VOLUME 2
Marline/Umetco
Technical Memoranda - 1984

September 1984

AN EVALUATION OF URANIUM DEVELOPMENT IN PITTSYLVANIA COUNTY, VIRGINIA
(October 15, 1983)

VOLUME 2

IX. TECHNICAL MEMORANDA - 1984

This section contains a compilation of technical analyses and clarifying statements developed during 1984 by Marline/Umetco consultants. These efforts were conducted in response to various interactions with Virginia regulatory agencies and the state's consultants. These Technical Memoranda (TM) supplement the Marline/Umetco October 15, 1983 report, and where noted in the text of the Technical Summary (Volume 1), they serve to modify or update that document.

Technical Memoranda included herein are:

1. Banister River Clay Volumes
2. Geochemical and Geotechnical Properties of Clays, Swanson Uranium Properties
3. Stability Evaluation of Tailings Facility
4. CSMRI Leachability Tests of Swanson Project Rock Materials
5. Summary of PABLM Input Parameters
6. Clarification on Clay Liner Issues
7. ANFO Dilution Calculation
8. PMF Dilution of Breach Volume Calculation
9. Chemical Analysis of Rock Materials
10. Chemical Analysis of Required Clay Volume per 1983 Geochemistry Work

11. Supporting Data on Evaporation from Rock Fills

12. PABLM Input Clarification Due to 1 X 10^{-7} cm/sec Liner

13. 1984 PABLM Radiological Assessment

TECHNICAL MEMORANDUM NUMBER 1

Banister River Clay Volumes

May 9, 1984

DRAVO ENGINEERS, INC.

Dravo Building
1250 14th Street
Denver, Colorado 80202
303 893-4500 Telex: 45-930

A Dravo Company

TECHNICAL MEMORANDUM NUMBER 1

TO: Roger Moose, Rogers, Golden & Halpern

FROM: Alan Notary, Dravo Engineers, Inc.

DATE: May 9, 1984

RE: Volumes of Available Clay in the Banister River Valley Alluvium

The purpose of this memorandum is to summarize our phone conversation of April 16, 1984 concerning availability of clay for the Swanson Project. As I stated at the time, this is not a commitment to any particular borrow area location or areal extent, but should be understood as a statement that sufficient quantities of suitable clay are in the area. There are other potential sources of liner construction material in addition to the Banister River area, specifically the soils overlying the mine pit and the tailings and overburden management areas. However, the volumes associated with these locations are not the subject of this memorandum.

Six auger holes, A-21 through A-26, were drilled in the Banister River alluvium during the 1983 drilling program. The locations of these holes are shown on Figure A.3-1, page A.3-2 of the October 15, 1983 report, and also on the last page of Appendix III (see attachment). Logs of the holes are shown on Figure A.3-11, page A.3-26. A summary of remolded permeability testing, Table III:3-2, is located on the last page of Appendix III, Section 2. A summary of laboratory test results (gradation, Atterberg limits, and classification) is located on the next to last page of Appendix III, and specific moisture-density curves may be found in Appendix III, Section 4.

Upon review of the logs, Chen and Associates estimated 9 feet of clay as an area average. This is equivalent to 14,500 cubic yards per acre. Assuming an upper limit of required clay volume to be 2 million cubic yards results in a required borrow area of 138 acres. (Note that the 2 million cubic yard volume is equivalent to 6.2 feet of clay over the 200 acre tailings management area.) A review of the map indicates an area of approximately 300 acres is covered by the six auger holes. Also, Marline and Umetco have agreements on other favorable river valley sites.

To summarize, the information collected to date indicates that sufficient volumes of local materials exist for liner construction at the Swanson Project. Obviously, as engineering progresses, clay requirements and clay borrow areas will be delineated with greater precision.

AN:blc
Attachment
cc: Richard Collins, Institute for Environmental Negotiation
John Yellich, Marline Uranium Corporation

TECHNICAL MEMORANDUM NUMBER 2

Geochemical and Geotechnical Properties of Clays
Swanson Uranium Project

May 31, 1984

Prepared by Roman Z. Pyrih, and Associates, Inc.
C. Sealy, Chen and Associates, Inc.
A. Notary, Dravo Engineers, Inc.

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1.0 Introduction

The purpose of this memorandum is to clarify the scope, methodology and conclusions of the geochemical and geotechnical clay studies that were conducted by Marline and Umetco (formerly Union Carbide) in 1983 and reported on in the October 15, 1983 submitted to the Uranium Administrative Group. As agreed upon at the May 2, 1984 technical meeting in Richmond, Virginia, coordinated by the Institute for Environmental Negotiation, this memo also contains a brief literature survey on the geochemical interactions of natural soils with uranium mill tailings fluids.

The major objectives of the 1983 geochemical studies were to identify the existence of locally available clay soils and demonstrate the contaminant trapping properties of those materials against three possible residual tailings fluids. These are the liquids contained in the tailings after filtration at the mill and placement in the tailings management area. The fluids studied in this program are considered "worst-case" because they were not diluted by the tailings washing procedures that will be part of the mill process, and therefore have elevated concentrations of contaminants. In addition, a limited geotechnical drilling program was conducted to provide initial estimates of material volumes to verify project feasibility.

The 1983 studies were not intended to be sufficient for a mill licensing study due to the following constraints:

- the time frame of the 1983 effort made it impossible to conduct the long-term (6 to 9 months) geochemical column testing required for a license study;

- the mill process engineering has not yet progressed to the point where a representative solution of the expected residual tailings fluid can be produced by a pilot plant;

- the reconnaissance level geotechnical drilling program conducted in 1983 was sufficient to identify and estimate volumes of locally available clay materials; however, additional drilling and sampling in conjunction with preliminary engineering would be
required prior to licensing.

In spite of the above limitations the 1983 effort did achieve its objectives. The program laid the foundation for designing an in depth, long-term testing program to be conducted for future licensing.

Furthermore, the geochemical and geotechnical program, however preliminary in nature, did identify material suitable to construct a clay liner having both the physical and chemical properties necessary to minimize seepage and trap the radiochemical and chemical constituents in the tailings fluids.

The following pages summarize the literature on the subject of the geochemistry of soils and tailings fluids, and also addresses the issues raised in the review of the 1983 geochemical program. Additional information may be found in the original submittal in sections A.3 Geology; E.3 Tailings Management; Appendix III, Geotechnical Data and Appendix V, Geochemical Program.

2.0 **Literature Review**

The chief waste products from the milling of uranium ore include the spent-ore tailings and the waste solutions that are produced during the milling process. The residual tailings fluids may contain various chemical and radiochemical impurities that are either leached from the uranium ore or are introduced as reagents during routine milling operations. The quality and quantity of the tailings fluids depend to a large extent on the specific milling process that is used to extract the uranium from the ore and on the steps that are taken to treat or wash the solid tailings prior to disposal.

The potential ground-water contaminants that are commonly associated with uranium mill effluents from acid-leach mills and alkaline-leach mills are illustrated in Table 1 (IAEA, 1976). Untreated tailings fluids from uranium mills that utilize an alkaline-leach process are basic in pH, typically ranging between 9.5 and 10.5. Carbonate, bicarbonate, and chloride are the principal major-ion impurities; molybdenum, selenium, vanadium, and uranium are the principal trace elements present in most untreated alkaline-leach effluents. When compared to typical effluents from acid-leach mills, the fluids from alkaline-leach mills are usually lower in radionuclide content (US Nuclear Regulatory Commission, 1980). The untreated tailings fluids which are usually associated with acid-leach mills are of higher salt content and generally contain greater concentrations of dissolved contaminants including sulfuric acid, heavy metals, and radionuclides. The pH of untreated acid-leach fluids varies from about 1.2 to about 3.0, and the total dissolved solids content may approach one percent by weight. Sulfate and chloride are the predominant impurities; however, numerous trace elements may be present at significant concentrations in the acidic fluids. Compared with alkaline-leach fluids, the acid-leach fluids are usually lower in uranium content but much higher in overall radionuclide content (US Nuclear Regulatory Commission, 1980).

TABLE 1
Potential Ground Water Contaminants in Uranium Mill Effluents

CONTAMINANT	ALKALINE-LEACH PROCESS	ACID-LEACH PROCESS
Radiochemical		
U	+	+
Ra 226	+	+
Th 230	+	+
Pb 210	+	+
Po 210		+
Chemical		
H_2SO_4		+
HCO_3	+	+
CO_3	+	
SO_4	+	+
PO_4		+
Cl	+	+
F	+	+
NH_3		+
NO_3	+	+
Na	+	+
Ca	+	+
Mg	+	+
As		+
Ba		+
Co		+
Cr		+
Cu		+
Fe		+
Mn		+
Mo	+	+
Ni		+
Pb		+
V	+	+
Zn		+
Kerosene		+
Alcohol		+
Phosphate		+
Amines		+

Source: International Atomic Energy Agency, 1976

Contamination of local ground waters by the chemical and radiochemical constituents which are present in residual tailings fluids is always a subject for concern. Indeed, evidence for ground water contamination by seepage from active and abandoned uranium tailings disposal sites which have included both acid and alkaline waste has been generally documented (Brown and others, 1981; Landa, 1980; Kaufman and others, 1976). Most case studies have focused on seepage from older, non-engineered and unlined structures. Typically, sulfate and chloride are the chief impurities detected in the affected ground water (Korte and others, 1984; White and other, 1984). Nitrate, selenium, and uranium are the trace element impurities most often detected. At some unlined tailings disposal sites, radionuclides and heavy metals present in the tailings fluids are immobilized and trapped in subsurface soils at nominal distances beneath and around the periphery of the site. For example, in a statistically reliable study of the subsoils beneath several inactive tailing ponds in Colorado, Colbert and Klusman (1982) concluded that any significant contamination of the subsoil with arsenic, molybdenum, nickel, lead, uranium and radium was almost completely confined to the top one foot of the subsoil. Markos and Bush (1981) sampled the soils underlying the Vitro tailings in Salt Lake City and concluded that radionuclides from the tailings penetrated the subsoil to a maximum depth of 30 centimeters (11.81 inches) below the tailings. Penetration of acid from the tailings was less than 40 centimeters (15.75 inches). The absence of heavy metal and radionuclide movement from several such sites is attributed in part to geochemical reactions between the seepage solutions and the subsurface soils or sediments (Taylor and Popielak, 1984; Longmire and Brookins, 1982; Taylor and Antommaria, 1978).

The subsurface soils and sediments that underlie existing tailings disposal sites are complex mixtures of minerals and impurities. The mixtures can include clays, carbonates, iron and manganese hydrous oxides, and organic matter. Under favorable conditions, the minerals or impurities can impart to the soils and sediments the ability to trap and to concentrate heavy metals and radionuclides from solution. The geochemical mechanisms through which clay-bearing material immobilizes ions from solution are analogous to the mechanisms that are credited with forming uranium ore bodies in sedimentary rocks (Doi and others, 1975).

2.1 Geochemical Mechanisms of Ion-Sorption

Cation and anion exchange between clay minerals and ions in solution is one mechanism with the potential to affect significant heavy metal and radionuclide trapping. Ion-exchange or replacement reactions can occur to some extent in all clay minerals. Highest cation-exchange capacities have been observed with montmorillonite, smectite, and vermiculite clays (Grim, 1968; Robinson, 1962).

Analogous reactions resulting in ion-exchange from solution can occur at the surface of iron and manganese oxide impurities in clay-bearing material. Jenne (1968) described the role of hydrous oxides in controlling cobalt, copper, nickel, and zinc concentrations in clayey soils.

Organic matter is often associated with clay-bearing soil material. Humic material can affect geochemical trapping through formation of chelate-type complexes with cations from solution. For example, peat will trap uranium from ground water and under favorable conditions can become enriched in uranium by a factor of 10,000. Enrichment factors are high for other ions, especially for cations of high valence (Th^{+4}) and atomic number (Ra^{+2}) (Schmidt-Collerur, 1978). Secondly, the organic matter in soils and sediments is to some extent a reducing agent. Contact of solutions with a reducing agent may trigger the precipitation or adsorption of redox sensitive elements such as arsenic, chromium, molybdenum, selenium, vanadium, or uranium.

Other geochemical mechanisms can be activated as solutions contact clay-bearing material. Reprecipitation and coprecipitation trapping mechanisms can immobilize some soluble constituents by removing the elements as insoluble precipitates. Such precipitation reactions are usually initiated by changes in solution chemistry, notably pH. For example, the neutralization of an acid solution by a soil or sediment containing carbonate minerals may trigger the precipitation or removal processes, as would conversely, the neutralization of an alkaline solution by an acidic clay. To a great extent, pH controls the tendency of ions to undergo ion-exchange, sorption, and precipitation reactions. As a general rule, a change in the solution pH to near-neutral, which is caused by reaction with the clay can promote the removal of ions from solution. Most sorption or precipitation occurs in a pH range between 4.5 and 9.0 (Deutsch and others, 1984; Opitz and Sherwood, 1984; Sherwood and Sherne, 1983; Griffin and others, 1977; Griffin and others, 1976; Griffin and Shimp, 1975).

2.2 Interaction Between Uranium Tailings Solutions and Soils, Sediments, and Clay Liners

Geochemical interactions between clay-bearing materials and actual residual tailngs fluids have been extensively studied. Numerous laboratory investigations for research purposes and for new license applications have focused on soils, sediments, and clay liner material interacting with uranium tailings fluids, tailings leachate solutions, and various mill-effluent solutions. Many of these investigations have been supported by field observations at active and inactive tailings sites. Most of the investigations have focused on two areas of concern; namely,

- the effect of uranium waste solutions on the geotechnical properties, such as permability of liner material;
- the ability of the soil, sediment, and liner material to attenuate the migration of potential ground water contaminants found in uranium waste solutions.

2.2.1 Geotechnical Stability of Liner Materials

The response of clay materials to long-term contact with residual tailings fluids has been under study for several years. Concern has been raised by several researchers whether highly acidic or alkaline seepage fluids from a uranium tailings facility could interact geochemically with clay-liner material and in time cause liner failure. Brown and Anderson (1980) described several mechanisms that could lead to such liner failure. The chief mechanisms by which the integrity or impermeability of a clay liner could deteriorate include shrinkage caused by mineral dissolution (Crim and others, 1979) or clay cracking (Griffin and others, 1976) and severe clay dispersion.

Dissolution of mineral phases and cracking of the clay-bearing material are more likely to contribute to or to cause system failure. Very dispersive clays can be identified through laboratory tests with actual waste solutions (Sherard and others, 1976). Based on these tests, such clays can be rejected as unsuitable for construction material.

The dissolution of mineral phases as a failure mechanism has been extensively investigated. Deterioration of geotechnical properties because of clay mineral dissolution is not commonly observed (Peterson and others, 1982; Gee and others, 1980), even in continuous column tests lasting many months. Very often carbonate minerals such as calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) in a liner material will be dissolved by acidic tailings solutions and in effect converted to another "secondary" mineral. Any adverse effect on impermeability due to such mineral dissolution is usually offset by reprecipitation of such secondary minerals as anhydrite ($CaSO_4$), gypsum ($CaSO_4.2H_2O$), jarosite ($KFe_3(OH)_6(SO_4)_2$), or alunite ($KAl_3(OH)_6(SO_4)_2$) (Erikson and Sherwood, 1982; Uziemblo and others, 1981; Peterson and Krupka, 1981). The formation of such secondary minerals appear to have a plugging effect on potential solution pathways. In effect, carbonate-containing liner materials, soils, and sediments may become less permeable after long-term exposure to acidic tailings fluids (Peterson and others, 1982; Gee and others, 1980).

Similar effects on soil or liner permeability by alkaline tailings fluids have been observed by Relyea and Martin (1982) and van Zyl (1983) and researched earlier by McNeal and others (1966). With alkaline fluids, decreases in permeability may not be related to dissolution and reprecipitation reactions, but rather to ion-exchange. High sodium concentrations typical of alkaline tailings fluids may decrease hydraulic conductivity (permeability) of a clay liner by causing swelling of the clay particles and resulting in a plugging up of conducting pores.

2.2.2 Attenuation Properties of Liner Materials

The ability of natural soil and rock materials to impede the movement of various chemical and radiochemical contaminants often found in uranium tailings fluids has been demonstrated in several laboratory investigations (Dodson and others, 1984; Thomas and Heggen, 1981). Gee and others (1980) reported on batch tests to measure the sorption or trapping characteristics of heavy metals and radionuclides. The tests were conducted on natural materials including clay liner samples under low (acidic) and neutral pH conditions. The radionuclides showed moderate to strong sorption on the liner material even at low pH. Most of the trace element constituents were removed from the acid tailings fluids whenever the pH of the tailings solution was neutralized by the liner material.

In subsequent studies, Serne and others (1983) percolated acidic tailings fluids through columns of the same liner material. Analyses of the liquids that exited the columns suggested that arsenic, barium, chromium, lead, silver, thorium, and vanadium are readily immobilized by a clay liner constructed of the material and will not be remobilized even if acid conditions are reestablished. Cadmium, cobalt, copper, iron, manganese, nickel, zinc, and uranium are immobilized by a clay liner as long as the solution pH is not below about 4.5. Selenium and molybdenum, along with sulfate and nitrate may be mobile under both acidic or neutral pH conditions.

As a general rule, the extent to which a clay liner will function as a geochemical trap depends upon the mineralogical composition of the clay-bearing material, upon the chemical composition of the residual tailings fluid, and upon the pH conditions that are established as the seepage solution penetrates into the clay liner. Overall, the pH buffering capacity is the single geochemical property most responsible for imparting favorable trapping characteristics to a liner material. Neutralization of either acid or alkaline seepage is the most important process influencing the rate and the extent of contamination migration at uranium tailings disposal sites (Shepard and Brown, 1982).

3.0 Swanson Uranium Project Geochemical Program

The geochemical program that is presented in Appendix V of the Marline Uranium/Union Carbide October 15, 1983 submittal to the Uranium Administrative Group was conceived as a reconnaissance study and designed to identify geochemical properties and to demonstrate attenuation properties, which is the ability to trap specific chemical elements, in foundation and construction materials located at the project site. The construction materials were evaluated in a preliminary geotechnical investigation conducted by Chen and Associates, Inc., and were determined to be geotechnically suitable for use in the construction of the liner and cover for the Swanson Uranium Project tailings impoundment. Typical samples represented by the geotechnical tests were utilized in the geochemical program testwork.

Although the geochemical program was preliminary in scope, the testwork involved in the study was extensive. In total, 24 column percolation experiments, each operating for about one month, were conducted as part of the study. In the 24 column tests, 8 different foundation and construction materials from 2 different terrains (Triassic Basin and Crystalline) were evaluated against 3 different tailings fluids (acid-leach, pH neutralized acid-leach, and carbonate-leach) prepared from actual Swanson ore.

The geochemical program was not intended to substitute for a license study; the depth and duration of the program were insufficient to support licensing action. However, the program lays the foundation for designing an in depth, long-term testing program that will satisfy a licensing study.

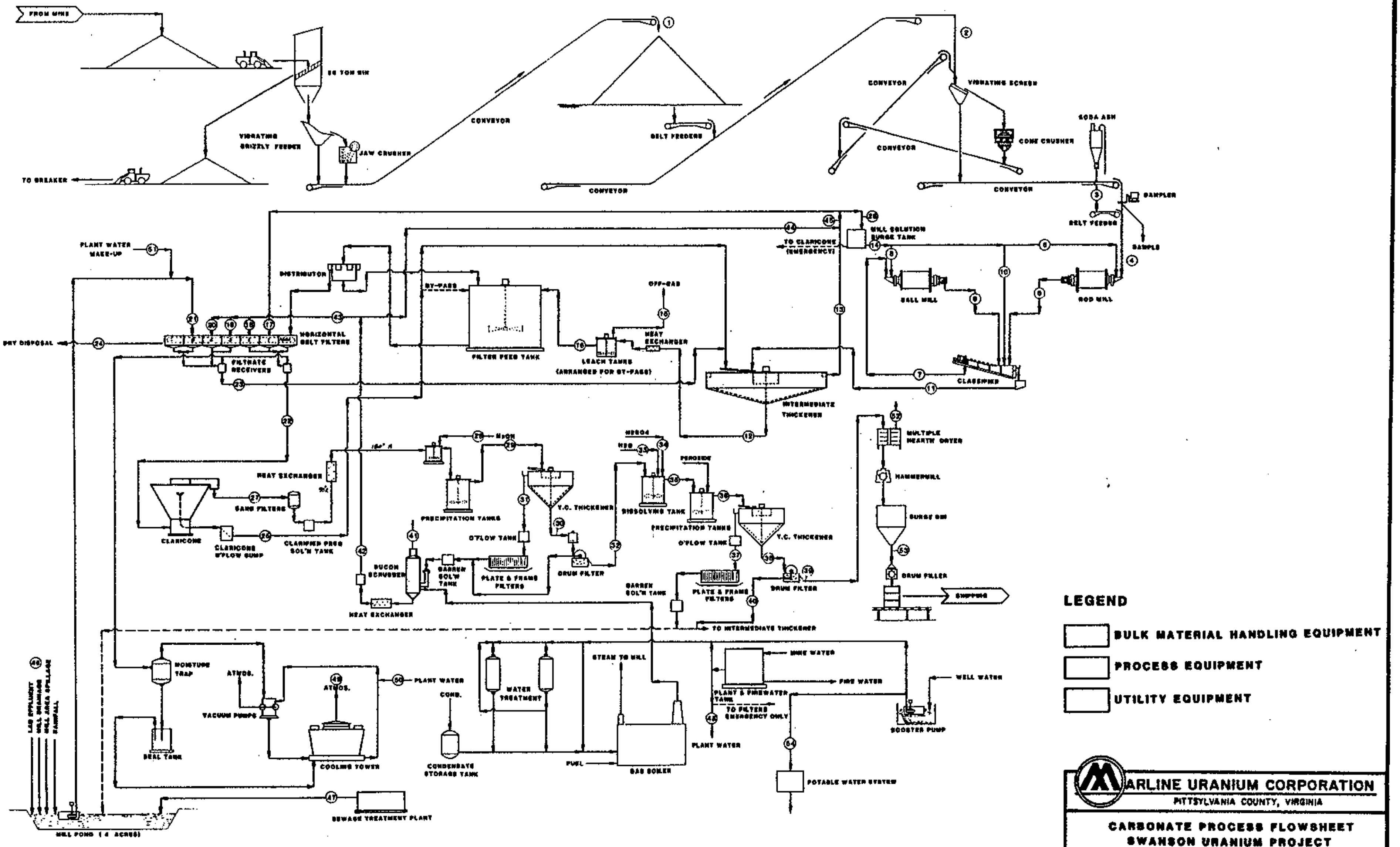
The objectives of this technical memo are to reiterate what was presented in the geochemical program report (Appendix V of the October 15, 1983 submittal) and to clarify several issues raised in the reviews of the geochemical study. Some questions will not be satisfactorily answered until completion of long-term testwork in support of licensing action.

3.1 Composition of Tailings Material

Swanson ore was crushed and assayed to obtain a complete chemical and radiochemical profile of the material. The composition of the tailings material, similar to fine sand, and the ore material is essentially the same except the uranium and some of the other constituents have been solubilized and removed by the milling process. Depending upon the process that is selected, certain mill reagents may remain in the tailings fluids.

3.2 Composition of Residual Tailings Fluids

The composition of the tailings fluids that were presented in the submittal are indicative of residual tailings fluids that have not been diluted by tailings wash procedures or by fresh water infiltration from precipitation on the tailings and therefore are "worst case" solutions. In reality, during operation the concentrations of the constituents in the tailings fluids could be lower than those tested as a result of multiple tailings washing cycles in the mill process prior to final disposal. (See flowsheet figures E.2-3 and E.2-4 in the original October 15, 1983 submittal.) Mill pond water and fresh water would be used to wash the tailings in the carbonate circuit, and pH neutralized raffinate, which is substantially lower in contaminants than the unwashed acid-leach tailings fluids, would be used to wash tailings in the acid circuit. The exact composition of the residual tailings fluids that will be discharged to tailings disposal will not be known until the milling flow sheet is finalized and the process is tested in pilot plant operations.



LEGEND

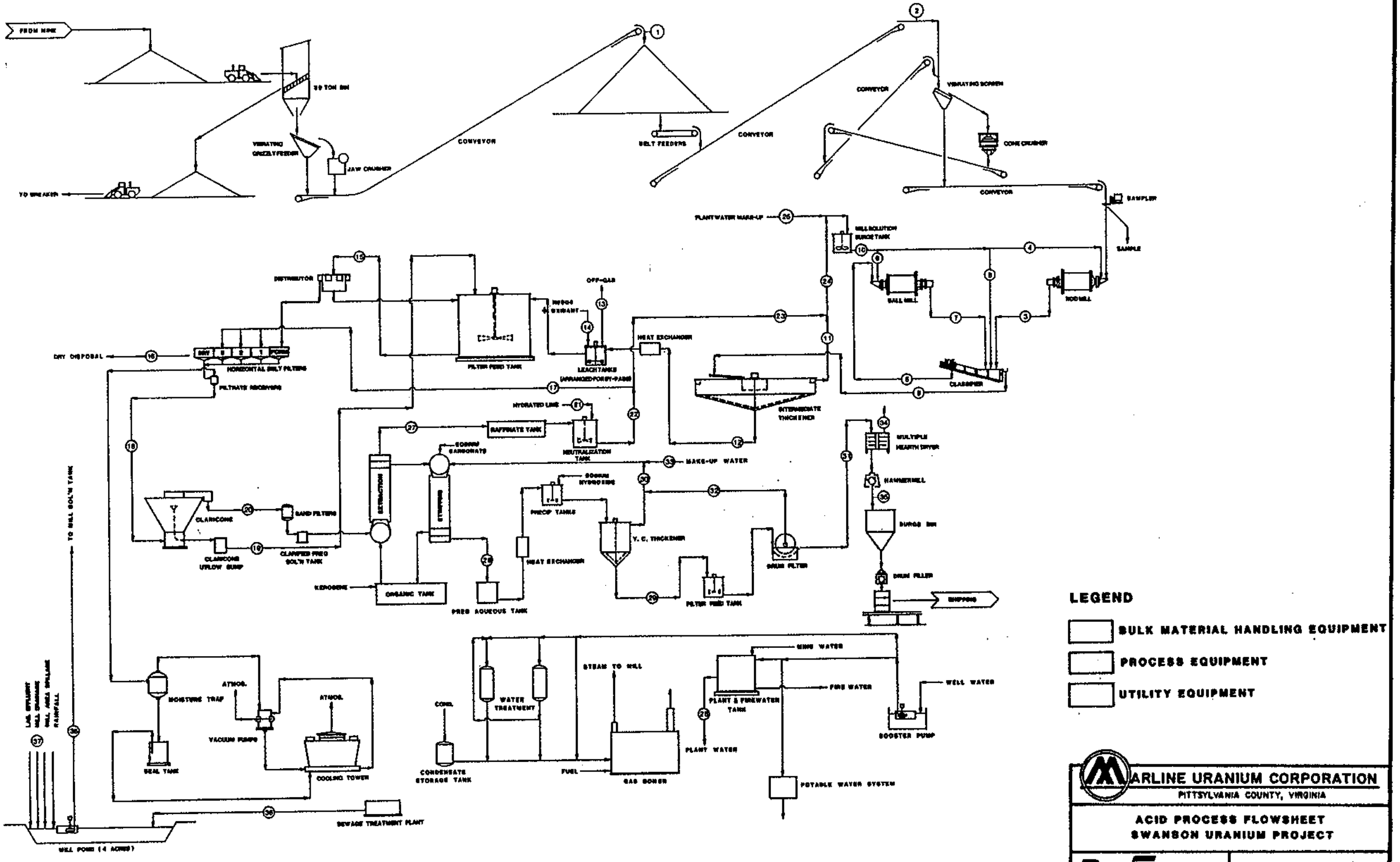
- ☐ BULK MATERIAL HANDLING EQUIPMENT
- ☐ PROCESS EQUIPMENT
- ☐ UTILITY EQUIPMENT

MARLINE URANIUM CORPORATION
PITTSYLVANIA COUNTY, VIRGINIA

CARBONATE PROCESS FLOWSHEET
SWANSON URANIUM PROJECT

Dravo

FIGURE E.2-3



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PITTSYLVANIA COUNTY, VIRGINIA

ACID PROCESS FLOWSHEET
SWANSON URANIUM PROJECT

Dravo

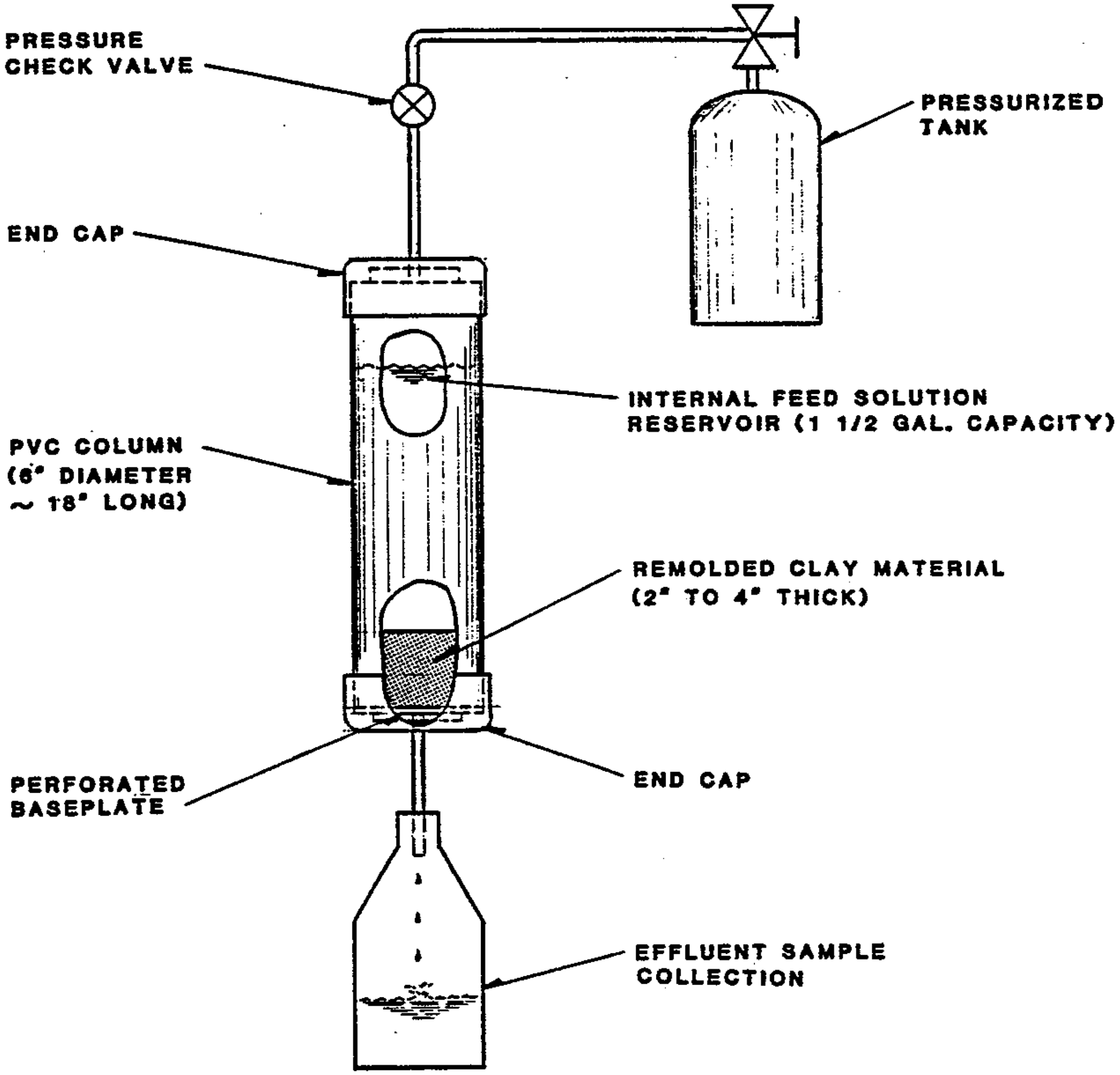
FIGURE E.2-4

3.3 Geochemical Program Column Percolation Experiments

A major objective of the column testwork was to demonstrate contaminant attenuation or trapping properties in the selected foundation and liner construction materials against 3 tailings solutions, and to relate the trapping characteristics to the geochemical properties of the materials. The column testwork accomplished this objective.

Some clay liner source materials were found to be more effective at trapping potential contaminants from acidic tailings solutions while other soil materials were found to be more effective at trapping contaminants from alkaline tailings solutions. Liner construction material that showed acid-consuming properties was more effective in trapping potential contaminants from acidic seepage solutions; material that was a base (alkaline) consumer was more effective in trapping potential contaminants from alkaline (carbonate-leach) seepage solutions.

The operation of the column experiments is illustrated in Figure V.5.2-1 of the original October 15, 1983 submittal and the illustration is reproduced in Figure 1. Each column was packed with foundation or construction materials by Chen and Associates, Inc. The thickness ("height") of the materials in each set of columns was chosen from the anticipated permeability of each source material. The clay liner source material which was likely to be least permeable, as determined by the geotechnical tests conducted by Chen and Associates, was packed into columns to a thickness of about 2 inches. Within each set of columns packed with the same source material, the column thickness, the sample volume, and the sample weight were kept as uniform as possible. No "experimental" errors were introduced by the differences in the thickness of the column sets. The specified moisture content, dry density, and wet density data were representative of the source materials used to pack the



MARLINE URANIUM CORPORATION
PITTSYLVANIA COUNTY, VIRGINIA

GEOCHEMICAL PERCOLATION EXPERIMENTS
SWANSON URANIUM PROJECT

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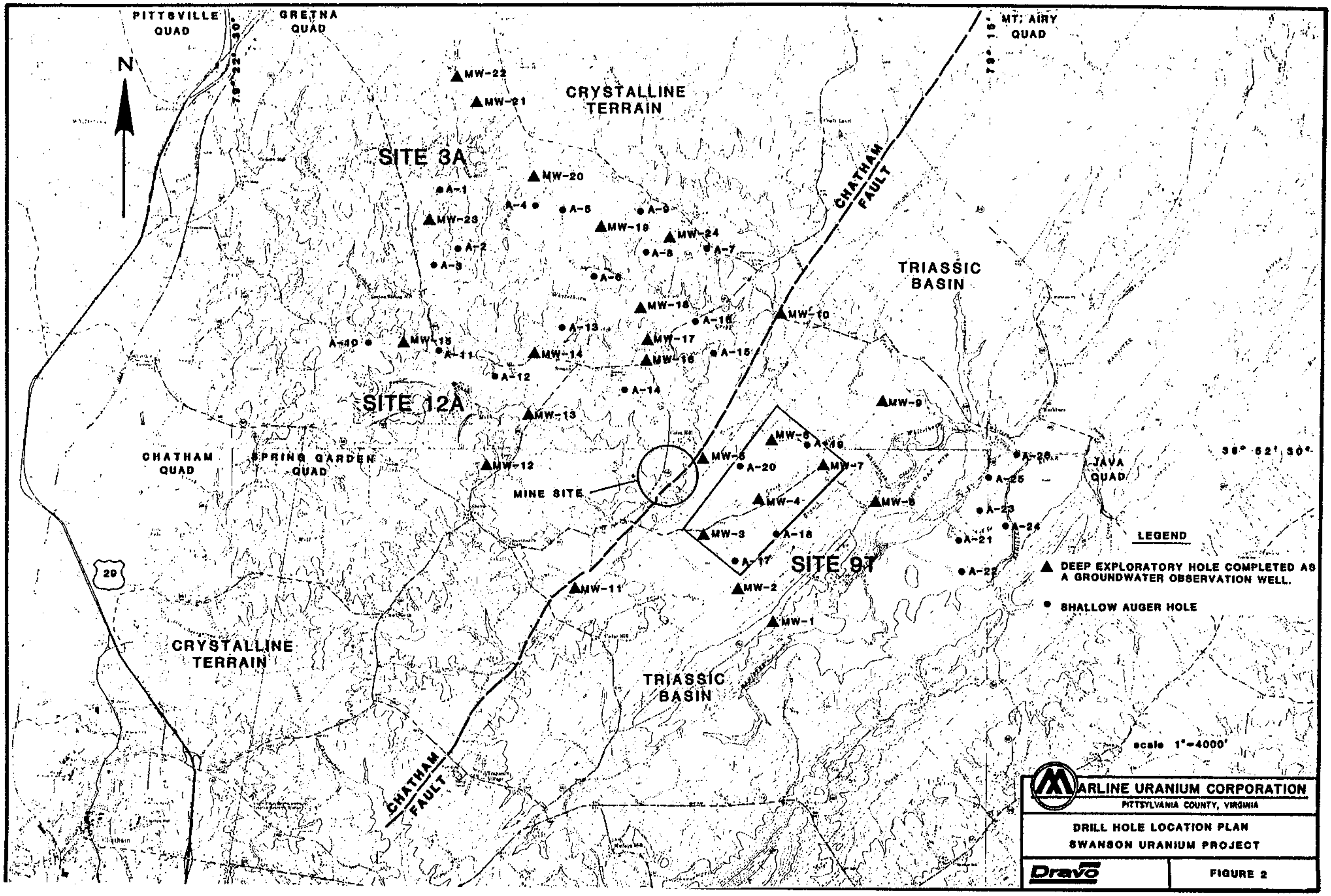
FIGURE 1

column sets.

During the course of the column experiments, the flow of tailings fluids through each column was not externally controlled. The percolation of feed solution (residual tailings fluid) through each column was controlled by the permeability of the recompacted column material itself. That several columns required pressure to force fluids through the column material only indicates that one source material was more impermeable than another source material. The volumes of actual feed solution that had percolated through each column during the course of the testwork are presented and noted (Effluent Volume, in ml) in tables V.5.2.1.1-1 thru 6 and V.5.2.1.2 thru 6, of the submittal.

3.3.1 Long-Term Geotechnical Stability

The purpose of the preliminary borrow study which was conducted as part of the geotechnical investigation by Chen and Associates, Inc., was to determine if soils suitable for use as cover and liner materials were available. Four areas in the crystalline terrain, the Triassic basin, and the Banister River alluvium were investigated by drilling auger borings, collecting composite samples, and testing the geotechnical properties of the samples in the laboratory. Figure 2 shows the areas and drilling locations. The results of the preliminary borrow study were provided in the original submittal in Appendix III, Geotechnical Data, and are reproduced in Table 2. The geotechnical studies indicated that the soils which were sampled and tested are suitable for use as lining and cover materials for the tailings facility. In the future, once a specific borrow site is selected, additional field and laboratory tests will be required to support a licensing action. Based on the drilling data collected to date, the estimated volumes of construction material in the four investigated locations are as follows:



MARLINE URANIUM CORPORATION
PITTSYLVANIA COUNTY, VIRGINIA

DRILL HOLE LOCATION PLAN
SWANSON URANIUM PROJECT

Dravo

FIGURE 2

Job No. 25,600
26,350

TABLE 2 (TABLE III.3-2)

SUMMARY OF REMOLDED PERMEABILITY TESTS

MATERIAL	SAMPLE HOLE	SAMPLE DEPTH	PERCENT PASSING NO. 200 SIEVE	LIQUID LIMIT (%)	PLASTICITY INDEX (%)	UNIFIED CLASS	REMOLDED PERMEABILITY ft/yr	REMOLDED PERMEABILITY cm/sec.	PERCENT STANDARD PROCTOR
Pedological Soils Crystalline Terrain	MW-14	0.0-5.0'	48	34	11	SC-CL	1.0	1.0×10^{-6}	94.0
	A-2	0.0-5.0'	41	—	NP	SM-ML	0.7	6.6×10^{-7}	99.2
Saprolite Crystalline Terrain	MW-15	6.0-15.0'	52	38	11	ML-SM	2.2	2.1×10^{-6}	95.5
	MW-19	9.0-20.0'	60	52	16	MH	0.8	8.0×10^{-7}	94.9
	A-19	5.0-20.0'	56	—	NP	ML-SM	0.7	7.3×10^{-7}	92.6
	A-13	5.0-15.0'	55	—	NP	ML-SM	0.7	7.3×10^{-7}	90.6
	A-15	10.0-15.0'	56	41	7	ML-SM	0.3	3.7×10^{-7}	91.2
Residual Soils Triassic Basin	MW-9	0.0-5.0'	74	46	24	CL	1.9	1.8×10^{-6}	94.8
	MW-10	0.0-15.0'	68	48	26	CL	3.5	3.4×10^{-6}	94.6
Alluvium Bannister River Valley Bottom	A-21	1.0-5.0'	42	49	26	SC-CL	0.3	2.7×10^{-7}	91.4
	A-22	1.0-5.0'	56	30	12	CL-SC	0.06	5.6×10^{-8}	95.3
	A-23	1.0-5.0'	80	42	27	CL	0.3	3.4×10^{-7}	94.2
	A-24	1.0-5.0'	38	38	17	SC	0.04	3.5×10^{-8}	91.8
	A-26	1.0-5.0'	59	33	20	CL-SC	0.03	2.5×10^{-8}	92.4
	Trench	0.0-5.0'	73	40	25	CL	0.03	3.0×10^{-8}	95.0

Source: Chen and Associates, Inc.

Location	Avg. Depth Material FT	Available Volume CY/AC	Approx. Area, AC	Approx. Total Volume CYx10^6
Site 3A	6	9,700	310	3.00
Site 12A	3	4,800	310	1.50
Site 9T	2	3,200	220	0.70
Banister River	9	14,500	300	4.35

CY = cubic yards
CYx10^6 = million cubic yards

Typical samples represented by the geotechnical test results were compacted into column molds for the geochemical testwork. The column tests were operated for about one month, not long enough to confirm long-term geotechnical stability in the liner-construction material. Typically, to satisfy licensing action, identical column percolation experiments are run between 6 and 9 months (Peterson and others, 1982). Such long-term column testwork would be conducted on representative samples of materials which have been extensively tested and found to be geotechnically suitable for use in liner construction. In the columns, the materials would be exposed to excess volumes of percolating solutions which are actual residual tailings fluids produced in a pilot plant. In this way, long-term geotechnical stability can be demonstrated. The long-term column studies will show if the impermeability of the liner material or its ability to act as a geochemical trap will deteriorate upon long-term exposure to percolating tailings fluids.

3.3.2 Contaminant Trapping Properties

The column percolation experiments were conducted on geotechnically suitable liner construction materials utilizing undiluted residual fluids generated by the acid-leach and carbonate-leach process. Use of such solutions assumed that no dilution of the waste will occur by the infiltration of fresh water through the engineered tailings cap.

The 24 columns in the study program were operated for at least one month. During this time, between about 4 pore volumes and about 15 pore volumes of fluid had passed through the liner material columns. Pore volume is defined as the volume of the small voids or pore spaces between the solid mineral matter in a soil material. During this one month, a substantial amount of tailings fluid percolated through relatively small volumes of liner material. The total volume of tailings fluid collected as effluent from each column is equivalent to a significant amount of seepage from the tailings impoundment.

For example, the carbonate-leach tailings fluid columns no. 6C and no. 8C percolated about 5 pore volumes and about 11 pore volumes of fluid, respectively. Column no. 6C was charged with Triassic basin residual soil MW-10, and column no. 8C was charged with Banister River alluvium FP-1. Assuming a liner thickness of 18 inches, and based upon the liner permeability and seepage assumptions stipulated in the original submittal, the probable annual seepage rate from the tailings impoundment will range between 0.15 and 0.05 gallons per minute per acre. The upper estimate is for short-term seepage rates through the liner beneath tailings exposed to rainfall; the lower estimate is for seepage over the long-term, after the tailings have been encapsulated and capped to minimize fresh water infiltration. Working with the upper seepage rate of 0.15 gallons per minute per acre, the effluent collected from columns no. 6C and no. 8C is roughly equivalent to about 9 years and 14 years, respectively, of seepage from the tailings impoundment lined with 18 inches of the clay. Working with the lower seepage rate of 0.05 gallons per minute per acre, the effluent collected from columns no. 6C and no. 8C is roughly equivalent to about 27 years and 42 years of seepage. The time calculations are approximate, but do show just how much equivalent seepage did percolate through each column of liner material during the course of the testwork.

The analyses of carbonate-leach tailings fluids that had percolated through the liner materials in the column tests clearly show attenuation or trapping of the chemical and radiochemical constituents by liner material. The analyses were reported in the original submittal, (Tables V.5.2.1.1-5 and V.5.2.1.2-5, Appendix V), and are reproduced in Tables 3 and 4. Against carbonate-leach fluids, the residual soil in column no. 6C (Table 3) and the saprolite of column no. 7C (Table 4) were most effective at trapping radionuclides and trace elements, even uranium; the residual soil in column no. 3C and the Banister River alluvium in column no. 8C (Table 3), along with the pedological soil in column no. 4C and the saprolite in column no. 5C (Table 4) were about equally effective at trapping radionuclides and most trace elements, including the heavy metals.

