not in my backyard) syndrome has become a fixture in our society. National efforts to develop the first nuclear waste repository seem to be all but paralyzed (Marshall, 1986).

In this atmosphere, any suggestion that the high level of concern and apprehension related to nuclear waste might be technically and logically unfounded would appear to border on heresy. Yet that is precisely the point that this paper will attempt to make. Stated succinctly, the potential hazard of nuclear waste is no greater than that of many other commonly accepted industrial activities in today's world and the concern related to its longevity (long half-life) is absurd when compared to current levels of concern related to use of stable toxic elements (e.g., lead, cadmium, mercury) which last forever. Section 2 of this report will review technical data on the comparative hazards of nuclear waste which indicate that the problem is far from serious. Section 3 will explore reasons on how the disparity between actual risks of nuclear waste and its perception evolved.

2. HAZARD ASSESSMENT

As previously discussed, the major concerns related to nuclear waste management can be expressed in terms of hazard and longevity. These concerns may be paraphrased as follows: First, nuclear waste is extremely toxic. The radioactive waste from a single nuclear reactor is enough to poison the entire population of the world several times over. It could cause malignancy and other diseases to exposed populations and genetic defects to their descendants. Second, because of the extremely long half life of plutonium and some of the other components, its toxicity will persist for thousands, and perhaps millions of years.

Both of these statements are true. However, when viewed in a different perspective, they lose their specter of severity. For example, a valid analogy to the first statement would be the observation that considering such items as cleaning compounds, pesticides, and other chemicals, there is enough toxic material in the average supermarket or hardware store to poison everyone in the community, if not the entire state. The problem has been one of confusing toxicity with hazard. The mere existence of a toxic substance does not necessarily constitute a hazard, unless that substance is readily available for dissemination and assimilation in the human body.

Consider, for example, that the lead used in the manufacture of automobile batteries in this country each year is also sufficient, if properly distributed, to poison the entire world population several times over. Although long half-lived radionuclides in radioactive waste may persist for centuries or millennia, lead, being a stable element, will exist forever. In addition, lead is also a carcinogen and a mutagen. Nevertheless, lead in automobile batteries is not generally considered to be a serious environmental threat, simply because of its low availability for human assimilation. The annual production of lead in this country, if administered by ingestion, would be sufficient to kill far more people than the annual amount of plutonium produced under the most ambitious nuclear power production program conceivable.

Similarly, one can calculate that the annual emission of lead from auto exhausts in this country, if properly distributed, would also be sufficient to kill off the the entire world population. Even in this readily dispersed and available form, the effects have not been all that catastrophic. The effects have not been catastrophic simply because the exhausted lead is naturally dispersed in such a way that only a minuscule fraction ever finds its way into human tissues. In comparison, the nuclear waste situation is neither unique nor unusual in its potential for hazard.

A difficulty in assessing the degree of hazard associated with nuclear waste (or any other potential danger) is in determining a meaningful quantitative measure of its severity. To measure how dangerous something is, what "yardstick" do we use? In the previous discussion, the number of lethal doses was used (i.e., by dividing the amount of material in question into equal quantities, and determining the maximum number of lethal doses to humans that could result). Using this same approach, Cohen (1976) summarized the potential hazard for various toxic materials produced annually in the USA and compared the number of lethal doses to that of the waste produced from the annual production of nuclear power. The results are shown in Table 2.1. From these data, it would appear that the potential hazard from nuclear waste is not remarkable. Although the "number of lethal doses" approach to hazard assessment may be technologically crude, it is certainly preferable to evaluating the problem by the number of articles on the subject in the news media or severity of rhetoric contained in them.

Perhaps a more technically descriptive (and accurate) method of expressing degree of hazard is the hazard index (HI). The HI is the quotient of the quantity of hazardous material in question divided by the concentration limit considered acceptable for public drinking water supplies. It can be expressed in units of volume and is indicative of the volume of water required to dilute a given quantity of toxic material to a concentration level considered safe for drinking. As the potential hazard increases, larger volumes of water will be required for dilution to safe levels. The index can therefore, serve as a measure of relative toxicity. Such indices have been applied in several previous studies on nuclear waste (Haug, 1977; Hamstra, 1975; Clairborne, 1975; and Gera & Jacobs, 1971), all of which indicate the potential danger is not particularly severe.

Other useful insights may be derived from application of the hazard index. For example, the consequences of nuclear waste disposal have been characterized as, "so dangerous that it threatens the very existence of life on this planet" (Abalone Alliance, 1979). In this regard, it should be noted that underground burial of nuclear waste would not be the first introduction of toxic materials into the geologic structure of the earth. Indeed, nature has already incorporated considerable quantities of toxic minerals in the earth's crust. Table 2.2 lists the estimated crustal abundance of naturally occurring toxic elements along with the hazard index for each. Table 2.3 provides analogous data for waste resulting from nuclear power production. From these data, assuming the accumulation of nuclear waste from 100 million Megawatt-years of power production (1000 power reactors each rated at 1000

