The following document is excerpted from the various references listed below.

CHEMICALS AND SOCIETY

The 20th century has seen the birth of three Ages, each with profound social implications. These have been called the Nuclear Age, the Electronic Age and the Chemical Age. The latter is the oldest (beginning ca. 1930), and although its impact has been less dramatic than the other two, its consequences have more thoroughly and deeply permeated our day-to-day lives. Our local grocery, hardware, garden and drug stores carry an impressive array of commonly used chemical "tools", such as detergents, adhesives, lubricants, fabrics, pesticides, pharmaceutical drugs, vitamins and a multitude of fabricated plastic items. Industrial applications of chemical tools include explosives, heat-transfer gases and liquids, specialized coatings, fire retardants and high-performance plastic components.

Despite our widespread use of chemical tools, indeed some might say because of our reliance on them, many people fear exposure to these materials, and have deep concerns regarding the use, storage and disposal of chemicals. Paradoxically, we find our desires for more abundant consumer goods, energy and personal mobility in conflict with maintenance of a healthful environment. To be sure, environmental degradation, with accompanying threats to health and disruption of ecosystems, is not a new phenomenon. From the earliest recorded history, human disturbance of the environment by deforestation, air pollution from cooking and heating fires, and careless sewage and waste disposal has been noted. Today, as global populations grow and per capita energy use and material consumption increases, pollution problems are exacerbated, and previously unnoticed secondary effects manifest themselves.

It must be emphasized that effective strategies for safeguarding our environment require knowledge and understanding. To this end, we must be able to answer the following questions:

- What potentially undesirable substances are present in our air, water, soil and food?
- Where did these substances come from?
- What options, alternative products and processes are available to reduce or eliminate undesirable contaminants?
- How does the degree of hazard depend on the extent of exposure to a given substance, and how shall we choose among various corrective options?

The first of these questions requires chemical analysis, and thanks to advances in instrumentation, our ability to detect extremely small amounts of a given substance is unprecedented, and sometimes leads to unwarranted concern. Answers to the second question usually involve collaborative investigations by analytical chemists together with biologists, meteorologists, volcanologists, oceanographers and other scientists. The development of options, as noted in the third question, calls upon our full range of chemical understanding, and often obliges us to make controversial choices. For example, the world mortality rate due to malaria was drastically reduced (over 95%) in the 1950s by widespread application of the insecticide DDT . Because of this chemical's environmental persistence and toxicity to certain birds and crustaceans, use of DDT was effectively terminated ca. 1964. Third world malaria cases immediately spiraled, reaching over 250 million in 1990. Cheap, effective and environmentally friendly alternatives to DDT are needed, but are not necessarily easy to find. The fourth question is addressed by physicians, toxicologists and epidemiologists. A substantial body of knowledge has accumulated on this subject, but there is also considerable public confusion surrounding it.
Our strategies for risk minimization and environmental protection should be based on realistic hazard thresholds, and on our ability to detect specific offending substances well before their presence reaches that threshold. In this sense, **detection can be equated to protection.** Unfortunately, the public, the media, and government officials all too often equate detection with hazard. This is based on the widely held belief that a substance known to be toxic at a certain concentration will be toxic at any concentration, no matter how low. This is not true, as will be shown below.

We should seek to minimize risk; but we must recognize that society cannot afford to pay the excessive costs of eliminating all risk, a virtually impossible goal in any event.

Risk Assessment

Every day we take risks and avoid others. About 250 people in the U.S. are electrocuted every year in accidents involving home wiring or appliances. This represents a risk of death of about $8*10^{-7}$ per year (250 divided by the U.S. population) or

$6*10^{-6}$ per lifetime (75 yr.). Nevertheless, most of us choose to live in electrically wired homes, and make extensive use of electrical appliances. Likewise, many people would be unwilling to live within 20 miles of a nuclear power plant, yet accept (even request) a 4,000 times greater radiation dose from medical x-rays or 6,500 times greater cosmic radiation at altitudes of a mile or more.

Getting to work or school is also risky. Whether we walk, cycle, drive or take public transport, we make choices based on risk, convenience and expense. Most of us act semi-automatically to balance our risks with expediency. We also expect society to minimize the risks suffered by its members, subject to moral and economic constraints. To recognize, understand and minimize risks requires knowledge of many factors. Some of this knowledge is gained through personal experience; much of it is acquired by others, and can be found in published reports. Some estimated risks are given in the following table.