The analyses that are summarized in Table 3 and 4 indicate an average concentration for tailings fluid percolating through and exiting each column. The analyses profile the average composition of seepage from the impoundment during the early years of impoundment use.

Very low levels of chemical and radiochemical impurities in the effluent solutions necessitated a large volume of sample solution for thorough analysis. For this reason, several continuous pore volumes of fluid throughput were combined to give enough volume of solution sample for analysis. By necessity, the samples of effluent collected from each column represent several continuous pore volumes of fluid throughput. The effluent samples analyzed in Tables 3 and 4 represent roughly between the second and the fifth pore volumes of fluid throughput in columns no. 3C and no. 6C; the second and seventh pore volumes in columns no. 4C, 5C, and 7C, and the second and eleventh pore volumes of throughput in column no. 8C. As previously noted, the total volume of tailings fluid that pecolated through the columns during the course of the column tests is equivalent to many years of seepage from the proposed impoundment.

TABLE 3

(Table V.5.2.1.1-5)

Chemical and Radiochemical Analyses of Effluent Solutions Produced by Columns Charged With Recompacted Foundation and Construction Materials From Triassic Basin (Carbonate Leach Tailings Solution)

COLUMN NO. SAMPLE NO. DESCRIPTION	1C P0808-1 Siltstone	3C P0808-3 Soil	6C P0808-6 Soil	8C P0808-8 Local Clay	COLUMN FEED SOLUTION
General Parameters:					
Effluent Vol (in ml)	300-3425	410-3060	475-2460	215-2550	-
TDS (in g/l)	5.77	4.11	3.62	6.39	7.34
pH	9.8	8.9	8.0	9.0	9.8
EMF (in mv)	+150	+125	+135	-85	+100
Chemical Profile:			Concentration, mg/l		
SO_4 (in g/l)	1.15	1.18	1.32	1.48	1.20
HCO_3	2210.	2310.	1110.	3130.	446.
CO_3	960.	80.	<1.	502.	2370.
Cl	163.	298.	303.	168.	396.
F	7.6	1.2	2.8	28.2	11.6
Na	2100.	939.	1090.	2180.	2700.
Ca	9.9	45.	35.	14.	9.0
Mg	33.	320.	15.	130.	17.
As	0.21	0.03	<0.01	0.02	0.08
Ba	0.2	<0.1	<0.1	<0.1	<0.1
Cd	<0.01	<0.01	<0.01	<0.01	0.01
Cr	<0.01	<0.01	<0.01	<0.01	<0.01
Cu	0.09	0.02	<0.01	0.03	0.17
Fe	0.55	0.12	7.4	0.09	0.51
Hg	0.0013	<0.0003	<0.0003	<0.0003	<0.0003
Mo	1.5	1.3	<0.1	1.8	2.2
Pb	0.05	<0.01	<0.01	<0.01	4.9
Se	<0.01	<0.01	<0.01	<0.01	<0.01
V	0.5	<0.1	<0.1	<0.1	0.5
Zn	0.04	0.03	0.32	0.02	0.02
PO_4-P	0.92	0.01	0.02	0.40	1.09
NH_3-N	0.36	7.13	1.15	0.22	1.61
NO_3-N	0.1	0.1	<0.1	<0.1	<0.1
NO_2-N	0.02	0.01	0.04	<0.01	0.01
Radiochem Profile:			Concentration, pCi/l		
U_3O_8 (in mg/l)	28.	13.	0.13	17.5	35.
Gross α	23343±590	8719±252	40±10	4772±177	19817±280
Gross β	11705±260	1356±94	53±7	841±76	7719±124
Th 230	129±64	0.5±0.3	0.3±0.2	0.6±0.4	162±88
Ra 226	1.2±0.2	0.7±0.5	0.0±0.1	0.2±0.1	22±2
Pb 210	4.5±1.2	2.5±0.9	0.5±0.4	3.3±0.9	6.7±1.1
Po 210	3.7±1.2	1.3±0.5	0.5±0.3	0.5±0.3	0.8±0.4

TABLE 4

(Table V.5.2.1.2-5)

Chemical and Radiochemical Analyses of Effluent Solutions Produced by Columns Charged With Recompacted Foundation and Construction Materials From Crystalline Terrain (Carbonate-Leach Tailings Solution)

COLUMN NO. SAMPLE NO. DESCRIPTION	2C P0808-2 Amphibolite	4C P0808-4 Soil	5C P0808-5 Saprolite	7C P0808-7 Saprolite	COLUMN FEED SOLUTION
General Parameters:					
Effluent Vol (in ml)	270-3565	405-3195	325-2688	360-2640	-
TDS (in g/l)	6.23	4.08	5.80	3.65	7.34
pH	9.7	7.6	9.2	8.2	9.8
EMF (in mv)	+160	+20	-80	0	+100
Chemical Profile:			Concentration, mg/l		
SO_4 (in g/l)	1.28	1.26	1.37	1.36	1.20
HCO_3	2460.	2300.	2440.	1450.	446.
CO_3	916.	28.	650.	40.	2370.
Cl	167.	174.	189.	175.	396.
F	8.3	1.1	7.5	2.0	11.6
Na	2300.	685.	2160.	1240.	2700.
Ca	6.3	150.	6.6	3.8	9.0
Mg	15.	420.	5.2	41.	17.
As	0.04	<0.01	<0.01	<0.01	0.08
Ba	0.1	0.1	<0.1	<0.1	<0.1
Cd	<0.01	<0.01	<0.01	<0.01	0.01
Cr	<0.01	<0.01	<0.01	<0.01	<0.01
Cu	0.02	0.02	0.02	0.03	0.17
Fe	0.07	0.64	0.57	0.13	0.51
Hg	0.0003	<0.0003	<0.0003	0.0004	<0.0003
Mo	1.4	0.6	1.8	0.1	2.2
Pb	<0.01	<0.01	0.01	<0.01	4.9
Se	<0.01	<0.01	<0.01	<0.01	<0.01
V	0.3	0.1	0.1	0.2	0.5
Zn	0.02	0.05	0.08	0.27	0.02
PO_4-P	0.92	0.02	0.27	0.02	1.09
NH_3-N	0.51	0.71	0.62	0.91	1.61
NO_3-N	<0.1	<0.1	<0.1	<0.1	<0.1
NO_2-N	<0.01	<0.01	<0.01	<0.01	0.01
Radiochem Profile:			Concentration, pCi/l		
U_3O_8 (in mg/l)	32.	12.	6.3	<0.001	35.
Gross α	7265±156	4684±148	3180±408	0±5	19817±280
Gross β	6019±109	6019±54	1235±217	26±7	7719±124
Th 230	0±7	0.3±0.2	1.5±0.6	1.2±0.5	162±88
Ra 226	0.3±0.2	0.3±0.2	1.0±0.7	0.7±0.4	22±2
Pb 210	0.0±1.1	0.0±0.7	0.6±0.7	0.0±0.7	6.7±1.1
Po 210	0.0±0.3	0.1±0.1	0.3±0.2	0.0±0.1	0.8±0.4

The use of the term "~ 0" in several tables of the original submittal means just what the term suggests, that about zero percent, or very little, if any of the particular constituent was trapped by the column material. This term was used to represent very slight decreases or increases in various constituents. The appearance of higher concentrations of some constituents in the column tailings solutions are not surprising and are not random. Several source materials that were less effective at neutralizing the acidic pH of the acid-leach tailings fluid or the alkaline pH of the carbonate-leach tailings fluid were susceptible to leaching and release of such constituents as uranium and fluorine from the source material to the percolating tailings fluids. On the other hand, cation-exchange reactions between clay minerals in the liner material and sodium in the alkaline-leach tailings solutions were probably responsible for desorbing and leaching such constituents as calcium and magnesium. For example, major increases in magnesium concentration in the effluent of columns no. 3C, 8C, and 4C correspond to materials in which magnesium is the principal exchangeable cation. Such desorption reactions are common and are indicative that cation-exchange between clay and solution is occurring (Grim, 1968; Robinson, 1962).

3.3.3 Interpretation of Distribution Coefficients

Distribution coefficients, a parameter of relative contaminant trapping ability, were calculated and presented in the original submittal to better compare the trapping properties of liner materials contained in each set of column experiments. This was advisable since the sample weight of material in the columns varied from column set to column set. Sets of columns were packed with liner material ranging in weight from about 6.5 pounds to about 4.0 pounds. The distribution coefficients calculated in the original submittal were not intended to be used in any definitive contaminant migration study nor were the distribution coefficients intended for use in a licensing action. The distribution coefficients were presented to better compare one source material against another source material in the reconnaissance study.

In a typical licensing study, identical column experiments would be run. However, the duration of the column tests would be extended so that several column effluent samples representing many pore volumes could be collected and assayed. Each column effluent sample would represent one or more pore volumes of tailings fluid throughput in succession. Such long-term attenuation tests are usually run until general "breakthrough" of chemical and radiochemical constituents is observed. Such breakthrough is the indication that the trapping capacity of the liner material for a constituent has been exhausted (Serne and others, 1983).

4.0 **References**

Brown, K.W. and Anderson, D., 1980, Effects of organic chemicals on clay liner permeability: Proceedings of the Sixth Annual Research Symposium on Hazardous Waste, Chicago, Illinois.

Brown, R., Fyfe, W.S., Murray, F. and Kronberg, B.I., 1981 Immobilization of U-Th-Ra in mine wastes; Canadian Mining Journal, Vol. 102, No. 3, p. 71-76.

Colbert, T. and Klusman, R.W., 1982, Evaluation of radionuclide and trace metal migration beneath an inactive tailings impoundment: Fifth Symposium on Uranium Mill Tailings Management, Colorado State University, p. 275-293.

Crim, R.G., Shepard, T.A., and Nelson, J.D., 1979, Stability of natural clay liners in a low pH environment: Second Symposium on Uranium Mill Tailings Management, Colorado State University, p. 41-53.

Deutsch, W.J., Bell, N.E., Mercer, B.W., Serne, R.J., Shade, J.W., and Tweeton, D.R., 1984, Aquifer restoration techniques for in-situ leach uranium mines: U.S. Nuclear Regulatory Commission, NUREG/CR-3104, Washington, D.C.

Dodson, M.E., Gee, G.W., and Serne, R.J., 1984, The effects of crystalline Fe and Mn oxides on contaminant migration through soil liners: Sixth Symposium on Uranium Mill Tailings Management, Colorado State University, p. 125-134.

Doi, K., Hirono, S., and Sakamaki, Y., 1975, Uranium mineralization by groundwater in sedimentay rocks, Japan: Economic Geology, v. 70, p. 628-646.

Erikson, R.L. and Sherwood, D.R. 1982, Interaction of acidic leachate with soils materials at Lucky McPathfinder Mill, Gas Hills, Wyoming:

Fifth Symposium on Uranium Mill Tailings Management, Colorado State University, p. 335-351.

Gee, G.W., Campbell, A.C., Sherwood, D.R., Strickert, R.G., and Phillips, S.J., 1980, Interaction of uranium mill tailings leachate with soils and clay liners: U.S. Nuclear Regulatory Commission, NUREG/CR-1494, Washington, D.C., 49 p.

Griffin, R.A., Cartwright, K., Shimp, N.F., Steele, J.D., Ruch, R.R., White, W.A., Hughes, G.M., and Gilkeson, R.H., 1976, Attenuation of pollutants in municipal landfll leachate by clay minerals, Part 1 - Column leaching and field verification: Environmental Geology Notes, Illinois State Geological Survey, Number 78, 34 p.

Griffin, R.A., Frost, R.R., Au, A.K., Robinson, G.D., and Shimp, N.F., 1977, Attenuation of pollutants in municipal landfill leachate by clay minerals, Part 2 - Heavy-metal adsorption: Environmental Geology Notes, Illinois State Geological Survey, Number 79, 47 p.

Griffin, R.A. and Shimp, N.F., 1975, Leachate migration through selected clays: U.S. Environmental Protection Agency, EPA-600/9-76-004, Cincinnati, p. 92-95.

Griffin, R.A., Shimp, N.F., Steele, J.D., Ruch, R.R., White, W.A., and Hughes, G.M., 1976, Attenuation of pollutants in municipal landfill leachate by passage through clay: Environmental Science & Technology, v. 10, no. 13, p. 1262-1268.

Grim, R.E., 1968, Clay mineralogy: McGraw-Hill Book Co., New York, 596 p.

International Atomic Energy Agency, 1976, Management of wastes from the mining and milling of uranium and thorium ores: Vienna, 45 p.

Jenne, E.A., 1968, Controls on Mn, Fe, Co, Ni, Cu, and Zn concentrations in soils and water: The significant role of hydrous Mn and Fe oxides: Advances in Chemistry, no. 73, p. 337-387.

Kaufman, R.F., Eadie, G.G., and Russell, C.R., 1976, Effects of uranium mining and milling on groundwater in the Grants Mineral Belt, New Mexico: Ground Water, v. 14, no. 5, p. 296-308.

Korte, N.E., Kearl, P.M., Sewell, J.M., Fleishhauer, H.L., and Abramiuk, I.N., 1984, The Monticello, Utah uranium mill tailings site - A case history: Sixth Symposium on Uranium Mill Tailings Management, Colorado State University, p. 387-396.

Landa, E., 1980, Isolation of uranium mill tailings and their component radionuclides from the biosphere - Some earth science perspectives: U.S. Geological Survey Circular 814, Arlington, 32 p.

Longmire, P. and Brookins, D., 1982, Trace metal, major element, and radionuclide migration in groundwater from an acid leaching uranium tailings in the Grants Mineral Belt, New Mexico: Fifth Symposium on Uranium Mill Tailings Management, Colorado State University, p. 315-333.

Marcos, G. and Bush, K.J., 1981, Evaluation of interface between tailings and subtailings soil - A case study: Vitro tailings, Salt Lake City, Utah: Fourth Symposium and Uranium Mill Tailings Management, Colorado State University, p. 135-153.

McNeal, B.L., Norvell, W.A., and Coleman, N.T., 1966, Effect of solution composition on the swelling of extracted soil clays: Proceedings of the American Soil Science Society, v. 30, p. 313-317.

Opitz, B.E. and Sherwood, D.R., 1984, Neutralizing barrier for reducing contaminant migration from a uranium mill tailings disposal pond: Sixth Symposium on Uranium Mill Tailings Management, Colorado State University, p. 93-103.

Peterson, S.R., Erikson, R.L., and Gee, G.W., 1982, The long term stability of earthen materials in contact with acidic tailings solutions: U.S. Nuclear Regulatory Commission, NUREG/CR-2946, Washington, D.C., 71 p.

Peterson, S.R. and Krupka, K.M., 1981, Contact of clay liner materials with acidic tailings solutions II. Environmental modelling: Fourth Symposium on Uranium Mill Tailings Management, Colorado State University, p. 609-626.

Relyea, J.F. and Martin, W.J., 1982, Evaluation of inactive uranium mill tailings sites for liner requirements: Characterization and interaction of tailings, soil and liner materials: Fifth Symposium on Uranium Mill Tailings Management, Colorado State University, p. 507-519.

Robinson, B.P., 1962, Ion-exchange minerals and disposal of radioactive wastes - A survey of literature: U.S. Geological Survey Water-Supply Paper 1616, Washington, D.C., 132 p.

Schmidt-Collerur, J.J., 1978, Investigations of the relationship between organic matter and uranium deposits: Bendix Field Engineering Corporation, Final Report, Subcontract no. 76-030-E, Denver Research Institute, 265 p.

Serne, R.J., Peterson, S.R., and Gee, G.W., 1983, Laboratory measurements of contaminant attenuation of uranium mill tailings leachates by sediments and clay liners: U.S. Nuclear Regulatory Commission, NUREG/CR-3124, Washington, D.C., 78 p.

Shepard, T.A. and Brown, S.E., 1982, A generic model of contaminant migration from uranium tailngs impoundments: Fifth Symposium on

Uranium Mill Tailings Management, Colorado State University, p. 241-257.

Sherard, J.L., Dunnigan, L.P., and Decker, R.S., 1976, Identification and nature of dispersive soils: Journal of the Americal Society of Civil Engineers, Geotechnical Engineering Division, v. 101, no. GT4, p. 287-301.

Sherwood, D.R. and Serne, R.J., 1983, Tailings treatment techniques for uranium mill waste: A review of existing information: U.S. Nuclear Regulatory Commission, NUREG/CR-2938, Washington, D.C., 55 p.

Taylor, M.J. and Antommaria, P.E., 1978, Immobilization of radionuclides at uranium tailngs disposal sites: Symposium on Uranium Mill Tailings Management, Colorado State University, p. 13-45.

Taylor, J.J. and Popielak, R.S, 1984, Monitoring results and observations - Contaminant migration - Unlined uranium tailings disposal site: Sixth Symposium on Uranium Mill Tailings Management, Colorado State University, p. 369-375.

Thompson, B.M. and Heggen, R.J., 1981, Contaminant transport from uranium mill tailings in Ambrosia Lake, New Mexico: Fourth Symposium on Uranium Mill Tailings Management, Colorado State University, p. 415-437.

U.S. Nuclear Regulatory Commission, 1980, Final generic environmental impact statement or uranium mining: Project M-25, NUREG-0706, v. 1-3, appendices A-V, Washington, D.C.

Uziemblo, N.H., Erikson, R.L., and Gee, G.W., 1981, Contact of clay liner materials with acidic tailings solution, I. Mineral characterization: Fourth Symposium on Uranium Mill Tailings Management, Colorado State University, p. 597-608.

Van Zyl, D., 1982, Design, construction and field testing of a heap leach clay pad: Fourth Symposium on Uranium Mill Tailings Management, Colorado State University, p. 521-537.

White, A.F., Yee, A., Narasimhan, T.N., and Smith, A., 1984, Groundwater contamination at the inactive Riverton Wyoming uranium mill tailings: Sixth Symposium on Uranium Mill Tailings Management, Colorado State University, p. 185-195.

TECHNICAL MEMORANDUM NUMBER 3

Stability Evaluation of Tailings Facility

June 1, 1984

Prepared by C. Sealy, Chen and Associates, Inc.

chen and associates
CONSULTING GEOTECHNICAL ENGINEERS
96 SOUTH ZUNI STREET • DENVER, COLORADO 80223 • 303/744-7105

June 1, 1984

Subject: Technical Memorandum for Stability Evaluation of Tailings Management Facility, Swanson Uranium Project, Danville, Virginia

Job No. 26,350

Dravo Engineers, Inc.
1250 14th Street
Denver, Colorado 80202

Attention: Mr. Alan Notary

Gentlemen:

This technical memorandum is written to make clarifications on stability considerations of the proposed tailings management facility for the above referenced project. As with any tailings disposal system, stability considerations involve the following:

(1) Bearing capacity considerations
(2) Static stability
(3) Seismic stability

Bearing Capacity Considerations: The bearing capacity of the foundation is of prime importance. Consequently, geotechnical investigations will be conducted during later engineering analysis to determine the competency of the Triassic bedrock to support the proposed tailings facility. Borings will be drilled into the foundation materials and samples will be collected for laboratory testing. The testing will be performed to determine shear strength parameters and the modulus of elasticity of the rock. Analyses will then be made on the bearing capacity of the rock and the estimated deformations that will occur within the foundation due to loads imposed by the tailings and mine waste rock. Also, the proposed material that will be used as the rock fill pad to support the tailings impoundment will be analyzed as to its shear strength and deformation characteristics under the proposed loads.

For construction it is proposed that all of the residual soils be stripped to Triassic bedrock. The rock fill will then be placed under controlled conditions in order to eliminate excessive differential settlements. This will involve proper grading of the materials and compacting to a specified density. Quality control measures will be employed in the field to ensure that the geotechnical specifications are followed for the project.

It is my professional judgement that bearing capacity considerations should not pose a problem if the tailings impoundment is placed on a properly prepared foundation and rock fill pad system. As stated, this will involve developing a geotechnical drilling and testing program to determine strength parameters and developing a quality control program to ensure that the specifications are followed. We see no problems with bearing capacity or differential settlements if proper design and construction techniques are followed.

Static Stability Considerations: Static stability evaluations will be performed to design an appropriate configuration and geometry for the tailings impoundment. This will involve making an assessment of the strength parameters of the foundation, base pad, compacted tailings and cover materials. Stability would be a major concern near the edge of the impoundment where possible slope failure could occur if the embankments were not properly designed. Stability analysis will consider appropriate strength parameters and pore pressure buildup within the facility. Stability calculations will be made using computer methods by the Morganstern Price Method of stability analysis. In addition, other nonlinear failure modes will be considered so that an appropriate design can be formulated.

Seismic Stability Considerations: The tailings management facility is located in a region considered to have a moderate earthquake exposure (U.S. Army Corps of Engineers 1977). See the attached map. The facility will be designed to withstand strong ground shaking and other earthquake-related phenomena appropriate for the regional seismic exposure. Chen & Associates, Inc. has performed a preliminary seismic exposure evaluation for the site which was reported in the October 15, 1983 Marline submittal to the Uranium Administrative Group, (Sec. A.3.3). This preliminary study concluded that for the short term operational phase of the project (assuming a service life of 50 years) there is a 90% probability that strong ground shaking will not be greater than modified Mercalli intensity VI - VII. The analysis showed that a peak bedrock acceleration of 0.07g would not be exceeded at this probability level.

For the long-term post-reclamation phase of the project (considered to be at least 1,000 years) the preliminary analysis suggests that site intensities could be as high as IX - X for a maximum credible earthquake, and peak bedrock accelerations could be about 0.5g.

In order to develop final design for the tailings management facility, seismic stability analysis will be conducted. Earth structures, similar to the conceptual tailings pile proposed, have proven stable even under strong earthquake ground shaking when the embankment and foundations were not vulnerable to excessive strength loss or pore pressure buildup (Seed, 1983). The potential for excessive strength loss and pore pressure buildup can be evaluated by testing to be done as part of the final design and licensing investigations for the Swanson project. As conceptually planned, the tailings pile will be founded on hard rock and the reclaimed slopes will be a drained rock fill. Neither of these materials will be vulnerable to excessive strength loss or pore pressure buildup during strong earthquake ground shaking. The tailings in the pile interior will be tested to evaluate their potential for excessive strength loss and pore pressure buildup under operational and post-operational seismic loadings. If these tests show that there is not a potential for excessive strength loss and pore pressure buildup, the facility will be designed using a pseudostatic seismic analysis. Pseudostatic seismic coefficients, if appropriate for design, will be selected based on the U.S. Army Corps of Engineers criterion, see the attached map. The operational seismic coefficient will be for risk Zone 2 and a more conservative coefficient will be selected to evaluating the long-term post-reclamation phase. If excessive strength loss and pore pressure buildup are indicated, the facility design will be based on a dynamic stability analysis appropriate for the seismic exposure.

Geotechnical Monitoring: A geotechnical monitoring program will be established for the construction and operation phases of the facility, and also for the longterm after completion of milling operations and closure of the project. Information obtained from the monitoring program is necessary so that the safety and performance of the impoundment may be assessed, as well as assuring compliance with design drawings and specifications. Once the design and specifications have been formulated for the facility, a quality control program will be developed that will entail testing and inspections of each facet of the construction.

We hope that the above items clarify some of the aspects of geotechnical stability concerns for the project. After reviewing this letter, if you have any questions, please do not hesitate to contact our office.

Sincerely,

CHEN & ASSOCIATES, INC.

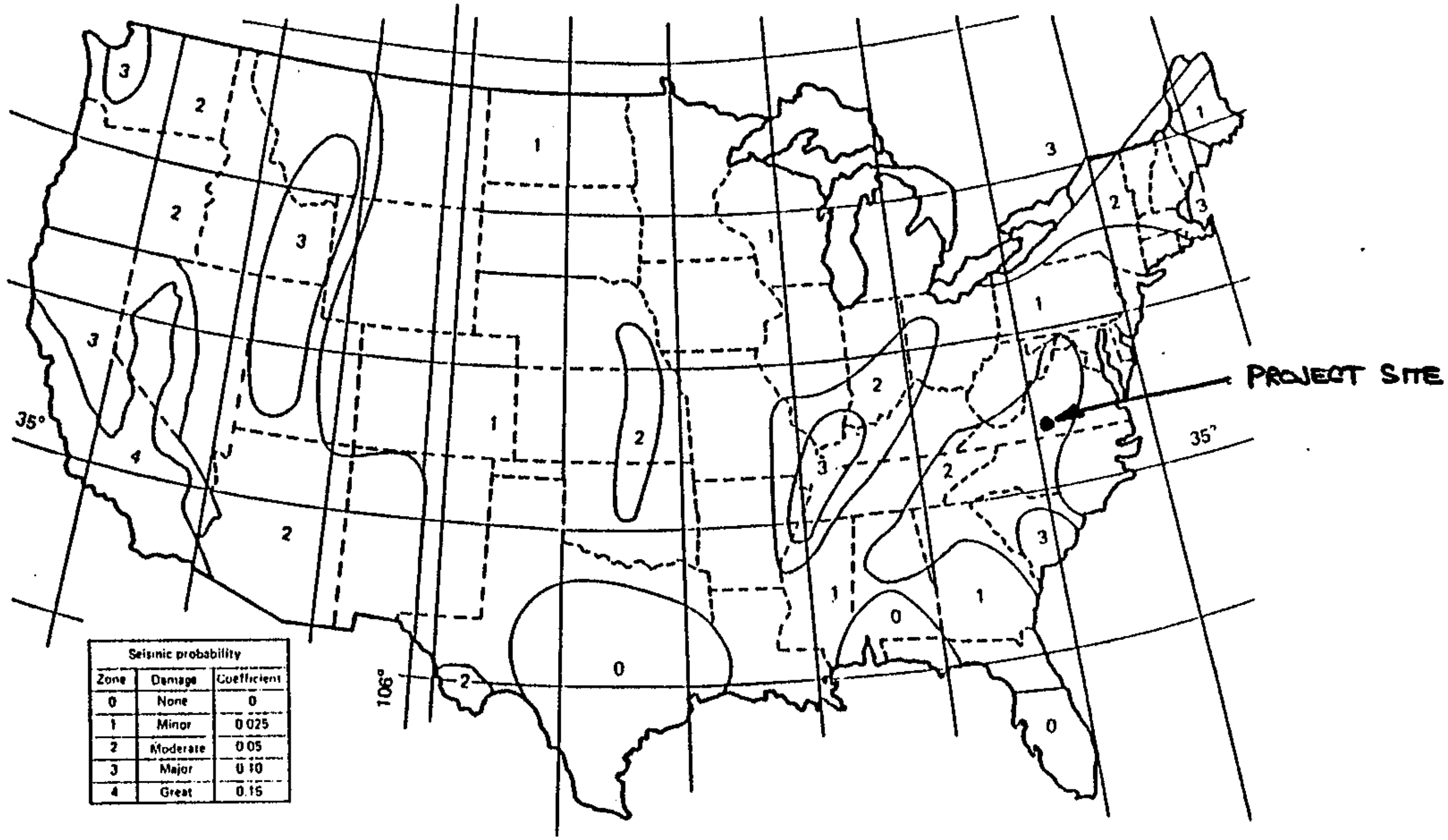
By Curtis O. Sealy
Curtis O. Sealy, P.E.

COS:cb
Encls.

REFERENCES

1) Corps of Engineers, 1977. "Engineering and Design, Earthquake Design Analysis for Corps of Engineers Dams," USACE, ER 1110-2-1806.

2) Seed, H.B., 1983, Earthquake-Resistant Design of Earth Dams in Seismic Design of Embankments and Caverns, Howard T.R., Editor: Amer. Soc. of Civil Engineers.



Seismic probability		
Zone	Damage	Coefficient
0	None	0
1	Minor	0.025
2	Moderate	0.05
3	Major	0.10
4	Great	0.15

Seismic zoning map of the United States, showing seismic coefficients for pseudo-static analyses. (From Corps of Engineers, 1977.)

TECHNICAL MEMORANDUM NUMBER 4

CSMRI Leachability Tests of Swanson Project Rock Materials

July 30, 1984

Prepared by Colorado School of Mines Research Institute

Colorado School of Mines Research Institute

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CSMRI

July 2, 1984

CSMRI Project NP-842069

Mr. Roman Z. Pyrih
Roman Z. Pyrih & Associates, Inc.
416-B Violet Street
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Dear Mr. Pyrih:

This letter reports the results of a recent study on four selected rock samples representing the Swanson uranium properties in Virginia. The samples were identified as follows.

Sample 1:	Ore-grade composite
Sample 2:	Mineralized waste composite
Sample 3:	Barren precambrian rock
Sample 4:	Barren triasic sediment

The objective of this study was to evaluate these samples for the leachability of specific elements and radionuclides during contact with water from natural precipitation. The study consisted of bench-scale percolation contacts on approximately 4-lb samples, with the contact time limited to 166 hr.

This project was authorized by a signed agreement dated May 8, 1984.

The results of this study show generally low concentrations of nonradioactive elements, but with higher concentrations of Ra226. The results are summarized as follows.

SUMMARY

With the possible exception of U_3O_8 in the water leach solution from the ore-grade composite, none of the samples produced solutions containing excessive concentrations of the nonradioactive elements. Elements which are the most strictly regulated, such as As, Sb, Bi, Cd, Cr, Cu, Pb, Hg, Mo, Se, Ag, and Tl, were not leached to excessive concentrations by the conditions used in this study.

Under the conditions of these tests, U_3O_8 was leached from the ore grade composite (0.106% U_3O_8) to a concentration of 0.465 ppm (0.394 ppm U), which suggests that seepage from ore-grade material could become a problem for concern.

The radiochemical analysis showed the barren Triassic sediment to be the only material which did not give potentially problematic response. The barren Precambrian rock responded to water leaching with a Ra226 concentration of 3.7 pCi/l under the leaching conditions used. The ore-grade rock and the low-grade waste, respectively, responded with concentrations of Ra226 at 29 and 26 pCi/l with associated high alpha-beta counts.

Please let me know if you have any questions concerning the procedure or test results covered in this report.

Very truly yours,

Hal D Peterson

Hal D. Peterson
Technical Consultant
Process Division

/psg

Enc.

DISCUSSION

PROCEDURE

The work was initiated by crushing the four samples to -¼ in. Four 2-in. in diameter columns were prepared for leaching of 4-lb sample charges. The columns were connected to individual, aerated solution reservoirs and individual pumps. Deionized water was percolated up through the columns over a period of 166 hr. The column overflows were monitored twice daily during this period to establish flow rates, pH, emf, and conductivity.

Solution-sample contact was judged adequate when the monitored data reached near steady state. This condition was met within the 166-hr circulation period. The column flows were then stopped, and the reservoir solutions were recovered for analysis. Treatment of this solution consisted of millipore filtering at 0.45 μm and transferring the solutions to 1 gal polyethylene bottles. An initial supply of deionized water was also filtered and handled in the same manner. Two samples from each set of four were acidified. The solutions were then analyzed for a specific set of elements and radionuclides. The details of this study are listed in Exhibits 1 and 2. The results are discussed as follows.

RESULTS

The bed volumes of water pumped through the test samples ranged from 27 to 28 for Samples 2 and 3. The bed volumes of water contacting Samples 1 and 4 were calculated as approximately 33. As shown by the operating log data, each of the solutions were near equilibrium with the rock samples by the 3rd or 4th day of test operation. This is indicated by a steady-state pH over a 3-day period. It is felt that the emf readings have little or no useful meaning in these tests, since only trace levels of pertinent elements (including dissolved oxygen) were in solution. It can be seen that the solution conductivities were increasing slowly with time, which is to be expected. The conductivities logged represent an increase over a measured resistance of 60 micro-ohms for the deionized water. The downward shift in pH over the last 2 days of circulation was felt to be the effect of atmospheric CO_2 adsorption resulting from continuous aeration.

The elemental analyses obtained from these solutions indicate that, with the possible exception of U_3O_8 from the ore-grade composite, none of the samples showed a clear indication of contributing undesirable metals to contacting water. The highest elemental constituent in all cases was calcium, which was probably solvated as a bicarbonate. The most undesirable metals, such as As, Sb, Bi, Cd, Cr, Cu, Pb, Hg, Mg, Se, Ag, and Tl, were present at trace concentrations. The quantity of U_3O_8 leached from the ore-grade composite may become excessive, depending on the dilution factor.

Depending on contact duration and on the water to solids ratio involved, water which contacts either the normal grade ore or the mineralized waste would result in increases in Ra226.

APPENDIX

EXHIBIT 1

SAMPLE DESCRIPTION AND PREPARATION

Sample Description

Four samples of dried and crushed material were received for the study. These samples are described as follows.

Sample No.	Identification	Initial Crush in.	Approximate Weight lb
1	Ore-grade composite	-¼	75
2	Mineralized waste composite	-¼	20
3	Barren precambrian rock	-½	10
4	Barren triasic sediment	-½	10

Sample Preparation

Samples 1 and 2 were of suitable size and required no further crushing. Samples 3 and 4 were crushed to -¼ in. The samples were split to produce the following column charges:

Sample 1: 1,939.5 g
Sample 2: 2,072.4 g
Sample 3: 1,859.0 g
Sample 4: 1,819.0 g

Rejects from splitting were repackaged and saved for future needs.

EXHIBIT 2

PERCOLATION LEACHING STUDY

Percolation Leaching Tests 1 through 4

Objective

The objective of this study was to evaluate the potential for groundwater contamination due to the leaching of mineral constituents by natural precipitation.

Rock Samples

As described in Exhibit 1.

Test Apparatus

The test apparatus consisted of four individual units, each consisting of the following.

1. A covered 5-gal plastic reservoir for the reserve water.
2. A 2.0-in. or a 2¼-in. ID Plexiglas column prepared with top and bottom outlets. A fiber disk was placed over the bottom outlet for ore retention.
3. An air disperser for small air bubble generation and an air pump capable of independent operation and independent control.
4. A Masterflex solution metering pump with independent controls.
5. Pyrex and Tygon tubing as required for upflow percolation through the sample bed and recovery into the reservoir by overflow from the top of the column.

A diagram of an individual test unit is shown in Figure 1.

Description of Individual Test Units

The details of the individual test units just prior to initiation of circulation was as follows.

Sample No.	Column ID in.	Dry Charge Weight g	Charge Bed Height in.	Charge Bed Volume cc	Solution Above Charge in.
1	2-1/4	1,939.5	23-1/4	1,506	24-1/4
2	2-1/4	2,072.4	25	1,619	7-3/8
3	2-1/4	1,859.0	25-7/8	1,676	7
4	2	1,819.1	26-5/8	1,363	15-1/2

FIGURE 1

Diagram of an Individual
Percolation Leaching Test Unit

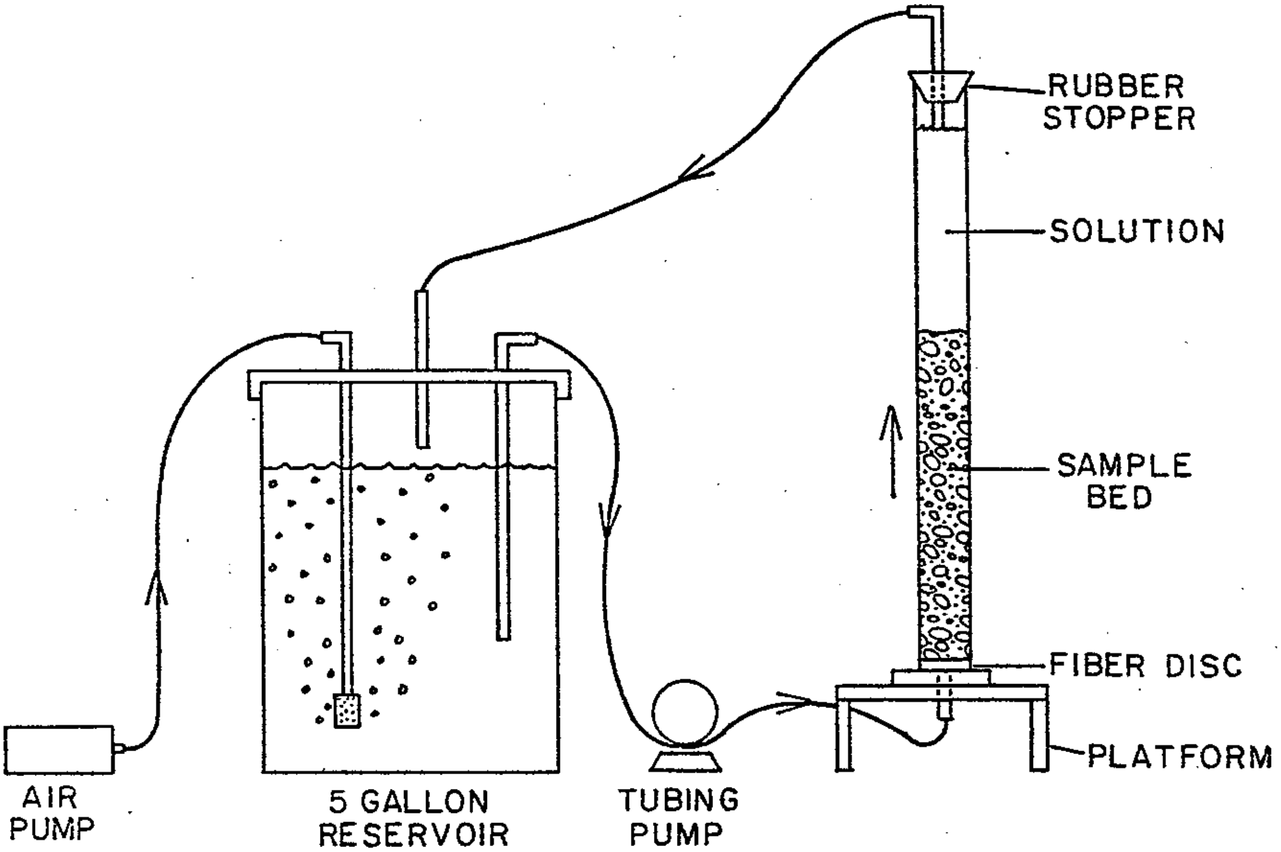


EXHIBIT 2

Percolation Leaching Tests
1 through 4 -- continued

Test Procedure

The tests were conducted using an initial volume of 4.0 gal of deionized water in each reservoir. Flow rates were maintained to provide approximately 5 bed volumes of throughput per 24 hr day. The sample beds were initially wetted by upflow, and the freeboard space above the beds was filled to the point of initial circulation. The liquid level in the reservoirs was then marked and maintained by replacement of evaporation loss on a once per day basis using deionized water. Aeration of the reservoirs was maintained at a rate of 200-300 cc/min on a continuous basis. The column overflows were monitored by sampling twice daily and recording the solution flow rates, pH, emf, and conductivity. Circulation was maintained for a total of 166 hr. The columns were then clamped off and left to stand against possible further operation. The solution in the reservoirs was filtered at 0.45 µm and transferred to 1-gal polyethylene bottles. Additionally, 4 gal of the initial reserve deionized water was also filtered at 0.45 µm and transferred to 1-gal bottles. Two of the samples from each test plus two samples of the deionized water were acidified for stabilization.

Two of the 1-gal samples from each test plus 2 gal of demineralized water were submitted for a predefined series of elemental and radiochemical analysis. Duplicate samples were retained for possible additional samples.

EXHIBIT 2

Results:

Operating Log

		Sample 1				Sample 2			
Date	Time	Flow Rate cc/min	pH	-mv	Conductivity μΩ	Flow Rate cc/min	pH	-mv	Conductivity μΩ
5/14/84	1400	~4.0	--	--	--	~4.0	--	--	--
5/15/84	0900	4.9	8.20	324	1,300	4.6	8.40	314	1,375
5/15/84	1610	4.9	8.22	284	1,175	4.8	8.50	284	1,400
5/16/84	0800	3.9	8.22	324	1,170	3.8	8.42	309	1,400
5/16/84	1600	3.6	8.20	--	1,250	3.7	8.30	--	1,450
5/17/84	0800	4.6	8.20	284	1,300	4.6	8.30	294	1,450
5/17/84	1630	7.6	8.20	294	1,325	4.6	8.30	294	1,450
5/18/84	0830	6.3	8.20	304	1,400	5.3	8.30	304	1,550
5/18/84	1600	4.3	8.20	294	1,425	4.4	8.30	294	1,600
5/21/84	1200	4.5	7.40	334	1,425	4.8	7.72	334	1,700

		Sample 3				Sample 4			
Date	Time	Flow Rate cc/min	pH	-mv	Conductivity μΩ	Flow Rate cc/min	pH	-mv	Conductivity μΩ
5/14/84	1400	~4.0	--	--	--	~4.0	--	--	--
5/15/84	0900	5.3	8.50	324	1,100	5.5	8.48	319	800
5/15/84	1610	5.5	8.52	270	1,200	5.2	8.50	286	875
5/16/84	0800	3.6	8.30	314	1,200	3.4	8.40	324	900
5/16/84	1600	3.5	8.30	--	1,310	3.5	8.30	--	950
5/17/84	0800	3.8	8.30	304	1,300	3.8	8.30	304	950
5/17/84	1630	3.4	8.30	294	1,325	3.8	8.30	294	1,000
5/18/84	0830	3.5	8.30	304	1,400	3.8	8.25	334	1,025
5/18/84	1600	6.2	8.30	284	1,425	6.0	8.25	294	1,075
5/21/84	1200	6.3	7.54	354	1,550	6.5	7.52	354	1,175

EXHIBIT 2

Results:

Elemental Analysis, mg/liter

Elements	Deionized Water	Sample 1	Sample 2	Sample 3	Sample 4
Aluminum (Al)	<0.1	0.21	0.24	<0.1	0.13
Antimony (Sb)	<0.1	<0.1	<0.1	<0.1	<0.1
Arsenic (As)	<0.004	0.022	0.024	0.038	0.008
Barium (Ba)	<0.005	0.071	0.220	0.170	0.024
Beryllium (Be)	<0.002	<0.002	<0.002	<0.002	<0.002
Bismuth (Bi)	<0.3	<0.3	<0.3	<0.3	<0.3
Boron (B)	<0.01	0.1	0.1	0.05	0.05
Cadmium (Cd)	<0.01	<0.01	<0.01	<0.01	<0.01
Calcium (Ca)	<0.1	10	10	9	9
Chromium (Cr)	<0.02	<0.02	<0.02	<0.02	<0.02
Cobalt (Co)	<0.01	<0.01	<0.01	<0.01	<0.01
Copper (Cu)	<0.01	<0.01	<0.01	<0.01	<0.01
Iron (Fe)	<0.01	<0.01	<0.01	<0.01	<0.01
Lead (Pb)	<0.04	<0.04	<0.04	<0.04	<0.04
Magnesium (Mg)	<0.02	0.76	1.84	1.36	1.17
Manganese (Mn)	<0.005	<0.005	0.006	0.019	0.037
Mercury (Hg), ug/l	<0.4	<0.4	<0.4	<0.4	<0.4
Molybdenum (Mo)	<0.01	0.08	0.03	<0.01	<0.01
Nickel (Ni)	<0.01	<0.01	<0.01	<0.01	<0.01
Selenium (Se)	<0.004	<0.004	<0.004	<0.004	<0.004
Silver (Ag)	<0.02	<0.02	<0.02	<0.02	<0.02
Strontium (Sr)	<0.03	0.22	0.22	0.27	0.06
Thallium (Tl)	<0.1	<0.1	<0.1	<0.1	<0.1
Titanium (Ti)	<0.02	<0.02	<0.02	<0.02	<0.02

EXHIBIT 2

Results:

Elemental Analysis, mg/liter -- continued

Elements	Deionized Water	Sample 1	Sample 2	Sample 3	Sample 4
Uranium (U_3O_8)	<0.001	0.465	0.046	0.043	0.005
Vanadium (V)	<0.01	0.02	0.02	<0.01	<0.01
Zinc (Zn)	<0.01	0.03	0.01	<0.01	<0.01
Zirconium (Zr)	<0.03	<0.03	<0.03	<0.03	<0.03
Cerium (Ce)	<0.02	0.34	0.32	0.41	0.10
Lanthanum (La)	<0.02	<0.02	<0.02	<0.02	<0.02
Thorium (Th)	<0.1	<0.1	<0.1	<0.1	<0.1
Yttrium (Y)	<0.2	<0.2	<0.2	<0.2	<0.2
TDS (calculated)	8	53	58	41	28
Sulfate (SO_4)	<5	<5	<5	<5	<5
Chloride (Cl)	2	4	2	4	2
Total Alkalinity[1] [3]	2	40	44	38	34
Phosphate[2] [3]	<0.01	0.03	<0.01	0.02	<0.01
Fluoride (F)[3]	0.01	0.11	0.12	0.07	0.05

[1] pH 3.7 as $CaCO_3$.
[2] Total (PO_4-P).
[3] Filterable.