MWe capacity and all operating for 100 years) were buried deep in the earth's crust, the net hazard index of the earth's crust would increase by a factor of 1/100 of 1% for 10 year old waste and only 1/10,000,000 of 1% after 1000 years of decay. This would not appear to be a major perturbation on the earth's content of toxic materials. However, it could be argued that this assessment is inappropriate since toxic minerals have a widespread distribution while nuclear waste would be concentrated in a few repositories. Nonetheless, such comparisons can be considered valid in light of the fact that toxic elements in the earth's crust are also found in concentrated form in mineral ore bodies. For example, Figure 2.1 taken from the environmental impact statement on the Management of Radioactive Waste [DOE/EIS-0046, 1979] shows how the relative hazard index of nuclear waste compares to that of certain toxic ore bodies. In this assessment, the hazard index for a typical (0.2%) uranium ore body (from which the nuclear fuel was extracted in the first place) is assigned a value of unity, all other values are proportioned to it. Even relatively fresh nuclear waste (when it is at its most toxic) is comparable in degree of hazard to a mercury ore body. After a few thousand years of decay, the relative hazard of the waste becomes equivalent to that of a uranium ore body from which the nuclear fuel was originally extracted. A more comprehensive survey on the relative hazards of nuclear waste and toxic minerals may be found in UCRL-78746 (1976).

Another insight that may be gained from the analysis in Figure 1 is that after a few thousand years, the potential hazard from the nuclear waste becomes <u>less</u> than that of the original uranium ore body from which it was extracted. Other studies (Williams, 1980; Wick & Cloniger, 1980) also indicate that a deep geologic nuclear waste repository poses comparable (or less) hazard than do typical uranium ore deposits. Indeed, considering extended time periods (beyond a few millennia) nuclear fission power production has been characterized as a means of "cleansing the earth of radioactivity" (Cohen, B., 1977). To gain further insight, consider the analysis presented in Figure 2.2. This graph follows the hazard index of one kilogram of natural uranium under two possible scenarios. In the first (solid line) it is assumed that every uranium atom in the kilogram of material is fissioned. The initial hazard index of the fission products becomes very high since extremely radiotoxic nuclides such as strontium-90 and cesium-137 are included. With time, these fission products decay and the hazard index decreases accordingly as shown. Eventually there is ingrowth of the stable end products of radioactive decay including such elements as bismuth and arsenic. Note that the material never becomes totally innocuous since the stable end products are also toxic.

In the second scenario (dotted line), it is assumed that the kilogram of natural uranium remains intact and undisturbed in its ore body. In time, with the radioactive decay of the uranium isotopes we observe the effects of the ingrowth of radium, a radionuclide whose unit toxicity is significantly greater than the parent uranium. In about one million years a condition of secular equilibrium is reached where one curie of radium exists for each curie of uranium remaining. Eventually, after a few billion years, the entire system decays to stable lead, which itself is very toxic and significantly more toxic than the stable end products of fission product decay. The cross-over of the two curves at about one million years indicates that there is some validity to Cohen's statement about the cleansing of the earth. It all depends upon the period of time over which one chooses to view the problem.

Again, it might be argued that the hazard index approach is simplistic and inappropriate since it considers only the inherent toxicity of the material but not its relative environmental mobility, its biological availability, or its potential for eventual assimilation in human tissue. To rectify this deficiency, Smith and his associates at LLNL developed the Geotoxicity Hazard Index (GHI) which considers all of the above factors in addition to the environmental persistence of the hazardous material (UCRL-52889, 1980). The GHI provides an index related to the overall hazard from either naturally occurring or man-made toxic materials buried underground. Figure 2.3 shows the results of applying the GHI to one cubic meter of various materials including 10 and 100 year-old nuclear waste. This assessment also indicates that nuclear waste presents no unique or unusual hazard. Toxic elements in mineral form are at least as likely to be leached and transported as is vitrified nuclear waste. For example, Goldberg (1979) estimates that over 30 million kg of lead and 10 million kg of arsenic are leached from their natural mineral state in the conterminous USA annually finding their way to surface waters and eventually discharging into the ocean.

The accumulation of toxic elements in the world's ocean waters over geologic ages has resulted in a considerable pool of natural "pollution." Table 2.4 presents the oceanic burden of certain toxic elements along with the associated toxicity index. Consideriang only these data it can be calculated that a uniform distribution of the dissolved 1,000-year-old nuclear waste from the production of 100 million megawatt-years of electricity into oceanic waters (certainly a "worst case") would increase the average oceanic toxicity by 1/100 of 1%. It is truly unfortunate that extreme environmental concern (sometimes bordering on hysteria) related to oceanic disposal of radioactive waste has precluded serious consideration of this alternative. Systematic study (Cohen, B, 1980) has shown that oceanic disposal would likely provide the safest method for disposing nuclear waste. In addition, it would be the least expensive and most readily implemented.

