GEOTOXIC CONSIDERATIONS FOR UNDERGROUND BURIAL OF HAZARDOUS MATERIALS

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INTRODUCTION

The incorporation of toxic material into the geosphere is not a phenomenon unique to underground burial of radioactive or chemically hazardous wastes. The earth's crust contains many diverse toxic mineral constituents (e.g., Pb, Hg, Cr, Ra, U, asbestos, etc.). These have existed from primordial times, throughout the entire development of man and, for that matter, the evolution of all biological life. Determination of the extent to which burial of toxic waste would marginally increase geotoxic levels generally or at specific sites can provide useful insights on the nature and degree of resultant hazards.

In order to evaluate the hazard of toxic material buried underground, the concept of geotoxicity is presented in this paper. This concept permits the development of a tool for quantifying the degree of hazard of such material, and this tool is formulated as the geotoxicity hazard index. The components of the geotoxicity hazard index (GHI) are described and discussed. Finally, some sample results results are offered. A detailed description of the original development of the GHI can be found in the report "A Hazard Index for Underground Toxic Material," UCRL-52889, June 1980.[1]

BACKGROUND

Predictive modeling based largely upon theoretical principles has found wide application in determining potential consequences of underground burial of radioactive wastes. This approach, however, has definite limitations.[2] The analog approach can provide another assessment tool, which may be applied in parallel with theoretical modeling to gain additional insight.

The basis for the analog approach is field observation and data resulting from study of the movement and biological effects of natural underground toxic materials. Obviously, field work may be guided by theoretical considerations, and observed data may be useful in revision or verification of theory. In other words, insights useful in development and validation of theory can be drawn from natural analog investigations.

GEOTOXICITY

The overall approach we apply to problem definition is the geotoxicity study. This study involves the characterization and assessment of the harmful effects of hazardous material buried in the earth's crust by either man or nature. It should be recognized that incorporation of toxic materials in the earth's crust via radioactive or toxic waste burial does not present unique or unprecedented risks to health and the environment. Nature has done essentially the same throughout the entire history of the earth in toxic mineral deposits.[3] The geotoxicity concept utilizes this perspective to provide useful insights on the fate of these materials in the biosphere. B. L. Cohen[4] has characterized the approach as using the earth itself as a large analog computer. In any case, it is most useful to have a measure or "yardstick" with which one may characterize the hazard of toxic material buried underground. With this objective in mind we have developed an analog index of toxic material hazard. This index may be used:

- to provide an easy to use comparative tool
- to gain perspective on geotoxicity
- to enable screening of concepts for the disposal of toxic material
- to provide insight on the relative hazard of toxic components
- to permit examination of the source of toxic hazard

It should be noted that this analog index is not intended to substitute for detailed systems modeling used for prediction of specific consequences and their magnitude. However, it can be used to provide additional insight on the severity of the general problem (or lack of it). Also, the results of deterministic analysis can provide valuable input to hazard index determinations.

THE GEOTOXICITY HAZARD INDEX

To accommodate the parameters known to influence hazard, the geotoxicity hazard index (GHI) was developed.[1] This index includes terms for toxicity, persistence or time effects, availability or transport potential, and the buildup of toxic decay daughters. The index is defined as follows:

$$GHI_i = TI_i \cdot P_i \cdot A_i \cdot C_i$$

$$GHI = \sum TI_i \cdot P_i \cdot A_i \cdot C_i$$

where

TI = toxicity index
P = persistence
A = availability
C = buildup correction
i = material index

For a given material i, GHI is determined as a product of four factors which represent toxicity, persistence, availability, and decay product buildup. The index can be viewed as a toxicity index which is modified by three dimensionless parameters to successively incorporate time, transport, and decay effects. For a mixture of toxic materials, the total GHI is obtained through summation of the individual indices for the toxic components.

In the formulation of the geotoxicity hazard index, toxicity, persistence, and buildup are factors that highlight the differences between the subject toxic material and its natural analog. Availability, on the other hand, is the term describing behavior in a manner analogous to the natural (stable element) transport counterpart.

As a first approximation, data have been presented by Cohen and Jow[5] which describe the relationship between human intake rates and crustal abundance for each element based on its overall gross natural average. This value may then be appropriately modified to reflect deviations from the gross average resulting from specific characteristics of the waste form or its geologic setting which may differ from that of the natural analog. In the following sections, each term of the GHI will be discussed in turn.

Toxicity Index

TI (Toxicity Index) represents the inherent toxicity of the geologic volume or toxic material inventory under consideration. It can be determined as the net inherent toxicity of the toxic constituents under consideration relative to that contained in some standard volume of earth (e.g., the net toxicity of the average million cubic meters of earth crust or soil). TI is calculated considering the MPC's of radioactive constituents and the EPA Drinking Water Standards for chemically toxic components of the land volume or inventory under consideration. In the case of chemically hazardous waste, definitive information on standards is often unavailable and the TI must be inferred on the basis of toxicological data. In addition, there are several different sets of standards that can be used in specifying MPC's for radioactive constituents. Although the toxicity values resulting from such standards may be somewhat inconsistent, the nature of the overall approach does not call for great precision, and the insights derived may still be considered valid. Utilization of ICRP-30 toxicity values for radionuclides will be discussed in a later section of this paper.