EXHIBIT 2

Results:

Elemental Duplicates, mg/liter

Elements	Deionized Water	Sample 1	Sample 2	Sample 3	Sample 4
Cadmium (Cd)	<0.01	<0.01	<0.01	<0.01	<0.01
Molybdenum (Mo)	<0.01	0.08	0.03	0.01	<0.01
Uranium (U_3O_8)	<0.001	0.455	0.044	0.043	0.005
Zinc (Zn)	<0.01	0.03	0.01	<0.01	<0.01

EXHIBIT 2

Results:

Radiochemical Analysis, pCi/l

	Deionized Water	Sample 1	Sample 2	Sample 3	Sample 4
Gross Alpha	0.0 ± 0.5	1,472 ± 29	377 ± 14	20 ± 43	2.5 ± 1.6
Gross Beta	0.0 ± 1.0	332 ± 9	83 ± 4	3 ± 42	1.8 ± 1.7
Lead 210	0.5 ± 0.6	0.1 ± 0.7	0.4 ± 0.7	0.1 ± 0.7	0.1 ± 0.7
Polonium 210	0.0 ± 0.1	0.9 ± 0.2	0.4 ± 0.2	0.0 ± 0.1	0.0 ± 0.1
Radium 226	0.0 ± 0.1	29 ± 1	26 ± 1	3.7 ± 0.3	0.9 ± 0.2
Radium 228	0.0 ± 0.5	0.3 ± 0.6	0.1 ± 0.5	0.1 ± 0.5	0.1 ± 0.5
Thorium 230	0.2 ± 0.2	0.4 ± 0.1	0.1 ± 0.1	0.6 ± 0.1	0.0 ± 0.1
Thorium 232	0.6 ± 0.3	0.0 ± 0.1	0.0 ± 0.1	0.0 ± 0.1	0.0 ± 0.1

TECHNICAL MEMORANDUM NUMBER 5

Summary of PABLM Input Parameters

June 26, 1984

Prepared by A. Notary, Dravo Engineers, Inc.
N. Savignac, Ph.D.

SUMMARY OF PABLM INPUT PARAMETERS

Justification is presented below for values to be entered into the PABLM computer assessment of radiation doses from the water pathway at the Marline Uranium Corporation Swanson Project. Please review each value and its justification as being applicable to a fairly homogeneous group of humans that would be impacted by radiological releases from the project. The impacts to humans with unusual habits or under unusual circumstances will be addressed subsequently through the use of multipliers to the results from the PABLM computations.

I. Normal Discharge into Mill Creek Diversion

A. Net Water Discharge Rate = 0.37 cfs

This flow rate is based on a preliminary project water balance that incorporated the mine, mill and tailings management area, as summarized on the attached Figure II-12. This figure is a revision of a similar diagram that was in the October, 1983 report. A detailed discussion of the various flow rates indicated on the figure is in the Technical Summary. Other supporting calculations are attached to this PABLM input summary document.

B. Suspended and Dissolved Radionuclide Content of Mine Water Discharge

U-238 & 234	0.5 mg/l
Th-230	0.4 pCi/l
Ra-226	3.0 pCi/l
Pb-210	0.1 pCi/l
Po-210	0.9 pCi/l

Based on the results of the CSMRI leaching studies, where deionized water was percolated through crushed Swanson ore, an attempt was made to synthesize a water quality representative of mine water. The exercise produced a water quality much better than the well (M-5) sample discussed on page E.1-37 of the October 15, 1983 report. Based on this data, and the demonstrated ability of the proposed barium chloride treatment process to successfully treat Swanson mine waters, the above parameters are proposed for PABLM input. Additionally, Table I summarizes data collected from industry practice which support the applicability of barium chloride treatment.

TABLE 1

Radionuclide Content of Uranium Mine Water Treated with Barium Chloride (suspended plus dissolved fractions in pCi/l)

	Th-230	Ra-226	Pb-210	Po-210
Mine A	3.9	0.7	4.5	3.4
Mine B	0.1	2.5	10.0	10.0
Mine C	4.0	---	18.0	14.0
Mine D	0.4	0.9	1.0	1.0
Mine E	0.1	2.8	6.9	6.5
Mine F	0.006	2.0	0.001	---
Average	1.4	1.8	6.7	7.0

Table I presents a partial listing of the radionuclide content of uranium mine waters discharged to waterways in the U.S. The values were obtained from state regulatory agencies or uranium mine companies with the commitment not to reveal the source of specific values. All samples were of mine water treated with barium chloride and settling or flocculation of the precipitate formed. The average concentrations in treated mine water are presented at the bottom of the table. Each value is a combination of suspended and dissolved components.

The Ra-226 concentration proposed for PABLM input is the maximum allowable soluble discharge to streams under the EPA New Source

Performance Standards (40 CFR 440). The other four parameter concentrations are taken from the CSMRI test results.

C. Receiving Water Flow Rate - Average Flows

Mill Creek	10.5 cfs
Whitethorn Creek (at confluence with Mill Creek)	30 cfs
Banister River (at Halifax)	550 cfs

PABLM calculates radiological doses from chronic intakes of radionuclides. Both the intakes and calculated doses are expressed as annual values. Thus, the average flow rates for the streams receiving effluents are used to calculate the annual doses.

D. Mill Creek Receptor

Deleted

See the justification presented under item V.A.

E. Cedar Hill Hunt Club Receptor

Location (Figure B.2.2-3 Vol. 1a)	#33
Gamma exposure rate is only from standing in irrigated field	
Irrigation by sprinkler system at	0.6 ac ft/yr
Dietary consumption of locally raised plants and animals	50%
Drinking water consumed from Whitethorn	0 gal/yr
Fish consumed from Whitethorn	2.2 kg/yr

See location justification under item V.A., Cedar Hill Hunt Club. The gamma exposure rate is only from standing in an irrigated field because Cedar Hill Hunt Club is not immediately adjacent to

Whitethorn Creek. The sprinkler irrigation rate is considered reasonable for that area of Virginia. The 50% dietary consumption of locally raised plants and animals results from the purchase of many food products at local stores. The typical resident of this area is not completely self-sustaining for his food supply.

F. Halifax Receptors

All drinking water from alum-flocculation treatment
plant is consumed by - 1200 people
Consumption of fish from Banister River - 2.2 kg/yr

The Halifax water treatment plant is the nearest plant downstream from the Swanson site and provides water to approximately 1200 people.

II. SEEPAGE

Due to the low permeability of the Triassic rocks, and the fact that local ground water gradients follow the area topography, seepage from the Swanson Project will ultimately end up in the local streams. Ignoring the expected benefit of geochemical trapping of radionuclides in local soils and rocks, the simplifying assumption is made that all seepage discharges directly to the streams. The following outlines various sources of seepage.

A. Seepage from Tailings

1. Quantity - 0.065 cfs

Assuming an average depth of 30 feet of saturated tailings results in a seepage rate through the clay liner of 0.15 gpm/acre (see attached calculations). Applying this rate to the 191 acre facility results in (191) (0.15) = 29 gpm, or 0.065 cfs.

2. Radionuclide Content

Two cases are proposed for PABLM analysis, an unattenuated, ("worst case"), undiluted carbonate tailings fluid and a geochemically attenuated carbonate tailings fluid.

Case 1 - Unattenuated:

U-283 & 234	35 mg/l
Th-230	162 pCi/l
Ra-226	22 pCi/l
Pb-210	7 pCi/l
Po-210	1 pCi/l

Case 2 - Attenuated:

U-238 & 234	1 mg/l
Th-230	1 pCi/l
Ra-226	1 pCi/l
Pb-210	2 pCi/l
Po-210	1 pCi/l

B. Seepage from Mine Overburden

1. Quantity

a. Unvegetated Overburden - 0.274 cfs

The total acreage containing mine overburden equals 915 acres. Subtracting the lined tailings management area (191 acres) results in 724 acres of overburden. It is assumed that 10% of this area is unvegetated. Continuous reclamation and local climatic conditions make this assumption reasonable. Therefore, (0.10) (724), or 72 acres will be unvegetated. The addition to this acreage, it is assumed that 20% of the reclaimed tailings area is unvegetated, resulting in (191-10) (0.20), or 36 additional acres, for a grand total of 108 acres.

From water balance calculations, 22 inches of annual rainfall (42 inches) will result in seepage from this area. This is equivalent to 1.137 gpm/acre, for a total of (1.137) (108), or 123 gpm (0.274 cfs). Refer to the attached calculations for water balance calculation details.

b. Vegetated Overburden - 0.540 cfs

The remaining vegetated overburden area is 724-72, or 652 acres. From water balance calculations, 6.1 inches of the annual rainfall will result in seepage. This is equivalent to 0.315 gpm/acre, for a total of (0.315) (652), or 205 gpm (0.457 cfs).

For those areas where overburden will cover tailings, the clay cap will inhibit vertical percolation and therefore will force the water to flow laterally through the overlying drainage blanket. This acreage is estimated to be 80% of the covered tailings area, or (191-10) x (0.80) = 145 acres. Water balance calculations result in 5 inches of the annual rainfall flowing through this drain and ultimately off of the tailings area. This is equivalent to 0.258 gpm/acre, for a total flow of (0.258) (145), or 37.45 gpm (0.083 cfs). Therefore, the total flow from vegetated overburden areas is 0.457 + 0.083 = 0.54 cfs.

2. Radionuclide Content

The radionuclide content of seepage through mine overburden storage piles was estimated from the CSMRI leaching studies conducted on barren Triassic rock, mineralized crystalline rock and barren crystalline rock. The reported radiological concentrations were averaged based on weighting each parameter by the total tonnage of the various categories of rock. (The ratio of Triassic:mineralized crystalline:barren crystalline = 1.44:1:1). The results are as follows:

U-238 & 234	0.028 mg/l
Th-230	0.203 pCi/l
Ra-226	9.01 pCi/l
Pb-210	0.187 pCi/l
Po-210	0.116 pCi/l

C. **Receiving Water Flow Rate** - same as I.C. above.

D. **Cedar Hill Hunt Club Receptor** - same as I.E. above.

E. **Halifax Receptors** - same as I.F. above.

III. RUNOFF

Two types of surface water runoff will occur at the project site: runoff from controlled areas that will be collected and used as mill process makeup water (mill site, exposed tailings area, etc.), and runoff from other larger areas, such as the overburden storage areas, that may have some radiological content. The latter type will be routed through sedimentation structures to remove particulates. The following outlines the various sources of runoff that will impact the local surface water system and therefore only considers the second category of runoff.

A. Runoff from Mine Overburden Areas

1. Quantity

a. Unvegetated Overburden - 0.002 cfs

As discussed in II.B.1.a. above, an estimated 108 acres of unvegetated overburden is the basis of this calculation. Based on water balance calculations, the runoff from this area is 0.2 inches out of the total annual precipitation. This number is relatively low due to the porous nature of the overburden rock piles inhibiting direct runoff. This depth of water over 108 acres is equivalent to 0.010 gpm/acre or (0.01) (108) = 1.116 gpm (0.002 cfs).

b. Vegetated Overburden

This source is not considered due to the soil and vegetative cover isolating the surface runoff from contamination.

2. Radionuclide Content

The quality of runoff from overburden areas will be better than that of seepage due to less contact time with the material. It is assumed that the radiological concentrations of the runoff will be one half that of the seepage described in II.B.2 above:

U-238 & 234	0.014 mg/l
Th-230	0.102 pCi/l
Ra-226	4.505 pCi/l
Pb-210	0.094 pCi/l
Po-210	0.058 pCi/l

B. **Receiving Water Flow Rate** - Same as I.C. above.

C. **Cedar Hill Hunt Club Receptor** - Same as I.E. above.

D. **Halifax Receptors** - Same as I.F. above.

IV. POND BREACH

A potential accident considered for PABLM analysis is the breaching of the mill pond. The following discusses the associated PABLM input parameters.

A. Volume of Water Released - 4 acre ft. (2.02 cfs for 24 hrs)
The volume of water associated with the mean annual precipitation event (2 yr frequency) was considered. This is equivalent to 3.5 inches over 24 hours, and was considered over less frequent events because of the greater probability of such a volume being held at any given time. In the case of rarer, more extreme rainfall events, the associated high stream flows would dilute the volume of liquid breached.

The collapse of a pond dike is assumed to release 2.02 cfs over a 24-hour period. This is equivalent to 3.5 inches over 14 acres, or 4 acre-ft. (The area of exposed tailings and the pond itself is estimated at 14 acres).

B. Radionuclide Content
To arrive at a radionuclide content representative of what would be contained in the mill pond, values typical of industry practice were applied. The following values were taken from ORNL-TM-4903 "Correlation of Radioactive Waste Treatment Costs and the Environmental Impact of Waste Effluents in the Nuclear Fuel Cycle for Use in Establishing as Low as Practicable Guides - Milling of Uranium Ores," 1975:

TABLE 2
Radionuclide Concentration
in Alkaline Tailings Liquids (pCi/l)

	Alkaline Liquids
U-238 & 234	10,000
Th-230	20
Ra-226	100
Pb-210	80
Po-210	20

Assuming a 50% dilution due to the additional waters from rainfall itself results in the following PABLM inputs:

U-238 & 234	5,000 pCi/l
Th-230	10 pCi/l
Ra-226	50 pCi/l
Pb-210	40 pCi/l
Po-210	10 pCi/l

C. **Receiving Water Flow Rate** - See average values in 1.C.
A dam break could possibly occur any time, e.g., during high flow or low stream flow conditions. Thus, average stream flow values were considered appropriate for this evaluation.

D. **Cedar Hill Hunt Club Receptor** - same as I.E. above

E. **Halifax Receptors**
Drinking water from alum-flocculation treatment plant - 1200 people
Consumption of fish from Banister River - 0 kg/yr
The people of Halifax are assumed to drink water at the time of the pond breach. No fish are assumed to be caught and consumed during the breach because of the limited time for the slug of liquids from the breach to pass down Whitehtorn Creek and the Banister River, i.e., possibly two days out of 365 days.

V. SCENARIOS

A. Determine the total radiation dose with and without radon during normal operations

1.	To	From
	Mill Creek receptor #30	Mill Creek diversion Air pathway

DELETED

The Mill Creek receptor location #30 was deleted from the scenarios considered because the Mill Creek diversion, which receives the treated mine water, will be within the Swanson Project boundaries. The use of water directly from the Mill Creek diversion will be controlled by Marline. The water will not be available for irrigation use until the diversion waters flow into Whitethorn Creek. Seepage and surface water runoff from the Swanson Project ultimately flow into Whitethorn Creek. That stream will likewise be within the Swanson Project boundaries from the point where seepage and surface water runoff enter Whitethorn down to the confluence of the Mill Creek diversion with Whitethorn. Thus, the nearest downstream use of surface waters for irrigation is Cedar Hill Hunt Club, location #33, discussed below.

2.	To	From
	Cedar Hill Hunt Club #33	Mill Creek diversion Seepage Surface water runoff Air pathway

Receptor location #33 on Figure B.2.2-3 in Volume 1a was selected because that location is the nearest downstream potential user of surface waters impacted by treated mine water (from Mill Creek diversion), seepage, and by surface water runoff. Receptor location #33 is near a group of residences that could use the water for irrigation. In addition, the doses from the airborne particulates and from radon were calculated for that location which allows the determination of total dose from both the water and air pathway at that location.

3.	To	From
	Halifax	Mill Creek diversion Surface water runoff Seepage

Halifax is the location of the nearest municiple water treatment plant downstream from the project site and on the Banister River.

Water is taken directly from the Banister for treatment and distributed to 1200 people. At Halifax, the Banister contains effluents from treated mine water (Mill Creek diversion), seepage, and surface water runoff. All of the drinking water for the people of Halifax is assumed to come from the water treatment plant.

B. Determine the total radiation dose with radon after a pond breach.

1.

To	From
Cedar Hill Hunt Club #33	Mill Creek diversion Seepage Surface water runoff Pond breach Air pathway

See the justification for the Cedar Hill Hunt Club #33 in V.A. above. In this scenario, the impact from a potential pond breach is added to the impacts from the release of treated mine water (Mill Creek diversion), seepage, surface water runoff, and the air pathway. Results include the impacts of radon because a comparison with the 25 mrem per year standard is not appropriate since that standard applies to releases from normal operations as opposed to accident conditions.

2.

To	From
Halifax	Mill Creek diversion Seepage Surface water runoff Pond breach

See the justification for Halifax in V.A. above. In this scenario, the impact from a pond breach is added to the impacts from the release of treated mine water (Mill Creek diversion), seepage, and the surface water runoff. The impacts from the air pathway are not considered because Halifax is too far away, approximately 25 miles, from the project site to be significantly impacted. See the calculated airborne impact at Danville, location #33, approximately 19 miles away in nearly the same direction as presented in Table B.2.2-9 on page B-2-46 of Volume 1a.

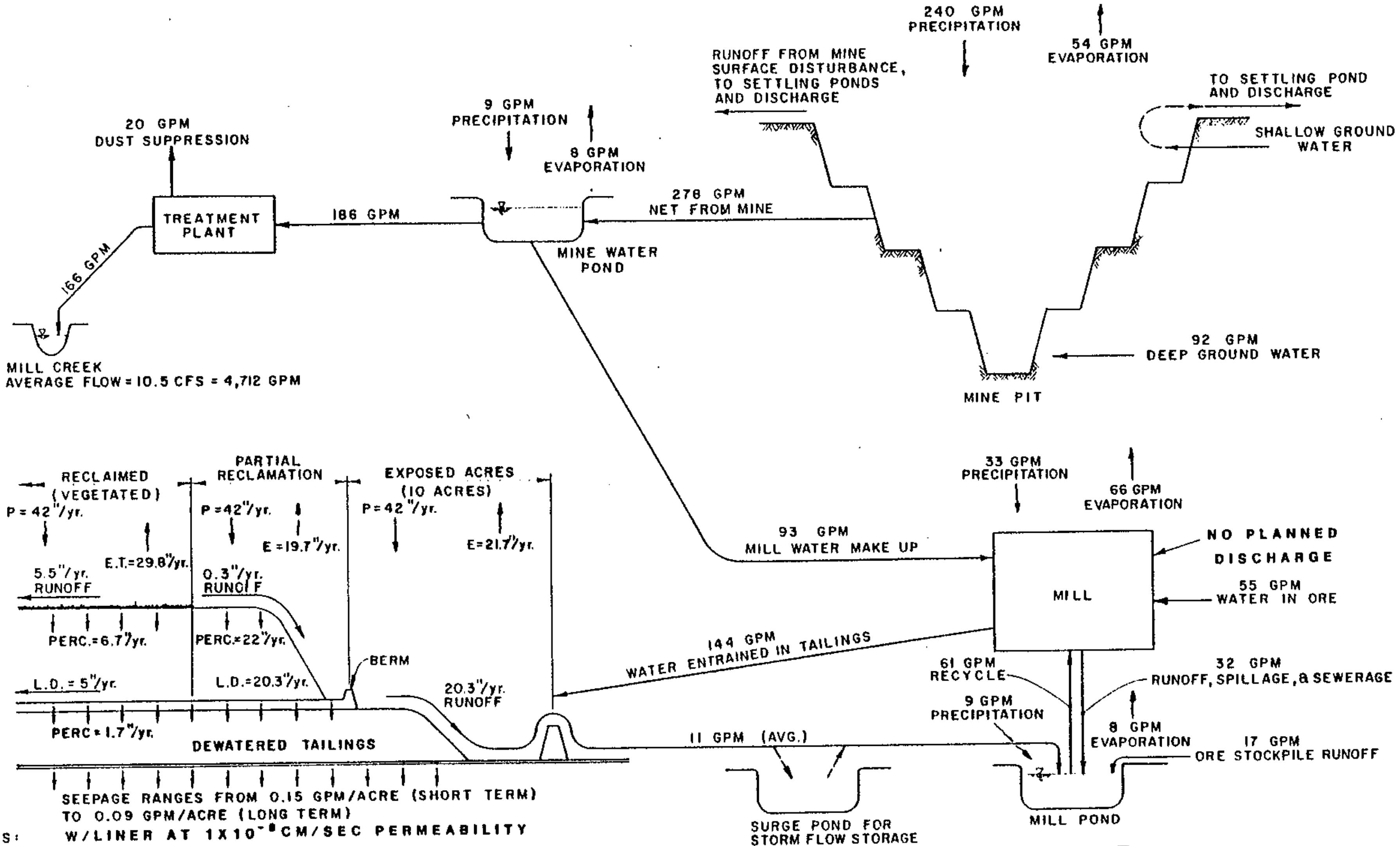
Attachments to PABLM Inputs Summary

1) Summary Table
2) Preliminary Project Water Balance
3) Tailings Seepage Calculations
4) Water Balance Calculations - EPA Method
5) Water Balance Calculations - "HELP" Model
6) Typical "HELP" Output
7) "HELP" Documentation
8) Swanson Project Area Water Use & Food Consumption Survey - Summary

SUMMARY OF PABLM INPUTS

	MINE	MILL	TAILINGS MANAGEMENT			OVERBURDEN	
	(TREATED DISCHARGE)	(POND BREACH)	VEGETATED	UNVEGETATED	EXPOSED	VEGETATED	UNVEGETATED
1. SEEPAGE			VIA LATERIAL DRAIN:				
a. QUANTITY (cfs)	N/A	N/A	INCLUDED WITH OVERBURDEN	INCLUDED WITH OVERBURDEN	N/A	0.540	0.274
			SEEPAGE THRU LINER = 0.065 cfs				
b. RADIONUCLIDE CONTENT			CASE 1:		CASE 2:		
U- 238 & 234 mg/l	-	-	35		1	0.028	
Th - 230	-	-	162		1	0.203	
Ra - 226	-	-	22		1	9.01	
Pb - 210	-	-	7		2	0.187	
Po - 210	-	-	1		1	0.116	
2. RUNOFF (& OTHERS)	TREATED DISCHARGE:	POND BREACH:					
a. QUANTITY (cfs)	0.37	2.02 cfs (over 24 hours)	N/A	0.002	N/A	N/A	0.002
b. RADIONUCLIDE CONTENT							
U - 238 & 234 mg/l	0.5	5000 (pCi/l)	-	0.014	-	-	0.014
Th - 230	0.4	10	-	0.102	-	-	0.102
Ra - 226	3.0	50	-	4.505	-	-	4.505
Pb - 210	0.1	40	-	0.094	-	-	0.094
Po - 210	0.9	10	-	0.058	-	-	0.058

N/A = Not Applicable



NOTES:

P PRECIPITATION
E EVAPORATION
E.T. EVAPOTRANSPIRATION
PERC. PERCOLATION
L.D. LATERAL DRAINAGE
1 CUBIC FOOT PER SECOND (CFS) = 448.8 GALLONS PER MINUTE (GPM)

MARLINE URANIUM CORPORATION
PITTSYLVANIA COUNTY, VIRGINIA

PRELIMINARY PROJECT WATER BALANCE
(CARBONATE)
SWANSON URANIUM PROJECT

Dravo revised AUG/84

FIGURE II-12

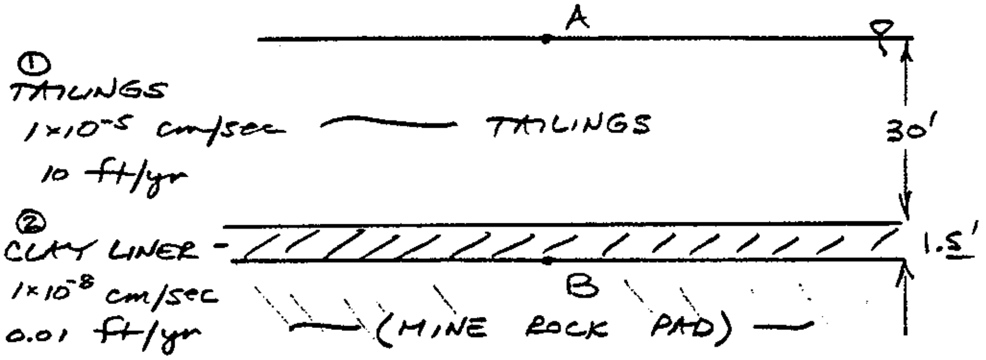
Dravo
Denver Operating Center

ENGINEERING COMPUTATIONS

EST NO.
CONT NO. 8079
DIVISION

COMPANY Marline Uranium
LOCATION Danville, VA
DESCRIPTION Tailings' Seepage @ Saturation

DATE 4-10-84
DR ALN CH
REF



- ASSUME TAILINGS SATURATED: ~30' HEAD
- CALCULATE SEEPAGE RATE PER DARCY'S LAW:

$$Q = kiA$$

HEAD LOSS $A \rightarrow B = h = 31.5' = h_1 + h_2$

$$Q = Q_1 = Q_2 \quad \text{(CONTINUITY)}$$

$$Q = \frac{k_1 h_1}{L_1} = \frac{k_2 h_2}{L_2} \Rightarrow \frac{10 h_1}{30} = \frac{(31.5 - h_1)0.01}{1.5}$$

$$\therefore \quad h_1 = 0.618', \quad h_2 = 30.882'$$

$$\therefore Q = 0.206 \text{ ft}^3/\text{yr}/\text{ft}^2 \times \frac{7.48 \times 43560}{365 \times 24 \times 60}$$

= 0.13 gpm/acre (

SAY 0.15 gpm/acre

NOTE: $0.15 \text{ GPM/ACRE} \cdot \frac{365 \cdot 24 \cdot 60 \cdot 12}{7.48 \cdot 43560} = 2.9"/\text{YR}$

SHEET NO. 1 OF 1

Dravo
Denver Operating Center

ENGINEERING COMPUTATIONS

EST NO.
CONT NO. 8079
DIVISION

COMPANY MARLINE URANIUM
LOCATION DANVILLE, VA
DESCRIPTION WATER BALANCE PER EPA, 1975

DATE 5-14-84
DR ALN CH
REF

REFERENCE : "USE OF WATER BALANCE METHOD FOR PREDICTING LEACHATE GENERATION FROM SOLID WASTE DISPOSAL SITES" OCTOBER '75, EPA/530/SW-168.

1) SOIL MOISTURE STORAGE @ FIELD CAPACITY :

ASSUME SILTY/CLAYEY LOAM.
FROM TABLE 2 : AVAILABLE WATER = 250 mm/m
ROOT ZONE = 0.8m (2+ FT) (LIMITED BY SOIL DEPTH)

∴ SOIL MOISTURE STORAGE = 250 (0.8) = 200 mm @ FIELD CAPACITY

∴ <u>USE 8" THORNWAITE TABLE</u> (#18)

2) SURFACE R/O COEFFICIENT = $C_{R/O}$ = GRASS & HEAVY SOIL

@ 3% = 0.18, DRY SEASON } (TABLE 3)
0.22, WET SEASON }

PERCOLATION = P − R/O − ΔST − AET

G.503

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PITTSBURGH, PENNSYLVANIA

ENGINEERING COMPUTATIONS

EST NO.
CONT NO. 8079
DIVISION

COMPANY MARLINE URANIUM
LOCATION
DESCRIPTION EPA WATER BALANCE METHOD

DATE 5-14-84
DR KW CH
REF

	J	F	M	A	M	J	J	A	S	O	N	D	ANNUAL	
PE, IN. ADJ	0	0.26	0.93	2.31	3.66	4.80	6.00	5.27	3.71	2.04	0.77	0.25	30.00"	
P, IN.	3.4	3.3	4.2	3.5	3.9	3.6	3.9	3.8	3.8	3.6	3.1	3.4	43.5"	
$C_{R/O}$	0.22	0.22	0.22	0.22	0.22	0.18	0.18	0.18	0.22	0.22	0.22	0.22		
R/O	0.75	0.73	0.92	0.77	0.86	0.65	0.70	0.68	0.84	0.79	0.68	0.75	9.12"	
I	2.65	2.57	3.28	2.73	3.04	2.95	3.20	3.12	2.96	2.81	2.42	2.65	34.38"	I = P - R/O
I-PET	2.65	2.31	2.35	0.42	-0.62	-1.85	-2.80	-2.15	-0.75	0.77	1.65	2.40	4.38"	
ΣNEG (I-PET)					-0.62	-2.47	-5.27	-7.42	-8.17					
ST	8	8	8	8	7.40	5.86	4.13	3.15	2.87	3.64	5.29	7.69		
ΔST	0.31	0	0	0	-0.6	-1.54	-1.73	-0.98	-0.28	+0.77	+1.65	+2.40		
AET	0	0.26	0.93	2.31	3.64	4.49	4.93	4.10	3.24	2.04	0.77	0.25	26.96"	AET = PET + [(I-PET) - ΔST]
PERC	2.34	2.31	2.35	0.42	0	0	0	0	0	0	0	0	7.42"	

PERC + R/O = 16.54"

SHEET NO. 2 OF 4

Dravo
Denver Operating Center

ENGINEERING COMPUTATIONS

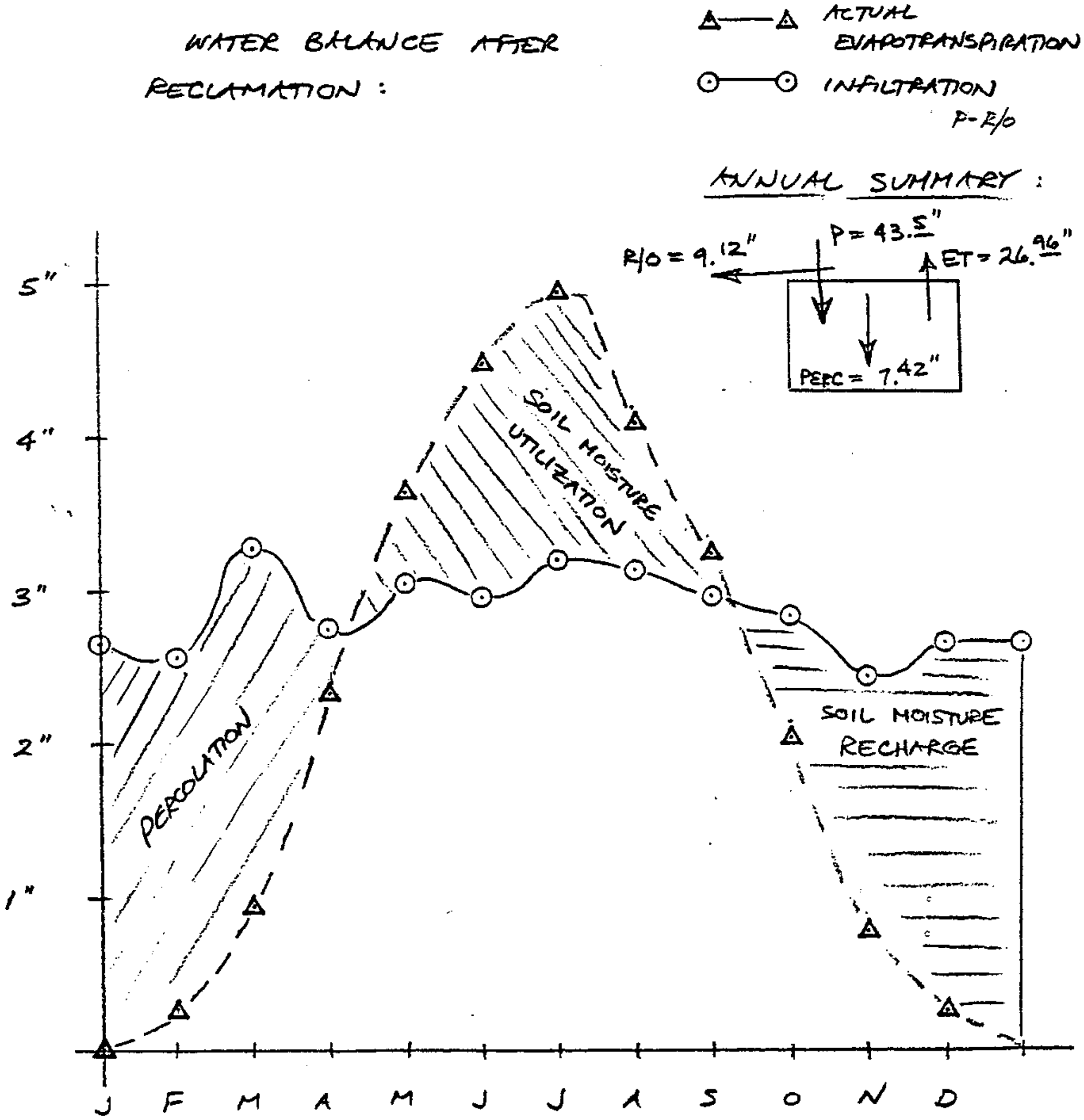
EST NO.
CONT NO. 8079
DIVISION

COMPANY MARLINE URANIUM
LOCATION DANVILLE, VA
DESCRIPTION EPA WATER BALANCE METHOD

DATE 5-14-84
DR ALN CH
REF

SWANSON PROJECT

WATER BALANCE AFTER RECLAMATION:



SHEET NO. 3 OF 4

Dravo
Denver Operating Center

ENGINEERING COMPUTATIONS

EST NO.
CONT NO. 8079
DIVISION

COMPANY MARLINE URANIUM
LOCATION DANVILLE, VA
DESCRIPTION EPA WATER BALANCE, SWANSON SITE

DATE 5-15-84
DR ALN CH
REF

SUMMARY OF CALCULATIONS W/ VEGETATION

PRECIP.	RUNOFF	INFILT.	AET	PERC.
43.5"	9.12"	34.38"	26.96"	7.42"

OTHER CONSIDERATIONS:

INTERMEDIATE COVER SOIL CONDITIONS:

a) SHALLOW DEPTH REDUCES SOIL MOISTURE STORAGE
∴ MORE PERCOLATION

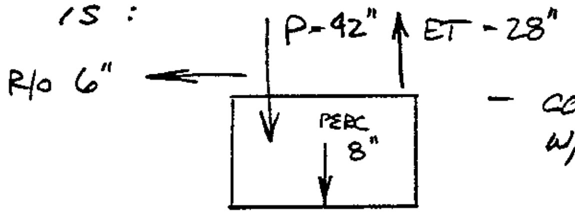
b) NO VEG. MEANS GREATER R/O BUT LESS AET.
(2-3 × R/O W/ VEG)

c) EPA ESTIMATES AET FROM BARE SOIL =
50% P FOR "HEAVY" SOILS & 30% P FOR SANDY

~ SUMMARY OF CALCS W/O VEGETATION:

PRECIP	RUNOFF	INFILTRATION	AET	PERC.
43.5"	(1.5 × ABOVE) 13.68"	29.82"	30% P 13.05	16.77"
43.5"	(2 × ABOVE) 18.24"	25.26"	50% P 21.75	3.51"

NOTE: BASED ON HYDROGRAPH SEPERATION TECHNIQUES (AS REPORTED IN VOL. 1, A.4.3.2.1, PG A.4-21 OF OCTOBER 15, 1983 REPORT) REGIONAL WATER BALANCE IS:



- COMPARES FAVORABLY W/ BALANCE.

SHEET NO. 4 OF 4

Dravo
Denver Operating Center

ENGINEERING COMPUTATIONS

EST NO.
CONT NO. 8079
DIVISION DENVER

COMPANY MARLINE URANIUM
LOCATION DANVILLE, VA
DESCRIPTION WATER BALANCE - HELP MODEL ESTIMATE

DATE 6-20-84
DR ALN CH
REF

REFERENCE : "THE HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE (HELP) MODEL", USER'S GUIDE & DOCUMENTATION - EPA. INTERAGENCY AGREEMENT NUMBER AD·96·F·2-A140

THE "HELP" MODEL WAS RUN TO VERIFY THE MONTHLY HAND CALCULATIONS. HELP CALCULATES A WATER BALANCE ON A DAILY BASIS USING ACTUAL CLIMATOLOGICAL DATA (FROM LYNCHBURGH) COLLECTED BY NOAA. THE DATA IS FROM 1974 THROUGH 1978. (SEE ATTACHED DOCUMENTATION EXCERPTS.)

THE FOLLOWING PAGES SUMMARIZE THE RESULTS FROM 5 CASES :

CASE 1 : VEGETATED TAILINGS AREA
CASE 2 : UNVEGETATED, COVERED TAILINGS
CASE 3 : EXPOSED TAILINGS
CASE 4 : UNVEGETATED OVERBURDEN
CASE 5 : VEGETATED OVERBURDEN

THE HELP MODEL RESULTS WERE ADJUSTED FOR A 42" ANNUAL RAINFALL. AVERAGE ANNUAL PRECIP. @ LYNCHBURG FROM '74 TO '78 = 44.65."

SHEET NO. 1 OF 7

G.503

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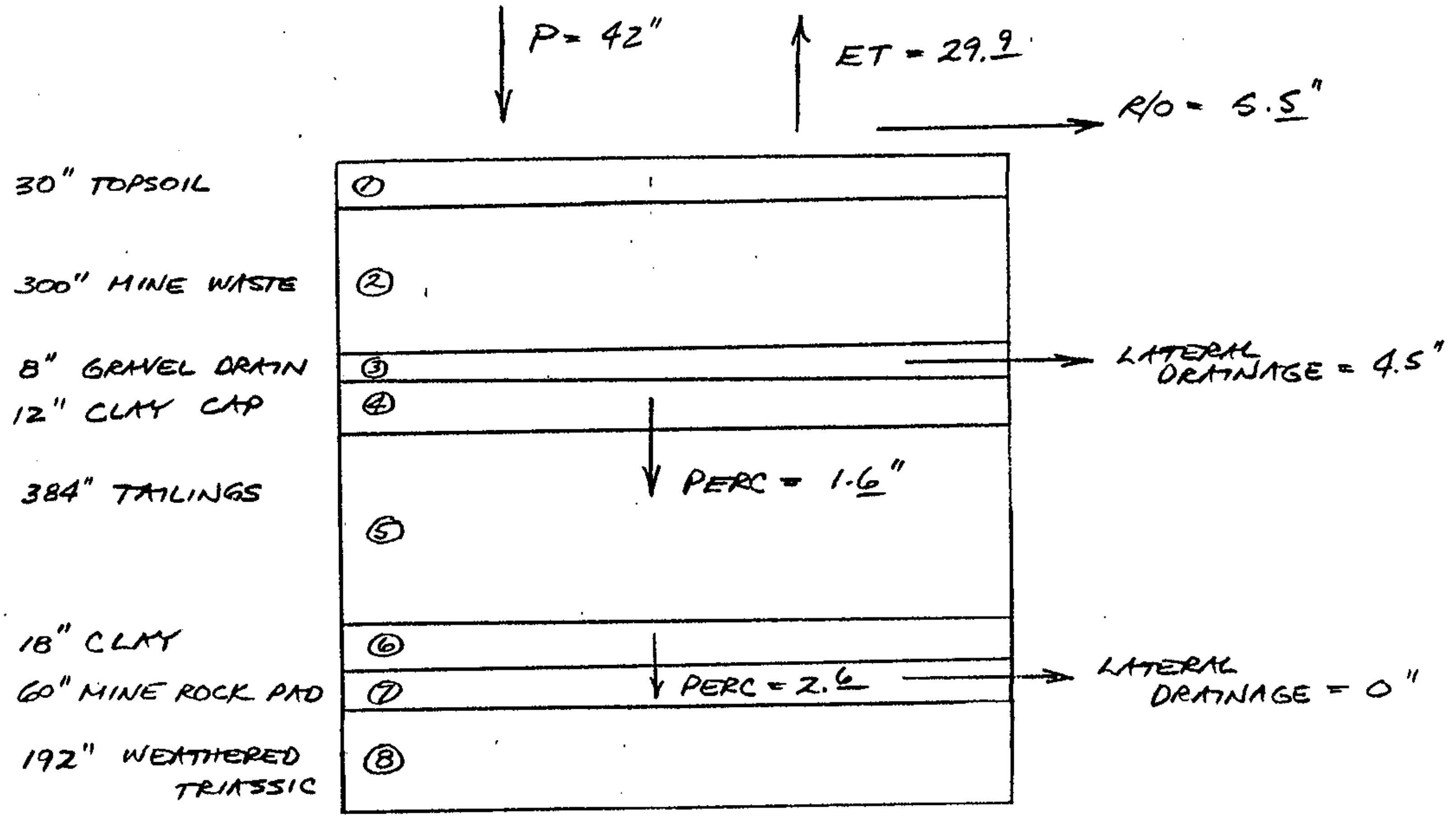
ENGINEERING COMPUTATIONS

EST NO.
CONT NO. 8079
DIVISION DENVER

COMPANY MARLINE URANIUM
LOCATION DANVILLE, VA
DESCRIPTION WATER BALANCE SUMMARIES - RESULTS FROM "HELP" MODEL

DATE 6-20-84
DR AW CH
REF

CASE 1 : VEGETATED TAILINGS AREA - ANNUAL AVERAGE OF 5 YEARS



NOTE: HEAD IN TAILS CAUSES GREATER LINER SEEPAGE DUE TO INITIAL HIGH MOISTURE CONTENT.

SHEET NO. 2 OF 7

G.503

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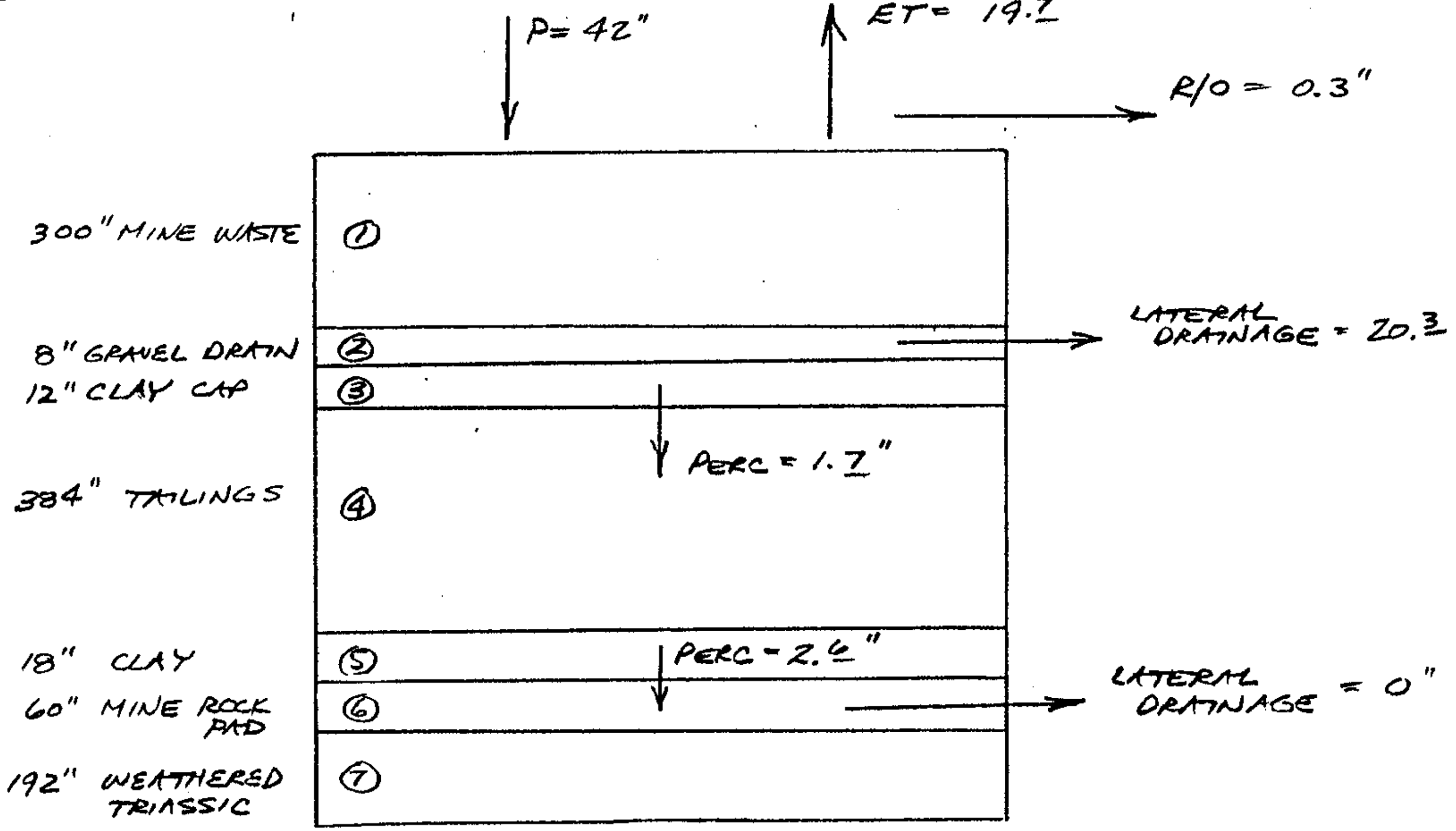
ENGINEERING COMPUTATIONS

EST NO.
CONT NO. 8079
DIVISION DENVER

COMPANY MARLINE URANIUM
LOCATION DANVILLE, VA
DESCRIPTION WATER BALANCE SUMMARIES - RESULTS FROM "HELP" MODEL

DATE 6-20-84
DR ACN CH
REF

CASE 2 : UNVEGETATED, COVERED TAILINGS - ANNUAL AVERAGES



NOTE: THE HELP MODEL ALGORITHM CANNOT ACCURATELY DEAL WITH THIS CASE DUE TO HIGH INITIAL WATER CONTENT OF TAILS.