The discussion to this point has focused on the relative hazard of nuclear waste and has attempted to show that this hazard poses neither a unique nor an unusual threat. The second major concern related to the long half-life components of nuclear waste can also be shown to be untenable for two basic reasons. First, it would seem inconsistent if not illogical to worry about plutonium with its 24,000-year half-life and not devote equal or far greater concern to the stable toxic elements such as lead, cadmium, and mercury which will persist forever. One possible explanation for this disparity is the apparent mystique surrounding plutonium that engenders special fears. For example, in an early draft of their policy statement on nuclear energy, the National Council of Churches labeled plutonium "an intrinsically evil element." However, in light of scientific analysis, plutonium does not seem to live up to the sinister image portrayed in the public media and reflected in related policies and regulations. For example, via ingestion (the predominant pathway of concern associated with geologic disposal of nuclear waste), plutonium per unit or radioactivity is 2000 fold less toxic than Radium which is ubiquitous in nature. Of course, plutonium can also be considered ubiquitous since over 10 tons of this material were disseminated throughout the world during the period of atmospheric nuclear weapons testing. No discernibly adverse biological effects have been observed as a result. This is understandable considering, for example, that the oceanic inventory of natural radium is about 80 million tons, which is equivalent in ingestion radiotoxicity to 100 billion tons of plutonium. It should be noted that about 250 tons of plutonium would be produced by 100 million megawatt years of nuclear power generation.

Second, a basic radiation physics principle indicates that special concern related to long half-life radionuclides is unwarranted. The specific activity of any radioactive isotope is inversely proportional to its half-life. Simply stated, the longer its half-life, the less radioactive it is! A recent study (Cohen, 1986), noting this problem, proposed a semantic solution. It suggested that only radionuclides with a half-life of less than one million years be called radioactive. Those with half-lives greater than one million but less than one trillion years could be termed radiopassive and those with half-lives exceeding a trillion years would be radioquiescent. Such a classification system might tend to counter perceptions such as that expressed by W. D. Rowe (Rowe, 1976), former head of the EPA Office of Radiation Programs who stated, "We feel that some of the long half-lived materials such as plutonium can indeed be very dangerous because of their half-lives." It is somewhat of an enigma why half-life, per se, is equated with danger; yet this concept seems to be well embedded in current mythology.

A manifestation of this phenomenon can be found in the extensive research related to evaluation of Iodine-129, a major component of nuclear waste with a half-life of 15 million years (Kocher, 1979; McKay, 1980; Oztunali, 1983). This research was likely motivated by concern over the extremely long half-life of the radionuclide. Yet, it has been calculated (Cohen, 1986), that if every atom of iodine in the human body were I-129 (a ridiculously conservative assumption), the resultant whole-body equivalent dose would be less than

600 mrem/yr, close to the allowable limit for public exposure to radiation. This should not be surprising considering that I-129 is barely radioactive in the first place.

From the material discussed in this section, it would appear that the perceived hazard related to nuclear waste is well out of proportion to actual levels of danger likely to be posed. Possibly more interesting than assessing the hazards of nuclear wastes is a study of how the wide disparity between actual and perceived hazard came to exist. This topic is dealt with in the next section.

3. PERCEPTIONS AND POLICIES

Previous discussion supports the concept that problems related to nuclear waste management and disposal are not nearly as serious or intractable as is commonly believed. Yet this concept itself would appear to be incredible. One might reasonably ask, if nuclear waste were in fact a relatively minor problem, why then after decades of research costing hundreds of millions of dollars have we no accepted solution? Why is a multi-billion dollar program pursuant to the NWPA necessary to develop a nuclear waste repository? Could the decision makers be unaware of the data and insights presented in the previous section? Certainly that information was available in the open literature. Could it be that they are aware of this material but have chosen to ignore it in the formulation of policies? Surely it would be reasonable to conclude that if, in fact, nuclear waste disposal posed no serious technological problem, current plans and policies constitute a gross "overkill." Could it be true that, as Fred Singer (1985) concluded, "Nearly everyone agrees privately that safe disposal of spent fuel or other high-level radioactive material is not a technical problem, but a political one"? If the problem is political, why are billions of dollars being spent on technological research and development? Questions such as these are, in my opinion, by far the most interesting and the most important to consider in gaining an understanding of the nuclear waste issue. If one accepts the view held by the majority of scientists working in the nuclear waste field that public apprehension regarding the problem is grossly exaggerated, then it is reasonable to ask how this condition came to exist. How did the myth evolve?

The causes for the current climate of apprehension toward nuclear waste are certainly complex and would likely involve political, social, and psychological as well as technical factors. I have pondered the situation at some length and have thought it would be fascinating to perform an anthropological study on the various groups involved with the nuclear waste problem similar to the studies done on primitive and advancing societies. Unfortunately, I do not have the expertise to do such a study. Nonetheless, from several years of personal experience and association with others working in nuclear waste research, I have formed certain impressions and can share my opinions and conjectures on the subject.

To explore the evolution of nuclear waste mythology, it can be useful to look at the role that various groups have played in influencing public opinions and policies. Probably the most vocal and outspoken of these groups are the so-called environmentalists represented by such organizations as Friends of the Earth and the Abalone Alliance. Frequently members of the technical community have accused these groups of exaggerating the nuclear waste problem beyond all reasonable bounds and needlessly inflaming public fears in their zeal to preserve what they envision to be a pristine environment. Others have described them as "coercive utopians" (Metzger, 1977) and advocates of halting all technical progress for which the development of nuclear power provides them with a rallying point. Although the environmental groups are seen as a potent force in today's society, I, for one, do not believe they have been nearly as effective in influencing either public opinion or government policies as my colleagues in the technical community give them credit for. The vast majority of the general public has the sense to see these "environmentalists" for what they are and takes this into account.