Estimated Commonplace Death Risks (mean values)

Action	Annual Risk	Uncertainty	50 Year Period
Motor vehicle accident (total)	$2.4*10^{-4}$	10%	1 in 100
Motor vehicle accident (pedestrian only)	$4.2*10^{-5}$	10%	1 in 500
Home accidents	$1.1*10^{-4}$	5%	1 in 200
Electrocution	$5.3*10^{-6}$	5%	1 in 5,000
Firearms Accident	$1.0*10^{-5}$	10%	1 in 2,000
Cigarette smoking (1 pk/day)	$3.6*10^{-3}$	factor of 3	1 in 5
Background radiation (sea-level)	$2.0*10^{-5}$	factor of 3	1 in 1,000
Alcohol (moderate drinker)	$2.0*10^{-5}$	factor of 10	1 in 1,000
Cancer (all)	$2.8*10^{-3}$	10%	1 in 7
Drinking water (EPA limit of chloroform)	$6*10^{-7}$	factor of 10	1 in 33,000
Drinking water (EPA limit trichloroethylene)	$2*10^{-9}$	factor of 10	1 in 107
Asteroid Impact on Earth	ca. 10^{-6}	large	1 in 10,000

Risk factors are often reported as a number between zero and one (0 for no risk and 1 for absolute risk). Such notation can be converted to "odds" by taking the reciprocal. Thus, a risk factor of $2*10^{-3}$ corresponds to odds of 1 in 500.

The concept of risk and the notion of uncertainty are closely related. The lifetime risk of dying from cancer is roughly 22%, and is somewhat greater for those who smoke. However, even if an individual is a heavy smoker, we cannot say with certainty he(she) will die of lung cancer. On the other hand, if that individual is dying as the result of a serious automobile accident, the risk of dying from cancer drops to nearly zero.

The way in which risks are perceived is correlated with the way in which they are calculated. Risks based upon long term data, such as automobile accidents, are understandable and usually regarded as reliable. The long term approach to estimating risk can only be used when the hazard has been present and identified for some time, and the risk is large enough to be observed. This is the case for many kinds of accidents, as well as many technological and general chemical risks. On the other hand, we have no experience with asteroid collisions, and any estimate of an individual's risk of dying due to such a collision with our planet will have a large uncertainty. Over a fifty year period, this has been estimated as 1 in 10,000. This probability is much larger than the odds of winning the lottery, due in part to the fact that an enormous number of people would die in an asteroid collision, whereas the lottery has only one winner.

References:
R.Wilson and E.Crouch, **Science**, April 17, 1987. (This issue has many articles on risk)
R. Hooke, "How to Tell the Liars from the Statisticians"

Using Chemicals

As with any other kind of tool, chemicals must be handled correctly, with proper care and precaution. Although chemicals vary in the hazards they present, it is generally wise to treat all chemicals as though they are potentially dangerous. Among the recognized hazardous properties of chemicals are: explosiveness, flammability, corrosiveness, irritation, sensitivity, toxicity and radioactivity. One of the most useful sources of information about chemical hazards is the material safety data sheet (MSDS). Information about these data sheets is available at MSDSonline. It is an interesting exercise to examine the MSDS for common chemicals such as acetic acid (vinegar) and naphthalene (mothballs).

Of all the hazardous properties noted above, toxicity seems to constitute the greatest concern in the minds of the public. Contrary to popular belief, the fact that a substance is toxic does not mean it will always kill people or animals exposed to it. Virtually all substances are lethal if taken in sufficient amount. As noted by the Swiss Physician Paracelsus, *It is the dose that makes the poison!* Thus, 1.5 grams of arsenic trioxide will kill a 180 pound man; 2 milligrams will not. Small amounts of vitamin D (ca. 10 micrograms per day) are necessary for good health, but in larger amounts it is more toxic than arsenic compounds.

Most of the poisons we are familiar with are acute toxins, that is they cause immediate death in sufficient dose. The relative toxicity of such substances is roughly indicated by an LD_{50} dosage, the amount of a chemical (adjusted for subject body weight) that kills one half of a large group of test animals. Clearly, the smaller the LD_{50} the more toxic the substance. Some examples of LD_{50}'s for common substances are given in Table 1. For highly toxic materials the LD_{50} is usually given as mg per kg, as in Table 2. Note that LD_{50}'s vary markedly with the animal species used, and the way in which the test substance is administered. Most of the compounds in Tables 1 & 2 were administered orally.