SHEET NO. 3 OF 7

G.503

Dravo
PITTSBURGH, PENNSYLVANIA

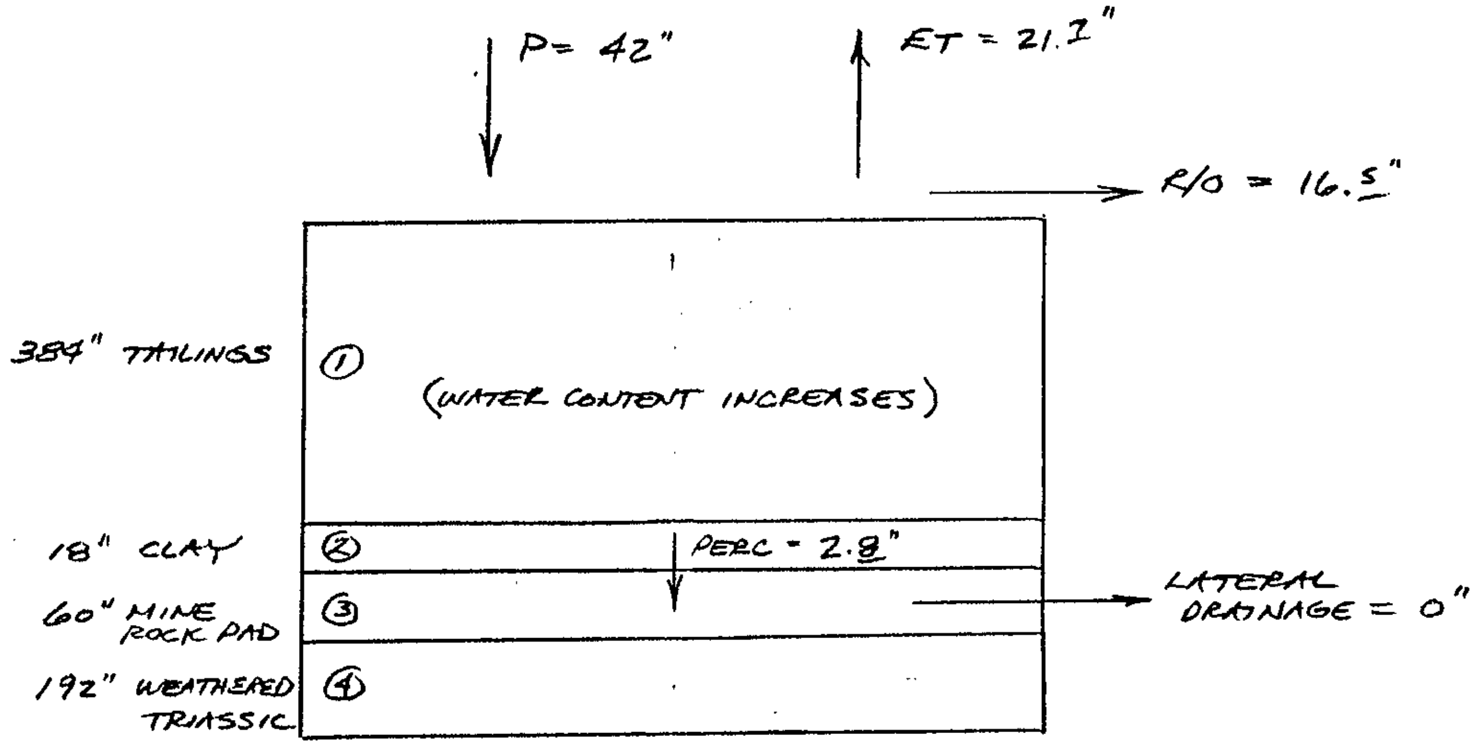
ENGINEERING COMPUTATIONS

EST NO.
CONT NO. 8079
DIVISION DENVER

COMPANY MARLINE URANIUM
LOCATION DANVILLE, VA
DESCRIPTION WATER BALANCE SUMMARIES - RESULTS FROM "HELP" MODEL

DATE 6-20-84
DR AKN CH
REF

CASE 3 : EXPOSED TAILINGS - ANNUAL AVERAGES



SHEET NO. 4 OF 7

G.503

Dravo
PITTSBURGH, PENNSYLVANIA

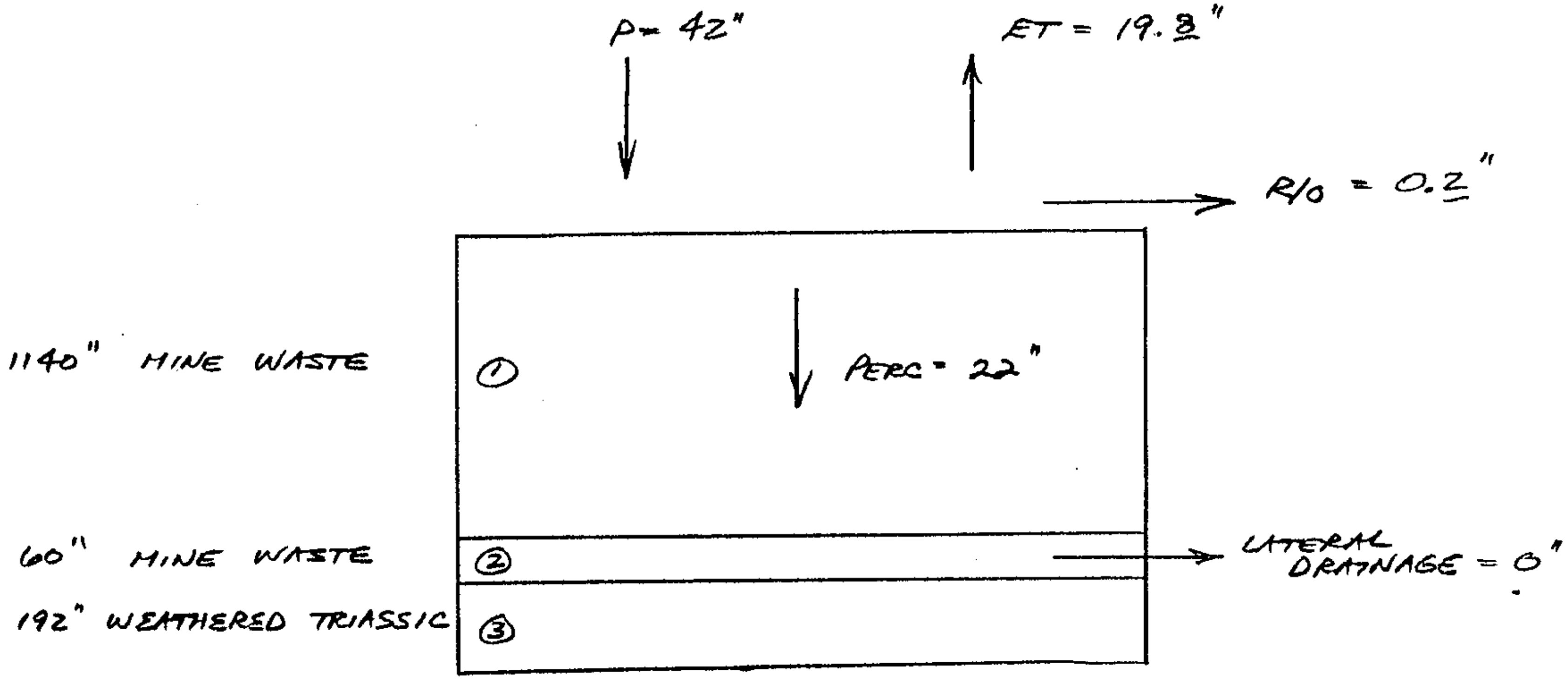
ENGINEERING COMPUTATIONS

EST NO. ____
CONT NO. 8079
DIVISION DENVER

COMPANY MARLINE URANIUM
LOCATION DANVILLE, VA
DESCRIPTION WATER BALANCE SUMMARIES - RESULTS FROM "HELP" MODEL

DATE 6-20-84
DR AWN CH ____
REF ____

CASE 4: UNVEGETATED OVERBURDEN - ANNUAL AVERAGES



SHEET NO. 5 OF 7

G.503

Dravo
PITTSBURGH, PENNSYLVANIA

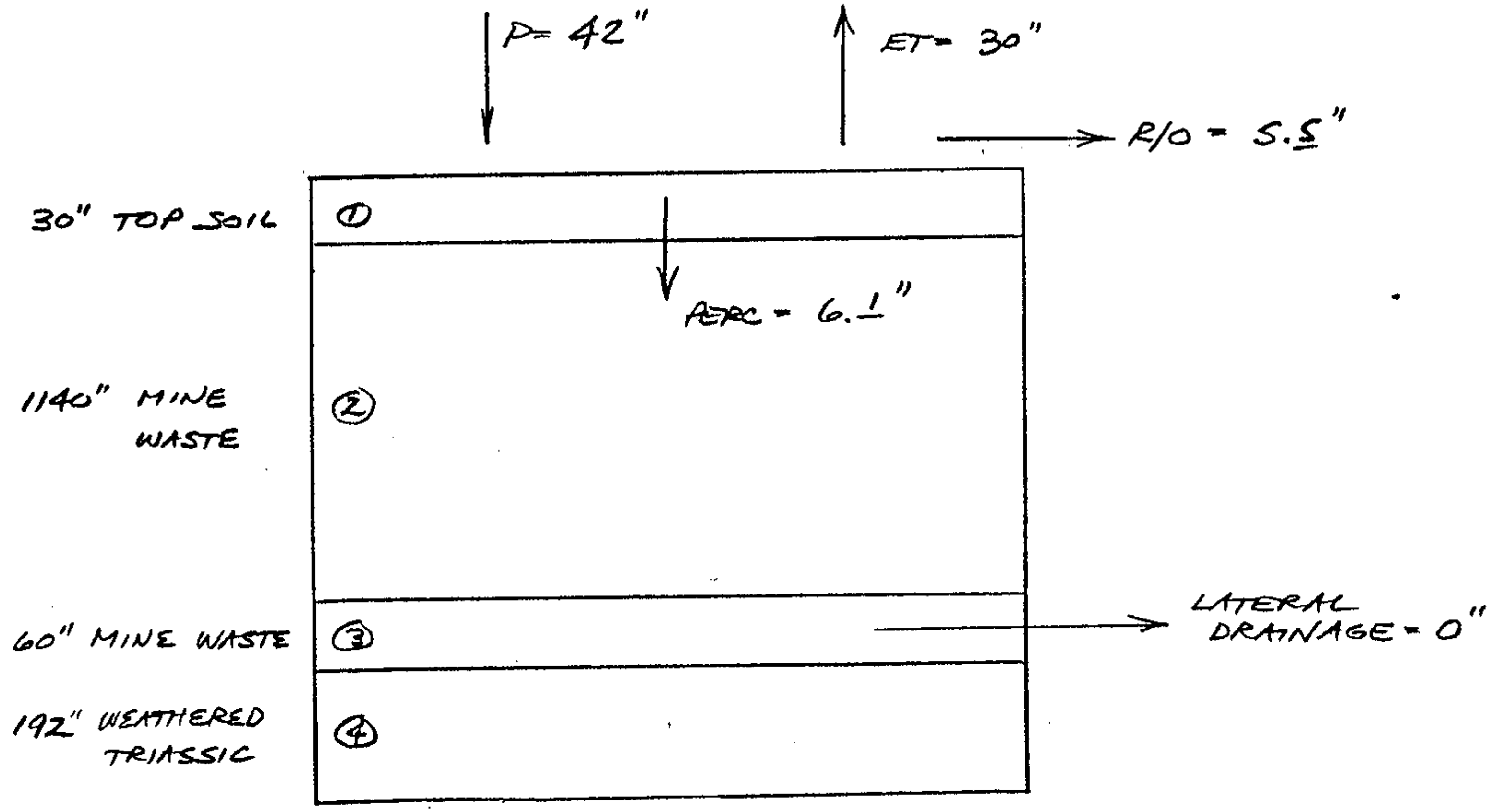
ENGINEERING COMPUTATIONS

EST NO.
CONT NO. 8079
DIVISION DENVER

COMPANY MARLINE URANIUM
LOCATION DANVILLE, VA
DESCRIPTION WATER BALANCE SUMMARIES - RESULTS FROM "HELP" MODEL

DATE 6-20-84
DR ALN CH
REF

CASE 5 : VEGETATED, RECLAIMED OVERBURDEN - ANNUAL AVERAGES



SHEET NO. 6 OF 7

Dravo
Denver Operating Center

ENGINEERING COMPUTATIONS

EST NO.
CONT NO. 8079
DIVISION

COMPANY MARLINE URANIUM
LOCATION DANVILLE, VA
DESCRIPTION WATER BALANCE CALCULATIONS

DATE 6-20-84
DR AHN CH
REF

MISC. CALCULATIONS BASED ON "HELP" RESULTS:

① ORE STOCKPILE RUNOFF (TO MILL):

TREAT AS CASE 4: UNVEGETATED ROCK PILE –

RUNOFF + SEEPAGE = $22.^{\underline{3}}$".

$$\frac{22.^{\underline{3}}}{12} \times \frac{15\text{ AC} \times 43560 \times 7.^{\underline{48}}}{365 \times 24 \times 60} = \underline{17.2\text{ GPM}}$$

② RUNOFF FROM EXPOSED TAILINGS (TO MILL):

CASE 3: P = 42" · E.T. = $21.^{\underline{7}}$"

$\Delta = 42 - 21.\underline{7} = 20.\underline{3}$"

USE THIS (Δ) FOR HIGH ESTIMATE:

$$\frac{20.^{\underline{3}}}{12} \times \frac{10\text{ AC} \times 43560 \cdot 7.^{\underline{48}}}{365 \cdot 24 \cdot 60} = \underline{10.5\text{ GPM}}$$