The news media have also been accused of playing a nefarious role in needlessly inflaming public fears with frequent horror stories on the predicted consequences of nuclear waste disposal. To become a hero to the media it seems that all one needs to do is view with alarm any real or imagined environmental problem. It matters little whether the frightening story has any basis in fact or logic. Fear sells. I believe it was Walter Kronkite who said, "The public is not interested in the number of cats and dogs who do not get lost every day." It is certainly the job, if not the duty, of the news media to bring any real or potential health and safety threat to the public's attention. They have neither the capability nor the responsibility to evaluate the technical validity of every news item that comes to their attention. They do have the responsibility to remain financially solvent by selling newspapers or maintaining high viewer ratings if they wish to stay in business. Since sensational or fearful news is more likely to attract attention, the media have a natural and understandable bias toward such stories. In reporting them, the media is just "doing their thing" and, I believe, the majority of the public has the sense to take this fact in consideration.

In evaluating the role that the public itself has had in nuclear waste developments I cannot agree with colleagues in the technical community who disparage non-technical people for their stupidity in failing to understand the problem. Nor can I agree with H. L. Menken who claimed that, "Nobody ever went broke by underestimating the ignorance of the public." Regarding nuclear waste, the public has been most rational. Their fears and apprehensions are most understandable, given the information available to them. Discounting, for the moment, the media horror stories on the subject, suppose that one totally unfamiliar with the subject were to gain their entire knowledge from a review of government laws, regulations, and policies related to nuclear waste. Suppose that in addition they were to review all of the government sponsored research on the subject and evaluate the enormous budgets expended on that research. The only conclusion that one could arrive at by rational inference is that nuclear waste: (1) is hazardous beyond all comprehension, and (2) poses a threat of unprecedented duration. I can sympathize with the public's fear. Were I not technically conversant with the subject I would share that fear. It is unreasonable to expect the general public to have the same understanding of complex technical subjects as do scientists. The public depends on guidance from the technical community to gain that understanding.

In viewing the role of those in the technical community who perform the nuclear waste research along with the political officials who provide the necessary taxpayer funds and the bureaucrats who administer those funds and write the policies, I am reminded of a quotation from the comic strip Pogo; "We have met the enemy, and he is us."

To solve the problem in this country we have managed to set up a heavily funded nuclear waste establishment of scientists and bureaucrats. We have simultaneously given that establishment a strong disincentive to solve the problem. Previously in this paper, arguments were presented indicating that from a technological standpoint, the nuclear waste problem was relatively minor. Obviously it is difficult, if not impossible, to maintain huge levels of funding support for research on relatively minor problems. Since self-perpetuation is a fundamental characteristic of bureaucracies, especially those with giant budgets, there seems to be little incentive for the nuclear waste establishment to discourage the perception that nuclear waste disposal is anything but a serious and complex problem that requires extensive research and development efforts. It is difficult to be optimistic that an acceptable solution to the waste management problem will be found as long as those with the responsibility for solving it would find it to their disadvantage to do so.

I am not implying that all of the individuals and organizations involved in nuclear waste research are sinister and would place their self interest above the public welfare. In some cases that description might be appropriate; however, for the most part I believe those scientists and managers in nuclear waste are basically trying to do the best job they can within a system that appears to have been designed for failure.

What caused this sorry state of affairs? In considering this question, I am reminded of an idea that Leonard Sagan of the Electric Power Research Institute facetiously "proposed" several years ago. In addressing the "Environmental Crisis," Sagan, with tongue in cheek, suggested we recycle human waste by universally applying a medical procedure in which a connection is established between the rectum and the stomach--a single closed loop system to reduce human pollution and assure recycling. He then went on to conjecture on the reaction of various groups:

- Government regulatory agencies concerned that the primary loop might fail will demand a second loop--the so-called "double loop system."
- Conservationists will declare that the proposal has no merit at all since small releases will continue to occur. They will demand zero release. This is technologically feasible, but risk-benefit analyses seem to rule it out.
- Lawyers will feel that the issue could only be resolved in court, particularly since the surgeons themselves are not free of taint.
- Industry will respond with full-page ads which point out that the small amounts to be released from the loop are far less than the background levels to which we have always been exposed, particularly in families which own cats and dogs.
- Public relations men will propose painting the effluent white.
- Economists will argue that we can accomplish the same thing by raising dime toilets to a quarter.

The point Sagan wanted to make was this: In discussions of the environmental crisis, each discipline tends "to see its own expertise as providing solutions superior to all others." Thus, instead of a cooperative effort by interested parties there has developed an atmosphere of suspicion and hostility, name calling and holier-than-thou ism.

An early and significant milestone in the evolution of our waste management policies occured in the mid-fifties with the report of a National Academy of Science panel suggesting the geologic disposal of nuclear waste in salt deposits. Since that panel was composed predominantly of geologists, it was apparently preordained that nuclear waste was to be a geological problem. It remains that way to this day. Singer (1983) appropriately describes the Nuclear Waste Policy Act of 1982 as being a "geologist's full employment act." He further asserts that this legislation, "...is known irreverently as the Nuclear WPA--and for good reasons. NWPA may be the largest public-works program ever foisted onto the American public by Congress. Unlike cross-country canals, flood control and other water-management projects, there is not even a useful output here. Just $100 billion (or so, depending on inflation), spent over 25 years, with a bunch of people digging deep holes in the ground and another bunch filling them in."