Persistence

The second factor in the GHI is the persistence factor, P. For stable materials, the persistence factor has a value of one, indicative of maximum persistence. For materials which decay, P has a value less than one. Persistence is defined as the average fraction of the original material which is present in undecayed form, over a reference 300 year time frame.

Availability

The third term in the GHI is the availability factor, A, that relates the ingestion of a material to its concentration in the earth's crust. The availability factor, A, is further defined as the product of a modification factor, m, and A_0 which is the average availability of the natural analog of the material under consideration. A_0 is defined as the ratio of the ingestion rate of the material to its crustal abundance, divided by the same ratio for naturally occurring Radium-226. The modification factor, m, is intended to account for differences between the actual burial conditions and the average conditions for the natural analog. For example, if a material is significantly less available than its natural analog because of isolation barriers, siting, waste form, depth, or other condition, the m factor would be significantly less than one. For availability no better or worse than the average natural conditions, m would be given a value of one. Data for human intake and natural abundance have been taken from Cohen and Jow.[5] Estimation of the availability modification factor, m, can be carried out using empirical data or analytical models. The important feature is that determination of availability uses the best information currently available, subject to improvement as better information is obtained.

Buildup Correction

The last component of GHI is C, the buildup correction factor. This factor is used to accommodate the buildup of decay progeny more toxic than the parent. Two examples might be the decay of

U-238 through Ra-226 to stable lead, and the transformation of elemental mercury into the more toxic methylated form. C is determined as the ratio between peak decay progeny toxicity and initial toxicity of the toxic material constituent under consideration. It should be noted that, in the majority of cases, C is equal to one. Materials with a significant buildup of decay toxicity are the exception rather than the rule. U-238 is the most extreme case which we have identified, where $C = 4.5 \times 10^3$ due to the buildup of Ra-226.

SAMPLE RESULTS

In order to demonstrate the use of the geotoxicity hazard index, several representative toxic material deposits were considered.[1] Table I shows the results of the GHI calculations for these sample cases. While they involve several assumptions and simplifications, they are shown to illustrate the nature of the calculational results and to indicate the types of applications for which the GHI could be used.

As an additional application to the problem of hazardous waste disposal, a GHI calculation based on the toxic metal content of 10^6 tons of municipal wastewater sludge was carried out. In this calculation, the availability modification factor was assigned the value 1 since shallow land disposal was assumed. Table II shows the results of this calculation which used sludge composition values from reference 6. The sludge inventory of 10^6 tons was taken as a reasonable estimate for a large city. Note that the annual U.S. municipal wastewater sludge disposal rate is 7.3×10^6 tons.[7]

AREAS OF CONTINUING EFFORT

The development and application of the GHI represents an ongoing effort focusing on several areas for improvement. Future effort on the GHI will include converting the index into dimensionless form, and normalization to avoid the large powers of ten seen in the results.

Another goal toward which future effort will be devoted is improvement in estimation of the availability factor (A). This work is seen as an iterative process by incorporating new information into improved estimates. Further refinement of the calculational parameters will provide increased confidence in the results.

Table I
Results of Sample GHI Applications

Site	GHI
Low Level Waste Repository	2.7×10^{11}
High Level Waste Repository	4.4×10^{13}
Uranium Ore Deposit	3.0×10^{12}
Mercury Ore Deposit	1.3×10^{13}
Lead Ore Deposit	9.7×10^{12}

Table II
Municipal Wastewater Sludge: GHI Based on 10^6 Tons of Sludge

Component	Inventory (grams)	GHI
Mn	3.8×10^{8}	1.2×10^{10}
B	7.7×10^{7}	4.9×10^{8}
Hg	7.3×10^{8}	1.0×10^{14}
Cu	1.2×10^{9}	3.2×10^{10}
Zn	2.8×10^{9}	4.8×10^{10}
Pb	1.4×10^{9}	2.9×10^{11}
Cd	1.1×10^{8}	2.6×10^{12}
	Total GHI	1.0×10^{14}

Conversion of radiotoxicity values to incorporate ICRP-30[8] information is currently being carried out. Table III compares selected specific toxicity values using 10CFR-20[9] MPC's and MPC's derived from the ICRP Annual Limits for Intake (ALI's).

Evaluation of alternative expressions for persistence, extension of the methodology to inhalation pathways, and developing comparable measures of toxicity between radioactive and nonradioactive components are other study areas requiring additional effort.

SUMMARY

In summary, the natural analog approach can provide useful insights and perspectives into problems of disposal of radioactive as well as nonradioactive hazardous materials. The approach can be useful in the area of model verification; in addition, the approach can make use of insights derived from analytical models in improving the characterization of the parameters of the analog formulation. Finally, the approach provides a focus for studying and understanding geotoxic phenomena and the role of natural minerals in human health and disease.

Table III
Comparative Specific Ingestion Toxicities:
10CFR-20 Vs. ICRP-30

Specific Toxicity (m^3/curie)

Material	10CFR-20	ICRP-30*
H-3	10	14
Sr-90	10^5	3.2×10^4
I-129	10^5	6.1×10^4
Cs-137	2.5×10^3	1×10^4
Ra-226	2.5×10^6	2.9×10^5
U-238	10^3	5.6×10^4
Np-237	10^4	1.4×10^7
Pu-239	10^4	9.8×10^4
Am-241	10^4	4.8×10^5

*Values derived from reference 10.

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