EC-555

SHEET NO. 7 OF 7

```
1.1 HOW MANY YEARS OF OUTPUT DO YOU WANT?
(BETWEEN 2 AND  5 YEARS MAY BE USED.)



************************************************************************
************************************************************************
CASE 1: VEGETATED TAILINGS AREA



************************************************************************
************************************************************************
SWANSON PROJECT



************************************************************************
************************************************************************
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```
8 JUNE 1984

                         GOOD GRASS


                          LAYER 1
                          -------


        VERTICAL PERCOLATION LAYER
        THICKNESS                          =    30.00 INCHES
        INITIAL SOIL WATER CONTENT         =    13.00 INCHES
        EVAPORATION COEFFICIENT            =     4.000 MM/DAY**0.
        POROSITY                           =     0.5820 VOL/VOL
        FIELD CAPACITY                     =     0.5000 VOL/VOL
        WILTING POINT                      =     0.3400 VOL/VOL
        EFFECTIVE HYDRAULIC CONDUCTIVITY   =     0.04999999 INCHES/HR


                          LAYER 2
                          -------


        VERTICAL PERCOLATION LAYER
        THICKNESS                          =   300.00 INCHES
        INITIAL SOIL WATER CONTENT         =    52.00 INCHES
        EVAPORATION COEFFICIENT            =     3.300 MM/DAY**0.
        POROSITY                           =     0.3510 VOL/VOL
        FIELD CAPACITY                     =     0.1740 VOL/VOL
        WILTING POINT                      =     0.1070 VOL/VOL
        EFFECTIVE HYDRAULIC CONDUCTIVITY   =    11.9499989  INCHES/HR


                          LAYER 3
                          -------


        LATERAL DRAINAGE LAYER
        SLOPE                              =     3.00 PERCENT
        DRAINAGE LENGTH                    =     0.0 FEET
        THICKNESS                          =     8.00 INCHES
        INITIAL SOIL WATER CONTENT         =     1.40 INCHES
        EVAPORATION COEFFICIENT            =     3.300 MM/DAY**0.
        POROSITY                           =     0.3510 VOL/VOL
        FIELD CAPACITY                     =     0.1740 VOL/VOL
        WILTING POINT                      =     0.1070 VOL/VOL
        EFFECTIVE HYDRAULIC CONDUCTIVITY   =    11.9499989  INCHES/HR


                          LAYER 4
                          -------
```

```
BARRIER SOIL LAYER
THICKNESS                            =    12.00 INCHES
INITIAL SOIL WATER CONTENT           =     6.00 INCHES
EVAPORATION COEFFICIENT              =     3.100 MM/DAY**0.
POROSITY                             =     0.5200 VOL/VOL
FIELD CAPACITY                       =     0.4500 VOL/VOL
WILTING POINT                        =     0.3600 VOL/VOL
EFFECTIVE HYDRAULIC CONDUCTIVITY     =     0.00014200 INCHES/HR


                    LAYER 5
                    -------

WASTE LAYER
THICKNESS                            =   384.00 INCHES
INITIAL SOIL WATER CONTENT           =   220.00 INCHES
EVAPORATION COEFFICIENT              =     4.200 MM/DAY**0.
POROSITY                             =     0.5880 VOL/VOL
FIELD CAPACITY                       =     0.5040 VOL/VOL
WILTING POINT                        =     0.3550 VOL/VOL
EFFECTIVE HYDRAULIC CONDUCTIVITY     =     0.04099999 INCHES/HR


                    LAYER 6
                    -------

BARRIER SOIL LAYER
THICKNESS                            =    18.00 INCHES
INITIAL SOIL WATER CONTENT           =     9.00 INCHES
EVAPORATION COEFFICIENT              =     3.100 MM/DAY**0.
POROSITY                             =     0.5200 VOL/VOL
FIELD CAPACITY                       =     0.4800 VOL/VOL
WILTING POINT                        =     0.4000 VOL/VOL
EFFECTIVE HYDRAULIC CONDUCTIVITY     =     0.00001420 INCHES/HR


                    LAYER 7
                    -------

LATERAL DRAINAGE LAYER
SLOPE                                =     1.00 PERCENT
DRAINAGE LENGTH                      =     0.0 FEET
THICKNESS                            =    60.00 INCHES
INITIAL SOIL WATER CONTENT           =    16.00 INCHES
EVAPORATION COEFFICIENT              =     3.300 MM/DAY**0.
POROSITY                             =     0.3510 VOL/VOL
FIELD CAPACITY                       =     0.1740 VOL/VOL
```

```
          WILTING POINT                         =     0.1070 VOL/VOL
          EFFECTIVE HYDRAULIC CONDUCTIVITY      =    11.9499989  INCHES/HR


                              LAYER 8
                              -------

          BARRIER SOIL LAYER
          THICKNESS                             =   192.00 INCHES
          INITIAL SOIL WATER CONTENT            =   100.00 INCHES
          EVAPORATION COEFFICIENT               =     5.000 MM/DAY**0.
          POROSITY                              =     0.5350 VOL/VOL
          FIELD CAPACITY                        =     0.4210 VOL/VOL
          WILTING POINT                         =     0.2220 VOL/VOL
          EFFECTIVE HYDRAULIC CONDUCTIVITY      =     0.10999995 INCHES/HR


                      GENERAL SIMULATION DATA
                      -----------------------

          SCS RUNOFF CURVE NUMBER               =      80.00
          TOTAL AREA OF COVER                   = 6534000. SQ. FT
          EVAPORATIVE ZONE DEPTH                =      18.00 INCHES
          EFFECTIVE EVAPORATION COEFFICIENT     =       4.000 MM/DAY**0.5
          UPPER LIMIT VEG. STORAGE              =      10.4760 INCHES
          INITIAL VEG. STORAGE                  =       7.8000 INCHES


       CLIMATOLOGIC DATA FOR    LYNCHBURG         VIRGINIA

              MONTHLY MEAN TEMPERATURES, DEGREES FAHRENHEIT

    JAN/JUL     FEB/AUG     MAR/SEP     APR/OCT     MAY/NOV     JUN/DEC
    -------     -------     -------     -------     -------     -------
     36.11       38.32       45.35       55.31       65.55       73.30
     76.50       74.29       67.27       57.30       47.07       39.31

             MONTHLY MEANS SOLAR RADIATION, LANGLEYS PER DAY

    JAN/JUL     FEB/AUG     MAR/SEP     APR/OCT     MAY/NOV     JUN/DEC
    -------     -------     -------     -------     -------     -------
    190.79      250.96      337.60      427.49      496.56      526.29
    508.71      448.54      361.90      272.01      202.94      173.21

                       LEAF AREA INDEX TABLE

                          DATE         LAI
                          ----         ----
                             1         0.0
                           110         0.0
                           129         1.23
                           148         2.01
```

```
                                  167         2.01
                                  186         2.01
                                  205         2.01
                                  223         2.01
                                  242         1.81
                                  251         1.31
                                  280         0.64
                                  299         0.33
                                  366         0.0

                                   GOOD GRASS

                             WINTER COVER FACTOR =    1.20




*******************************************************************************



    AVERAGE MONTHLY TOTALS FOR   74 THROUGH   78

                               JAN/JUL FEB/AUG MAR/SEP APR/OCT MAY/NOV JUN/DEC
                               ------- ------- ------- ------- ------- -------

  PRECIPITATION (INCHES)         4.05    1.54    4.58    3.17    4.99    4.36
                                 2.67    4.27    4.30    4.16    2.90    3.65


  RUNOFF (INCHES)               0.687   0.050   0.574   0.792   0.513   0.165
                                0.120   0.181   0.799   1.240   0.351   0.373


  EVAPOTRANSPIRATION            1.358   1.385   2.341   2.416   5.214   4.960
       (INCHES)                 2.748   3.880   2.870   1.863   1.375   1.357


  PERCOLATION FROM BASE        0.1545  0.1778  0.1818  0.1917  0.1759  0.1479
  OF COVER (INCHES)            0.1403  0.1208  0.0874  0.0707  0.1063  0.1292


  INTERMEDIATE BARRIER         0.2471  0.2233  0.2483  0.2501  0.2522  0.2280
  PERCOLATION (INCHES)         0.2285  0.2224  0.2049  0.2186  0.2142  0.2260


  PERCOLATION FROM BASE        1.3558  0.2235  0.2401  0.2499  0.2525  0.2280
  OF LANDFILL (INCHES)         0.2286  0.2225  0.2049  0.2186  0.2141  0.2258


  DRAINAGE FROM BASE OF         0.569   0.681   0.628   0.722   0.591   0.394
  COVER (INCHES)                0.258   0.144   0.076   0.124   0.204   0.356


  INTERMEDIATE BARRIER          0.0     0.0     0.0     0.0     0.0     0.0
  DRAINAGE (INCHES)             0.C     0.0     0.0     0.0     0.0     0.0
```

```
DRAINAGE FROM BASE OF     0.003   0.000   0.000   0.000   0.000   0.000
LANDFILL (INCHES)         0.000   0.000   0.000   0.000   0.000   0.000

AVERAGE DAILY HEAD ON     9.23   11.88   10.63   12.16    9.90    6.84
BASE OF COVER (IN.)       4.24    2.40    1.36    2.10    3.58    5.80

AVERAGE DAILY HEAD ON   282.60  281.79  281.15  280.43  279.60  278.68
2ND BARRIER (INCHES)    277.67  276.57  275.28  273.59  272.10  270.88

AVERAGE DAILY HEAD ON     0.26    0.02    0.02    0.02    0.02    0.02
LANDFILL BASE (IN.)       0.02    0.02    0.02    0.02    0.02    0.02



**********************************************************************


STD. DEVIATIONS OF MONTHLY TOTALS FOR   74 THROUGH   78

                          JAN/JUL FEB/AUG MAR/SEP APR/OCT MAY/NOV JUN/DEC
                          ------- ------- ------- ------- ------- -------

PRECIPITATION (INCHES)     2.39    0.98    2.67    2.03    2.10    1.81
                           1.44    1.98    2.53    4.56    1.51    0.54

RUNOFF (INCHES)           1.016   0.064   0.844   0.948   0.601   0.239
                          0.259   0.253   0.810   1.789   0.477   0.224

EVAPOTRANSPIRATION        0.073   0.325   0.240   0.511   0.894   1.704
     (INCHES)             1.502   1.947   0.676   1.116   0.287   0.091

PERCOLATION FROM BASE     0.0990  0.0783  0.0551  0.0641  0.0528  0.0392
OF COVER (INCHES)         0.0216  0.0316  0.0526  0.0646  0.0681  0.0829

INTERMEDIATE BARRIER      0.0099  0.0149  0.0285  0.0063  0.0116  0.0163
PERCOLATION (INCHES)      0.0224  0.0138  0.0093  0.0174  0.0172  0.0208

PERCOLATION FROM BASE     2.4748  0.0150  0.0284  0.0063  0.0116  0.0161
OF LANDFILL (INCHES)      0.0224  0.0141  0.0090  0.0175  0.0173  0.0208

DRAINAGE FROM BASE OF     0.480   0.520   0.430   0.461   0.370   0.278
COVER (INCHES)            0.188   0.123   0.088   0.127   0.240   0.356

INTERMEDIATE BARRIER      0.0     0.0     0.0     0.0     0.0     0.0
```

```
DRAINAGE (INCHES)          0.0      0.0      0.0      0.0      0.0      0.0

DRAINAGE FROM BASE OF      0.006    0.000    0.000    0.000    0.000    0.000
LANDFILL (INCHES)          0.000    0.000    0.000    0.000    0.000    0.000

AVERAGE DAILY HEAD ON      7.70     8.72     7.12     7.04     5.82     4.60
BASE OF COVER (IN.)        3.15     2.25     1.67     2.19     4.14     5.72

AVERAGE DAILY HEAD ON     21.95    20.90    20.53    20.42    20.19    20.00
2ND BARRIER (INCHES)      19.89    19.80    19.34    18.92    18.50    17.86

AVERAGE DAILY HEAD ON      0.54     0.00     0.00     0.00     0.00     0.00
LANDFILL BASE (IN.)        0.00     0.00     0.00     0.00     0.00     0.00

*****************************************************************************



*****************************************************************************



*****************************************************************************


   AVERAGE ANNUAL TOTALS FOR   74 THROUGH   78
  ---------------------------------------------------------------------------
                                         (INCHES)     (CU. FT.)    PERCENT
                                         --------     ---------    -------
   PRECIPITATION                          44.65       24313760.    100.00

   RUNOFF                                  5.845       3182670.     13.09

   EVAPOTRANSPIRATION                     31.765      17295904.     71.14

   PERCOLATION FROM BASE OF COVER          1.6841       917011.      3.77

   INTERMEDIATE BARRIER PERCOLATION        2.7634      1504669.      6.19

   PERCOLATION FROM BASE OF LANDFILL       3.8721      2108342.      8.67

   DRAINAGE FROM BASE OF COVER             4.748       2585382.     10.63
```

```
   INTERMEDIATE BARRIER DRAINAGE        0.0             0.      0.0

   DRAINAGE FROM BASE OF LANDFILL       0.003        1386.      0.01
*******************************************************************




*******************************************************************

STD. DEVIATIONS OF ANNUAL TOTAL FOR,   74 THROUGH   78
 -------------------------------------------------------------------
                                      (INCHES)     (CU. FT.)   PERCENT
                                      --------     ---------   -------
   PRECIPITATION                        6.66       3625182.     14.91

   RUNOFF                               1.791       974940.      4.01

   EVAPOTRANSPIRATION                   3.816      2077850.      8.55

   PERCOLATION FROM BASE OF COVER      0.5557       302568.      1.24

   INTERMEDIATE BARRIER PERCOLATION    0.1091        59422.      0.24

   PERCOLATION FROM BASE OF LANDFILL   2.4071      1310653.      5.39

   DRAINAGE FROM BASE OF COVER          2.626      1430048.      5.88

   INTERMEDIATE BARRIER DRAINAGE        0.0             0.      0.0

   DRAINAGE FROM BASE OF LANDFILL       0.006         3091.      0.01
*******************************************************************




*******************************************************************

              PEAK DAILY VALUES FOR   74 THROUGH   78
    -------------------------------------------------------
                                        (INCHES)    (CU. FT.)
                                        --------    ---------
```

```
      PRECIPITATION                     3.67      1998314.0

      RUNOFF                            2.314     1260054.0

      PERCOLATION FROM BASE OF COVER    0.0149       8134.0

      INTERMEDIATE BARRIER PERCOLATION  0.0128       6996.0

      PERCOLATION FROM BASE OF LANDFILL 2.3634    1286897.0

      DRAINAGE FROM BASE OF COVER       0.078       42330.8

      INTERMEDIATE BARRIER DRAINAGE     0.0             0.0

      DRAINAGE FROM BASE OF LANDFILL    0.007        3585.2

      HEAD ON BASE OF COVER              31.0

      HEAD ON INTERMEDIATE BARRIER      315.0

      HEAD ON BASE OF LANDFILL           23.2

      SNOW WATER                          0.0           0.0


      MAXIMUM VEG. SOIL WATER (VOL/VOL)      0.5548

      MINIMUM VEG. SOIL WATER (VOL/VOL)      0.3400
**********************************************************************
**********************************************************************




****************************************
       FINAL SOIL WATER CONTENTS

           LAYER     INCHES
           -----     ------

             1        14.85

             2        52.20

             3         2.40

             4         6.00

             5       214.60

             6         9.00
```

```
          7       10.49

          8      100.00


1.1 DO YOU WANT TO ENTER OR CHECK DATA OR TO OBTAIN OUTPUT?

ENTER 1 FOR CLIMATOLOGIC INPUT,
      2 FOR SOIL OR DESIGN DATA INPUT,
      3 TO RUN THE SIMULATION AND OBTAIN DETAILED OUTPUT,
      4 TO STOP THE PROGRAM, AND
      5 TO RUN THE SIMULATION AND OBTAIN ONLY SUMMARY OUTPUT.



1.4 ENTER RUNHELP2 TO RERUN PROGRAM OR
ENTER LOGOFF TO LOGOFF COMPUTER SYSTEM.
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DRAFT 3/84

THE HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE (HELP) MODEL

Volume I. User's Guide for Version 1

by

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Interagency Agreement Number AD-96-F-2-A140

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though the default data set contains actual historical observations of precipitation, no attempt is made to model the exact weather conditions existing on any given day.

The default climatologic data base includes values for two variables that relate to the effects of vegetation on evapotranspiration: leaf area index (LAI) and winter cover factor. LAI is defined as the dimensionless ratio of the leaf area of actively transpiring vegetation to the nominal surface area of land on which the vegetation is growing. The HELP program assumes that LAI may vary from a minimum value of 0 to a maximum value of 5. The former is representative of no actively growing vegetation (i.e., bare ground or dormant vegetation) and the latter represents the most dense stand of actively growing vegetation considered. Default LAI data sets consist of thirteen Julian dates (spaced throughout the entire year) and corresponding maximum LAI values for a good row crop and an excellent stand of grass. A different set of LAI data is provided for each of the 102 cities listed in Table 1. The program adjusts these maximum values downward if necessary, depending upon the vegetative cover specified, and interpolates for daily values in order to model evapotranspiration during the growing season. For the remainder of the year, transpiration is assumed not to occur. However, even dormant vegetation can serve to insulate the soil and, thus, affect evaporation. Winter cover factors, which vary from 0 for row crops to 1.8 for an excellent stand of grass, are used to account for this effect.

Manual Data Option--

When the manual climatologic data input option is utilized, the user must provide daily precipitation data for each year of interest. The maximum allowable period of record is 20 years and the minimum is 2 years. A separate set of temperature, insolation, LAI, and winter cover factor data may be entered for each year, or a single set of data may be used for all years. The information needed to enter climatologic data using the manual input option is presented in Section 4.

For most locations, observed precipitation and temperature data are readily available. Possible sources include local weather stations, libraries, universities, agricultural and climatologic research facilities, and the National Climatic Center, NOAA, Federal Building, Ashville, North Carolina 28801. Insolation data may be more difficult to obtain; however, average values are commonly reported in architectural publications, solar heating handbooks, and general reference works. A general discussion pertaining to LAI values for different types of vegetation is presented in the program documentation (5).

Vegetative Cover Data

If the default climatologic or soil data options are used, the user must specify one of seven types of vegetative cover. Acceptable default types of vegetation are bare ground (i.e., no vegetation); excellent, good, fair and poor stands of grass; and good and fair stands of row crops. The default LAI data sets for a good row crop and an excellent stand of grass are modified for lesser stands of vegetation when these types are specified by the user. The values for a good row crop are multiplied by 0.5 for a fair row crop and the values for an excellent stand of grass are multiplied by 0.17, 0.33, and 0.67 for poor, fair and good stands of grass, respectively. Similarly, the hydraulic conductivity of the top soil layer is corrected for the effects of roots when the user specifies one of the 21 default soil types for the top layer. The hydraulic conductivity of soil without vegetation is multiplied by 5.0, 4.2, 3.0, 1.8, 1.9 and 1.5 for excellent, good, fair and poor stands of grass, and good and fair row crops, respectively.

The user must also specify an evaporative zone depth as one of the climatologic variables. The evaporative zone depth may be thought of simply as the maximum depth from which water may be removed from the landfill by evapotranspiration. Thus, where vegetation is present, the evaporative depth should at least equal the expected average depth of root penetration. In actual fact, the influence of plant roots generally extends well beyond the depth of root penetration because of capillary suction created as water is extracted from the soil. However, limiting the evaporative depth to the expected average depth of root penetration may be justified as a conservative approach to landfill evaluation since this results in reduced estimates of evapotranspiration and increased estimates of lateral drainage and percolation. Evaporation will, of course, occur even if no vegetation is present. Thus, it is reasonable that some evaporative depth be specified even for the bare ground (no vegetation) condition. Suggested conservative values of evaporative depth range from 4 inches for bare ground, to 10 inches for a fair stand of grass, to 18 inches for an excellent stand of grass. The program does not permit the evaporative depth to be greater than the depth to the top of the topmost barrier soil layer.

Design and Soil Data

The user must specify data describing the various materials contained in the landfill (e.g., top soil, clay, sand, waste) and the physical layout (design) of the landfill (e.g., size, thickness of various layers, slopes, etc.). Either the default or manual input options may be utilized for soil data; however, design data must be entered manually.

Landfill Profile--

The HELP program may be used to model landfills composed of up to nine distinct layers. However, there are some limitations on the order in which the layers may be arranged which must be observed if meaningful results are to be obtained. Also, each layer must be identified as either a vertical percolation, lateral drainage, waste, or barrier soil layer. This identification is very important because the program models water flow through the various types of layers in different ways. However, in all cases, the program assumes that each layer is homogeneous with respect to hydraulic conductivity, transmissivity, wilting point, porosity, and field capacity. A typical closed landfill profile is shown on Figure 2. The circled numbers indicate the layer identification system used by the program.

Vertical percolation layers (e.g., layer 1 on Figure 2) are assumed to have great enough hydraulic conductivity that vertical flow in the downward direction (i.e., percolation) is not significantly restricted. Lateral drainage is not permitted, but water can move upward and be lost to evapotranspiration if the layer is within the specified evaporative zone. Percolation is

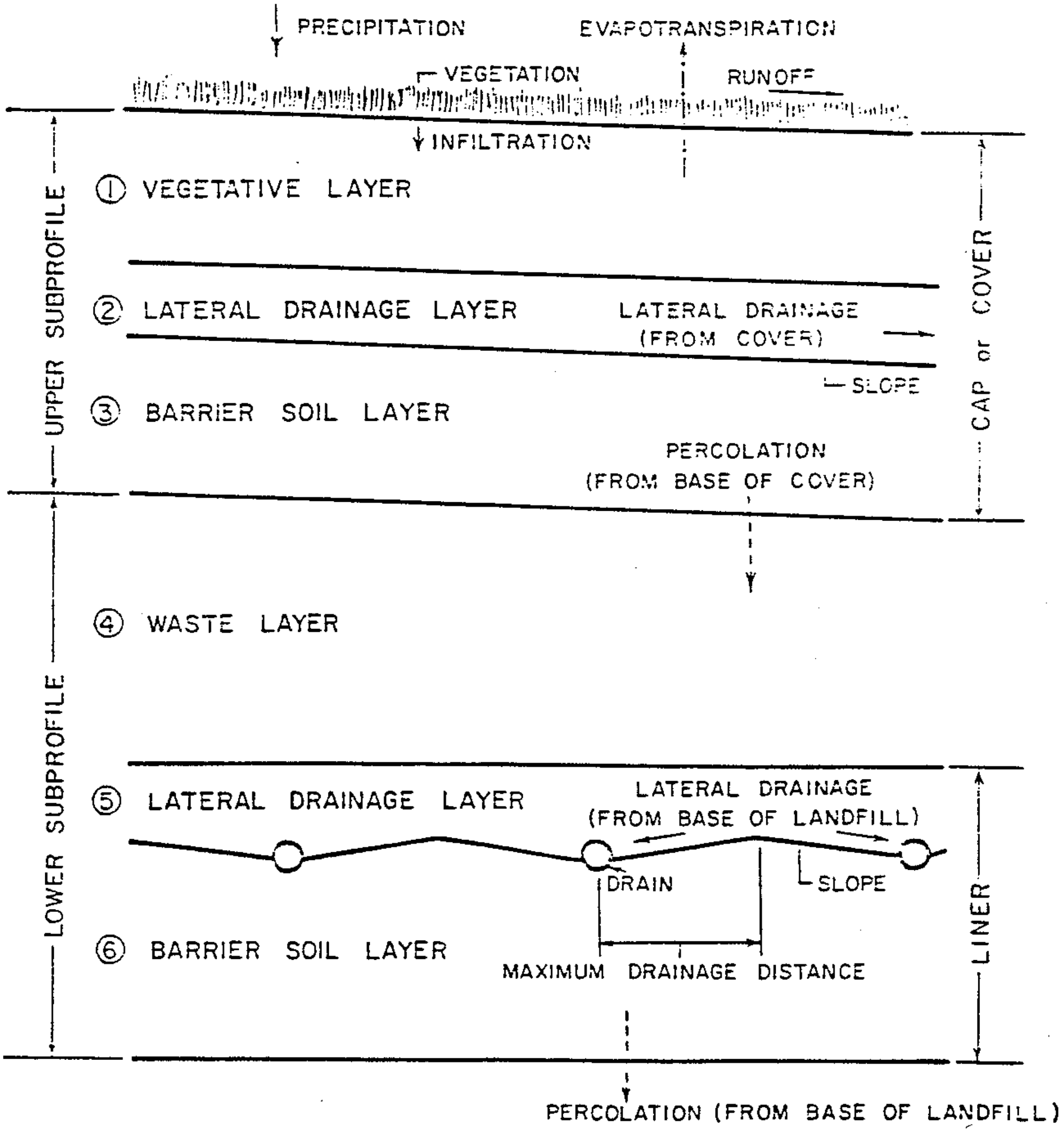


Figure 2. Typical landfill profile.

modeled as being independent of the depth of water saturated soil (i.e., the head) above the layer. Layers designed to support vegetation should generally be designated as vertical percolation layers.

Lateral drainage layers are assumed to have hydraulic conductivity high enough that little resistance to flow is offered. Therefore, the hydraulic conductivity of a drainage layer should be equal to or greater than that of the overlying layer. Vertical flow is modeled in the same manner as for a vertical percolation layer; however, lateral outflow is allowed. This lateral drainage is considered to be a function of the slope of the bottom of the layer, the maximum horizontal distance that water must traverse to drain from the layer, and the depth of water saturated soil above the top of the underlying barrier soil layer. (Note: a lateral drainage layer may be underlain by only another lateral drainage layer or a barrier soil layer.) The lateral drainage submodel has been calibrated for drainage slopes between 0 and 10 percent and for maximum drainage distances between 25 and 200 feet. Layers 2 and 5 on Figure 2 are lateral drainage layers.

Barrier soil layers restrict vertical flow. Thus, such layers should have hydraulic conductivity substantially lower than for vertical percolation, lateral drainage, or waste layers. The program only allows downward flow in barrier soil layers. Thus, any water moving into a barrier layer will eventually percolate through it. Percolation is modeled as a function of the depth of water saturated soil (head) above the base of the layer. The program recognizes two types of barrier layers; those composed of soil alone, and those composed of soil overlain by an impermeable synthetic membrane. In the latter case, the user must specify some membrane leakage fraction. This factor may be thought of simply as the fraction (range 0 to 1) of the maximum daily potential percolation (i.e., the percolation that would occur, in response to some given head, in the absence of the membrane) through the layer that is expected to actually occur on a day when the membrane is in place, assuming the barrier layer is subjected to the same head. The net effect of specifying the presence of a membrane is to reduce the effective hydraulic conductivity of the layer. The factor may also be considered as the fraction of the area that drains into the barrier soil layer through leaks in the membrane liner. The program does not model aging of the membrane. Layers 3 and 6 shown on Figure 2 are barrier layers.

Water movement through a waste layer is modeled in the same manner as for a vertical percolation layer. However, identifying a layer as a waste layer indicates to the program which layers should be considered part of the landfill cap or cover (see Figures 1 and 2), and which layers should be considered as part of the liner/drainage system. Layer 4 shown on Figure 2 is a waste layer.

If the topmost layer of a landfill profile is identified as a waste layer, the program assumes that the landfill is open. In this case the user must specify a runoff curve number (discussed above) and the fraction (a factor that may vary from 0 to 1) of the potential surface runoff that is actually collected and removed from the landfill surface.

The HELP program can model up to nine layers in the landfill profile. As many as three layers may be identified as barrier soil layers. While the program is quite flexible, there are some basic rules that must be followed relative to the order in which the layers are arranged in the profile. First, a vertical percolation layer or a waste layer may not be placed directly below a lateral drainage layer. Second, a barrier soil layer may not be placed directly below another barrier soil layer. Third, when a barrier soil is not placed directly below the lowest drainage layer all drainage layers in the lowest subprofile are treated as vertical percolation layers. Thus, no lateral drainage is allowed in this subprofile. Fourth, the top layer may not be a barrier soil layer.

Important nomenclature used by the program is indicated on Figure 2. For computational purposes the soil profile is partitioned into subprofiles which are defined in relation to the location of the barrier soil layers. For example, the upper subprofile shown on Figure 2 extends from the surface to the bottom of the upper barrier soil layer (layer 3), while the lower subprofile extends from the top of the waste layer to the base of the lower barrier soil layer. If an intermediate barrier soil layer had been specified, a third (intermediate) subprofile would have been defined. Since there can be no more than three barrier soil layers there can be no more than three subprofiles. The program models the flow of water through one subprofile at a time with the percolation from one subprofile serving as the inflow to the underlying subprofile, and so on through the complete profile.

Soil Data--

The type of soil present in each layer must be specified by the user. This can be accomplished using either the default or manual data input options. Characteristics for 21 default soil types are presented in Table 2. The first three columns represent soil texture designations used by the HELP program, and two standard classification systems--the U.S. Department of Agriculture system and the Unified Soil Classification System. The numerical entries represent typical values corresponding to the various soil types and are used by the HELP program, as needed, for computational purposes. These values were obtained mainly from agricultural soils which may be less dense and more aerated than typical soils placed in landfills (6, 7, 8). Clays and silts in landfills would generally be compacted except for a well managed vegetative layer which may be tilled to promote vegetative growth. Untilled vegetative layers would generally be more compacted than the loams listed in Table 2. Soil texture type 19 is representative of typical municipal solid waste that has been compacted. Soil texture types 20 and 21 denote very well compacted clay soils that might be used for barrier layers. Default soil data may be accessed and used simply by entering the appropriate soil texture number in response to a straightforward command from the program.

The user may also enter soil characteristics manually. In this instance, the program will require that numerical values be entered for porosity, field capacity, wilting point, hydraulic conductivity (i.e., saturated hydraulic conductivity) in inches per hour, and evaporation coefficient in millimeters per square root of day. (Note: porosity, field capacity, and wilting point are all dimensionless.) In some cases these data may not be actually used by the program. Specifically, the porosity, wilting point, and evaporation

Sr K

TABLE 2. DEFAULT SOIL CHARACTERISTICS

Soil Texture Class			MIR[d]	Porosity	Field Capacity	Wilting Point	Hydraulic Conductivity	CON[e]
HELP[a]	USDA[b]	USCS[c]	In/hr	Vol/Vol	Vol/Vol	Vol/Vol	in/hr	mm/day$^{0.5}$
1	CoS	GS	0.500	0.351	0.174	0.107	11.95	3.3
2	CoSL	GP	0.450	0.376	0.218	0.131	7.090	3.3
3	S	SW	0.400	0.389	0.199	0.066	6.620	3.3
4	FS	SM	0.390	0.371	0.172	0.050	5.400	3.3
5	LS	SM	0.380	0.430	0.16	0.060	2.780	3.4
6	LFS	SM	0.340	0.401	0.129	0.075	1.000	3.3
7	LVFS	SM	0.320	0.421	0.176	0.090	0.910	3.4
8	SL	SM	0.300	0.442	0.256	0.133	0.670	3.8
9	FSL	SM	0.250	0.458	0.223	0.092	0.550	4.5
10	VFSL	MH	0.250	0.511	0.301	0.184	0.330	5.0
11	L	ML	0.200	0.521	0.377	0.221	0.210	4.5
12	SIL	ML	0.170	0.535	0.421	0.222	0.110	5.0
13	SCL	SC	0.110	0.453	0.319	0.200	0.084	4.7
14	CL	CL	0.090	0.582	0.452	0.325	0.065	3.9
15	SICL	CL	0.070	0.588	0.504	0.355	0.041	4.2
16	SC	CH	0.060	0.572	0.456	0.378	0.065	3.6
17	SIC	CH	0.020	0.592	0.501	0.373	0.033	3.8
18	C	CH	0.010	0.680	0.607	0.492	0.022	3.5
19	Waste		0.230	0.520	0.320	0.190	0.283	3.3
20	Barrier Soil		0.002	0.520	0.450	0.360	0.000142	3.1
21	Barrier Soil		0.001	0.520	0.480	0.400	0.0000142	3.1

---

[a] Soil classification system used in the HELP model (see discussion in text).

[b] Soil classification system used by the U.S. Department of Agriculture.

[c] The Unified Soil Classification System.

[d] MIR = Minimum Infiltration Rate.

[e] CON = Evaporation Coefficient (Transmissivity).

coefficient are not used for barrier soils, and the wilting point and evaporation coefficient are not used for any layer below the effective evaporative zone. Brief definitions for some terms used to describe soil moisture content, and the movement of water through soil, are presented below.

Porosity--the ratio of the volume of voids to the total volume occupied by a soil.

Field capacity--the ratio of the volume of water that a soil retains after gravity drainage ceases to the total volume occupied by a soil.

Wilting point--the ratio of the volume of water that a soil retains after plants can no longer extract water (thus, the plants remain wilted) to the total volume occupied by a soil.

Available (or plant available) water capacity--the difference between the soil water content at field capacity and at the wilting point.

Hydraulic conductivity--the rate at which water moves through soil in response to gravitational forces.

Evaporation coefficient--(also called transmissivity) an indicator of the relative ease by which water is transmitted through soil in response to capillary suction.

Users opting for manual soil data input should recognize that certain logical relationships must exist among the soil characteristics of a given layer. The porosity, field capacity, and wilting point are all represented by dimensionless values varying between 0 and 1, but the porosity must be greater than the field capacity which must, in turn, be greater than the wilting point. The minimum permissible evaporation coefficient is 3.0 mm per square root of day.

The program is designed to accept a combination of default and manual soil data if such is desired. This is especially convenient for specifying characteristics of waste layers. To use this option the user simply specifies soil types 22 or 23. The program responds to these soil texture types by asking for the soil characteristics discussed above.

Soil Compaction--

Barrier soil layers and waste layers may be compacted to restrict the vertical flow of water. When using the default soil data option, the user may specify that any layer is to be considered compacted. For a layer so identified, the hydraulic conductivity is reduced by a factor of 20, and the drainable water (i.e., porosity minus field capacity) and plant available water (i.e., field capacity minus wilting point) are each reduced by 25 percent. When using the manual soil data option, the user simply enters soil data representative of compacted soil. Layers that support vegetation are not generally compacted.

Design Data--

The distinction between soil and design data is not always a clear cut one. However, in this section the term design data refers to those items discussed immediately below.

The user must enter the total surface area of the landfill to be modeled in square feet, and the thickness of each layer in inches. For drainage layers the slope of the bottom of the layer (in percent) and the maximum horizontal drainage distance (in feet) must also be supplied. The lateral drainage submodel has been calibrated for slopes between 0 and 10 percent and for maximum drainage distances between 25 to 200 feet. When drain tiles are to be used, the appropriate distance is one half the maximum spacing. When drains are not used, the appropriate distance is the maximum horizontal distance that water must travel to reach a free discharge. Depending upon the soil profile chosen and the input option selected, other data such as runoff curve number, membrane leakage fraction, and potential runoff fraction may be requested by the program. Each of these are discussed in the appropriate paragraphs above. Some general guidance for selection of runoff curve numbers is provided in Figure 3 (4, 9). Typical values for minimum infiltration rates are provided in Table 2.

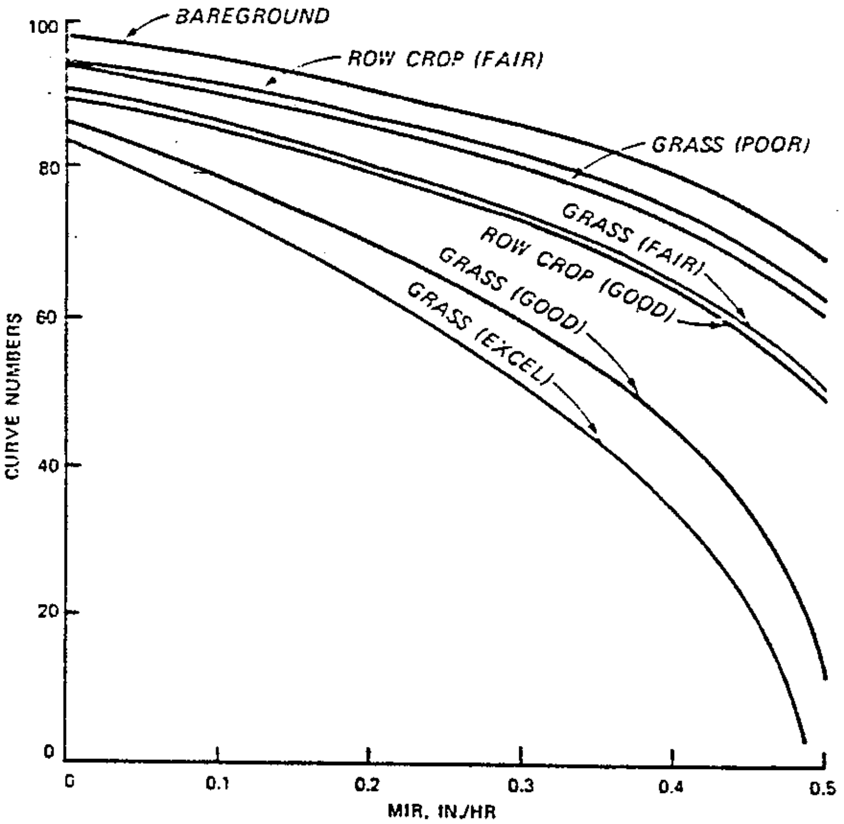


Figure 3. Relationship between SCS curve number and minimum infiltration rate (MIR) for various vegetative covers

INTER-OFFICE MEMO

DATE June 27, 1984

TO John Yellich

FROM Mark Fetzer

SUBJECT Swanson Project Area Water Use and Food Consumption Survey

Marline has completed a survey of twelve households within or near the Swanson Project Area to obtain information on local water and food consumption patterns. The households, representing a total of 38 persons, were interviewed on June 23, 25 and 26. These households were chosen primarily to provide a geographical representation of the Swanson Project and the general vicinity including: mine site, mill site, tailings management area, overburden storage areas, clay borrow area, Sonans, Sheva and Fairview.

Specific responses were provided by each household in personal interviews based upon detailed questionnaires. Questions concerning local water use and consumption dealt solely with surface water sources. The questions treating food consumption included the following general categories of food or produce:

A. Fruits, including nuts and honey
B. Vegetables, grown as cash crops or in gardens
C. Livestock
D. Dairy Products
E. Wild Game
F. Fish

All households interviewed consume food that is produced locally. For the purpose of this interview, "locally" was explained to be within two miles of the household. Due to the geographical distribution of the survey population, the area from which the food consumed in these households is produced represents a 50 square mile area. This area is circular in shape, and can be roughly inscribed within a four mile radius of the mine/mill complex.

The average rate of local food consumption indicated by the surveyed households is approximately 45 to 50%.

SURFACE WATER CONSUMPTION

None of the interviewed households utilize local surface waters for drinking water. No member of any of the households would drink from local surface water courses on an occasional basis. In the distant past, some household members have taken an occasional drink from surface waters, however, the convenience of other sources of refreshment in recent years, the residents' concern for contamination related to agriculture and a heightened awareness of public health concerns, combine to cause for people to take their own water with them "to the fields".

IRRIGATION BY SURFACE WATERS

One half (6) of the households use surface waters to irrigate their gardens or edible cash crops. It should be noted that the majority (85%) of this irrigation water comes from ponds instead of local streams. Of the irrigation that utilizes local streams, less than 1/2 to 1/6 acre-foot per year of water is applied from local streams, as opposed to the figure of 1 acre-foot used by Marline in its PABLM computer model. *

PRODUCE: Fruits

A weighted average of all households responding reveals that approximately one third (33%) of all fruits, nuts and honey consumed is produced locally. No household consumed more than 60% of its fruit from local sources. Total maximum annual household (2 adults +) consumption of fruits: 649.5552 kg.

PRODUCE: Vegetables

Similarly, a weighted average for vegetables indicates that nearly sixty (60%) percent of all vegetables consumed are produced locally. One household consumes 95% of its vegetable diet from local sources. Total maximum annual household (2 adults +) consumption of vegetables: 549.7632 kg.

LIVESTOCK

A weighted average for consumption of beef, pork, eggs, poultry and other foods prepared directly from livestock reveals that 46% of the meat diet for these households is supplied by local livestock. Total maximum annual household (2 adults +) consumption of livestock: 680.4 kg.

FISH

Of the twelve households, four consumed no local fish. Only three consumed one quarter of their "seafood" or fish from local sources. The weighted average for this item reveals that the average household consumes about 15% of its fish from local sources. Total maximum annual household (2 adults +) consumption of fish: 4.536 kg. 2.2 kg.

DAIRY PRODUCTS

Only two households consumed locally (personally) produced dairy products. The household producing and consuming the largest quantity used 100 gallons of milk and 100 pounds of butter between two persons. Total maximum annual household (2 adults +) consumption of dairy products: 51.7104 kg.