After the geologists staked their claim on this valuable territory, the material scientists came along proclaiming the need for development of ever more stable waste forms to assure that there would be no dissolution of the buried deadly waste in groundwater. Later the systems analysts boarded the gravy train and applied increasingly more complex calculational models to predict the radiological consequences of these geologically isolated, chemically stabilized, nuclear wastes in future millenia. The results ofthese calculations generally indicated those consequences would be miniscule; however, because of the vast uncertainties in their models and calculational assumptions, it was usually concluded that further refinements in the modeling process and further study were required. Commenting on the nature of expertise being brought to bear on the nuclear waste problem, Ida

Hoos (1977) observed, "If the only tool one has is a hammer, all problems tend to be treated as if they were nails."

Topping the melange of technical talents working the nuclear waste problem are battalions of government bureaucrats who administer the taxpayers' and ratepayers' financial contributions to the effort. Finally, orchestrating the whole show are the politicians applying their well-known wisdom and judgement to assure that the public is well protected against the "dire threat" that nuclear waste poses. Should you ever wonder why, after three decades of intensive research and the expenditure of enormous sums of money on the nuclear waste problem, we seem no closer to an accepted solution than we were in the beginning, perhaps the insights in this papaer will provide some clue as to the answer.

It somehow seems appropriate to close this discussion on the nature of the nuclear waste problem with an excerpt from "Alice in Wonderland":

> "I was wondering what the mouse-trap was for," said Alice. "It isn't very likely there would be any mice on the horse's back."
> "Not very likely, perhaps," said the Knight; "but, if they <u>do</u> come, I don't choose to have them running all about."
> "You see," he went on after a pause, "it's as well to be provided for <u>everything</u>.
> That's the reason the horse has all those anklets around his feet."
> "But what are they for?" Alice asked in a tone of great curiosity.
> "To guard against the bites of sharks," the Knight replied. "It's an invention of my own . . ."

I sometimes conjecture that an untold part of this tale was that much of the wealth of the realm had been spent to study the chrystalline structure of the anklet metal to assure it would be impenetrable to shark teeth. So successful was this effort, that not one horse was afflicted by shark bite throughout the entire kingdom; even those horses that didn't wear them. Unfortunately, half of the horses starved to death because there were no research funds left to study methods for the prevention of oat blight.

TABLE 2.1

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

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

From Cohen [1976]

Table 2.2

CRUSTAL ABUNDANCE OF TOXIC ELEMENTS

TOXIC ELEMENT	CRUSTAL ABUNDANCE (GM)		HAZARD* INDEX (m^3)
ARSENIC	1.0×10^{20}		2.0×10^{21}
BARIUM	8.6×10^{21}		8.6×10^{21}
CADMIUM	3.6×10^{18}		3.6×10^{20}
CHROMIUM	4.0×10^{21}		8.0×10^{22}
LEAD	3.2×10^{20}		6.4×10^{21}
MERCURY	1.0×10^{19}		5.0×10^{21}
SELENIUM	1.8×10^{18}		1.8×10^{20}
URANIUM	4.0×10^{19}		3.5×10^{17}
		TOTAL	10^{23} m^3

*HAZARD INDEX: Volume of water required to dilute indicated quantity of material to level of safe drinking water standards.

Table 2.3

HAZARD INDEX OF NUCLEAR WASTE PRODUCED FROM 10^8 MWe-Yr* OF POWER PRODUCTION

AGE OF WASTE WASTE (Yr)	HAZARD INDEX (m^3)
100	7.0×10^{16}
10^3	5.0×10^{13}
10^4	1.0×10^{13}
10^5	4.0×10^{12}
10^6	1.0×10^{12}

*One thousand nuclear power reactors each operating for 100 years and each capable of generating 1000 MWe.