Many people are surprised to learn that the toxicity of a given substance has no relationship to whether it is synthetic (manufactured) or natural. Nearly two thirds of the extremely toxic substances in Table 2 are of natural origin.

Table 1 LD_{50}'s of Some Common Substances
(using mice or rats)

Substance	Animal	LD_{50} (g/kg)
Acetaminophen (analgesic in Tylenol)	Mice	0.34
Acetic Acid (component of vinegar)	Rats	3.35
Arsenic Trioxide	Rats	0.015
Aspirin	Mice & Rats	1.50
BHA (antioxidant food additive)	Mice	2.0
Caffeine	Mice	0.13
Ethyl Alcohol	Rats	10.3
Ibuprofin (analgesic in Advil)	Rats	1.0
Nicotine	Mice	0.23

Table 2 LD_{50}'s of Some Toxic Substances
(using mice or rats)

Substance	LD_{50} (mg/kg)
Botulinum Toxin A	$3x10^{-8}$
Ricin (castor bean toxin)	$3x10^{-6}$
Tetanus Toxin A	$3x10^{-6}$
Diphtheria Toxin	$3x10^{-4}$
TCDD (dioxin)	$3x10^{-2}$
Muscarine (a mushroom toxin)	0.2
Sarin (a nerve gas)	0.4
Strychnine	0.5
Soman & Tabun (nerve gases)	0.6

Sodium Benzoate (food preservative)	Rats	4.1
Sodium Chloride	Rats	3.73
Vitamin B_1 (thiamine hydrochloride)	Mice	8.2
Vitamin A	Mice	2.5

Curare (tubocurare)	0.7
Rotenone (a natural insecticide)	3.0
Parathione (a synthetic insecticide)	4.0 (female) 13.0 (male)
Sodium Cyanide	15.0

Acute toxicity is only one of several harmful characteristics that should be considered when evaluating the hazards posed by contaminants. Other more subtle and long range effects may exist, as described in Table 3.

Table 3 Test Methods for Toxicity of Chemicals

Test	Procedure
Acute Toxicity (LD_{50})	Groups of animals are treated with a range of doses, and the number of dead are counted after a set time (usually 24 hr). The dosing method may vary (eg. oral, intravenous, topical, inhaled etc.).
Chronic Toxicity	Animals are treated repeatedly with sublethal doses. Pathological examinations are made at set times (eg. 1 month, 6 months, 1 year etc.). Method of dosing should reflect practical risk (eg. oral, topical, inhaled etc.).
Carcinogenicity	Identical to chronic toxicity study, paying attention to tumors and incipient changes in tissues.
Mutagenicity	The Ames test. Mutations of microorganisms that have been altered by genetic manipulation are studied. Gross effects on chromosomal DNA are examined microscopically.
Teratogenicity	Pregnant animals are treated with appropriate doses at early stages. The number of aborted, defective and surviving fetuses are counted. Pathological examinations are conducted.

Because cancer ranks among the most serious and feared human health problems, and is generally slow to develop to the point of diagnosis, Ames' studies of mutagenicity in microorganisms and tumors in rodent populations provide an indication of possible carcinogenic hazards to humans. By comparing the average daily human exposure to a substance with the rodent testing results, Ames is able to rank the carcinogenic potential of different compounds. The results of his study are remarkable. Roasted coffee contains more than twenty carcinogenic compounds, and three cups of brewed coffee pose 100 times the potential hazard as the chloroform in a daily consumption of chlorinated tap water. The limonene in a glass of orange juice proved to be over 30 times more hazardous than tap water. Surprisingly, synthetic pesticides, such as DDT, lindane and captan, were among the least problematic at their average exposure level. Humans vary considerably in their sensitivity to natural and synthetic chemicals. Strawberry, peanut and latex allergies are relatively common, and reports of asthma-like symptoms on exposure to synthetic plasticizers exist. A more complex and less well-defined syndrome, known as **multiple chemical sensitivity**, is the subject of medical controversy, although it is very real to those who suffer its effects. One thing is certain. If you wish to avoid exposure to chemicals, the planet earth is a poor place to live.

References:

Chemistry and Society, H. D. Crone
Opportunities in Chemistry, G. Pimental & J. Coonrod
The Consumers Good Chemical Guide, J. Emsley
The Dose Makes the Poison, M. A. Ottoboni
Phantom Risks, K. R. Foster, B. E. Bernstein & P. W. Huber
Toxic Terror, The Truth Behind the Cancer Scares, E. W. Whelan
Why Things Bite Back, The Revenge of Unintended Consequences, E. Tenner