WILD GAME

Three households consumed no wild game. Of the remaining nine, the consumption ranged from 25 pounds to approximately 250 pounds of flesh from wild game annually. Total maximum annual household (4 adults) consumption of wild game: 143.3376 kg.

MSF/tbd

TECHNICAL MEMORANDUM NUMBER 6

Clarification on Clay Liner Issues

July 25, 1984

Prepared by C. Sealy, Chen and Associates, Inc.

Chen & Associates
Consulting Geotechnical Engineers

96 South Zuni
Denver, Colorado 80223
303/744-7105

Casper
Cheyenne
Colorado Springs
Glenwood Springs
Rock Springs
Salt Lake City

July 15, 1984

Subject: Tailings Management Facility, Swanson Uranium Project, Pittsylvania County, Virginia

Job No 26,350

Dravo Engineers, Inc.
1250-14th Street
Denver, CO

Attn: Mr. Alan Notary

Gentlemen:

The following letter is intended to answer the concerns that were addressed in a letter to Mr. Rich Collins, of the Institute for Environmental Negotiations dated June 21, 1984 from Rogers, Golden and Halpern.

As you know, the extent of geotechnical studies that had been performed to date on the project have been of a reconnaissance nature. These investigations were designed primarily to support Senate Bill 155 and a decision on whether to proceed with more detail studies on the basis of the data collected. Obviously, additional geotechnical investigation stages (preliminary stage and design stage) will be performed to further delineate subsurface conditions, obtain design parameters, and prepare final geotechnical plans and specifications for the project. Consequently, we will attempt to answer questions posed by the review committee based on the level of our investigations.

In our letter of June 1, 1984, we attempted to make clarifications on the stability considerations of the proposed tailings management facility as presently envisioned in the conceptual stage. At this time we attempted to provide answers on how we would approach bearing capacity considerations, static stability and seismic stability. At this stage of the project, sufficient geotechnical data had not been collected and analyzed to provide design recommendations for definite configurations of slopes, settlement questions, and behavior of the compacted liner.

The June 21, 1984 letter by the review committee states that our previous discussions were limited to conditions significant to the overall stability of the tailings/waste rock pile. The committee apparently feels that there should be a discussion of the clay liner, bedding material, and the potential of differential settlement or loss of liner integrity under tailings and waste rock loads and the contributions to the stability of the structure overall. Until the site is thoroughly characterized from a geotechnical standpoint, an exact analysis of liner stability and performance cannot be precisely described. However, the following discussion summarizes our professional judgment on the issues of foundation preparation, base and liner construction and liner stability.

From a geotechnical standpoint, the conceptual tailings management plan is feasible. The prime factor of insuring the integrity of the entire structure, both for the short and long term would be to place the facility on competent foundation materials. Preliminary investigations suggest that the Triassic bedrock at Site 9T is an extremely competent material for construction of an embankment type tailings facility as proposed. Modulus of elasticity values for this rock will typically be in excess of 1 x 10^6 psi.

The most critical aspect of providing a competent foundation will be to insure that the foundation is stripped to depths sufficient to remove materials having undesirable engineering qualities such as low shear strength, high compressibility, or materials that will interfere with compaction operations of the base. This will involve removal of all overburden soils, loose rock and projecting knobs by scaling, hand picking or wedging. The exposed foundation rock beneath the facility footprint will be graded to provide a reasonably smooth, clean surface. As part of the ongoing geotechnical investigations, the large areas of the Triassic bedrock exposed and cleaned will be inspected by a geologist and geotechnical engineer for the presence of knobs, open joints, cracks and soft or loose areas. By exposing the surface, appropriate design measures can be made and incorporated into the construction plans and specifications. If these conditions are found, the rock will be excavated further or the open joints and cracks covered with granular materials. This granular material will vary from sand to mixtures of sand and gravel. Gradation of the granular material will depend upon a size and joint opening. On irregular rock surfaces, the granular material will also serve as a leveling course for base placement. In certain cases, if extremely erratic conditions are encountered, measures will be undertaken to mitigate this condition as determined by the on-site geotechnical engineer. Such procedures may involve rock grouting as necessary. However, initial investigations indicate that this type of condition should not be encountered within the upper surface of the Triassic bedrock.

The base will be constructed from waste rock materials from the project. Observations made on core samples indicate that the Crystalline and

Triassic materials are extremely competent. The rockfill base will be compacted in layers to achieve a relative density (ASTM D-2049) on the order of 70%. This density requirement is roughly equivalent to 100% of standard Proctor density (ASTM D-698). In order to determine exact densities that will provide adequate bearing capacity for the facility and limit differential settlements to within tolerable limits, test fills will be constructed. In situ tests will then be conducted on these fills to evaluate the integrity of the base and predict settlements under the anticipated loadings. From this information, exact specifications for gradation of rock materials and compaction requirements can be made for the actual facility.

The surface of the base must be smooth in order that the liner can be properly constructed. In addition, proper sizing of the base material is mandatory in order that piping of the clay liner will not occur into the base. This will be accomplished by proper gradation of the base material or providing filter materials between the base and clay liners. Requirements have been developed by the Corps of Engineers at Vicksburg, Mississippi for filter materials. Filter specifications relate the grading of fill or protective filter to that of the soil being protected. Such criteria will be used in the base-liner design.

The clay liner will be constructed on top of the properly graded base or filter blanket. The liner will consist of clays obtained from the Banister River alluvium material or a combination of suitable clays and overburden materials from surrounding areas. This blanket will be similar to the impervious clay zones which have been constructed on the upstream side of water resource dams for seepage control. Often these blankets are connected into the inner clay core of such structures. Consequently, they lie beneath the upstream face of embankment and therefore support the weight of the upstream embankment. For the proposed facility, the clay liner will extend into the clay berm starter dikes or extend well beyond these dikes. A typical analysis of stability conditions for this liner at the edge of the facility is shown in the attached figure. The ability of a relatively thin clay liner to support high embankment fills will not pose a problem if this clay liner is properly designed and constructed. The liner will be placed and compacted at a sufficient density to minimize long term settlements. Consolidation testing will be performed on compacted clay samples at different densities in order that settlements may be predicted under the anticipated loadings and that the liner can be designed and constructed to minimize these settlements. Plate load tests during construction will be made to verify laboratory tests.

It is important that the density and integrity of the liner be maintained prior to deposition of the tailings. Protection will be provided against water erosion, freeze-thaw cycles, desiccation and construction equipment. The liner will be protected by either deposition of a layer of tailings or placement of a protective compacted granular soil cover. The integrity of the upper surface of the liner can be maintained by reworking, adjusting the liner material for proper moisture content and compacting according to project specifications just prior to placement of tailings. Obviously, this will involve proper geotechnical monitoring during operations to insure that tailings are not placed on a liner that has been disturbed by construction equipment or that has been allowed to desiccate. Incapsulation of the clay liner will improve its confinement and stability characteristics for the long term as the clay liner will gain strength over time with the drainage and consolidation process.

The starter dikes will be compacted of clay or silt materials (CL-ML soils). At this time, these dikes are proposed to be designed according to the design of Small Dams Manual by the United States Department of Interior, Bureau of Reclamation. It is envisioned that these structures will be of a homogeneous nature and will be connected directly into the clay blanket of similar materials. The exact design details will be formulated during the preliminary and final design stages of the project. Typically, these dikes will have side slopes of 2.5 or 3 horizontal to 1 vertical and top widths of 14 to 18 feet.

It has been documented that well constructed earthfill and rockfill structures are generally not susceptible to all but extremely large accelerations associated with strong ground motion shaking. Clays tend to act as springs or dampeners within the tailings system and will tend to attenuate forces associated with earthquakes. We have enclosed two articles entitled "Considerations in the Earthquake-Resistant Design of Earth and Rockfill Dams by H. Bolten Seed" and "Performance of Earth Dams during Earthquakes by H. Bolten Seed and Others". The articles mention that clays with a low degree of sensitivity or dense sands are the most stable materials against earthquakes for geotechnical type construction. Embankment failures during earthquakes are not attributed to methods of analysis but to poor construction of the dams themselves. The articles address the fact that dams constructed on clay or rock foundations have withstood extremely strong shaking ranging from 0.35g to 0.8g from a magnitude of 8-1/4 earthquake with no apparent damage. In any event, additional seismic studies will be performed in the design stage and the tailings/waste facility will be designed using current state of the art techniques for analyzing earthquakes.

The belt filtered tailings will be placed in the impoundment and shaped and graded with dozers. Settlement of these tailings is expected to occur due to placement, self weight, construction of the reclamation cover and placement of the incapsulated rock waste. The time rate of settlement of these tailings will be dependent upon their permeability and the permeability of the clay liner beneath the tailings. Settlement plates will be installed to determine when settlements have ceased to be significant. At that time, the reclamation cover and mine waste materials will be placed on the tailings. It has been suggested that the reclamation cover not be placed directly on the belt filtered tailings and that mine waste rock be placed above the tailings. The reclamation cover would then be an intermediate layer between the waste rock. At this time, we agree that this may be a viable solution and that placement of waste rock could accelerate the consolidation process. This could possibly allow for a more stable reclamation cover. However, depending on the characteristics of the waste rock, filter zones may be required between the waste rock and reclamation cover to insure that piping and internal erosion of the reclamation cover will not occur into the mine waste rock. This aspect of the conceptual design deserves further consideration during the preliminary phase of the study.

We hope this letter has answered your concerns regarding the geotechnical concepts that have been formulated to date. Again, it should be realized that the facility cannot be fully designed and every geotechnical aspect answered until further investigations, testing and analysis are made. This will include evaluation of foundation rock, proposed liner material, tailings, reclamation cover material and mine waste rock materials. Once the properties of these materials are fully characterized, a specific geotechnical design can then be formulated. At this stage of the study we see no unusual geotechnical conditions which cannot be accounted for in the design of the facility.

Sincerely,

Chen & Associates, Inc.

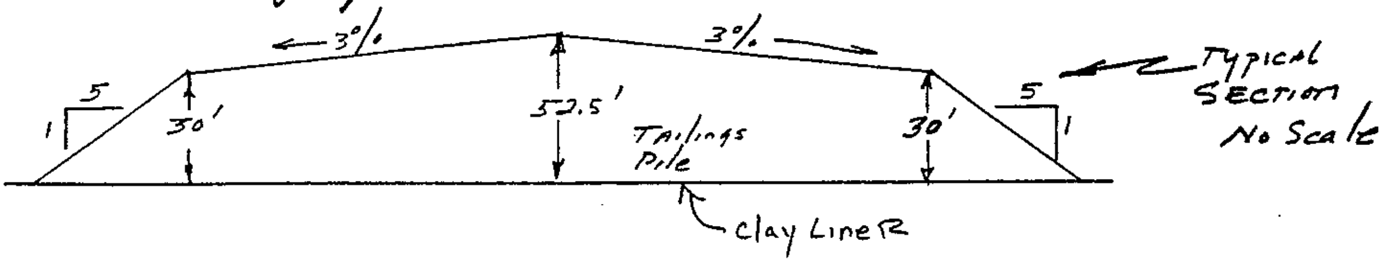
By
Curtis O. Sealy, P.E.

COS/moc

CA-

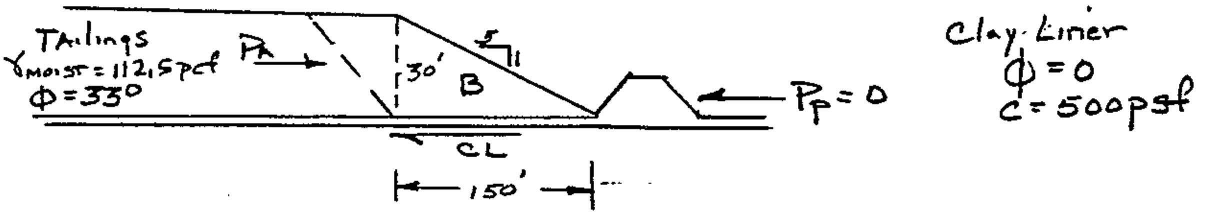
chen and associates, inc.
CONSULTING ENGINEERS

JOB NO. 26,350 JOB TITLE Marline - Swanson Project DATE 7/12/84 BY COS
SUBJECT Liner integrity CHECKED ___ SHEET 1 OF 1



Worst case analysis - End of Construction
Tailings placed on liner - No resistance at pile edge due to confinement of overburden & Waste Rock

For above condition at edge
No scale



For stability at edge of pile

$$SF = \frac{clb + \cancelto{0}{w\tan\phi} + \cancelto{0}{P_p}}{P_A}$$

$$SF = \frac{(500)(150)(1)}{14{,}924}$$

SF = 5.0 Against sliding

SF = Safety Factor
c = unit cohesion of liner
l = length of base effected
b = unit distance = 1
W = weight of Block B
P_p = Resultant passive pressure on Block B
P_A = Resultant active pressure on Block B

$$P_A = \frac{\gamma H^2}{2} K_A$$

where $K_A = \frac{1-\sin\phi}{1+\sin\phi}$ (Tailings)

For $\phi = 33^\circ$ $K_A = 0.2948$

$$P_A = \frac{(112.5)(30)^2(0.2948)(1)}{2}$$

$P_A = 14{,}924$ lbs

TECHNICAL MEMORANDUM NUMBER 7

ANFO Dilution Calculation

July 10, 1984

Dravo
Denver Operating Center

ENGINEERING COMPUTATIONS

EST NO.
CONT NO. 8079
DIVISION

COMPANY Marline Uranium
LOCATION Danville, VA
DESCRIPTION Nitrate & Ammonium Conc. due to ANFO

DATE 4-13-84
DR ALN CH
REF

GIVEN : 2030 TPY ANFO USE IN SWANSON PIT
ASSUME 1% TOTAL ANFO LOSS, PER YEAR (PER SENES)

FIND : INCREASE IN CONCENTRATIONS OF NO_3 & NH_4 IN STREAM (MILL CREEK).

① FIND TOTAL WT. OF LOSSES:

$$\text{ANFO} = \underbrace{NH_4NO_3} + \underbrace{\text{FUEL OIL}}$$

94% BY WT + 6% = 100%

ATOMIC WT.S = N 14
H 1
O 16

$$\frac{NH_4}{NH_4NO_3} = \frac{14+4}{18+14+3(16)} = 22.5\%$$

$$\frac{NO_3}{NH_4NO_3} = 77.5\%$$

ANNUAL LOSS OF NH_4 = 2030 TONS (0.94)(0.225)(0.01)
= 4.29 TONS/YR

ANNUAL LOSS OF NO_3 = 2030 TONS (0.94)(0.775)(0.01)
= 14.79 TONS/YR

② CHECK INCREASE IN CONCENTRATIONS ASSUMING ALL MATERIALS LEAVE PIT IN THE AVG. FLOW OF 258 GPM

$$NH_4 : \frac{4.29 \text{ TONS} \quad 2000^{\#} \cdot 453.6 \text{ gm} \quad 1000 \frac{\text{mg}}{\text{gm}}}{258 \frac{\text{GAL}}{\text{MIN}} \quad 60 \cdot 24 \cdot 365 \quad \frac{1}{7.48} \frac{\text{FT}^3}{\text{GAL}} \quad 28.32 \frac{\ell}{\text{FT}^3}}$$

$= 7.58 \text{ mg}/\ell$ IN WASTE STREAM

SHEET NO. 1 OF 3

Dravo
Denver Operating Center

ENGINEERING COMPUTATIONS

EST NO.
CONT NO. 8079
DIVISION

COMPANY MARLINE URANIUM
LOCATION DANVILLE, VA
DESCRIPTION NITRATE & AMMONIUM CONC. DUE TO ANFO

DATE 4-13-84
DR ALW CH
REF

$$NO_3 : \frac{14.79 \times 2000 \times 453.6 \times 1000}{258 \times 60 \times 24 \times \frac{365}{7.48} \quad 28.32}$$

$$= 26.13 \ \frac{mg}{\ell} \ \text{WASTE STREAM}$$

③ CHECK INCREASE IN MILL CREEK CONCENTRATIONS ASSUMING $Q_{AVG.} = 10.5$ CFS IN CREEK & AVG.

DISCHARGE TO STREAM = 166 GPM

NH_4 :

166 GPM = 0.370 CFS

TOTAL FLOW = 10.5 + 0.37 = 10.87 CFS

$$28.32 \ \frac{\ell}{CFS} \ 0.37 \ CFS \times 7.58 \ \frac{mg}{\ell} \ NH_4 = 79.4 \ mg \ NH_4$$

$$\frac{79.4 \ mg}{10.87 \ CF} \ \frac{1 \ CF}{28.32 \ \ell} = \underline{\underline{0.26 \ \frac{mg}{\ell} \ NH_4 \ \text{IN MILL CR}}}$$

NO_3 :

$$28.32 \quad 0.37 \quad 26.13 = 273.8 \ mg \ NO_3$$

$$\frac{273.8}{10.87} \ \frac{1}{28.32} = \underline{\underline{0.89 \ \frac{mg}{\ell} \ NO_3 \ \text{IN STREAM}}}$$

SHEET NO. 2 OF 3

EC-555

Dravo
Denver Operating Center

ENGINEERING COMPUTATIONS

EST NO.	
CONT NO.	8079
DIVISION	

COMPANY MARLINE URANIUM
LOCATION DANVILLE, VA
DESCRIPTION NO_3 & NH_4 CONCENTRATIONS

DATE 4-13-84
DR AWN CH
REF

④ RECALCULATE CONCENTRATIONS NEGLECTING DILUTION DUE TO PIT WATER & ASSUMING ALL MATERIAL ENDS UP IN MILL CREEK. ("WORST CASE")

NH_4 :

$$\frac{4.29 \frac{TONS}{YR} \times 2000\#}{10.5\ CFS\ \ 60\cdot 60\cdot 24\cdot 365} = 259 \times 10^{-5} \frac{LB}{CF}$$

$$\times 16.02 = 4.15\ 10^{-4} \frac{KG}{M^3} = 0.42 \frac{mg}{l}\ NH_4$$

NO_3 :

$$\frac{14.79 \times 2000\ \ 16.02}{10.5\ \ 60\cdot 60\cdot 24\cdot 365}\ 10^3 = 1.43 \frac{mg}{l}\ NO_3$$

SHEET NO. 3 OF 3

EC-555

TECHNICAL MEMORANDUM NUMBER 8

PMF Dilution of Breach Volume Calculation

July 10, 1984

Dravo
Denver Operating Center

ENGINEERING COMPUTATIONS

EST NO. ______
CONT NO. 8079
DIVISION DENVER

COMPANY MARLINE URANIUM
LOCATION DANVILLE, VA
DESCRIPTION POND BREACH DURING PMP

DATE 7-3-84
DR ACN CH ______
REF ______

PURPOSE - TO COMPARE IMPACT OF BREACH DURING PMP VS. BREACH OF 2-YR STORM VOLUME AS PROPOSED IN "SUMMARY OF PABLM INPUT PARAMETERS" TRANSMITTED JUNE 26, 1984.

① CALCULATE INCREASE IN STREAM CONCENTRATIONS DURING BREACH POSTULATED IN PABLM INPUT SUMMARY DOCUMENT (SEE COPY OF TABLE, ATTACHED)

(1.1) ASSUME - 10.5 CFS IN MILL CREEK (NORMAL AVG.)
- U CONCENTRATION = 5000 pCi/l (SEE TABLE)
- 2.02 CFS BREACH FLOW

(1.2) IN ONE SECOND:

$$2.02\ CF \cdot \frac{28.32\ \ell}{CF} \cdot 5000\ \frac{pCi}{\ell} = 286{,}032\ pCi$$

$$\text{TOTAL FLOW} = 10.5 + 2.02 = 12.52\ CFS$$

$$\underline{\text{NEW STREAM CONC.}} = \frac{286{,}032\ pCi}{12.52 \cdot 28.32\ \ell} = \boxed{807\ pCi/\ell}$$

② CALCULATE INCREASE IN STREAM CONCENTRATIONS DURING BREACH OCCURING DURING PMF.

(2.1) ASSUME - BREACHED VOLUME CONCENTRATIONS DILUTED DUE TO PMP
- BREACH OCCURS OVER 6 HOURS (NOTE: THIS IS MORE SEVERE THAN ①, RESULTS IN LARGER INPUT TO STREAM.

Dravo
Denver Operating Center

ENGINEERING COMPUTATIONS

EST NO.
CONT NO. 8079
DIVISION DENVER

COMPANY MARLINE URANIUM
LOCATION DANVILLE, VA
DESCRIPTION POND BREACH DURING PMP

DATE 7-3-84
DR ALW CH
REF

(2.2) DILUTION DUE TO INTERCEPTION OF PMP:

*ASSUME DILUTION ONLY DUE TO 29" PMP DIRECTLY ON 4 AC. POND (CONSERVATIVE - RESULTS IN LESS DILUTION)

$$\left(\frac{29}{12}\right)4 + 4 = 13.\underline{67} = \text{NEW POND VOLUME (AC FT)}$$

URANIUM ORIGINALLY IN POND

$$4 \text{ AC FT} \; \frac{43560 \text{ FT}^2}{\text{AC FT}} \; \frac{28.\underline{32} \; \ell}{\text{FT}^3} \; 5000 \text{ pCi}/\ell = 2.\underline{47} \times 10^{10} \text{ pCi}$$

$$\text{WITH DILUTION}: \; \frac{2.\underline{47} \times 10^{10}}{13.\underline{67} \times 43560 \times 28.\underline{32}} = 1463 \text{ pCi}/\ell$$

(2.3) BREACH FLOW ASSUMING 6-HR DURATION =

$$\frac{13.\underline{67} \times 43560}{6 \times 60 \times 60} = 28 \text{ CFS}$$

(2.4) PMF FLOW IN STREAM -

PMF PEAKS @ ~ 5000 CFS / SQ MI.

5000 × 10.5 □ MI. = 52,500 CFS @ MILL CREEK IMMEDIATELY UPSTREAM OF PIT.

(NOTE: 5000 CFS/SQ.MI. COMPARES FAVORABLY WITH "MAXIMUM FLOODFLOWS IN U.S.", USGS WSP #1887, COPY OF CURVE ATTACHED)

$$\text{ASSUME "AVG." FLOW OF PMF} \sim \tfrac{1}{3} \text{ PEAK} = \frac{52,500}{3}$$

$$= 17,500 \text{ CFS}$$

Dravo
Denver Operating Center

ENGINEERING COMPUTATIONS

EST NO.
CONT NO. 8079
DIVISION DENVER

COMPANY MARLINE URANIUM
LOCATION DANVILLE VA
DESCRIPTION POND BREACH DURING PMP

DATE 7-3-84
DR KLN CH
REF

(2.5) CALCULATE DILUTION IN STREAM:

IN ONE SECOND:

$$28\ CF \times 1463\ pCi/\ell \ \frac{28.32\ \ell}{CF} = 1.16\times10^{6}\ pCi$$

NEW STREAM CONC. $= \dfrac{1.16\times10^{6}}{(28+17{,}500)\ 28.32} = \boxed{2.34\ pCi/\ell}$

CONCLUSION: POND BREACH OF 2-YR STORM VOLUME MORE CRITICAL THAN PMP BREACH. (ALSO, ADDITIONAL FLOW IN BANISTER RENDERS IMPACT BELOW DETECTABLE.)

(3.0) RECALCULATE PMP CASE ASSUMING 29" ON 14 AC, ALL @ 5000 pCi/ℓ U. (VERY CONSERVATIVE)

$$\frac{29''}{12} \times 14 \times 43560 = 1{,}474{,}000\ CF$$

@ 5000 pCi/ℓ : $1{,}474{,}000 \times 28.32\ \frac{\ell}{CF} \times 5000 = 2.09\times10^{11}\ pCi$

ASSUMING 6 hr BREACH:

$$\frac{1{,}474{,}000}{6\times60^{2}} = 68\ CFS$$

∴ TOTAL FLOW = 68 + 17,500

IN ONE SECOND -

$$68\ \frac{CF}{SEC}\ 28.32\ \frac{5000\ pCi}{\ell} = 9{,}629{,}000\ pCi$$

NEW STREAM CONC. $= \dfrac{9.63\times10^{6}}{(68+17500)\ 28.32} = \boxed{19.4\ pCi/\ell}$

SHEET NO. 3 OF 5

4 of 5

SUMMARY OF PABLM INPUTS

	MINE	MILL	TAILINGS MANAGEMENT			OVERBURDEN	
	(TREATED DISCHARGE)	(POND BREACH)	VEGETATED	UNVEGETATED	EXPOSED	VEGETATED	UNVEGETATED
1. SEEPAGE			VIA LATERIAL DRAIN:				
a. QUANTITY (cfs)	N/A	N/A	INCLUDED WITH OVERBURDEN	INCLUDED WITH OVERBURDEN	N/A	0.540	0.274
			SEEPAGE THRU LINER = 0.065 cfs				
b. RADIONUCLIDE CONTENT			CASE 1:		CASE 2:		
U- 238 & 234 mg/l	-	-	35		1	0.028	
Th - 230	-	-	162		1	0.203	
Ra - 226	-	-	22		1	9.01	
Pb - 210	-	-	7		2	0.187	
Po - 210	-	-	1		1	0.116	
2. RUNOFF (& OTHERS)	TREATED DISCHARGE:	POND BREACH:					
a. QUANTITY (cfs)	0.37	2.02 cfs (over 24 hours)	N/A	0.002	N/A	N/A	0.002
b. RADIONUCLIDE CONTENT							
U - 238 & 234 mg/l	0.5	5000 (pCi/l)	-	0.014	-	-	0.014
Th - 230	0.4	10	-	0.102	-	-	0.102
Ra - 226	3.0	50	-	4.505	-	-	4.505
Pb - 210	0.1	40	-	0.094	-	-	0.094
Po - 210	0.9	10	-	0.058	-	-	0.058

N/A = Not Applicable

5 OF 5

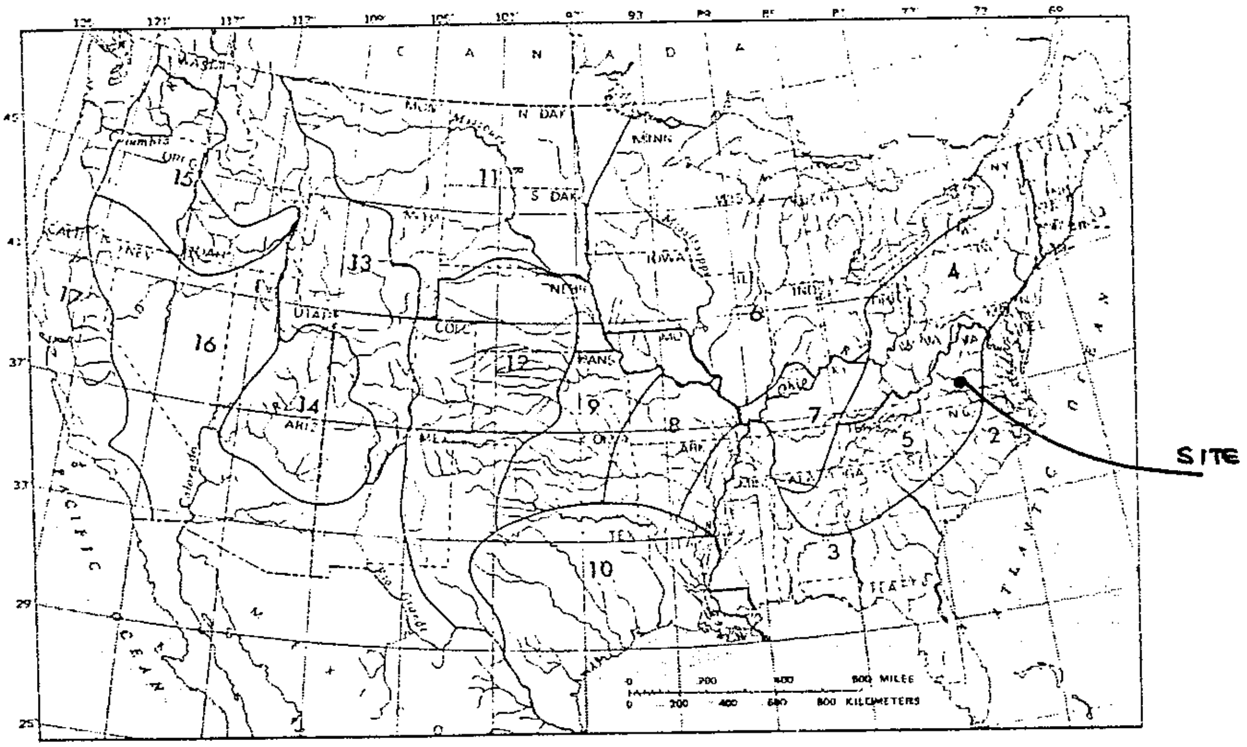


FIGURE 1.—Map of the conterminous United States showing flood-region boundaries.

NOTE: USING C.O.E. & NWS TECHNIQUES FOR PMP EAST OF 105th MERIDIAN RESULTS IN 29" IN 6 HR. APPLYING UNIT HYDROGRAPH TECHNIQUES RESULTS IN 5,000 CFS/SQ. MI. FOR PMF PEAKS.

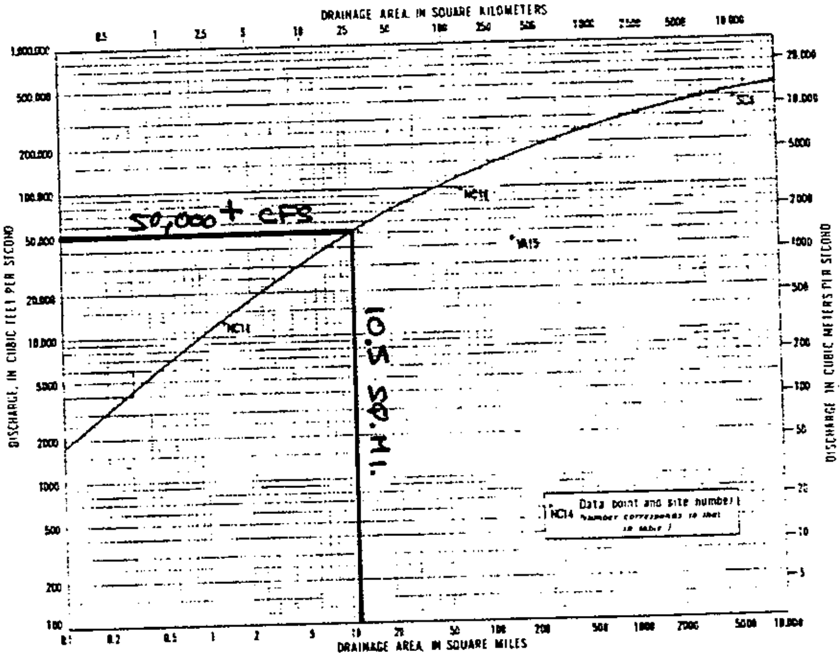


FIGURE 7.—Peak discharge versus drainage area, and envelope curve for region 5.

TECHNICAL MEMORANDUM NO. 9

Chemical Analysis of Rock Materials

June 14, 1984

MARLINE URANIUM CORPORATION
104 ANNHURST DRIVE • P.O. BOX 1626 • DANVILLE, VIRGINIA 24543
TELEPHONE (804) 836-2021

MEMORANDUM

TO: Donald M. Gorber - SENES Consultants Limited
Jack A. Halpern - Rogers, Golden & Halpern
Richard Collins - Institute for Environmental Negotiation

FROM: John A. Yellich John A. Yellich

DATE: June 14, 1984

SUBJ: Analyses of Swanson Composites

Enclosed are copies of the Virginia Division of Mineral Resources Ore composite and Marline's analyses of the waste rock. Chris Halladay has put together a summary sheet of all the analyses submitted to the UAG in 1983 and the data received from the Virginia Division of Mineral Resources and Marline. You will note that Chris has compared worldwide rock analyses to the rocks in the project area.

Stan Johnson and the Division of Minerals will no doubt be doing their own complete comparison sheet. Please note, Chris Halladay did treat and correct some of the recent data to oxides, similar to the 1983 UAG data and the radionuclides are not on this sheet. The Marline summary is for the overburden analysis.

JAY:dfb

Enclosures

cc: Al Notary
Noel Savignac
Kirk Jackson
Chris Halladay
Stan Johnson

645 MADISON AVENUE • NEW YORK • TELEPHONE (212) 758-8500

CHEMICAL ANALYSES OF COMPOSITED SAMPLES, SWANSON URANIUM PROJECT

All values in parts per million (ppm), except those indicated as per cent (%)[1]

	UAG - '82-'83			1984								1984			
	MARLINE/UNION CARBIDE ANALYSES[2]			TASK FORCE ORE-GRADE COMPOSITE (VDMR-JC)								WASTE ROCK COMPOSITES[4] (mass spectro.)			WORLD WIDE CRUSTAL AVERAGE[5]
	CSMRI COMPOSITE		BARRINGER COMP.	Hazen Research		Blue Ridge Labs		Accu-Labs (AAS)		Accu-Labs (mass spectro.)[3]		Mineral Waste Comp.	Barren Cryst. Comp.	Barren Triass. Comp.	
Element	CSMRI	Geolabs		JC-1	JC-5	JC-3	JC-7	JC-4	JC-8	JC-4	JC-8				
URANIUM (U_3O_8) %	.104	.106	.095	.114	.119	.116	.139			~.212	~.142	.018	.003	.0003	.0002
ALUMINUM (Al_2O_3) %	15.87		16.5	18.8	18.9	13.47	13.50			+1	+1	+1	+1	+1	15.36
ANTIMONY (Sb)		-1		-1	-1	-5	-5	.30	-.25	.30	-.21	-.21	-.21	-.21	.2
ARSENIC (As)	-10	5	2.2	4	4	-1	-1	5.7	8.0	4.6	3.0	5.5	1.8	.69	1.8
BARIUM (Ba)	780		733	530	480	303	338			~1800	640	~1800	~1800	~1800	425
BERYLLIUM (Be)			1.97	1	1	1.5	1.5			2.1	.93	.56	12	2.1	2.8
BISMUTH (Bi)				4	4	-5	-5			.39	-.35	-.35	-.35	-.35	.2
BORON (B)	20		10	-10	-10	-5	-5			10	18	18	10	15	10
CADMIUM (Cd)			-1	2	2	-.2	-.2	1.2	1.3	.39	.23	.19	.33	.17	.2
CALCIUM (CaO) %	3.92		4.21	3.46	3.43	1.20	1.33			+1	+1	+1	+1	+1	5.08
CERIUM (Ce)				12	14					120	100	170	68	170	60
CHLORINE (Cl)				100	-100	135	85			15	42	6.3	15	13	130
CHROMIUM (Cr)			39	27	31	8	5	24	24	31	22	75	37	170	100
COBALT (Co)			15	19	20	4	4	10	11	19	2.1	8.6	3.2	7.6	25
COPPER (Cu)		8	97.1	8	9	9	9	7.0	7.0	9.4	9.4		6.6	22	55
FLUORINE (F) %	.14		.14	.17	.18	.02	.02			~.34	~.5	~.19	~.14	~.045	.063
IRON (total as Fe_2O_3) %	3.72		4.35	2.19	2.33	2.97	2.97			+1	+1	+1	+ 1	+1	+1
LANTHANUM (La)				10	12	300	325			140	82	82	62	140	30
LEAD (Pb)		35		35	42	40	40	40	46	85	43	24	24	36	13
MAGNESIUM (MgO) %	1.19		1.35	.907	.986	.44	.45			~.36	~.5	.398	.829	.481	3.47
MANGANESE (Mn)			528	300	310	250	250			770	550	900	410	680	950
MERCURY (Hg)		.01		.04	.04	-.02	-.02	.02	.01			-.01	-.01	-.01	.08
MOLYBDENUM (Mo)	4	2	-20	13	8	1	.5	2.1	2.4	4.5	2.1	2.4	2.1	1.8	1.5
NICKEL (Ni)			8	20	18	7	7	9.5	9.2	14	3.3	14	14	24	75
PHOSPHORUS (P_2O_5) %	1.72		1.85	1.82	1.78	1.70	1.05			+1	+1	~.825	~.665	~.229	1.05
SELENIUM (Se)				-.1	-.1	-.1	-.1	-.25	-.25	-.10	.13	.13	.31	1.3	.05
SILVER (Ag)		-.5	-5	-2	-2	-.5	-.5			.10	.10	-.10	-.10	-.10	.07
STRONTIUM (Sr)			427	76	83	105	118			790	460	500	320	320	375
SULFUR (as SO_3) %	.08			.237	.129	-.01	-.01			.105	.162	.050	.018	.011	.026
THALLIUM (Tl)		-.2		-1	-1					-.4	-.4	-.4	-.4	.57	.5
THORIUM (Th)	-50		17	7	8					24	12	12	12	12	7.2
TITANIUM (Ti) %			.352	.364	.363	.250	.260			+1	~.5	+1	+1	+1	.440
VANADIUM (V)	105		102	160	160	-10	-10	120	100	450	180	250	67	220	135
YTTRIUM (Y)				4	4	-10	-10			25	19	15	9.3	25	33
ZINC (Zn)		42	30	43	41	73	58	47	42	56	28	42	28	42	70
ZIRCONIUM (Zr)	200		65	140	160	-1000	-1000			830	330	110	240	420	165
LUTETIUM[6] (Lu)										.50	.25	.28	.25	.25	.50
YTTERBIUM (Yb)										1.8	.79	.92	.92	.92	3.4
THULIUM (Tm)										.51	.22	.31	.22	.26	.50
ERBIUM (Er)										5.0	1.2	1.8	1.2	1.2	2.8
HOLMIUM (Ho)										.74	.29	.74	.35	.26	1.2
DYSPROSIUM (Dy)										3.6	.90	2.2	1.5	1.5	3.0
TERBIUM (Tb)										1.5	.51	1.1	.51	.51	.9
GADOLINIUM (Gd)										11	3.2	8.0	4.6	4.6	5.4
EUROPIUM (Eu)										4.6	1.2	3.1	2.3	1.2	1.2
SAMARIUM (Sm)										25	3.7	12	3.7	5.3	6.0
NEODYMIUM (Nd)										76	20	100	44	38	28
PRASEODYMIUM (Pr)										32	14	27	16	24	8.2

---

[1] Several values have been recalculated as oxides for uniformity. A (-) preceding a number indicates "less than"; a (+) indicates "greater than."

[2] Analyses of ore-grade composites previously submitted to the UAG.

[3] mass spectrographic analysis: approx. +/- 40% error.

[4] preparation of composites overseen by VDMR

[5] from "Principles of Geochemistry", 3rd ed., by Brian Mason, 1966: John Wiley & Sons, New York.

[6] total rare-earth oxides (Hazen): JC-1 = .22%; JC-5 = .28%.

MARLINE URANIUM CORPORATION
104 ANNHURST DRIVE • P.O. BOX 1626 • DANVILLE, VIRGINIA 24543
TELEPHONE (804) 836-2021

MEMORANDUM

TO: Donald M. Gorber - SENES Consultants Limited
Jack A. Halpern - Rogers, Golden & Halpern
Richard Collins - Institute for Environmental Negotiation

FROM: John A. Yellich John A. Yellich

DATE: June 28, 1984

SUBJ: Erratta Chemical Analyses Composite Table of June 14, 1984

We have found several typographical errors in the summary sheet of chemical analyses of composited Swanson Project samples that was enclosed with my memorandum of June 14, 1984. A revised, corrected table is attached for your records.

JAY:dfb

Attachment

cc: ✓Al Notary
Noel Savignac
Kirk Jackson
Stan Johnson

645 MADISON AVENUE • NEW YORK • TELEPHONE (212) 758-8500

CORRECTED 6/28/84

CHEMICAL ANALYSES OF COMPOSITED SAMPLES, SWANSON URANIUM PROJECT

All values in parts per million (ppm), except those indicated as per cent (%)[1]

	UAG -'82-'83			1984								1984			
	MARLINE/UNION CARBIDE ANALYSES[2]			TASK FORCE ORE-GRADE COMPOSITE (VDMR-JC)								WASTE ROCK COMPOSITES[4] (mass spectro.)			WORLD-WIDE CRUSTAL AVERAGE[5]
	CSMRI COMPOSITE		BARRINGER COMP.	Hazen Research		Blue Ridge Labs		Accu-Labs (AAS)		Accu-Labs (mass spectro.)[3]		Mineral Waste Comp.	Barren Cryst. Comp.	Barren Triass. Comp.	
Element	CSMRI	Geolabs		JC-1	JC-5	JC-3	JC-7	JC-4	JC-8	JC-4	JC-8				
URANIUM (U_3O_8) %	.104	.106	.095	.114	.119	.116	.139			~.21	~.14	.018	.003	.0003	.0002
ALUMINUM (Al_2O_3) %	15.8		16.5	18.8	18.9	13.47	13.50			+1	+1	+1	+1	+1	15.36
ANTIMONY (Sb)		-1		-1	-1	-5	-5	.30	-.25	.30	-.21	-.21	-.21	-.21	.2
ARSENIC (As)	-10	5	2.2	4	4	-1	-1	5.7	8.0	4.6	3.0	5.5	1.8	.69	1.8
BARIUM (Ba)		780	733	530	480	303	338			~1800	640	~1800	~1800	~1800	425
BERYLLIUM (Be)			1.97	1	1	1.5	1.5			2.1	.93	.56	12	2.1	2.8
BISMUTH (Bi)				4	4	-5	-5			.39	-.35	-.35	-.35	-.35	.2
BORON (B)	20		10	-10	-10	-5	-5			10	18	18	10	15	10
CADMIUM (Cd)			-1	2	2	-.2	-.2	1.2	1.3	.39	.23	.19	.33	.17	.2
CALCIUM (CaO) %	3.9		4.21	3.46	3.43	1.20	1.33			+1	+1	+1	+1	+1	5.08
CERIUM (Ce)				12	14					120	100	170	68	170	60
CHLORINE (Cl)				100	-100	135	85			15	42	6.3	15	13	130
CHROMIUM (Cr)			39	27	31	8	5	24	24	31	22	75	37	170	100
COBALT (Co)			15	19	20	4	4	10	11	19	2.1	8.6	3.2	7.6	25
COPPER (Cu)		8	97.1	8	9	9	9	7.0	7.0	9.4	9.4		6.6	22	55
FLUORINE (F) %	.14		.14	.17	.18	.02	.02			~.34	~.5	~.19	~.14	.045	.063
IRON (total as Fe_2O_3) %	3.7		4.35	2.19	2.33	2.97	2.97			+1	+1	+1	+1	+1	7.15
LANTHANUM (La)				10	12	300	325			140	82	82	62	140	30
LEAD (Pb)		35		35	32	40	40	40	46	85	43	24	24	36	13
MAGNESIUM (MgO) %	1.2		1.35	.907	.986	.44	.45			~.60	~.8	~.40	~.8	~.48	3.47
MANGANESE (Mn)			528	300	310	250	250			770	550	900	410	680	950
MERCURY (Hg)		.01		.04	.04	-.02	-.02	.02	.01			-.01	-.01	-.01	.08
MOLYBDENUM (Mo)	4	2	-20	13	8	1	.5	2.1	2.4	4.5	2.1	2.4	2.1	1.8	1.5
NICKEL (Ni)			8	20	18	7	7	9.5	9.2	14	3.3	14	14	24	75
PHOSPHORUS (P_2O_5) %	1.7		1.85	1.82	1.78	1.70	1.05			+1	+1	~.83	~.67	~.23	.24
SELENIUM (Se)				-.1	-.1	- 1	- 1	-.25	-.25	-.10	.13	.13	.31	1.3	.05
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VANADIUM (V)	105		102	160	160	-10	-10	120	100	450	180	250	67	220	135
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ZIRCONIUM (Zr)	200		65	140	160	-1000	-1000			830	330	110	240	420	165
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[2] Analyses of ore-grade composites previously submitted to the UAG.

[3] mass spectrographic analysis: approx. +/- 40% error.

[4] preparation of composites overseen by VDMR

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[6] total rare-earth oxides (Hazen): JC-1 = .22%; JC-5 = .28%.

TECHNICAL MEMORANDUM NO. 10

Calculation of Required Clay Volume
per 1983 Geochemistry Work

July 10, 1984

Dravo
Denver Operating Center

ENGINEERING COMPUTATIONS

EST NO.
CONT NO. 8079
DIVISION

COMPANY MARLINE URANIUM
LOCATION DANVILLE, VA
DESCRIPTION CLAY ATTENUATION

DATE 7-3-84
DR AEW CH
REF

BASED ON PYRIH'S WORK* 2.335 ℓ (0.617 gal) OF TAILINGS FLUID THRU 0.034 CF OF BANISTER R. CLAY RESULTED IN:

50% REDUCTION IN U_3O_8
>99% " " Th-230
>99% " " Ra-226

CALCULATE HOW MUCH CLAY REQUIRED <u>ASSUMING</u> CLAY WAS EXHAUSTED GEOCHEMICALLY:

TOTAL LIQUID IN TAILINGS =

$$144\ \frac{\text{GAL}}{\text{MIN}} \times 13\ \text{YRS} \times \frac{350\ \text{DAYS}}{\text{YR}}\ \underline{24 \cdot 60}$$

$$= 9.435 \times 10^8 \text{ GALLONS}.$$

$$\therefore \quad \frac{0.034 \text{ CF}}{0.617 \text{ GAL}}\ 9.435 \times 10^8 \text{ GAL} = 52 \times 10^6 \text{ CF CLAY REQ'D.}$$

OVER 191 ACRES:

$$\frac{52 \times 10^6 \text{ CF}}{191 \times 43560} = 6.\underline{25} \text{ FT. OF CLAY}$$

(NOTE: PARKER ESTIMATES $2 \times 10^6\ m^3$ OF CLAY AVAILABLE
$= 2.62 \times 10^6$ CY $= 70.\underline{63} \times 10^6$ CF)

* THIS <u>VERY</u> CONSERVATIVE ANALYSIS ASSUMES <u>NO</u> ATTENUATION AFTER PYRIH'S SHORT TIME PERIOD. IN REALITY, CLAYS WOULD HANDLE MORE FLUID.

EC-555

SHEET NO. 1 OF 1

TECHNICAL MEMORANDUM NO. 11

Supporting Data on Evaporation from Rock Fills

July 25, 1984

DRAVO ENGINEERS, INC.

Dravo Building
1250 14th Street
Denver, Colorado 80202
303 893-4500 Telex: 45-930

A Dravo Company

July 25, 1984

Mr. Richard Collins
Institute for Environmental Negotiations
University of Virginia, Campbell Hall
Charlottesville, VA 22903

Re: Geotechnical Aspects of Clay Liner and Evaporation from Rock Fills

Dear Rich:

Enclosed is a brief letter report from Curt Sealy of Chen and Associates that addresses the Rogers, Golden & Halpern concerns on clay liners raised in their June 21, 1984 memo to you.

I have also enclosed a copy of a technical paper and telephone conversation record that addresses Pat Kennedy's concerns about my estimates of evaporation from unvegetated mine overburden and waste rock. After spending considerable time searching for hard data, the Minnesota example is all I have yet to discover. That particular study monitored seepage, runoff and rainfall on waste rock dumps in a humid environment, and indicated that evaporation losses ranged from 42 to 56 percent. My estimate for the Swanson site was 47 percent.

One unknown in my analysis is the particle size distribution of the material in the rock piles. The data attached to the Minnesota report shows the size distribution for that particular study. I have also included another table from the Canada Centre for Mineral and Energy Technology (CANMET) that summarizes data from 11 open-pit mine waste sites. It appears that the material in the Minnesota Study is somewhat coarser than the waste rock piles sampled by CANMET. Based on that fact and the fact that the Minnesota climate is similar to Virginia (in terms of moisture surpluses and deficiencies), my original evaporation estimate appears reasonable.

If there are any questions on the enclosures, please contact me.

Sincerely,

Al Notary

AN:blc

Enc.

cc: E. Baker
D. Gorber
J. Halpern
J. Parker
C. Sealy
J. Yellich

Dravo
Denver Operating Center

ENGINEERING COMPUTATIONS

EST NO.
CONT NO. 8079
DIVISION

COMPANY MARLINE URANIUM
LOCATION DANVILLE, VA
DESCRIPTION PHONE CONVERSATION – KIM LAPAKKO

DATE 7/23/84
DR AGN CH
REF

SUMMARY OF PHONE CONVERSATION W/ KIM LAPAKKO, MINNESOTA DNR, DIVISION OF MINERALS, 7/23/84 :

RE: EVAPORATION FROM MINE WASTE ROCK:

① 6 YEARS OF DATA TAKEN @ MINNESOTA SITE =>
44 – 58 % OF ANNUAL PRECIP. = "RUNOFF" (ie., PERCOLATION <u>PLUS</u> SURFACE R/O)

∴ EVAPORATION = 42 – 56 % OF ANNUAL PRECIPITATION.

② PRECIP. @ SITE = 28.6"
PAN EVAP. = 28.5" ∴ LAKE EVAP. = 0.79(28.5) = 22.5"
(0.79 COEFFICIENT FROM NOAA)

∴ NET PRECIP. = 28.6 – 22.5 = 6.1"

③ PARTICLE SIZE DISTRIBUTION OF MINNESOTA WASTE MONITORED IN DNR STUDY:

PARTICLE SIZE (MM, INCHES)			% FINER THAN
305	12	COBBLES (32.3%)	89
152	6		82.2
76.2	3		67.7
25.4	1	GRAVEL (48.5%)	38.3
19.0	0.75		33.8
12.7	0.50		27.1
6.4	0.25		19.2
2.0	0.079	SAND (15.8%)	12.2
1.4	0.055		10.8
0.84	0.033		10.6
0.425	0.017		7.7
0.250	0.0098		6.1
0.149	0.0059		4.6
0.105	0.0041		3.4
0.074	0.0029	SILT (3.4%)	3.1
0.053	0.0021		1.4 – 1.7

<u>NOTE</u>: COMPARE TO ATTACHED CANMET DATA.

SHEET NO. 1 OF 2

Dravo
Denver Operating Center

ENGINEERING COMPUTATIONS

EST NO. ______
CONT NO. 8079
DIVISION ______

COMPANY MARLINE URANIUM
LOCATION DANVILLE VA
DESCRIPTION MINNESOTA EVAP. STUDY

DATE 7-23-84
DR ALN CH ______
REF ______

④ COMPARISON OF VA. & MINNESOTA :

	VIRGINIA	MINNESOTA
PRECIP. P	42"	28.6"
EVAP.	38"	22.5"
NET P.	4"	6.1"
% EVAP. FROM ROCK	47% (a)	42-56% (b)
NATURAL WATERSHED YIELD	14" (c)	10.7" (d)
% YIELD, NATURAL WATERSHED	33%	37%

(a) AS CALCULATED BY H.E.L.P. MODEL : $\frac{19.8''}{42} = 47\%$

(b) AS MEASURED BY MINNESOTA DNR OVER 6 YEARS.

(c) AS CALCULATED BY DRAVO USING HYDROGRAPH SEPERATION.

(d) AS REPORTED BY LAPAKKO.

SHEET NO. 2 OF 2

Table 2: Characteristics of waste rock

Property		Mean	Range	No.*
Particle size distribution	% <2 mm	24	10 - 78	67
	% sand	70	35 - 99	68
	% silt	24	9 - 39	57
	% clay	10	1 - 29	57
Moisture retention	0.1 bar %	15	4 - 28	42
	0.3 bar %	12	3 - 22	41
	15 bar %	5	0 - 11	41
Available water storage capacity	%	9	3 - 17	41
Bulk density	g/cm^3	2.04	1.19 - 3.02	39
Particle density	g/cm^3	2.73	2.05 - 3.06	25
pH	water	7.7	3.5 - 9.4	80
Cation exchange capacity	meq/100 g	11.4	0.3 - 32.4	80
Organic matter	%	2.5	0.1 - 19.5	69
Electrical conductivity	mmhos/cm	0.9	0.3 - 3.5	47
Available elements	P ppm	4.4	0 - 33.4	80
	K ppm	85	4 - 193	69
	Ca ppm	14,900	1540 - 45,500	69
	Mg ppm	260	15 - 1186	69
Total analysis	N %	0.01	0 - 0.12	76
	S %	0.04	0 - 0.15	38
	Fe %	7	1 - 50	24
	Al %	6.2	0.1 - 13.2	26
	Mn %	0.12	0.01 - 0.32	26
	K %	1.09	0.01 - 2.97	19
	Na %	1.29	0.01 - 2.75	27
	Mg %	4.3	0.01 - 36	27
	Ca %	4.5	0.01 - 35	27
	Cd ppm	175	1 - 620	27
	Zn ppm	15	2 - 30	18
	Ti ppm	8500	500 - 50,000	18
	Ni ppm	85	20 - 250	13
	Mo ppm	136	10 - 450	10
	Co ppm	150	10 - 300	10

* Number of observations from 11 mine waste sites

SOURCE: PIT SLOPE MANUAL, SUPPLEMENT 10-1, VOL.1 - MINE WASTE DESCRIPTION AND CASE HISTORIES, P. 15, CANMET, 1977.

Dravo
Denver Operating Center

ENGINEERING COMPUTATIONS

EST NO.
CONT NO. 8079
DIVISION

COMPANY MARLINE URANIUM
LOCATION
DESCRIPTION

DATE 7/23/84
DR CH
REF

SUMMARY OF MINNESOTA DNR STUDY:

PURPOSE : QUANTITY & QUALITY OF LEACHATE FROM MINE WASTE ROCK PILES, & EFFECTS OF VARIOUS RECLAMATION TECHNIQUES.

RELEVANCE TO SWANSON PROJECT : PROVIDES INDICATION OF HOW MUCH OF ANNUAL RAINFALL IS LOST DUE TO EVAPORATION FROM UNVEGETATED ROCK PILES IN A HUMID ENVIRONMENT.

CONCLUSION : H.E.L.P. MODEL EVAPORATION ESTIMATE IS REASONABLE, ESPECIALLY WHEN ONE CONSIDERS THE COOLER TEMPERATURES & GREATER NET PRECIP. OF MINNESOTA.

SHEET NO. 1 OF 1

Symposium on Surface Mining Hydrology, Sedimentology and Reclamation
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THE LEACHING AND RECLAMATION OF LOW GRADE MINERALIZED STOCKPILES

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NOTE: "RUNOFF" IN THIS PAPER REFERS TO PERCOLATION + SURFACE R/O.

SEE PG. 161 FOR SUMMARY OF FLOW VALUES THRU PILES. ALSO, FIG. 8, PG. 162.

Abstract. The leaching behavior of test stockpiles containing metal sulfides, and the effects of revegetation on the quality and quantity of leachate generated, have been studied since 1978. Six small (1600-2100 mt) stockpiles were constructed, ranging in composition from 0.30% to 0.35% copper, 0.083% to 0.85% nickel, and 0.63% to 1.41% sulfur. In 1978, topsoil was added to one pile, and two additional piles were covered with coarse sand. In 1980, sandy till was added to one of the piles originally covered with coarse sand. All soil covered piles were fertilized and seeded. Concentrations of trace metals (copper, nickel, cobalt, zinc), calcium, sodium, and sulfate in the leachates were 20 to 200,000 times ambient background levels. Leachate pH decreased with time and with increasing percent sulfur, causing an increase in trace metal concentrations. None of the reclamation treatments have yet been successful in improving leachate quality, but reductions in runoff coefficients and sulfate release rates have occurred. The runoff coefficients for the piles covered with topsoil and sandy till were 24-60% lower than untreated controls, and sulfate release rates were 30-66% lower.