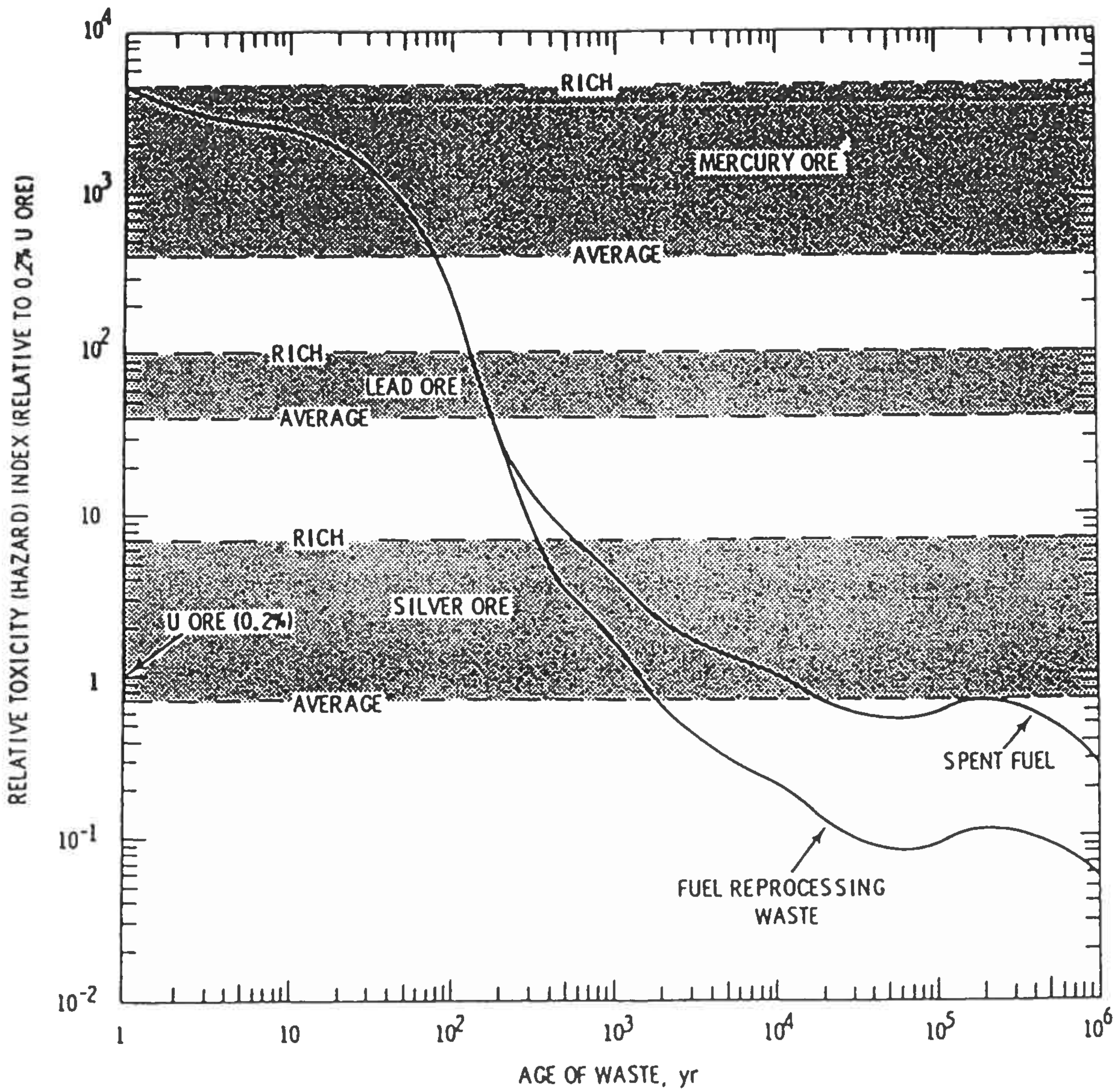
Table 2.4

TOXIC ELEMENTS IN THE WORLD'S OCEANS

TOXIC ELEMENT	OCEANIC BURDEN (GM)	HAZARD INDEX (M^3)
ARSENIC	8×10^{15}	1.6×10^{17}
BARIUM	4×10^{16}	4.0×10^{16}
LEAD	3×10^{15}	6.0×10^{16}
MERCURY	3×10^{14}	5.0×10^{16}
SELENIUM	3×10^{13}	3.0×10^{17}
		6.1×10^{17}

Figure 2.1

RELATIVE HAZARD OF NUCLEAR WASTE
VARIOUS ORE BODIES



Toxicity of Spent Fuel and Reprocessing Waste from Uranium-Plutonium Recycle Relative to 0.2% Uranium Ore Necessary to Produce 1 MT of Reactor Fuel