Introduction

Northeastern Minnesota contains an estimated 25% of the United States' copper resource and also the nation's largest nickel sulfide resource.[1,2] These metal sulfides are found in several large, low-grade sulfide deposits along the contact between the Duluth Gabbro intrusive and the underlying metamorphosed sedimentary rocks (Figure 1). The major sulfide minerals present in the gabbro are pyrrhotite, chalcopyrite, cubanite and pentlandite, but the large majority (87%) of the rock is composed of silicate minerals (Table 1). Although underground operations would be required to recover two thirds of the resource[3], conceptual models[4,5] of potential mining operations indicate that large open pits (100,000 mtpd) would also be required due to the low grade disseminated nature of the ore bodies. Based on these models, the projected mass of waste rock and lean ore would range from 6.5×10^8 to over 10^9 mt, and would require a storage area estimated as 1000 to 2500 acres. Previous research[6,7] indicates that stockpiles and tailings basins associated with sulfide mining can produce acidic runoff with trace metal concentrations toxic to aquatic organisms.[8]

As a result, the Minnesota Department of Natural Resources and AMAX Environmental Services, Inc. began a cooperative research program in 1978. The program was designed to investigate the leaching potential of the gabbro and evaluate methods of stockpile reclamation. The specific objectives of the study were to:

1.) examine metal sulfide oxidation, acid production, and trace metal release characteristics of stockpiled gabbro,
2.) develop methods for establishing vegetation on test stockpiles, and
3.) evaluate the effects of reclamation activities on leachate quality and quantity.

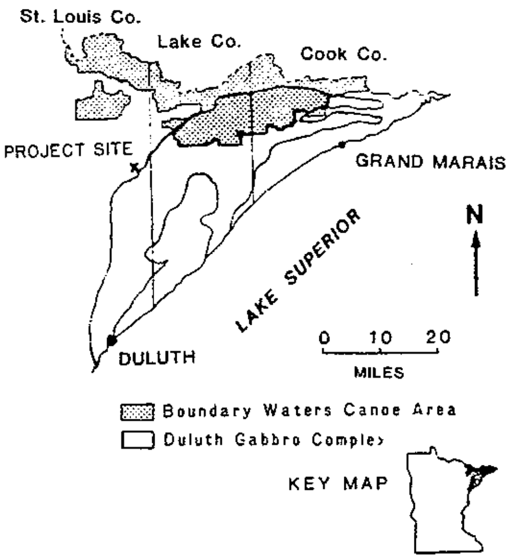


Figure 1. Minnesota Copper-nickel area minnamax project site.

Table 1. MINERALOGICAL COMPOSITION[1]

		Vol. %
Plagioclase	$NaAlSi_3O_8$ - $CaAl_2Si_2O_8$	59.1
Olivine	$(Fe,Mg)SiO_4$	10.5
Clinopyroxene	$Ca(Fe,Mg)Si_2O_6$	11.2
Orthopyroxene	$(Fe,Mg)_2Si_2O_6$	3.7
Other Silicates[2]		10.4
Non-silicates[3]		3.6
Chalcopyrite	$CuFeS$	.77
Cubanite	$CuFe_2S_3$	
Pentlandite	$(Fe,Ni)_9S_8$	.04
Pyrrhotite	Fe_7S_8 - FeS	.84

[1] Sample from Pile 1.
[2] Includes minor amounts of amphibole, serpentine, chlorite, iddingsite, sericite, biotite, smectite, epidote, and cordierite.
[3] Includes minor amounts of ilmenite, apatite, and calcite.

This paper will focus on the leaching characteristics of stockpiled gabbro and the effects of reclamation on leachate quality and quantity.

Metal sulfides are not thermodynamically stable when exposed to an oxidizing environment such as that which exists in waste rock stockpiles, mine walls, and tailings basins.[9,10-13] In such an environment sulfide is oxidized to sulfate and trace metals (Fe, Cu, Ni, Co, Zn) are released from the highly insoluble metal sulfide form.[9,11,12,14] The rate of mineral sulfide oxidation is proportional to the available sulfide surface area[11,12,15] and oxygen concentration,[14,15,17] with only a slight dependence on pH.[14,18]

The appearance of a given component in solution is the net result of release to solution by dissolution and removal from solution by precipitation, coprecipitation, exchange reactions, and adsorption. Sulfate, calcium, and magnesium are mobile in most aqueous systems[14-21] and, therefore, the rate of their appearance in solution equals the rate of release from the solid phase. The trace metals have a greater tendency to participate in reactions which may result in their removal from solution. They may precipitate as hydroxides, carbonates, or oxides,[14,19,21,22] coprecipitate with other solids such as iron oxides,[23,24] or be removed by exchange reactions with metal sulfides of greater solubility.[25] Trace metals may also be adsorbed onto solid silicates,[20,26-29] metal sulfides,[30] iron oxides,[19,20,31,32] manganese oxides,[25,26,33] and titanium oxides.[26,27] The rate of appearance of these metals in solution may not equal the rate at which they are released from the mineral phase since removal from solution may occur concurrently with mineral dissolution.

Reclamation treatments have been designed to restrict the access of oxygen and water to metal sulfides present in coal refuse piles and abandoned coal mines.[34,35] Physical barriers, such as plastic films and concrete, and surface sealants, including lime, gypsum, sodium silicate, and latex were marginally effective treatment techniques.[34] The most effective and widely used technique has been the use of a vegetated soil cover.[34] Treatments typically include physical modifications of the waste disposal area, lime application, soil addition (preferably clay), and revegetation.[36,37] Treatments of this type have increased surface runoff, and reduced acid release by as much as 91%.[36]

Note: Lake evap. = ~22-24" (NOAA)

Climatic setting

28.4"

Annual precipitation in the study area averages 72.1 cm,[38] and the average watershed runoff is 26.2 cm/yr.[39] Temperatures are extreme, averaging -14°C in January and 19.1°C in July, with an annual mean of 3.6°C. The ground is covered with snow for an average of 140 days per year.

10.3"

Materials and Methods

Pile construction

Six test stockpiles containing 1600 to 2100 metric tons of low-grade copper-nickel material were constructed in 1977 (Figure 2). The compositional ranges for the piles were 0.30-0.35% Cu, 0.083-0.085% Ni, and 0.63-1.41% S (Table 2).

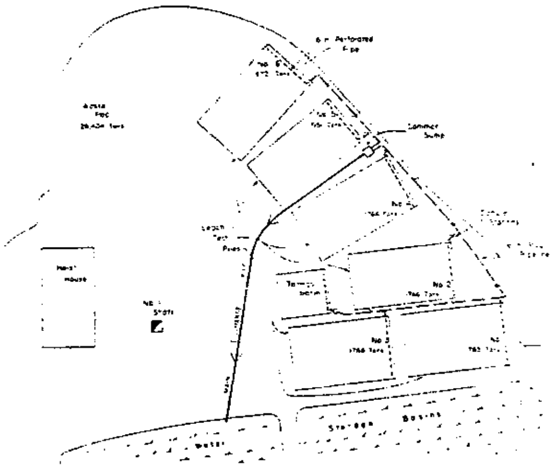


Figure 2. Leachate collection system.

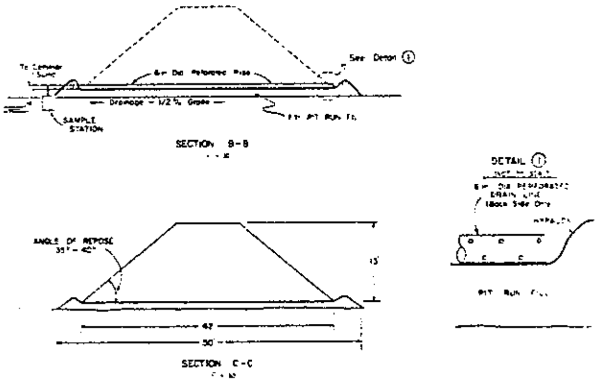


Figure 3. Leachate collection sampler attachment on individual leach piles.

Table 2. CHARACTERIZATION DATA FOR STOCKPILES

	Pile 1	Pile 2	Pile 3	Pile 4	Pile 5	Pile 6
Composition						
% S	.63	.63	.63	.63	1.41	.79
% Cu	.35	.35	.35	.35	.30	.34
% Ni	.083	.083	.083	.083	.085	.084
Mass metric tons	1622	1622	1622	1622	2155	1566
Collecting Area m^2	295	342	295	327	339	320
Date Constructed	(----------April 20, 1977----------)				September 10, 1977	September 30, 1977
Reclamation	None	Topsoil (18 cm)	Coarse Sand (29 cm)	None	Sandy till (30 cm) over coarse sand(28 cm)	None

Piles 1-4 were constructed of rock mined during the shaft sinking operation, while piles 5 and 6 contain material from underground drifts. For runoff collection each pile is underlain by an impervious hypalon liner (30 mil) which is sloped toward a 15.2 cm perforated plastic pipe (Figure 3). The runoff collected flows to a common sump and is subsequently pumped to settling basins (Figure 2).

Revegetation

The variables in the revegetation study included soil type, seed mixes, and seeding rate. Three of the piles were left uncovered, as controls, and the remaining three piles were covered (May 1978) with 18-29 cm of soil obtained from a nearby borrow pit (Table 2). Pile 2 was covered with fertile topsoil obtained from the top 30 cm of the borrow pit, while piles 3 and 5 were covered by infertile coarse sand. In 1980 an additional 30 cm of sandy till was added to pile 5.

In June of 1978, all covered piles were fertilized with 10-20-30 fertilizer (392 kg/ha), broadcast seeded, and mulched with straw (3.4 mt/ha). Minnesota Highway #5, United States Forest Service wildlife mix, and native seed mixes were applied at rates of 34 and 67 kg/ha. In 1979, an additional plot containing jack pine, red pine, trembling aspen, and an upland willow was established on each of the covered piles. Additional seed was also applied to piles 3 and 5. When the sandy till was applied to pile 5 in 1980, the entire pile was reseeded with a mixture of alfalfa, U.S. Forest Service wildlife mix, and sweet clover at rates of 45, 67, and 113 kg/ha, respectively. A 13-12-12 fertilizer (730 kg/ha) was added to piles 2,3, and 5 at this time. The degree of vegetation was quantified as kg organic matter/ha (1978, 1979) or percent cover, as determined by a ten point sampler (1979, 1980).

Water sampling procedure

During 1978, each pile was fitted with a cumulative flow meter, event recorder, and a flow weighted composite sampler (Figure 4). Each time pump discharge occurred a fixed volume of sample was placed into the compositing container and the discharge registered on a Rustrak event recorder (Model 292-4). The samples from either a rain event or extended base flow period were filtered through 0.45 micron filters to remove suspended materials prior to analysis. Volumes of input precipitation were measured with a standard rain gauge (Science Associates, Inc. NWS Spec. 450.230); time and duration of rain events were obtained using a recording rain gauge (Science Associates, Inc., NWS Spec. 450.220).

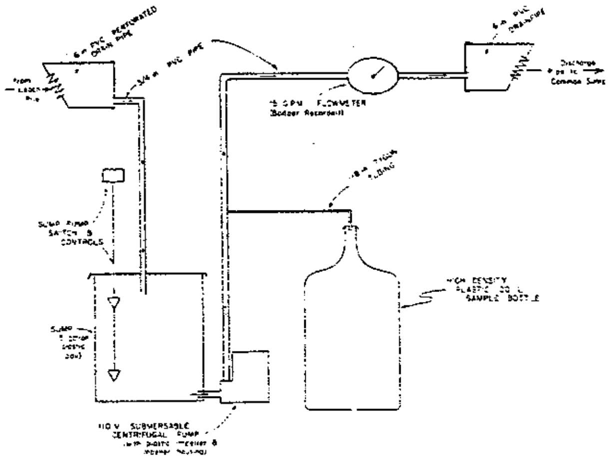


Figure 4. Flow proportional sampler.

Results

Leachate quality

Concentrations of trace metals (Cu, Ni, Co, Zn) calcium, sodium, and sulfate in runoff from test stockpiles were 20 to 200,000 times ambient background levels (Table 3). Nickel comprised 70 to 83% of the total trace metal concentration, and sulfate contributed greater than 90% of the anion concentration. For 1977-80, the median pH was greater than 7.0 for pile 1 through 4, 5.42 for pile 6, and 3.50 for pile 5.

This paper will focus on leachate pH and the release of sulfate and nickel. Leachate pH is an indicator of acid production, sulfate provides a measure of the rate of sulfide oxidation, and nickel is used to represent trace metal behavior. Results for the other trace metals are similar to those for

Table 3. Water Quality Summary, Median Values, 1977-80

Parameter[3]	Pile 1 (Control)	Pile 2[1] (topsoil cover)	Pile 3[1] (Coarse sand cover)	Pile 4 (Control)	Pile 5[2] (Sandy till over coarse sand)	Pile 6 (Control)	Ambient water quality for streams in the area[4]
pH	7.40	7.20	7.05	7.20	3.50	5.42	6.8 - 7.0
Alkalinity	31.2	21.0	13.4	19.0	0.	2.4	15. - 25.
Specific conductance	1774	1538	1532	1276	3251	3364	60.
Copper	.030	.110	.106	.026	33.0	1.8	.001-.0015
Nickel	.370	.365	.960	.320	138.0	9.0	.001
Cobalt	.021	.022	.060	.027	10.0	.590	----
Zinc	.030	.060	.110	.085	4.56	.321	.001
Sulfate	1045	680	721	711	2350	1650	5.-10.
Iron	.021	.040	.030	.020	6.78	.052	.55
Manganese	.099	.142	.163	.160	12.0	3.40	----
Chloride	4.08	15.0	11.9	4.9	13.1	99.0	3.-5.
Calcium	260	170	160	186	312	327	6.-8.
Magnesium	23.0	22.8	36.8	18.4	125.	130.	3.-6.
Sodium	95.0	92.0	68.0	67.0	152.	200.	1.5
Potassium	25.6	20.0	24.4	35.0	17.0	6.8	----
Number of Samples	89	80	82	71	85	80	

[1] Soil cover applied 1978; [2] Coarse sand applied 1978, sandy till applied 1980; [3] All metal values are for samples filtered through a .45 micron filter, mg/l; [4] Metal values are for unfiltered samples.

nickel.[40]

Although the percentage of copper (0.30-35%) and nickel (0.085-0.085%) were essentially equal in all six test piles, the percent sulfur ranged from 0.63 to 1.41% (Table 2). The variation in sulfur concentration was due to varying amounts of iron sulfide, predominantly pyrrhotite.

As the percentage of sulfur increased, the median pH in the leachate decreased (Figure 5). During the period 1978-80, the median pH of test pile runoff decreased consistently, the largest decreases occurring for piles in which the sulfur exceeded 0.63%.

Median sulfate and nickel concentrations in test pile runoff generally increased with percent sulfur, with ranges of 530-4200 mg/l and 0.17-260 mg/l (Figures 6,7).

Effect of treatment. From 1978 to 1980, the median pH of runoff from piles of similar composition (piles 1-4) ranged from 6.76 - 7.80, and the ranges for median sulfate and nickel concentrations were 530-1180 mg/l and 0.23 - 2.2 mg/l. There was no apparent improvement in leachate quality as a result of treatment. Concentrations of sulfate and nickel in the leachate from the topsoil covered pile did not decrease over time. Over the period 1978-1980 sulfate and nickel concentrations continually increased in leachate from the pile covered by coarse sand. In 1980, sandy till was added to pile 5, which was initially covered by coarse sand, but pH did not change and median concentrations of sulfate and nickel increased.

Although sulfate and nickel concentrations from the topsoil covered pile increased from 1979 to 1980, the magnitude of the increase was less than that from other piles (5% vs 41-97%). As a result, median concentrations of sulfate and nickel in leachate from this pile were the lowest observed in 1980.

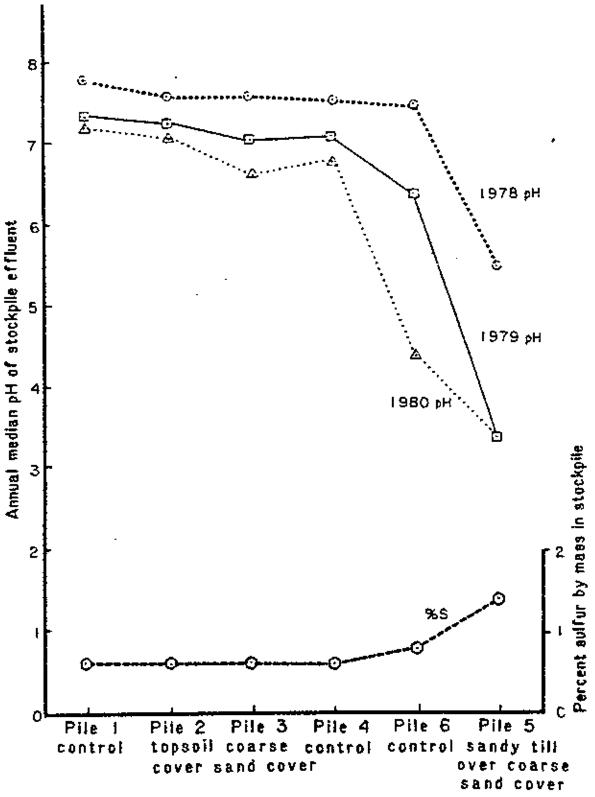


Figure 5. Annual median pH of stockpile effluent, and percent sulfur in stockpiles, 1978-1980.

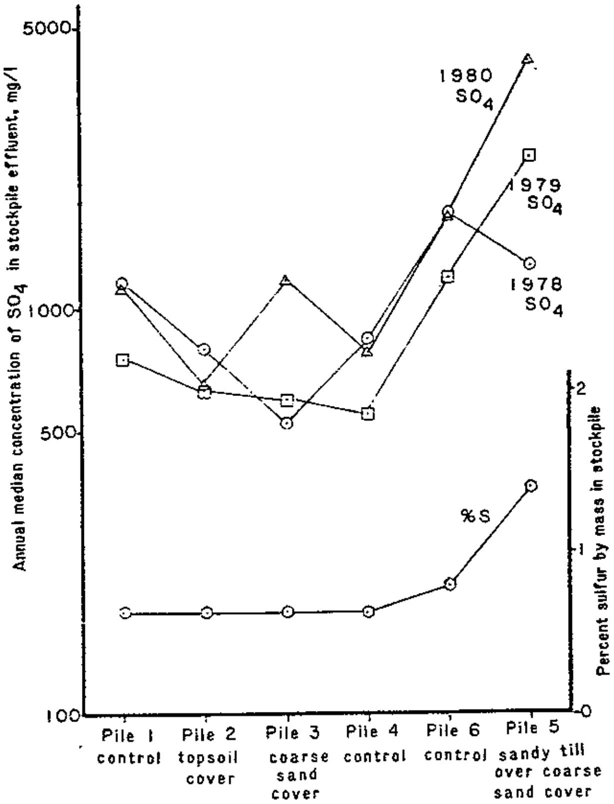


Figure 6. Annual median SO_4 concentration of stockpile effluent, and percent sulfur in stockpiles, 1978-80.

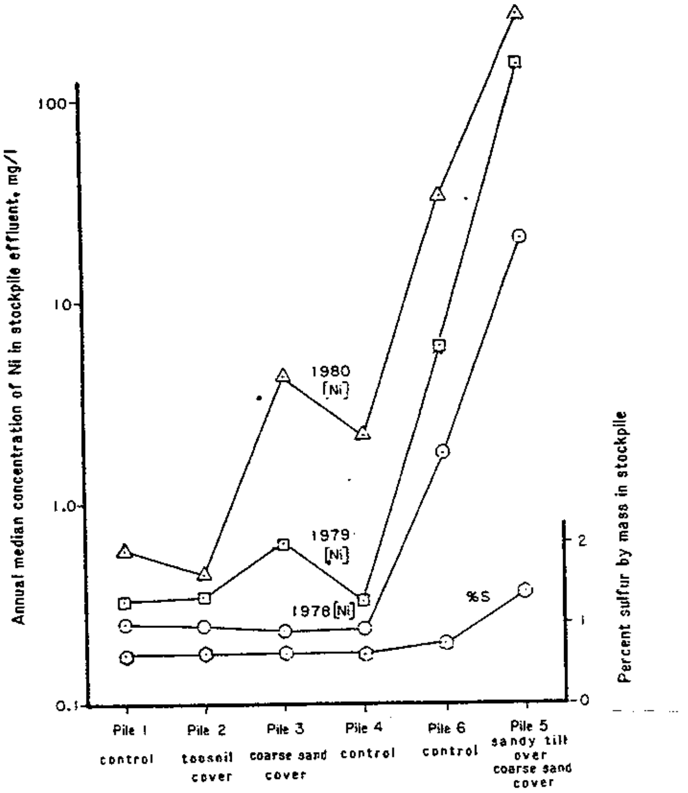


Figure 7. Annual median Ni concentration of stockpile effluent, and percent sulfur in stockpiles, 1978-80.

Flow

The effectiveness of topsoil, sandy till and coarse sand for reducing flow from test piles was evaluated by determining runoff coefficients for the various piles. The runoff coefficient r, is the ratio of runoff to precipitation input:

$$r_{ij} = \frac{V_{ij}}{P_j \times A_i} \qquad (1)$$

where r_{ij} = runoff coefficient for pile i, year j

V_{ij} = total volume of outflow from pile i for year j, measured from spring melt to freeze up, liters

P_j = total precipitation (snow and rain) that fell after flow stopped the preceding year, j-1, until flow freezes in year j, cm

A_i = collecting area of pile i, m^2

Precipitation in 1978 was within 2 cm of the annual average for the study area, but was 6% lower in 1979 and 17% lower in 1980.

Over this period, runoff coefficients also decreased continually for both the test piles and the natural watersheds in the area (Figure 8).

The runoff coefficients for the untreated piles (1,6) were 1-2 times those for natural watersheds.

The topsoil cover and the sandy till were effective in reducing the flow from the test piles (Figure 8). Runoff coefficients for the topsoil covered pile (pile 2) were the lowest of all the piles, ranging from 24-50% less than the untreated control (pile 1). When sandy till was applied to pile 5 in 1980, the runoff coefficient decreased by 65%. The coarse sand cover was not effective in reducing runoff, the runoff coefficient being within 10% of the untreated control (pile 1).

In 1979, pile 4 produced very little base flow, indicating that a leak may have developed in the impermeable liner underlying the pile. Flow and mass release for this pile may be underestimated and will not be discussed.

Mass release

The objective of the reclamation treatment was to reduce mass release, which was calculated for each pile by combining the concentrations of flow weighted samples with flow data.

$$M_{ij} = C_{ij}\, Q_j \qquad (2)$$

where M_{ij} = total mass of i released during time period j, in milligrams

C_{ij} = flow weighted concentration of parameter i, during time j, in mg/l

Q_j = total flow from the pile during time j, liters

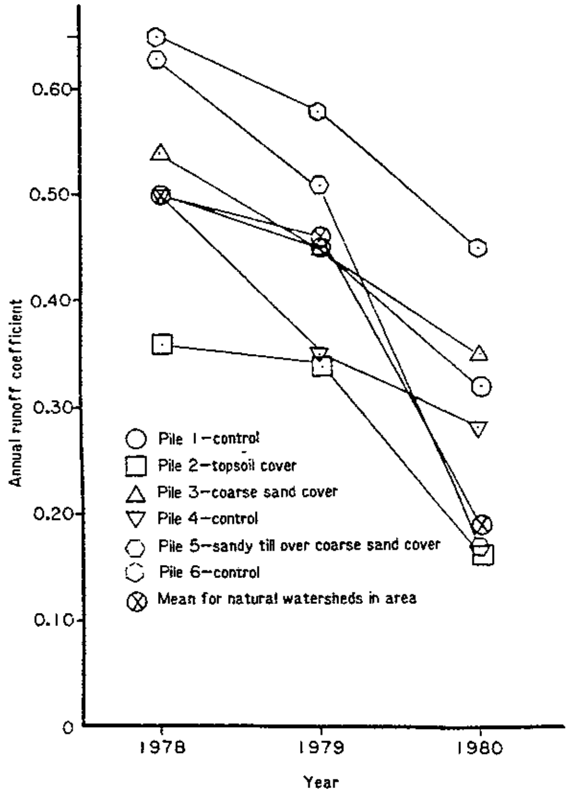


Figure 8. Annual runoff coefficient of stockpiles and natural watersheds, 1978-80.

The mass release rate was calculated from either

$$R_i = \frac{\sum_{i=1}^{n} C_{ij} Q_j}{W \quad (t_f - t_m)} \tag{3}$$

where R_i = mass release rate, mg/metric ton day

W = total mass of test pile, metric ton

t_f = date flow freezes in the fall

t_m = date flow begins in the spring

or

$$R_i = \frac{\sum_{j=1}^{n} C_{ij} Q_j}{W_i \quad (t_f - t_m)} \tag{4}$$

where W_i = total mass of component i in the test pile, metric ton

Effect of composition. The rates of sulfate and nickel release (mg release per metric ton of stockpile per day) tended to increase as the percent sulfur in the test pile increased (Figures 9, 10). For any given year, sulfate release rates for piles 5 and 6 (1.41 and 0.79% S) were 1.2-3 times the maximum rate observed for piles 1-4 (0.63% S). Maximum sulfate release rates occured in 1978 for piles 1,2,3,4, and 6 and in 1979 for pile 5. Nickel release rates increased as the percentage of sulfur in the test pile increased (Figure 10), ranging from 100 to 10,000 mg Ni/mt day.

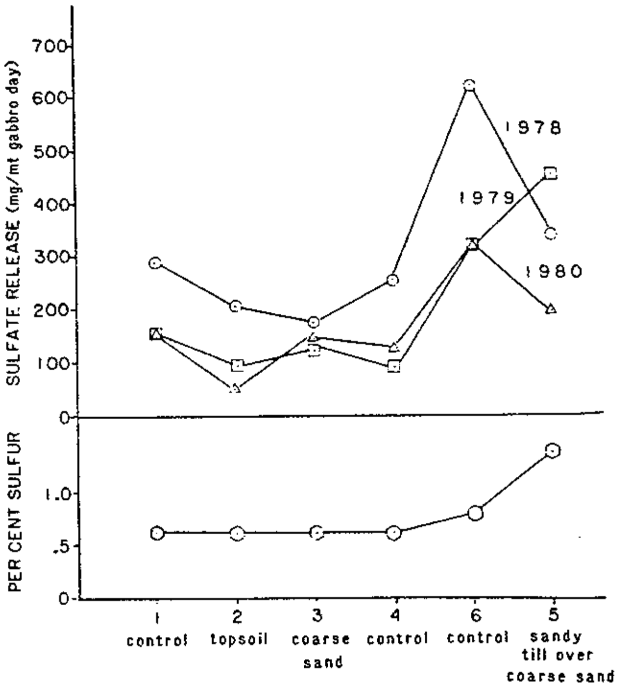


Figure 9. Rate of sulfate release, 1978-80.

Effect of treatment. The coarse sand cover did not reduce sulfate or nickel release rates. Sulfate rates increased from 1978 to 1979 in pile 5 and from 1979 to 1980 for pile 3. Nickel rates increased each year, and pile 3 had the highest nickel release of the piles containing 0.63% S.

The addition of a layer of sandy till over the coarse sand on pile 5 in 1980 produced a 57%

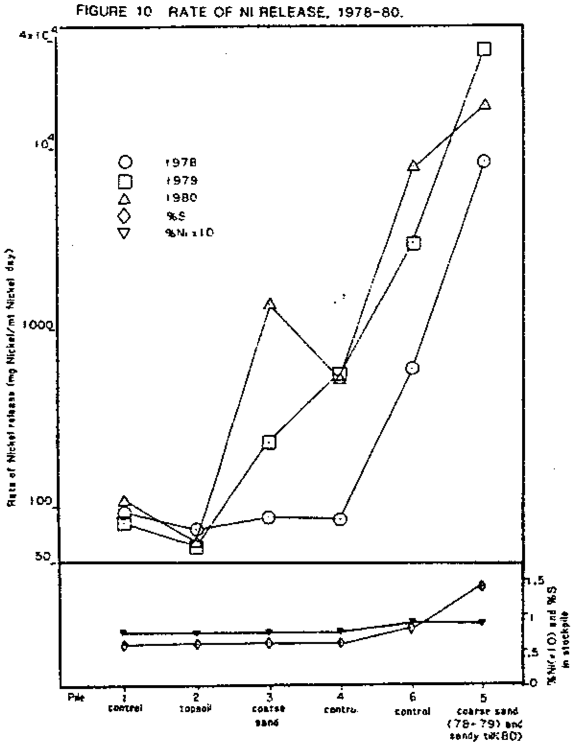


Figure 10. Rate of Ni release, 1978-80.

reduction in the sulfate release rate and a 51% reduction in the nickel release rate.

Sulfate release rates have declined 30-40% per year in the pile with the topsoil cover and in 1980 this pile had the lowest release rate. The nickel release rate from this pile was the lowest observed and remained relatively constant over the three year period (60-75 mg Ni/mt day).

Discussion

The release of sulfate, trace metals, and acid from stockpiles is a two step process involving the the oxidation of sulfide minerals and the subsequent transport of reaction products from the reaction site. The release of chemical components can be either reaction or transport limited.

Metal sulfides are not thermodynamically stable in the presence of oxygen and oxidize to release trace metals and sulfate,

$$MeS + 2O_2 = Me^{2+} + SO_4^{=} \qquad (5)$$

The rate of oxidation has been reported as first order with respect to sulfide surface area and oxygen concentration. The release of iron from sulfide minerals leads to the formation of lepidocrocite[14,22] and the generation of acid.

$$2Fe(s) + 3H_2O + 9/2\ O_2 = FeOOH(s) + 4H^+ + 2SO_4^{=} \qquad (6)$$

The acid that is generated can be consumed by the dissolution of the silicate minerals[45] present in the Duluth gabbro.

$$CaAl_2Si_2O_8(s) + 2H^+ + H_2O = Ca^{2+} + Al_2Si_2O_5(OH)_4(s) \qquad (7)$$

The balance between the rates of acid generation and acid consumption determines the solution pH.

The transport of the released components is controlled by the amount of water percolating through the stockpile, solution pH, the chemical character and surface area of solid surfaces present, and the chemistry of the released component. Sulfate is mobile in most aqueous systems, while trace metals can be removed from solution through precipitation or adsorption onto solid surfaces.

The reported first order dependence of the metal sulfide oxidation rate on surface area suggests that aqueous concentration of sulfate would increase with increasing percent sulfur of the stockpiled material. For piles of similar size distribution the sulfide surface area would be directly proportional to the percent sulfur of the pile. Therefore, the sulfide oxidation rate would be directly proportional to the percent sulfur, assuming that other variables on which the sulfide oxidation rate depends (e.g. oxygen concentration, temperature) do not vary greatly among the piles. The rate of acid production would also increase with increasing percent sulfur, since the variation in percent sulfur is largely due to variation in iron sulfide content. The leachate pH would depend on the balance of the rates of acid production (equation (6)) and acid consumption (equation (7)). The observed sulfate concentrations and pH are generally consistent with these hypotheses.

The median leachate pH decreased with increasing percent sulfur in all years, remaining near 7.0 for piles containing 0.63%, but becoming acidic for the piles with sulfur contents of 0.79% and 1.41%. To prevent the formation of acid leachate, the rate of silicate dissolution must exceed the rate of sulfide oxidation. The silicate dissolution rate was greater than the oxidation rate at 0.63% S, but was less than the oxidation rate at 0.79% S. A critical sulfur concentration may exist in the range of 0.63-0.79% S, such that material exceeding this critical concentration will produce acidic leachate. pH has also declined in piles with 0.63% S, and it is possible that the buffering capacity of these piles may eventually be exceeded. The dissolution of fine silicate particles may initially contribute to a faster rate of buffering, the rate decreasing as these particles dissolve.[42]

Although the percent nickel was virtually constant for all piles, nickel concentrations in the leachate increased with increasing sulfur content of the test piles. The increase in nickel concentrations was a result of the decreasing pH, a trend also observed for piles 3 and 4 (Figure 5). The observed variation of median annual nickel concentration with pH was expressed as:

$$\log\ [Ni] = -0.67\ pH + 4.65 \qquad (8)$$

$$r^2 = 0.92,\ n=18$$

The increase in nickel concentrations was the result of increasing nickel transport rather than increased dissolution, since there was no correlation between the sulfide oxidation rate, as measured by the sulfate rate of release rate, and pH (r^2=0.01, n=18). Transport would tend to increase with decreasing pH since the effectiveness of trace metal removal reactions (e.g. precipitation, adsorption) decreases.

The 1980 sulfate and nickel concentrations in leachate from the pile covered by topsoil were 43% and 20% lower than those in the control pile leachate, but no improvement in leachate quality was produced by the other covers. Effect of vegetation on leachate quality should initially occur at the pile with the topsoil cover, where revegetation has been most successful. The percent vegetative cover on the topsoil was 40-80% greater than on the coarse sand (Table 4).

A revegetated soil cover should reduce the oxygen content within the test pile, by providing a physical barrier to oxygen transport and creating an oxygen demand through respiration and decay processes. As the oxygen concentration decreases, the rate of sulfide oxidation (equations (5), (6)) will also decrease, consequently reducing sulfate and trace metal concentrations in the leachate. Additional data will be required to determine if an actual trend toward improved leachate quality exists.

Although coarse sand alone was ineffective, both the topsoil and sandy till over coarse sand were effective in reducing the quantity of leachate generated. The sandy till placed over the coarse sand and the topsoil reduced runoff coefficients by 24-60%. Soil cover alone can reduce infiltration

Table 4. Vegetation Results, Biomass, 1978, 79 and Percent Cover, 1979,80.

	Pile 2 Topsoil	Pile 3 Coarse sand	Pile 5 Coarse sand	n
1978 Vegetation Mean Biomass[1] (grams D.W/.065M^2	14.13	3.74	3.76	80
1979 Vegetation Mean Biomass	6.51	1.88	2.18	80
1979 Vegetation Mean % Cover[2]	47.0	26.0	25.5	80
1980 Vegetation Mean % Cover	55.5	40.5	Sandy till added	80

[1] Biomass figures are means in grams dry weight/.065M^2.

[2] Vegetation cover is % of ground surface as measured by 10-pt. sampler.

by providing a zone of moisture storage and may divert water away from the stockpile by enhancing surface runoff. Some rills and gullies were observed on the sandy till, but no evidence of surface runoff was observed on other piles, suggesting that evapotranspiration was the major factor in flow reduction. Assuming an evapotranspiration loss of 600 kg water per kg dry organic matter,[43] the vegetation on the topsoil pile could have reduced flow by 52,000 liters in 1978 and 24,000 liters in 1979. The observed reductions in comparison to an untreated control (pile 1) were 29,000 and 17,000 liters. The major flow reduction occurred from June 1 to September 30 which includes the major period of evapotranspiration in the study area.[40]

Mass Release

Mass release combines leachate quality and quantity and is an indicator of the overall success of the reclamation treatment.

Sulfate release rates for the topsoil covered pile were 30 to 66% lower than the untreated control (pile 1). For the control, sulfate release decreased from 1978 to 1979, but no further reduction occurred in 1980 (Figure 9). For the topsoil covered pile (pile 2), a consistent decrease has been measured. In 1980, sulfate concentration increased 41% for pile 1 but only 5% for pile 2, which may suggest a slight inhibition of the sulfide oxidation rate. Runoff coefficients for both piles decreased in 1980, but the decrease in pile 2 was 25% greater than in pile 1. The combination of a large flow reduction and only a slight concentration increase contributed to the lower sulfate release (Table 5). No comparable reduction in sulfate release rate has been obtained with the coarse sand cover (pile 3), the 1980 rate being within 5% of the rate for the control (pile 1) (Table 5).

After the addition of sandy till to pile 5 in 1980, the sulfate release rate was 57% less than in 1979, while release rates for untreated controls remained constant. Since the median sulfate concentration increased by 75% over this time period, the reduction in mass release was the result of a reduction in flow.

Nickel release rates increased with percent sulfur, due to an increase in metal transport as pH decreased. Nickel release rates can be expressed as a function of pH by:

$$\log R_{Ni} = -.60 \text{ pH} + 6.65 \qquad (9)$$

$$r^2 = .82, n=18$$

The lowest nickel release rates have been measured in the pile with the topsoil cover (pile 2), with

Table 5. The Effect of Soil Cover on Sulfate Release Rate, 1978-1980

Pile Treatment	1 Control	2 Topsoil	3 Coarse sand	6 Control	5 Sandy till over coarse sand
% Sulfur	0.63	0.63	0.63	0.79	1.41
Runoff Coefficient					
1978	0.50	0.36	0.54	0.65	0.63
1979	0.45	0.34	0.45	0.58	0.51
1980	0.32	0.16	0.35	0.45	0.18
Sulfate Median Concentration (mg/l)					
1978	1180	800	530	1700	1300
1979	760	630	600	1200	2400
1980	1130	660	1180	1700	4200
Release Rate (mg/mt day)					
1978	291	205	175	626	343
1979	156	94	123	326	457
1980	155	53	149	327	198

rates ranging from 21 to 42% less than the untreated control (pile 1).

The addition of sandy till to pile 5 reduced the nickel release rate by 51%. The decrease in rate was the result of the reduction in flow, since the median concentration increased by a factor of 2.4 from 1979 to 1980. Over the same time period, nickel release rates for the untreated controls (piles 1,6) increased 24 and 165% respectively.

Summary and Conclusions

1. Trace metal concentrations in leachate from test piles containing low grade sulfide mineralization exceed natural ambient levels by as much as five orders of magnitude.
2. As the percentage of sulfur in the test piles increases, pH of the leachate decreases, while trace metal and sulfate concentrations increase.
3. The sulfide composition of the test pile has a greater effect on the leachate quality than the reclamation treatment.
4. Covering test piles with topsoil (18 cm) reduced the runoff coefficient by 24-50%.
5. Covering test piles with sandy till (30 cm) over sand (28 cm) reduced the runoff coefficient by 60% in 1980.
6. The reduction in flow by the topsoil and sandy till over coarse sand covers has reduced the rates of sulfate and nickel release.

Continuing Research

Leachate flow and quality will continue to be monitored to determine if the trends toward lower release rates and improved leachate quality continue.

Alkaline sewage sludge mixed with wood chips has been added to the pile with the coarse sand cover (pile 3). The objectives of this treatment are to raise leachate pH, decrease metal mobility, and provide increased water retention and nutrients to the sandy soil.

Acknowledgements

This research has been supported in part by the Minnesota Iron Range Resources and Rehabilitation Board, the Legislative Committee on Minnesota's Resources and AMAX Exploration Inc. This is a joint research program with AMAX, who have the major responsibility for the revegetation aspects of the project. The vegetation data and other much appreciated assistance has been provided by James Sturgess and Tom Hargy of AMAX; water quality and flow data have been collected by Ann Weir of the Department of Natural Resources; and chemical analyses have been provided by the DNR laboratory in Hibbing, under the supervision of Al Klaysmat, and Serco Laboratories in Roseville.

REFERENCES

1. Minnesota Environmental Quality Board. 1980. Regional copper-nickel study, executive summary, V.1. Minnesota State Planning Agency, St. Paul, Minnesota.
2. Kingston, G.A., Carillo, F.V., Gray, J.J., McIlroy, P. 1970. Availability of U.S. primary nickel resources. Information circular 8469, U.S. Bureau of Mines.
3. Listerud, W.H., Meineke, D.G. 1977. Mineral resources of a portion of the Duluth complex adjacent rocks in St. Louis and Lake counties in northeastern Minnesota. Minnesota Department of Natural Resources, Division of Minerals, St. Paul, Minnesota.
4. Veith, D.L. 1978. Minnesota copper-nickel resource processing model. Report by the Regional Copper-Nickel Study, Minnesota Environmental Quality Board.
5. Sturgess, J. 1981. Personal communication. Minnamax, Babbitt, Minnesota.
6. Hawley, J.R. 1972. The problem of acid mine drainage in the Province of Ontario. Ministry of the Environment, Toronto, Canada.
7. Wentz, D.A. 1974. Effect of Mine Drainage on the quality of streams in Colorado, 1971-72. Colorado Water Resources Circular, No. 21.
8. United States Environmental Protection Agency. 1976. Quality criteria for water. U.S. Environmental Protection Agency, Washington, D.C.
9. Garrels, R.M., Christ, C.L. 1965. Solutions, minerals, and equilibria. Freeman, Cooper and Company, San Francisco, California.
10. Nickel, E.H., Ross, J.R., Thornber, M.R. 1974. The supergene alteration of pyrrhotite-pentlandite ore and Kambalda, Western Australia, Econ. Geol. 69. pp. 93-107.
11. Sato, M. 1960a. Oxidation of sulfide ore bodies, I. Geochemical environments in terms of Eh and pH. Econ. Geol. 55. pp. 928-61.
12. _____. 1960b. Oxidation of sulfide ore bodies, II. Oxidation mechanisms of sulfide minerals at 25°C. Econ. Geol. 55. pp.1202-31.
13. Sato, M., Mooney, H.M. 1960. The electrochemical mechanism of sulfide self-potentials. Geophysics 25 (1). pp. 226-249.
14. Nelson, M. 1978. The oxidation dissolution of ferrous monosulfides and the behavior of associated trace metals. Ph.D. Thesis, Stanford University, Palo Alto, California.
15. McKay, D.R., Halpern, J. 1958. A kinetic study of the oxidation of pyrite in aqueous suspension. Trans. of Metall. Soc. of AIME, June.
16. Corrans, I.J., Scholty, M.T. 1976. A kinetic study of the leaching of pentlandite in acidic ferric sulphate solutions. Journal of the

South African Inst. of Min. and Metall. pp. 403-411.

17. Dobrokhotov, G.R., Maiorova, E.V. 1962. Kinetics of autoclave leaching of chalcopyrite. Zhurnal Prikladnoi Khemii, 35(8). pp. 1702-1709.

18. Majima, H., Peters, E. 1966. Oxidation rates of sulfide minerals by aqueous oxygen at elevated temperatures. Trans. of Metallurg. Soc. of AIME 236. pp. 1409-1413.

19. Theis, T.L., Richter, R.O. 1979. Chemical specification of heavy metals in power plant ash pond leachate. Environ. Sci. Technol. 13(2). pp. 219-224.

20. Vuceta, J., Morgan, J.J. 1978. Chemical modeling of trace metals in fresh waters: role of complexation and adsorption. Environ. Sci. Technol. 12(12). pp. 1302-1309.

21. Smith, R.M., Martell, A.E. 1976. Critical stability constants V.4: Inorganic complexes. Plenum Press, New York.

22. Sung, W., Morgan, J.J. 1980. Kinetics and products of ferrous iron oxygenation in aqueous systems. Environ. Sci. Technol. 14. pp. 527-538.

23. Hem, J.D. 1977. Reactions of metal ions at surfaces of hydrous iron oxide. Geochem. Cosmochim. Acta. 41. pp. 527-538.

24. Ishikawa, T. 1976. The effect of copper (II) on the formation of FeOOH. Corros. Sci. 16. pp. 507-417.

25. Gaudin, A.M., Fuerstenau, D.W., Mao, G.W. 1959. Activation and deactivation studies with copper on sphalerite. Trans. A.I.M.E. 214. p. 430.

26. James, R.O., Healy, T.W. 1972. Adsorption of hydrolyzable metal ions at the oxide-water interface 1. Co(II) adsorption on SiO_2 and TiO_2 as model systems. J. Colloid Interface Sci. 40. pp. 42-52.

27. ______, ______. 1972. Adsorption of hydrolyzable metal ions at the oxide-water interface 2. Charge reversal of SiO_2 and TiO_2 colloids by adsorbed Co(II), La(III), and Th(IV) as model systems. J. Colloid Interface Sci. 40. pp. 53-64.

28. Mackenzie, J.M.W., O'Brien, R.T. 1969. Zeta potential of quartz in the presence of nickel(II) and cobalt(II). Trans. A.I.M.E. 244. pp. 168-173.

29. Dugger, D.L., Stanton, J., Irby, B., McConnel, B., Cummins, W., Maatman, R. 1964. The exchange of twenty metal ions with the weakly acid silanol groups of silica gel. J. Phys. Chem. 68. pp. 757-760.

30. Healy, T.W. 1973. Western Australia Conference 1973. Australasian Institute of Mining and Metallurgy, Melbourne. p. 477.

31. Davis, J.A., Leckie, J.O. 1978. Effect of adsorbed complexing ligands on trace metal uptake by hydrous oxides. Environ. Sci. Technol. 12 (12). pp. 1309-1315.

32. Jenne, E.A. 1968. Controls on Mn, Fe, Co, Ni, Cu, and Zn concentrations in soils and water: the significant role of hydrous Mn and Fe oxides. Adv. Chem. Ser., No. 73. p. 337.

33. Murray, J.W. 1975. The interaction of metal ions at the manganese dioxide-solution interface. Geochem. et Cosmochim. Acta. 39. pp. 505-519.

34. Grim, E.C., Hill, R.D. 1974. Environmental protection in surface mining of coal. EPA-670/2-74-093.

35. Doyle, W.S. 1976. Deep coal mining, waste disposal technology. Noyes Data Corp., Park Ridge, New Jersey.

36. Kosowski, Z.V. 1973. Control of mine drainage from coal mine mineral wastes, phase II. pollution abatement and monitoring. EPA-R2-73-230.

37. Wilkey, M., Zellmer, S. 1979. Land reclamation at an abandoned deep coal mine. ASCE Journal of the Environmental Engineering Division, 105:2, EE5. pp. 843-853.

38. Hickok, E.A. 1977. Water resources investigation for the possible MINNAMAX mining facility. 96pp.

39. Siegel, D.I., Ericson, D.W. 1980. Hydrology and water quality of the copper-nickel study region, Northeastern Minnesota. U.S. Geological Survey, Water-Resources Investigations 80-739, Open-File Report.

40. Eger, P. In progress. The leaching and revegetation of Duluth gabbro stockpiles: model development and environmental impact analysis. Ph.D. Thesis, University of Minnesota, Department of Environmental Health.

41. Stumm, W., Morgan, J. 1970. Aquatic chemistry. Wiley Interscience, New York.

42. Holdren, G.R., Berner, R.A. 1979. Mechanism of feldspar weathering-I. experimental studies. Geochem. Cosmochim. Acta. 43. pp. 1161-1171.

43. Wisler, C.O., Brater, E.F. 1959. Hydrology. John Wiley and Sons, Inc., London.

TECHNICAL MEMORANDUM NO. 12

PABLM Input Clarification Due to 1 x 10^{-7} cm/sec Liner

July 16, 1984

DRAVO ENGINEERS, INC.

Dravo Building
1250 14th Street
Denver, Colorado 80202
303 893-4500 Telex: 45-930

A Dravo Company

July 16, 1984

Mr. Richard Collins
Institute for Environmental Negotiation
University of Virginia
Campbell Hall
Charlottesville, VA 22903

Re: PABLM Input Parameters Clarification

Dear Rich:

Enclosed are calculations that demonstrate the effect of assuming the clay liner under the tailings management area has a permeability of 1x10^{-7} cm/sec, as opposed to the initially proposed (October, 1983) value of 1x10^{-8} cm/sec.

In past discussions with Professor Parker and RG & H, they stated that a change to 1x10^{-7} cm/sec would be more representative of construction field conditions. For the case using a 1x10^{-8} liner, I assumed a constant hydraulic head of 30 feet over the entire 191-acre facility. This was viewed as a conservatively high estimate due to the fact that the zone of saturation slowly decreases due to the ongoing placement of the cap. We felt that this conservatism was reasonable due to the length of time required for the zone of saturation to decrease.

However, when the effect of a 1x10^{-7} cm/sec permeability was assessed, we discovered that the accelerated decrease in the zone of saturation over the liner resulted in a significant decrease in seepage rates over time. Seepage rates are directly related to both permeability and head (saturated zone). In this case, the increase in permeability lowered the head rapidly enough to warrent calculating the seepage on an incremental basis. The enclosed calculations document the technical analysis. Our conclusion is that the new total seepage from the 1x10^{-7} liner to be input into PABLM should be 0.203 cfs, which is 3.1 times greater than at 1x10^{-8}.

Another clarification to PABLM inputs is that of the uranium concentration in the Case 1 (unattenuated) seepage through the clay liner. The summary table in the PABLM input document indicates 35 mg/l of uranium. In reality, Pyrih's work showed 35 mg/l of U_3O_8 compound in the unattenuated carbonate tailings solution, (See Column C, Table II-5 in the Technical Summary). This is equivalent to 29.7, or 30 mg/l of elemental uranium. Although we have run the PABLM model using the higher value (35 mg/l), we feel the elemental uranium is the real value (30 mg/l) to be considered in the unattenuated seepage analysis.

If you have any questions on the enclosure or the above discussion, please contact me.

Sincerely,

Alan Notary

AN:blc

Enc.

cc:
E. Baker
D. Gorber
J. Halpern
J. Parker
R. Pyrih
N. Savignac
C. Sealy
J. Yellich

Dravo
Denver Operating Center

ENGINEERING COMPUTATIONS

EST NO.
CONT NO. 8079
DIVISION

COMPANY MARLINE URANIUM
LOCATION DANVILLE, VA
DESCRIPTION SEEPAGE FROM 10^{-7} CM/SEC LINER

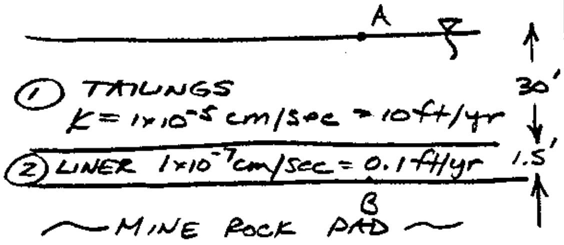
DATE 7-10-84
DR RZN CH
REF

ASSUMING CLAY LINER @ $k = 1 \times 10^{-7}$ CM/SEC, AND TAILINGS @ MAXIMUM AREAL EXTENT, 191 AC, CALC. SEEPAGE

<u>ASSUME</u>: - PROFILE SAME AS CASE 1, PABLM SUMMARY DOCUMENT

- 10 ACRES EXPOSED, REST OF TAILINGS COVERED.
- TAILINGS INITIALLY SATURATED @ 30'.

1.0 <u>BY DARCY'S LAW</u>



$$Q = kiA$$

$$H_{L(A-B)} = h = 31.5' = h_1 + h_2$$

$$Q = Q_1 + Q_2 \quad \text{(CONTINUITY)}$$

$$Q = \frac{k_1 h_1}{L_1} = \frac{k_2 h_2}{L_2} \Rightarrow \frac{10 h_1}{30} = \frac{(31.5 - h_1)\,0.1}{1.5}$$

$$\therefore h_1 = 5.25', \; h_2 = 26.25'$$

$$\therefore Q = \frac{10(5.25)}{30} = 1.\underline{75} \text{ FT}^3/\text{YR}/\text{DAY} \; \frac{\times 7.\underline{48} \times 43560}{365 \cdot 24 \cdot 60}$$

$$= 1.085 \text{ gpm/acre}$$

$$= 21''/\text{YR}$$

2.0 IN 1983 IT WAS ASSUMED THAT HEAD IN TAILINGS WAS CONSTANT DURING OPERATIONAL LIFE. THIS RESULTED IN 0.15 GPM/AC FOR 10^{-8} LINER. WITH 10^{-7} LINER, THIS RATE INCREASES $1.085 \div 0.15 = 7.2$ TIMES.

<u>HOWEVER</u>, HEAD IS <u>NOT</u> STATIC, BUT DROPS TO AN AVERAGE (EQUILIBRIUM) MINIMUM OVER TIME TO BALANCE W/ INFLOWS THRU CAP.