Figure 2.2

HAZARD INDEX OF URANIUM AND ITS FISSION PRODUCTS

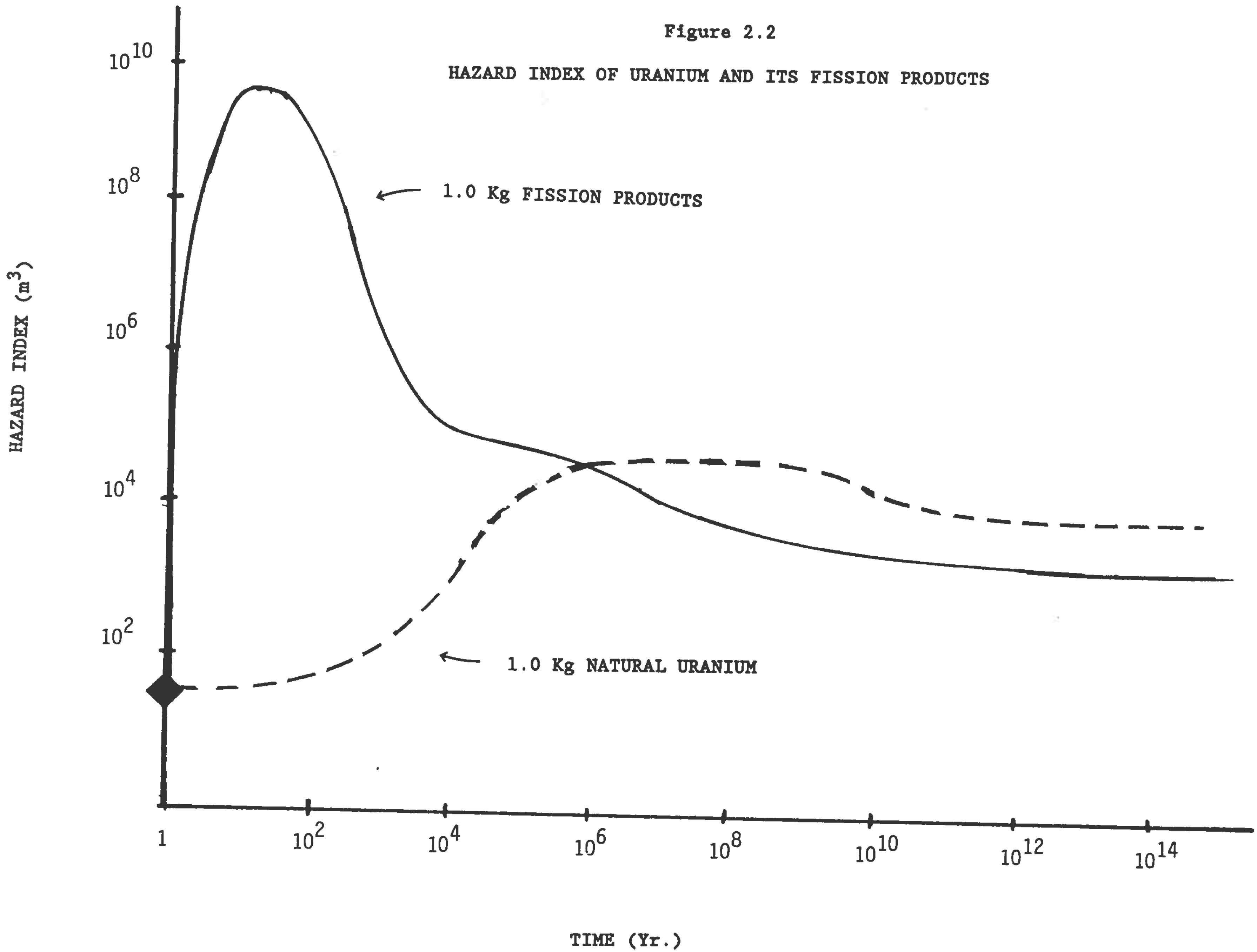
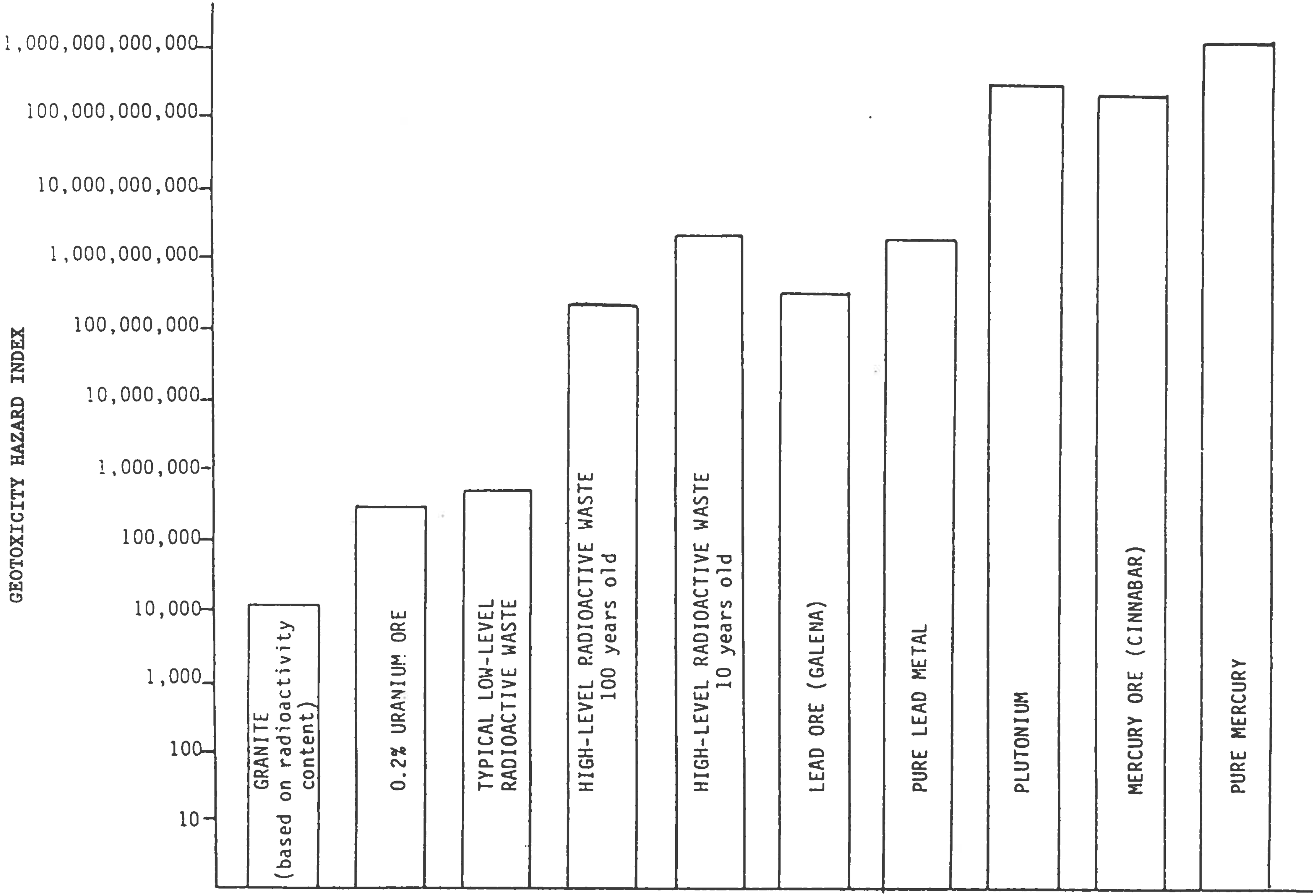


Figure 2.3

RELATIVE HAZARD OF VARIOUS MATERIALS BURIED UNDERGROUND
(Based on Ingestion Toxicity)



VALUES BASED ON <u>ONE CUBIC METER</u> OF INDICATED MATERIAL

REFERENCES

Abalone Alliance, "The Leaky Nuclear Fuel Cycle," Radioactive Times, Waller Press, San Francisco, CA (1979).

Claiborne, H.C., "Effect of Actinide Removal on the Long-Term Hazard of High Level Waste," Oak Ridge National Laboratory Report ORNL-TM-4724 (1975).

Cohen, B., "Environmental Impacts of High Level Radioactive Waste Disposal," I.E.E.E. Transactions on Nuclear Science, Vol. N5-73, No. 1, p. 56 (February, 1976).

Cohen, B., "High Level Radioactive Waste From Light Water Reactors," Review of Modern Physics, 49:1 (January, 1977).

Cohen, B., "Ocean Dumping of High Level Waste - An Acceptable Solution We Can Guarantee," Nuclear Technology, 47:163 (January, 1983).

Cohen, J.J., C.F. Smith, and A.J. Toy, "Characterizing the Risk of Long-Lived Radionuclides in Waste," Trans. American Nuclear Society, Reno, NV, Vol. 52, p. 37 (June, 1986).

DOE/EIS-0046F, "Final Environmental Impact Statement on Management of Commercially Generated Radioactive Waste," U.S. Dept. of Energy (1980).

Gera, F., and D.G. Jacobs, "Hazard Potential of Radioactive Wastes," in Proc. Intern. Conf. on Radioecology Applied to Protection of Man and His Environment, EUR-4800, Rome (1971).

Gera, F., and D.G. Jacobs, Considerations in Long-Term Management of High-Level Radioactive Wastes, Oak Ridge National Laboratory, Rept. ORNL-4762 (1972).

Goldberg, E.D., "Assimilative Capacity of U.S. Coastal Waters for Pollutants," U.S. Dept. of Commerce (December, 1979).

Hamstra, J., "Radiotoxic Hazard Measure for Buried Solidified Radioactive Wastes" Nucl. Safety, 16, (2) (1975).

Haug, H.O., "Some Aspects and Long-Term Problems of High-Level and Actinide-Contaminated Spent Fuel Reprocessing Wastes from the Nuclear Fuel Cycle," Oak Ridge National Laboratory, Rept. ORNL-TR-4302, translation of KFK-2022 (1977).

Hoos, I., Statement in Proceedings of a Public Forum on Environmental Protection Criteria for Radioactive Waste, USEPA, ORP/CSD-78-2 (1978).

Kocher, D.C., "A Dynamic Model of the Global Iodine Cycle for the Estimation of Dose to the Worlds Population from Releases of Iodine-129 to the Environment," Oak Ridge National Laboratory ORNL/NUREG-59 (1979).

Marshall, E., "Nuclear Waste Program Faces Political Burial," Science 233:835 (22 August 1986).

McKay, H.A.C., "Background Considerations in the Immobilization of Volatile Radionuclides," International Atomic Energy Agency, Vienna, IAEA-SM-245/8 (1980).

Oztunali, O.I. and K.D. Petschek, "Reexamination of Radiotoxicity of Iodine-129," Waste Management 83, Vol. 2, p. 353, U. of Arizona, Tucson, AZ (1983).

Physics Today, "The Nuclear Fuel Cycle: An Appraisal," pp. 32-39 (October, 1977).

Rowe, W.D., "What is EPA's Role in Radiation," EPA Journal 2:2:14 (1976).

Singer, S.F., "Seeking Some Ways to Store Nuclear Waste," Wall Street Journal (March 29, 1985).

Smith, C.F., J.J. Cohen, and T.E. McKone, "A Hazard Index for Underground Toxic Material," UCRL-52889, LLNL, Livermore, CA (June, 1980).

UCRL-15530, Cohen, J.J., C.F. Smith, and F.J. Ciminesi, "Nuclear Waste - A Perspectives Document," LLNL, Livermore, CA (February, 1983).

UCRL-78746, Tonnessen, K.A. and J.J. Cohen, "Summary of Naturally Occurring Hazardous Materials in Deep Geologic Formations," LLNL (November, 1976).

Wick, O.J. and M.O. Cloninger, "Comparisons of Potential Radiological Consequences from a Spent-Fuel Repository and Natural Uranium Deposits," Battelle-Pacific Northwest Laboratory, Richland, WA, PNL-3540 (1980).

Williams, W.A., "Population Risks from Uranium Ore Bodies," U.S. Environmental Protection Agency, EPA 520/3-80-009 (1980).