THE FOLLOWING PAGES SUMMARIZE "HELP" MODEL RESULTS, BASED ON 2 5-YR CYCLES USING DAILY CLIMATOLOGICAL DATA FROM LYNCHBURG, VA. (1974-1978 RECORDS).

- TAILINGS WERE INITIALLY SATURATED @ t=0 (CONSERVATIVE).
- INITIAL MOISTURE CONDITIONS OF OTHER LAYERS WERE DETERMINED BY PRIOR 5-YR SIMULATION.

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ENGINEERING COMPUTATIONS

EST NO.
CONT NO. 8079
DIVISION

COMPANY Marline Uranium
LOCATION Danville, VA
DESCRIPTION Seepage from 10^{-7} cm/sec liner

DATE 7-11-84
DR ALW CH
REF

MO./YR.	SEEPAGE OUT LINER, IN	AVG. DAILY HEAD ON LINER, FT
1/1	2.64	37.3
2/1	2.38	37.0
3/1	2.61	36.7
4/1	2.51	36.4
5/1	2.56	36.1
6/1	2.45	35.8
7/1	2.50	35.5
8/1	2.50	35.2
9/1	2.43	34.9
10/1	2.51	34.6
11/1	2.42	34.3
12/1	2.49	34.0
TOTALS	29.99"	
1/2	2.42	33.7
2/2	2.15	33.4
3/2	2.36	33.2
4/2	2.27	32.9
5/2	2.32	32.7
6/2	2.24	32.4
7/2	2.29	32.2
8/2	2.18	31.3
9/2	2.05	29.7
10/2	2.01	28.1
11/2	1.85	26.6
12/2	1.81	25.2
TOTAL	25.96"	

1974

ANNUAL PRECIP. = 40.04"

NOTE: HEAD CANNOT EXCEED TAILINGS DEPTH. EXCESS WATER WOULD EXIT VIA LATERAL DRAINAGE.

1975

ANNUAL PRECIP. = 55.6"

SOURCE OF DATA: "HELP" MODEL; 2 5-YR CYCLES BACK TO BACK.

SHEET NO. 2 OF 10

Dravo
Denver Operating Center

ENGINEERING COMPUTATIONS

EST NO.
CONT NO. 8079
DIVISION

COMPANY MARLINE URANIUM
LOCATION DANVILLE, VA.
DESCRIPTION SEEPAGE FROM 10^{-7} CM/SEC LINER

DATE 7-11-84
DR ALN CH
REF

MO./YR.	SEEPAGE OUT LINER, IN		AVG. DAILY HEAD ON LINER, FT.	
1/3	1.72		23.9	
2/3	1.54		22.8	
3/3	1.56		21.6	
4/3	1.44		20.4	
5/3	1.39		19.5	
6/3	1.28	1976	18.5	ANNUAL PRECIP. = 44.7"
7/3	1.25		17.6	
8/3	1.25		16.6	
9/3	1.18		15.6	
10/3	1.11		14.7	
11/3	1.00		14.0	
12/3	0.99		13.3	
TOTAL	15.69"			
1/4	0.97		12.7	
2/4	0.81		12.1	
3/4	0.84		11.6	
4/4	0.80		11.0	
5/4	0.78	1977	10.5	ANNUAL
6/4	0.71		10.0	P = 38.7"
7/4	0.70		9.6	
8/4	0.66		9.1	
9/4	0.63		8.6	
10/4	0.63		8.1	
11/4	0.58		7.6	
12/4	0.69		7.3	
TOTAL	8.80"			

SHEET NO. 3 OF 10

Dravo
Denver Operating Center

ENGINEERING COMPUTATIONS

EST NO.
CONT NO. 8079
DIVISION

COMPANY MARLINE URANIUM
LOCATION DANVILLE, VA
DESCRIPTION SEEPAGE FROM 10^{-7} CM/SEC LINER

DATE 7-11-84
DR AHW CH
REF

MO./YR	SEEPAGE OUT LINER, IN	AVG. DAILY HEAD ON LINER, FT
1/5	0.68	6.9
2/5	0.59	6.6
3/5	0.63	6.3
4/5	0.59	6.0
5/5	0.58	5.7
6/5	0.55	5.4
7/5	0.53	5.1
8/5	0.46	4.8
9/5	0.41	4.6
10/5	0.36	4.4
11/5	0.33	4.2
12/5	0.35	4.0
TOTAL	6.08"	

1978

ANNUAL
P. = 44.3"

SECOND 5-YR CYCLE:

MO./YR	SEEPAGE OUT LINER, IN	AVG. DAILY HEAD ON LINER, FT
1/6	0.39	3.8
2/6	0.40	3.6
3/6	0.42	3.4
4/6	0.41	3.2
5/6	0.40	3.0
6/6	0.34	2.8
7/6	0.34	2.6
8/6	0.30	2.5
9/6	0.24	2.4
10/6	0.24	2.2
11/6	0.23	2.0
12/6	0.23	1.8
TOTAL	3.94"	

1974

ANNUAL
P = 40.0"

SHEET NO. 4 OF 10

Dravo
Denver Operating Center

ENGINEERING COMPUTATIONS

EST NO.
CONT NO. 8079
DIVISION

COMPANY MARLINE URANIUM
LOCATION DANVILLE, VA
DESCRIPTION SEEPAGE FROM 10^{-7} CM/SEC LINER

DATE 7-11-84
DR AEN CH
REF

MO/YR	SEEPAGE OUT OF LINER, IN	AVG. DAILY HEAD, FT.
1/7	0.27	1.7
2/7	0.27	1.6
3/7	0.30	1.5
4/7	0.28	1.5
5/7	0.30	1.5
6/7	0.28	1.4
7/7	0.27	1.3
8/7	0.25	1.2
9/7	0.22	1.1
10/7	0.24	1.0
11/7	0.21	0.9
12/7	0.21	0.9
TOTAL	3.09"	

1975

ANNUAL
P = 55.6"

MO/YR	SEEPAGE OUT OF LINER, IN	AVG. DAILY HEAD, FT.
1/8	0.24	0.8
2/8	0.22	0.8
3/8	0.24	0.7
4/8	0.24	0.7
5/8	0.23	0.6
6/8	0.19	0.5
7/8	0.18	0.5
8/8	0.18	0.4
9/8	0.17	0.4
10/8	0.19	0.3
11/8	0.20	0.3
12/8	0.20	0.2
TOTAL	2.48"	

1976

ANNUAL
P = 44.7"

SHEET NO. 5 OF 10

EC-555

Dravo
Denver Operating Center

ENGINEERING COMPUTATIONS

EST NO.
CONT NO. 8079
DIVISION

COMPANY MARLINE URANIUM
LOCATION DANVILLE, VA
DESCRIPTION SEEPAGE FROM 10^{-7} CM/SEC LINER

DATE 7-11-84
DR ALN CH
REF

MO/YR	SEEPAGE OUT OF LINER, IN		AVG. DAILY HEAD, FT.	
1/9	0.19		0.2	
2/9	0.19		0.2	
3/9	0.19		0.2	
4/9	0.19		0.1	ANNUAL
5/9	0.19	1977	0.1	P=38.7
6/9	0.18		0.1	
7/9	0.16		0.03	
8/9	0.12		0	
9/9	0.13		0	
10/9	0.04		0	
11/9	0.09		0	
12/9	0.20		0.01	
TOTAL	1.88"			
1/10	0.19		0.04	
2/10	0.18		0.1	
3/10	0.20		0.2	
4/10	0.20		0.2	
5/10	0.22		0.2	ANNUAL
6/10	0.20	1978	0.2	P=44.3"
7/10	0.20		0.2	
8/10	0.20		0.2	
9/10	0.16		0.1	
10/10	0.16		0.1	
11/10	0.15		0.06	
12/10	0.17		0.04	
TOTAL	2.23"			

*SEEPAGE VS. TIME PLOTTED, NEXT 2 PAGES.

SHEET NO. 6 OF 10

EC-555

G.503

Dravo
PITTSBURGH, PENNSYLVANIA

ENGINEERING COMPUTATIONS

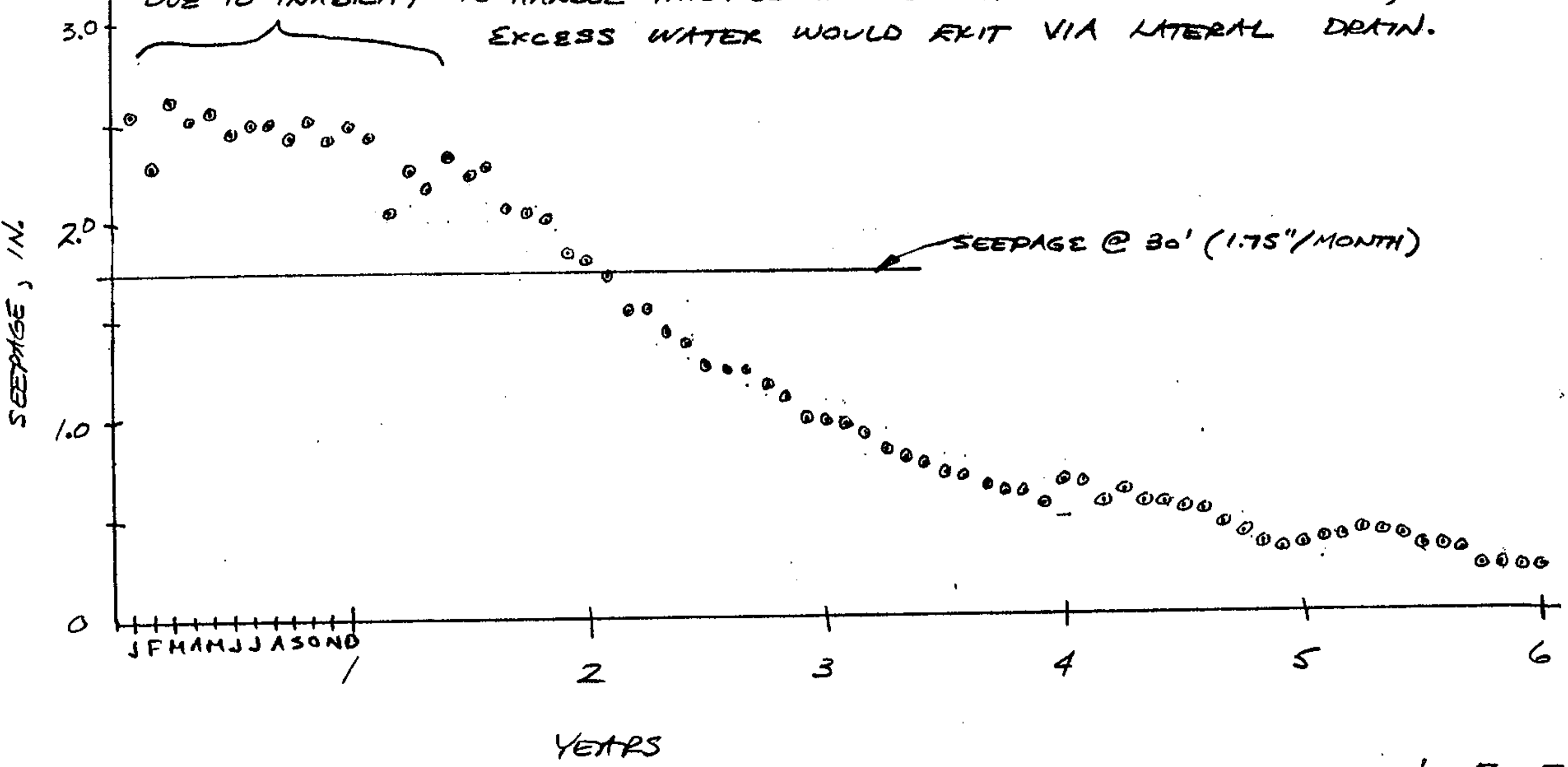
EST NO.
CONT NO. 8079
DIVISION

COMPANY MARLINE URANIUM
LOCATION DANVILLE, VA
DESCRIPTION SEEPAGE FROM 10^{-7} CM/SEC LINER

DATE 7-11-84
DR ALN CH
REF

NOTE: THE 5 YR LYNCHBURGH WEATHER DATA IS A RELATIVELY WET CYCLE, ∴ SEEPAGE RATES ARE SLIGHTLY CONSERVATIVE.

* PROGRAM OVERPREDICTS DUE TO INABILITY TO HANDLE TAILINGS' INITIAL SATURATION. IN REALITY, EXCESS WATER WOULD EXIT VIA LATERAL DRAIN.



SHEET NO. 7 OF 10

G-503

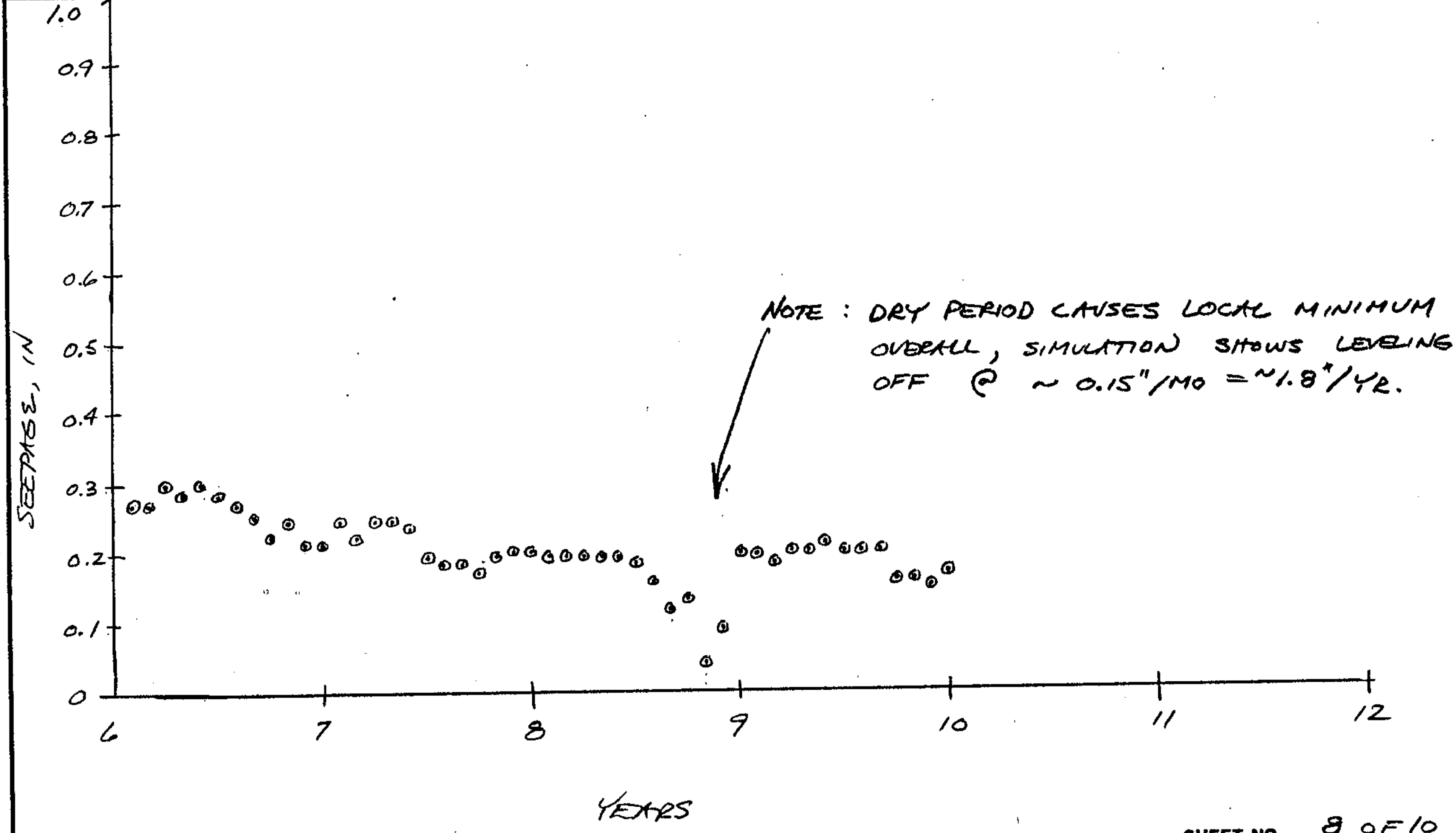
Dravo
PITTSBURGH, PENNSYLVANIA

ENGINEERING COMPUTATIONS

EST NO.
CONT NO. 8079
DIVISION

COMPANY MARLINE URANIUM
LOCATION DANVILLE VA
DESCRIPTION SEEPAGE FROM 10^{-7} CM/SEC LINER

DATE 7-11-84
DR AZN CH
REF



NOTE: DRY PERIOD CAUSES LOCAL MINIMUM OVERALL, SIMULATION SHOWS LEVELING OFF @ ~ 0.15"/MO = ~1.8"/YR.

SHEET NO. 8 OF 10

Dravo
Denver Operating Center

ENGINEERING COMPUTATIONS

EST NO.
CONT NO. 8079
DIVISION

COMPANY MARLINE URANIUM
LOCATION DANVILLE, VA
DESCRIPTION SEEPAGE FROM 10^{-7} CM/SEC LINER

DATE 7-11-84
DR ALN CH
REF

CONCLUSION - FALLING HEAD IN TAILINGS SIGNIFICANTLY LOWERS SEEPAGE RATES

(3.0) CALCULATE FACILITY SEEPAGE -

ASSUME :
- 191 AC, 10 ACRES EXPOSED, 13 YR LIFE
- $\frac{191}{10} = \sim 19$ "STRIPS", EACH ONE TAKING $\frac{13}{19} = 0.68$ YRS
- Ⓐ ASSUME ONE YEAR LAG TO ESTABLISH VEGETATION

AREA*	Ⓐ COVER TIME - 1 YEAR, YRS.	SEEPAGE RATE, IN/MO, FROM PLOT	
1	*	1.75	ASSUMES 50 ACRES @ 30' SATURATION (CONSERVATIVE)
2	*	1.75	
3	*	1.75	
4	*	1.75	
5	*	1.75	
6	2.40	1.3	
7	3.09	1.0	
8	3.77	.65	
9	4.46	.6	
10	5.13	.4	
11	5.81	.25	
12	6.49	.25	
13	7.17	.22	
14	7.85	.2	
15	8.53	.2	
16	9.21	.2	
17	9.89	.2	
18	10.57	.2	
19	11.26	.2	

$\Sigma = 14.62''$
AVG. = 0.769 "/MO = 9.23"/YR

* IGNORE COVER TIME, ASSUME 1ST 10 ACRES & NEXT 4 ALL SATURATED. (CONSERVATIVE - IN REALITY, SOME TRANSITION WILL OCCUR)
THIS ACCOUNTS FOR UNCERTAINTY IN TIMING OF CAP PLACEMENT. NOTE THAT 5 10 AC AREAS REPRESENTS 3.4 YRS OF OPERATION (5 · 0.68 = 3.4)

SHEET NO. 9 OF 10

Dravo
Denver Operating Center

ENGINEERING COMPUTATIONS

EST NO.
CONT NO. 8079
DIVISION

COMPANY MARLINE URANIUM
LOCATION DANVILLE, VA
DESCRIPTION SEEPAGE FROM 10^{-7} CM/SEC LINER

DATE 7-11-84
DR AZW CH
REF

∴ FACILITY SEEPAGE =

$$9.23\ \cancel{\text{IN}}/\cancel{\text{YR}} \times 191\ \cancel{\text{AC}}\ \frac{43560\ \text{FT}^2}{12\ \text{IN}\ \cancel{\text{AC}}}\ \cancel{\text{FT}}\ \frac{7.48\ \text{GAL}\quad \text{YR}}{\text{FT}^3\quad 365\cdot 24\cdot 60\ \text{MIN}}$$

$$= 91\ \text{GPM} \sim \underline{\underline{0.203\ \text{CFS}}}$$

BY COMPARISON, ASSUMING A STATIC 30' HEAD ON A 10^{-7} LINER RESULTS IN AN ESTIMATE OF $1.085 \times 191 =$ 207 GPM, WHICH DOES NOT REFLECT THE ACCELERATED REDUCTION OF HEAD ON THE MORE PERMEABLE LINER DURING TIME FRAME OF FACILITY OPERATION.

SHEET NO. 10 OF 10

TECHNICAL MEMORANDUM NO. 13

1984 PABLM Radiological Assessment

July 27, 1984

By N. Savignac, Ph.D.

1984 PABLM RADIOLOGICAL ASSESSMENT

SWANSON URANIUM PROJECT

by Noel Savignac, Ph.D.

for

MARLINE URANIUM CORPORATION

July 27, 1984

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B.2.2-11	Airborne radionuclide concentrations with radon and its decay products for emissions from the mine.*
B.2.2-12	Exposure pathways at Cedar Hill Hunt Club for airborne doses with radon and its decay products for emissions from the mine.

*Location 1 is the nearest residence, location 30 is the Cedar Hill Hunt Club. See Volume 1a of October 1983 report, Figure B.2.2-3.

The current analysis provides an assessment of the radiological pathways to man. PABLM was used to predict the radiological effects of the Swanson Project liquid effluents in surface waters and the subsequent transfer to man. PABLM calculates radiation doses from radionuclides to humans due to the intake of radionuclides in water that is directly consumed, in water that is used to irrigate crops consumed by humans, and water used to raise animals and animal products including wild game and fish consumed by humans. PABLM also was used to assess the radiation dose to people working in fields containing radionuclides present in irrigation water. The time period for the intake of radionuclides and the time for exposure from those radionuclides both were on an annual basis to match the time periods specified in NRC and EPA regulations.

2.0 REGULATORY FRAMEWORK

The Commonwealth of Virginia is currently developing a regulatory scenario for uranium mining and milling. However, a body of regulation already is in place at the national level which provides a basic framework for comparing results of the current analysis. The purpose of this presentation is not to debate the case for use of these federal regulations by Virginia, but rather to provide the best possible point of reference.

Regulations and recommendations exist which address such diverse concerns as worker health and safety, doses to the general population and conceptual facility design. However, two key dose limitations are most suitable for comparison with modeling results. The EPA has designed an annual dose limitation of 25 mrem/year (40 CFR 190) to persons in unrestricted areas resulting from any phase of the nuclear fuel cycle. This standard incorporates exposure from all potential pathways, but specifically excludes the contribution of radon, its daughter products and mine emissions. The International Commission on Radiological Protection (ICRP) Publications 2 (1959) and 26 (1977), however, provide a long standing limit of 500 mrem/year which includes doses from all sources including radon, radon daughters and mine emissions. Both the EPA and ICRP standards address whole body doses as well as doses to key organs. To provide the most complete set of radiological dose assessments for Virginia regulatory authorities, the dose from the airborne pathway is provided both with and without the dose from radon and its decay products.

In this analysis, the impact of all pathways includes waterborne effluents (PABLM) combined with the previous analysis of the impact of airborne effluents (MILDOS). The combined assessment of waterborne and airborne impacts permits an effective comparison with the cited standards.

Finally, the current analysis employs a tool designed to calculate both chronic and annual doses, the use of which is in keeping with current regulatory standards applicable to uranium facilities.

3.0 MAJOR REVISIONS - A SUMMARY

The 1984 PABLM analysis takes into account the following:

- The ongoing refinement of the design of the proposed facility.

- The assumed increase in clay liner permeability from 1 x 10^{-8} to 1 x 10^{-7} cm/sec, as suggested by state consultants.
- The results of a field survey of local residents regarding food and water consumption habits.
- The results of leaching tests on site-specific ores and waste rock (CSMRI).
- The consideration of all possible sources of waterborne contaminants including mine water, unattenuated and attenuated alkaline tailings seepage, overburden seepage, runoff from the site area and a postulated mill site pond breach.
- The use of average flow rates to better address the chronic nature of annual dose calculations.
- An update of the calculational models used in PABLM from the ICRP2 model to the ICRP10a model.
- Deletion of the Mill Creek receptor location because that location will be within the active mining area with restrictions on any private water use.

More details on revised input parameters are found in Section 9.

4.0 PABLM - THE MODEL

The selection of PABLM for use with the Swanson Project data was based on its extensive use by the U.S. Department of Energy (DOE), similarity between the NRC and DOE dose assessment models and PABLM's suitability to surface water dose assessments. Appendix A provides a detailed description from Battelle Publication PNL-SA-11937 of the PABLM code as presented in NUREG/CR-3209, "A Summary of Computer Codes for Radiological Assessment."

The DOE Office of Nuclear Waste Isolation states: "The PABLM code represents the most up-to-date combination of detailed and broad capabilities for dose-to-man functions of all the codes reviewed. The flexibility of the PABLM code is good with numerous user options and it is applicable to a variety of radionuclide release conditions."(2) In addition, as indicated in Appendices B and C, both the National Research Council and Atomic Energy of Canada Limited (AECL) have found that PABLM produces results similar to those obtained using other recognized dose assessment models. A comparison of PABLM with other computer codes is presented in NUREG/CR-3209 (USNRC).

The internal dose model used in PABLM is derived from that presented in ICRP Publication 2. That model has since been updated for uranium and radium in ICRP Publication 10a. To incorporate the newer model, the organ data library of PABLM, which contains data used for dose calculations to specific organs from ingested radionuclides, was modified as shown in Table 1. Those changes produce doses from Ra-226 that very closely follow the ICRP 10a recommendations for exposure times greater than one year. For exposure times less than one year, the PABLM modifications calculate Ra-226 doses that could be low by as much as a factor of two. This underestimate has only a small impact on the final calculated annual doses because Ra-226 is a minor contributor to the total dose. If this condition were not present, then a different set of program modifications would have been necessary to update the PABLM organ data library. The more recent ICRP Publication 30 models were not used in PABLM because the DOE review of those models has not been completed.

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(2) PNL-SA-11937 (Appendix A)

obtained from Figure 1, and referred to the corresponding section of Appendix D (PABLM printout). For example, the dose from treated mine water releases to a Halifax resident is 1B on Figure 1, and is found in Section 1B of Appendix D. Sources 2 and 3 (<u>attenuated</u> and <u>unattenuated</u> seepage) are independent sources and are not additive in computing the total dose. Accordingly, the total dose at a lettered receptor location is labeled in Appendix D as:

A-total <u>unattenuated</u>	B-total <u>unattenuated</u>
A-total <u>attenuated</u>	B-total <u>attenuated</u>

All of the radiological doses presented are total doses accumulated from one year's intake, and are expressed in the same type of dose unit specified by NRC and EPA regulations.

To assess the effects of the Swanson Project over the long term, a committed dose over 50 years was considered for two sets of exposure times. The first was the dose over 50 years due strictly to the operational mode from 13 years of treated mine water releases to streams potentially used at the Cedar Hill Hunt Club (maximally impacted receptor via the water pathway).(3) After 13 years of operation, the project is scheduled to be closed and the mine water releases will cease. However, a second set of doses were calculated to simulate a full 50 years of tailings seepage, overburden seepage, and runoff to the Cedar Hill Hunt Club location. The first is labeled in Appendix D as "MINE WATER 13/50." The second was subdivided into <u>unattenuated</u> and <u>attenuated</u> seepage and was labeled "50/50 UNATTENUATED ET AL." and "50/50 ATTENUATED ET AL." The doses from Set One then can be added to the calculated doses from Set Two to obtain a dose commitment over a 50-year period.

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(3) The Cedar Hill Hunt Club and Whitethorn Creek receptors are one in the same, and are used interchangeably in this report.

7.0 RESULTS - WATER PATHWAYS

Tables 3 through 7 present the radiological doses from the six project sources for both the Cedar Hill Hunt Club and the Halifax residents. For both locations, the doses to the total body, bone, and gastrointestinal tract are presented in millirems (mrem) per year. The last line of each table presents the population doses in person-rem per year for Halifax (population 1200).

A comparison of the individual doses in Tables 3 through 7 indicates that the Cedar Hill Hunt Club doses are higher than the Halifax doses, and the doses to the bone are higher than the doses to the whole body or to the gastrointestinal tract. The largest dose from all sources to the bone at Cedar Hill Hunt Club is 3.4 mrem/year (Table 4) and is attributable to the contribution of unattenuated seepage. Mine water, attenuated seepage, overburden seepage, and pond breach each contribute substantially less, with overburden runoff contributing only 0.00007 mrem/year.

Table 8 provides the total waterborne radiological dose summarized from Tables 3 through 7. The maximum calculated individual dose from Table 8 is 3.6 mrem/year to the bone of a person residing at the Cedar Hill Hunt Club and results from the food and water consumption habits specified in Table 2. The contribution of each modeled exposure pathway and the percentage contribution of each modeled radionuclide to the maximum waterborne dose of 3.6 mrem/year is presented in Table 9. Leafy vegetables, grains, and milk are the main source of dose, and uranium-234 and uranium-238 are the main contributors to the bone dose for a Cedar Hill Hunt Club resident.

Table 10 presents the long-term, 50-year, radiological dose assessment for both unattenuated and attenuated seepage conditions. In each case, the dose over 50 years for 13 years' mine water release was added to the dose over 50 years from 50 years of tailings seepage, overburden seepage, and runoff. The highest total dose is 747 mrem to the bone over 50 years. That value can be compared to a 50-year dose of 1250 mrem which represents EPA's maximum allowable annual dose (25 mrem) over 50 years.

8.0 RESULTS - TOTAL

Table 11 presents a summary of the total radiation dose (assuming unattenuated seepage) to maximally exposed individuals from the water pathway (PABLM), air pathway (MILDOS), including radon contributions from the mining and milling activities and from both pathways acting together. The table indicates that at Cedar Hill Hunt Club (Whitethorn Creek) the doses from the air pathway slightly exceed those from the water pathway to give a total bone dose of 9.0 mrem per year. Doses from combined air and water pathways to other organs are considerably less than 9.0 mrem/yr.

At the nearest residence (0.2 km N.E. of the mine) the air pathway is the most important because the house is located up-stream of the project. The nearest resident was assumed to eat 2.2 kg/yr of fish caught from Whitethorn Creek near the Cedar Hill Hunt Club. There the highest dose is 94.6 mrem to the bone, which is the highest of all calculated doses in the table, but still only 19% of the ICRP maximum of 500 mrem/year (whole body) for doses that include radon and its daughter products. In this case, radon and its daughter products contribute 96% of the 94.6 mrem/yr dose.(4) The doses at

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(4) See bone dose at nearest residence in Tables B.2.2-8 and B.2.2-9 in the October 15 report (Vol. 1a).

Halifax are due only to the water pathway because Halifax is far enough away from the project to reduce the airborne contribution to less than 0.1 mrem/yr to the bone. This is the same dose calculated for Danville, which is in the same direction from the project site, but closer than Halifax. Figures 2 and 3 illustrate the radiological effects of waterborne and airborne releases compared to the external radiation background level of 88 mrem/year (as measured during the summer of 1983). In addition, background radon at the Swanson Project site contributes approximately 130 mrem/yr(5), for a total background radiation from these sources of approximately 218 mrem/yr.

Table 12 presents the combined dose from air and water pathways, excluding radon, radon daughter products, and radionuclides from the mine. These values are comparable with the 25 mrem/year limitation of the EPA. None of the predicted doses in Table 12 exceeded the 25 mrem per year limitation for the combined air and water pathways.

9.0 COMPARISON OF 1983 AND 1984 PABLM ASSESSMENTS

The initial assessment of radiological doses from the Swanson Project liquid effluents was completed in 1983. In 1984, a different scenario with a new and a revised set of input data was formulated. The significant differences between the two analyses are presented below:

1) The Mill Creek receptor location in the 1983 PABLM assessment was assumed to be a location where people could use the water from the Mill Creek diversion for irrigation purposes. The 1984 PABLM assessment did not include that location because the Mill Creek diversion will be within the active mining area with a restriction on private water use.

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(5) Estimate provided by Senes Consultants for an average radon concentration on site of 0.5 pCi/l.

2) The Whitethorn Creek receptor location in the 1983 PABLM assessment is referred to, and is the same location as, the Cedar Hill Hunt Club receptor in the 1984 PABLM assessment.

3) The 1983 PABLM assessment contained three sources of radionuclides released as liquids to surface waters. The 1984 PABLM assessment contained six possible sources as indicated below:

1983 PABLM Sources	1984 PABLM Sources
Treated Mine Water	Treated Mine Water
Attenuated Tailings Seepage	Unattenuated Tailings Seepage or Attenuated Tailings Seepage
Pond Breach	Overburden Seepage
	Overburden Runoff
	Pond Breach

4) The quality and quantity of some liquid effluents differed between the 1983 and 1984 PABLM assessments as shown below:

		1983 PABLM	1984 PABLM(6)
Mine Water (with Ra-226 treatment)	U-nat	2 mg/l	0.5 mg/l
	Th-230	-------	0.4 pCi/l
	Ra-226(7)	10 pCi/l	3.0 pCi/l
	Pb-210	-------	0.1 pCi/l
	Po-210	-------	0.9 pCi/l
	Flow	0.37 CFS	0.37 CFS
Unattenuated Seepage	U-nat	-------	35. mg/l
	Th-230	-------	162. pCi/l
	Ra-226	-------	22. pCi/l
	Pb-210	-------	7. pCi/l
	Po-210	-------	1. pCi/l
	Flow	-------	0.203 CFS

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(6) Values derived after completion of mine waste rock leaching studies conducted by CSMRI with specific analytical data for each parameter, as agreed to by the State's consultants.

(7) The 1983 Ra-226 value of 10 pCi/l represents total Ra-226, whereas the 1984 Ra-226 value of 3 pCi/l represents dissolved Ra-226. The dissolved fraction is the concentration of interest that is modeled in the water pathway by the PABLM computer code.

Attenuated Seepage	U-nat	0.7 mg/l	0.7 mg/l
	Th-230	-------	1.0 pCi/l
	Ra-226	1.0 pCi/l	1.0 pCi/l
	Pb-210	-------	2.0 pCi/l
	Po-210	-------	1.0 pCi/l
	Flow	0.025 CFS	0.203 CFS
Overburden Seepage	U-nat	-------	0.028 mg/l
	Th-230	-------	0.203 pCi/l
	Ra-226	-------	9.01 pCi/l
	Pb-210	-------	0.187 pCi/l
	Po-210	-------	0.116 pCi/l
	Flow	-------	0.814 CFS
Runoff	U-nat	-------	0.014 mg/l
	Th-230	-------	0.102 pCi/l
	Ra-226	-------	4.505 pCi/l
	Pb-210	-------	0.094 pCi/l
	Po-210	-------	0.058 pCi/l
	Flow	-------	0.002 CFS
Mill Pond Breach(10)	U-nat	2.4 mg/l (1650. pCi/l)	7.4 mg/l (5000. pCi/l)
	Th-230	-------	10. pCi/l
	Ra-226	125. pCi/l	50. pCi/l
	Pb-210	-------	40. pCi/l
	Po-210	-------	10. pCi/l
	Flow	2.02 CFS	2.02 CFS

5) Receiving water volumetric flow rates differed between the 1983 and 1984 PABLM assessments, as agreed to by the State's consultants:

	1983 PABLM(8)	1984 PABLM(9)
Mill Creek	3.5 CFS	10.5 CFS
Whitethorn Creek	13.0 CFS	30.0 CFS
Banister River	120.0 CFS	550.0 CFS

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(8) The lowest 90-day average flow rate expected to occur on average once in a 10-year period ($Q_{90,10}$).

(9) Annual average flow rate (Q_{avg}).

(10) As described in Technical Memorandum No. 5, "Summary of PABLM Impact Parameters", the volume breached is equivalent to 3.5 inches of rain over a 14 acre area; the assumed radionuclide concentrations were taken from a review of the literature.

6) Sprinkler irrigation water application rates differed per June 1984 survey:

1983 PABLM	1984 PABLM
1.0 ac. ft/yr	0.6 ac. ft/yr

7) Food and water consumption pathways varied per the June 1984 survey as follows:

Location	Pathway	1983 PABLM	1984 PABLM
Whitethorn Creek	Fish	-------	2.2 kg/yr
	Water	-------	1.0 liter/yr
	% local consumption	50	50
Halifax	Fish	2 kg/yr	2.2 kg/yr
	Drinking Water	All	All

8) Dose calculational models varied between the assessments as follows:

	1983 PABLM	1984 PABLM
Model	ICRP 2	ICRP 10a

The final calculated radiological doses from the two PABLM assessments were as follows:

Receptor Location	1983 PABLM	1984 PABLM(11)
Mill Creek		
Total Body	10.1 mrem/yr	-------
Bone	17.5	-------
GI	0.5	-------
Whitethorn Creek		
Total Body	0.50	0.4
Bone	0.70	3.6
GI	< 0.1	1.5
Halifax		
Total Body	3.1	0.1
Bone	5.4	1.0
GI	0.1	0.4

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(11) Assumes unattenuated seepage.

10.0 PABLM SENSITIVITY

The input parameters of the PABLM code were applicable to a fairly homogenous group of humans that would likely be impacted by liquid radiological releases from the Swanson Project. The calculated radiological doses also are applicable to the same homogenous group or to individual members of that group. Those individuals do not have habits or circumstances that vary significantly from those described under "Pathway" in Table 2.

Specific individual variations from the conditions presented in Table 2, such as changes in food consumption habits or flow rates, can be assessed by the application of linear multipliers to the dose assessments calculated by PABLM. Except for the natural decay process of the radionuclides in PABLM, which for the long-lived radionuclides considered for the Swanson Project is small, PABLM calculations are all linear. Multiplying an input parameter by the factor "X" will increase or decrease the calculated dose by the factor "X". Table 13 summarizes the linear relationships in PABLM for the input parameters listed in Table 2. Table 14 presents examples of how the multiplier effect in Table 13 could be applied.

REFERENCES

ICRP2. International Commission on Radiological Protection, Report 2. 1959.

ICRP10a. International Commission on Radiological Protection Report 10a. 1969.

National Research Council. "A Study of the Isolation System for Geologic Disposal of Radioactive Wastes": Waste Isolation System Panel; Board of Radioactive Waste Management; Commission on Physical Sciences, Mathematics and Resources; National Research Council. 1983.

NUREG/CR-3209. "A Summary of Computer Codes for Radiological Assessment". M. Mills and D. Vogt. 1983.

PNL-3209-UC-70. "PABLM - A Computer Program to Calculate Accumulated Radiation Doses From Radionuclides in the Environment." B. A. Napier, W. E. Kennedy, Jr., J. K. Soldat. 1980.

PNL-SA-11937. "A Review and Comparison of the Environmental Transport, Exposure, and Dose Calculational Methods Used by DOE and NRC for Nuclear Waste Repositories". B. A. Napier and K. A. Haley. Presented at the Health Physics Society Annual Meeting, New Orleans, Louisiana. June 3-6, 1984.

TABLE 1

PABLM ORGAN DATA LIBRARY MODIFICATIONS TO
UPDATE ICRP2 DOSE MODEL TO
ICRP10a MODEL

Radionuclide	Organ	Model	Biol. t-1/2(1)	fw(2)
Ra-226	Whole body	2	18100	0.3
Ra-226	Whole body	10a	4950	0.006
Ra-226	Bone	2	16400	0.3
Ra-226	Bone	10a	4950	0.1
U-234, 235, 238	Whole body	2	----	0.01
U-234, 235, 238	Whole body	10a	----	0.006
U-234, 235, 238	Bone	2	----	0.0011
U-234, 235, 238	Bone	10a	----	0.00066

(1) Biological half-life, in days. The period of time that it takes one half of the radionuclide to leave the body.

(2) the fraction of ingested radionuclide reaching the organ of interest.

TABLE 2
SUMMARY OF PABLM INPUT PARAMETERS

Source	Quality	Quantity	Receiving Stream	Receptors	Pathway*
1) Treated Mine Water	U-nat - 0.5 mg/l Th-230 - 0.4 pCi/l Ra-226 - 3.0 pCi/l Pb-210 - 0.1 pCi/l Po-210 - 0.9 pCi/l	0.37 CFS	A. Mill Creek 10.5 CFS Whitethorn 30.0 CFS TOTAL 40.5 CFS	A. Cedar Hill Hunt Club	A. Vegetable Irrigation at 0.6 ac. ft/yr Fish at 2.2 kg/yr Water at 1 liter/yr Local Consumption = 50% of total
			B. Banister River 550. CFS	B. Halifax 1200 people	B. Fish at 2.2 kg/yr Water--all drinking water
2) Tailings Seepage-Unattenuated	U-nat - 35 mg/l Th-230 - 162 pCi/l Ra-226 - 22 pCi/l Pb-210 - 7 pCi/l Po-210 - 1 pCi/l	0.203 CFS	A. Mill Creek 10.5 CFS Whitethorn 30.0 CFS TOTAL 40.5 CFS	A. Cedar Hill Hunt Club	A. Vegetable Irrigation at 0.6 ac. ft/yr Fish at 2.2 kg/yr Local Consumption = 50% of total
			B. Banister River 550. CFS	B. Halifax 1200 people	B. Fish at 2.2 kg/yr All drinking water from Banister
3) Tailings Seepage-Attenuated	U-nat - 0.7 mg/l Th-230 - 1.0 pCi/l Ra-226 - 1.0 pCi/l Pb-210 - 2.0 pCi/l Po-210 - 1.0 pCi/l	0.203 CFS	Same as A. above	Same as A. above	Same as A. above
			Same as B. above	Same as B. above	Same as B. above
4) Overburden Seepage	U-nat - 0.028 mg/l Th-230 - 0.203 pCi/l Ra-226 - 9.01 pCi/l Pb-210 - 0.187 pCi/l Po-210 - 0.116 pCi/l	Nonvegetated Overburden: 0.274 +Vegetated overburden: 0.540 TOTAL: 0.814 CFS	Same as A. above	Same as A. above	Same as A. above
			Same as B. above	Same as B. above	Same as B. above
5) Runoff	U-nat - 0.014 mg/l Th-210 - 0.102 pCi/l Ra-226 - 4.505 pCi/l Pb-210 - 0.094 pCi/l Po-210 - 0.058 pCi/l	Nonvegetated Overburden: 0.002 CFS	Same as A. above	Same as A. above	Same as A. above
			Same as B. above	Same as B. above	Same as B. above
6) Pond Breach	U-nat - 5000 mg/l Th-210 - 10 p Ci/l Ra-226 - 50 pCi/l Pb-210 - 40 pCi/l Po-210 - 10 pCi/l	2.02 CFS in 24 hours	Same as A. above	Cedar Hill Hunt Club	Vegetable-1 day's intake. No fish Local Consumption = 50% of total
			Same as B. above	Halifax	No fish Water--drinking 1 day's intake

*Numerical values derived in large part from a survey of local food production characteristics and local food and water habits.

TABLE 3

CALCULATED RADIOLOGICAL DOSES DUE TO MINE WATER RELEASES (PABLM)(1)

Receptor	Total Body	Bone	GI-LLI(2)
Cedar Hill Hunt Club(3)	0.012	0.096	0.041
Halifax Resident(4)	0.003	0.026	0.011
Halifax Population(5)	0.004	0.031	0.013

NOTES

(1) Appendix D, Section 1-A, 1-B
(2) gastrointestinal -- lower large intestine
(3) mrem/yr
(4) mrem/yr (obtained by multiplying the population dose in man-rem/yr by 1000 to convert rem to mrem and by dividing by 1200 people)
(5) man-rem/yr

TABLE 4
CALCULATED RADIOLOGICAL DOSES DUE TO TAILINGS SEEPAGES (PABLM)(1)

Receptor	Total Body	Bone	GI-LLI(2)
	Unattenuated Seepage		
Cedar Hill Hunt Club(3)	0.41	3.4	1.4
Halifax Resident(4)	0.11	0.92	0.38
Halifax Population(5)	0.13	1.1	0.46
	Attenuated Seepage		
Cedar Hill Hunt Club(3)	0.009	0.074	0.03
Halifax Resident(4)	0.002	0.019	0.008
Halifax Population(5)	0.003	0.023	0.009

NOTES

(1) Appendix D, Sections 2-A, 2-B, 3-A, 3-B
(2) gastrointestinal -- lower large intestine
(3) mrem/yr
(4) mrem/yr (obtained by dividing population dose in man-rem/yr by 1200 people)
(5) man-rem/yr

TABLE 5

CALCULATED RADIOLOGICAL DOSES DUE TO OVERBURDEN SEEPAGE (PABLM)(1)

Receptor	Total Body	Bone	GI-LLI(2)
Cedar Hill Hunt Club(3)	0.013	0.059	0.036
Halifax Resident(4)	0.001	0.013	0.007
Halifax Population(5)	0.002	0.016	0.009

NOTES

(1) Appendix D, Sections 4-A, 4-B
(2) gastrointestinal -- lower large intestine
(3) mrem/yr
(4) mrem/yr (obtained by multiplying the population dose in man-rem/yr by 1000 to convert rem to mrem and by dividing by 1200 people)
(5) man-rem/yr

TABLE 6
CALCULATED RADIOLOGICAL DOSES DUE TO OVERBURDEN RUNOFF (PABLM)(1)

Receptor	Total Body	Bone	GI-LLI(2)
Cedar Hill Hunt Club(3)	0.00001	0.00007	0.00004
Halifax Resident(4)	0.000002	0.00002	0.00001
Halifax Population(5)	0.000002	0.00002	0.00001

NOTES

(1) Appendix D, Sections 5-A, 5-B
(2) gastrointestinal -- lower large intestine
(3) mrem/yr
(4) mrem/yr (obtained by multiplying the population dose in man-rem/yr by 1000 to convert rem to mrem and by dividing by 1200 people)
(5) man-rem/yr

TABLE 7

CALCULATED RADIOLOGICAL DOSES DUE TO POSTULATED POND BREACH (PABLM)(1)

Receptor	Total Body	Bone	GI-LLI(2)
Cedar Hill Hunt Club(3)	0.006	0.047	0.019
Halifax Resident(4)	0.0007	0.0058	0.0023
Halifax Population(5)	0.0008	0.0070	0.0028

NOTES

(1) Appendix D, Sections 6-A, 6-B
(2) gastrointestinal -- lower large intestine
(3) mrem/yr
(4) mrem/yr (obtained by multiplying the population dose in man-rem/yr by 1000 to convert rem to mrem and by dividing by 1200 people)
(5) man-rem/yr

TABLE 8

TOTAL WATERBORNE RADIOLOGICAL DOSES (PABLM)(1)

Receptor	Total Body	Bone	GI-LLI(2)
Unattenuated Tailings Seepage, Mine Water, Overburden Seepage, Runoff and Pond Breach			
Cedar Hill Hunt Club	0.4	3.6	1.5
Halifax Resident	0.1	1.0	0.4
Halifax Population(3)	0.1	1.1	0.5
Attenuated Tailings Seepage, Mine Water, Overburden Seepage, Runoff and Pond Breach			
Cedar Hill Hunt Club	< 0.1	0.3	0.1
Halifax Resident	< 0.1	< 0.1	< 0.1
Halifax Population(3)	< 0.1	0.1	< 0.1

NOTES

(1) mrem/yr (Appendix D, Sections A-Total Unattenuated, B-Total Unattenuated, A-Total Attenuated, B-Total Attenuated)
(2) gastrointestinal -- lower large intestine
(3) man-rem/yr

TABLE 9

CALCULATED RADIOLOGICAL DOSE TO THE BONE OF A CEDAR HILL HUNT CLUB RESIDENT BY EXPOSURE PATHWAY AND BY RADIONUCLIDE UNATTENUATED SEEPAGE(1)

Exposure Pathway	Bone
Leafy vegetables	0.98
Other above ground vegetables	0.21
Other root vegetables	0.30
Orchard fruit	0.32
Grains	0.79
Eggs	0.059
Milk	0.52
Beef	0.26
Pork	0.0027
Poultry	0.00005
Irrigated field exposure	0.014
Fish	0.13
Drinking water	0.014
TOTAL	3.6

Radionuclide	Bone	Percent of Total Dose(2)
U-234	1.8	51
U-235	0.075	2
U-238	1.6	43
Ra-226	0.069	1
Th-230, Pb-210, Po-210	0.018	1

(1) mrem/yr
(2) Percentages do not total 100 due to rounding.

TABLE 10

LONG-TERM, 50-YEAR, RADIOLOGICAL DOSE TO RESIDENTS AT CEDAR HILL HUNT CLUB(1)

Source	Whole Body	Bone	GI-LLI(2)
Unattenuated Tailings Seepage			
13 Years Mine Water, 50 Year Dose	0.07	6.8	0.73
50 Years of Tailings Seepage, Overburden Seepage and Runoff	78.	740.	110.
TOTAL	78.	747.	111.
Attenuated Tailings Seepage			
13 Years Mine Water 50 Year Dose	0.07	6.8	0.73
50 Years of Tailings Seepage, Overburden Seepage and Runoff	26.	120.	22.
TOTAL	26.	127.	23.

NOTES

(1) mrem/yr (Appendix E, Sections: Mine Water 13/50, 50/50 Unattenuated et. al., 50/50 Attenuated et. al.)
(2) gastrointestinal -- lower large intestine

TABLE 11

TOTAL RADIATION EXPOSURE TO MAXIMALLY EXPOSED INDIVIDUALS FROM WATER AND AIR PATHWAYS, INCLUDING RADON AND ITS DAUGHTER PRODUCTS (PABLM + MILDOS, mrem/yr)(1)

Pathway	Total Body	Bone	GI	Average Lung
Receptor Location: Halifax				
Water (unattenuated tailings seepage)	0.2	0.9	0.4	0.0
Air	0.0	0.0	N/A	0.0
TOTAL	0.2	0.9	0.4	0.0
Receptor Location: Cedar Hill Hunt Club - Whitethorn Creek				
Water (unattenuated tailings seepage)	0.4	3.6	1.5	0.0
Air	1.5	5.4	N/A	4.2
TOTAL	1.9	9.0	1.5	4.2
Receptor Location: Nearest Resident(2)				
Water(3)	0.0	0.1	0.1	0.0
Air	16.4	94.5	N/A	41.0
TOTAL	16.4	94.6	0.1	41.0

(1) See Figures 2 and 3 for diagramatic presentations of tabulated doses.
(2) Coles Hill, adjacent to mine pit.
(3) Assumes the nearest resident eats fish caught from Whitethorn Creek near the Cedar Hill Hunt Club.

TABLE 12

TOTAL RADIATION EXPOSURE TO MAXIMALLY EXPOSED INDIVIDUALS FROM WATER AND AIR PATHWAYS, EXCLUDING RADON, RADON DAUGHTER PRODUCTS AND MINE EMISSIONS (PABLM + MILDOS, mrem/yr)

Pathway	Total Body	Bone	GI	Average Lung
Receptor Location: Halifax				
Water (unattenuated tailings seepage)	0.2	0.9	0.4	0.0
Air	0.0	0.0	N/A	0.0
TOTAL	0.2	0.9	0.4	0.0
Receptor Location: Cedar Hill Hunt Club - Whitethorn Creek				
Water (unattenuated tailings seepage)	0.4	3.6	1.5	0.0
Air	0.2	2.0	N/A	2.4
TOTAL	0.6	5.6	1.5	2.4
Receptor Location: Nearest Resident(1)				
Water(2)	0.0	0.1	0.1	0.0
Air	0.3	3.6	N/A	12.2
TOTAL	0.3	3.7	0.1	12.2

(1) Coles Hill, adjacent to mine pit.
(2) Assumes the nearest resident eats fish caught from Whitethorn Creek near the Cedar Hill Hunt Club.

TABLE 13

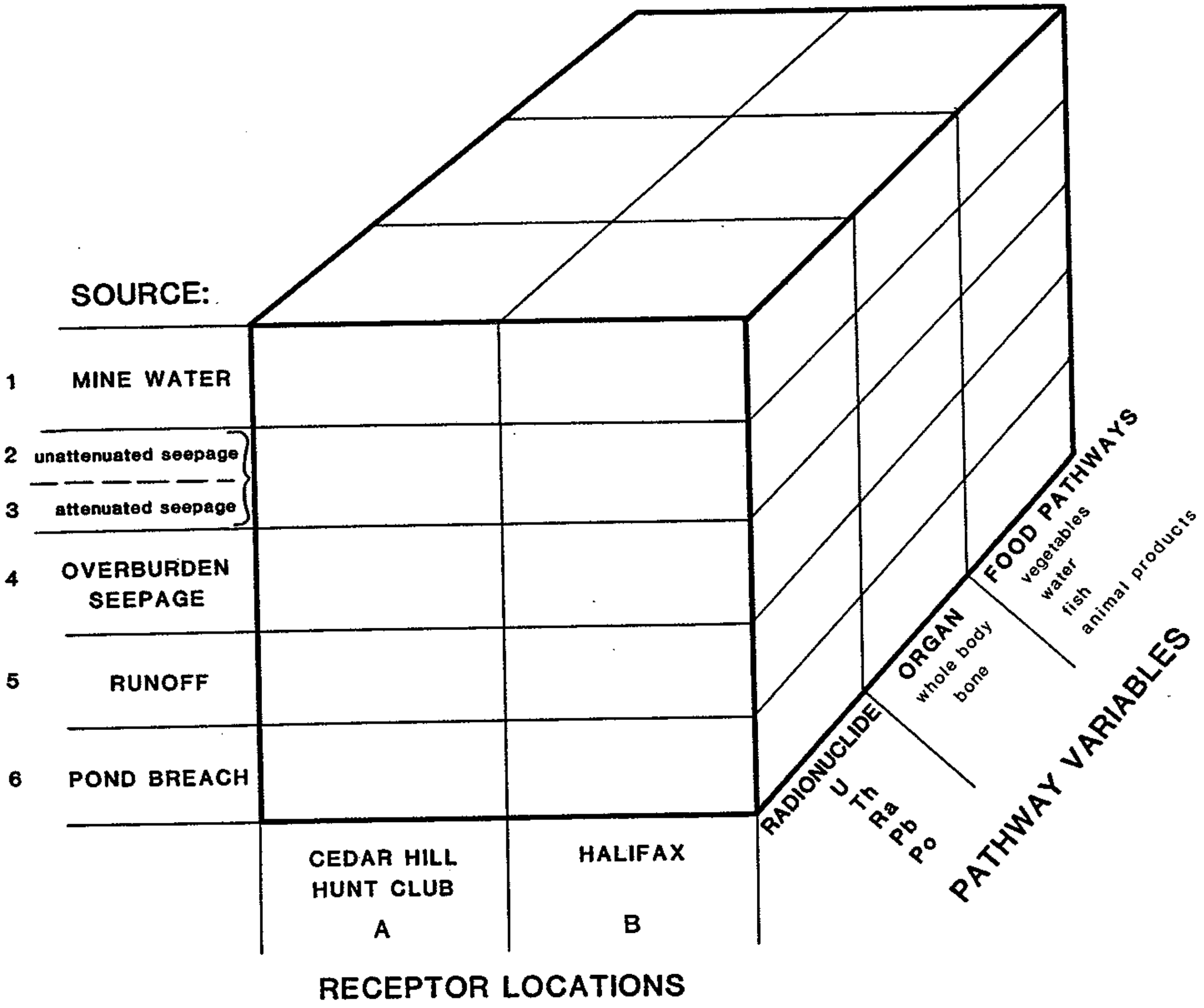
MULTIPLIER EFFECTS ON PABLM RESULTS

Parameter	Input Modification	Effect on Dose	Caution
Effluent quality. The set of radionuclides considered for each stream	Increase the concentration of each radionuclide by X	Increase dose for effluent stream by X	Consider entire set of radionuclides and not individual radionuclides.
	Decrease the concentration of each radionuclide by X	Decrease the dose for effluent stream by X	
Effluent stream flow rate	Increase by X	Increase dose by X	Use flow rate that enters surface waters.
	Decrease by X	Decrease dose by X	
Receiving stream flow rate	Increase by X	Decrease by X	Use stream flow at receptor location, e.g., Cedar Hill Hunt Club flow = Mill Creek flow + Whitethorn flow
	Decrease by X	Increase by X	
Pathway: Sprinkler irrigation % local consumption Fish consumption Water consumption	Increase by X	Increase by X	Determine that pathway exists, e.g., fish are consumed from receiving stream. Increased consumption of one food needs to correspond with a decreased consumption of other foods.
	Decrease by X	Decrease by X	

TABLE 14

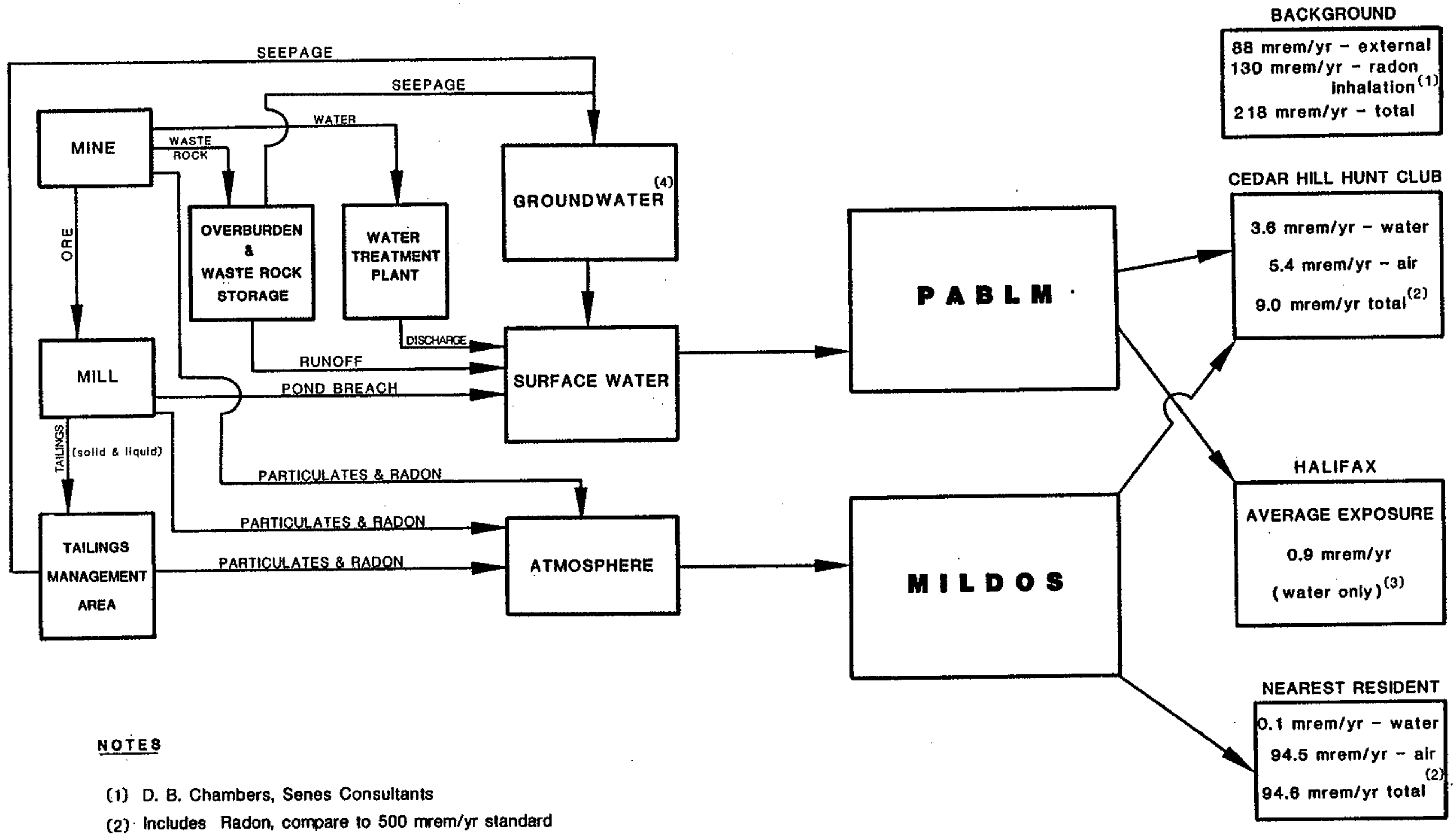
SAMPLE APPLICATION OF LINEAR MULTIPLIERS TO PABLM OUTPUT RESULTS

PARAMETER	INPUT MODIFICATION ORIGINAL VALUE	 NEW VALUE	ORIGINAL CALCULATED DOSE, mrem/yr	OUTPUT MODIFICATION	NEW CALCULATED DOSE mrem/yr
Bone dose at Cedar Hill Hunt Club from unattenuated tailings seepage. Table 4	Effluent flow rate: 0.203 CFS	0.406 CFS	3.4	$\frac{.406}{.203} = x\ 2$	6.8
Bone dose at Cedar Hill Hunt Club from all waterborne sources with unattenuated seepage. Table 8	Effluent flow rate: 0.203 CFS	0.406 CFS	3.6	6.8 -3.4 +3.4	7.0
Bone dose at Cedar Hill Hunt Club from unattenuated seepage. Table 4	Effluent flow rate assuming 10^{-7} cm/sec liner: 0.203 CFS	Assuming 10^{-8} cm/sec liner: 0.065 CFS	3.4	$\frac{0.065}{0.203} = x\ 0.32$	1.1
Bone dose at Cedar Hill Hunt Club from all waterborne sources with unattenuated seepage. Table 8	Assuming 10^{-7} cm/sec liner: 0.203 CFS	Assuming 10^{-8} cm/sec liner: 0.065 CFS	3.6	1.1 -3.4 -2.3	1.3
Bone dose at Halifax from mine water. Table 3	Receiving stream flow rate: 550 CFS	120 CFS	0.026	$\frac{550}{120} = x\ 4.58$	0.119
Bone dose at Halifax from all waterborne sources with attenuated seepage. Table 8	Receiving stream flow rate: 550 CFS	120 CFS	< 0.1	0.119 0.026 +0.093	0.2
Bone dose at Cedar Hill Hunt Club from mine discharge. Table 3	Mine effluent flow rate: 0.37 CFS	Due to doubling of deep ground water flow: 0.57 CFS	0.096	$\frac{0.57}{0.37} = x\ 1.54$	0.148
Bone dose at Cedar Hill Hunt Club from all waterborne sources with attenuated seepage. Table 8	Mine effluent flow rate: 0.37 CFS	Due to doubling of deep ground water flow: 0.57	0.3	0.148 -0.096 +0.052	0.35
Bone dose at Cedar Hill Hunt Club from pond breach. Table 7	Pond breach flow: 2.02 CFS	4.04 CFS	0.047	$\frac{4.04}{2.02} = x\ 2$	0.094
Bone dose at Cedar Hill Hunt Club from all waterborne sources with attenuated seepage. Table 8	Pond breach flow: 2.02 CFS	4.04 CFS	0.3	0.094 -0.047 +0.047	0.35



PABLM OUTPUT MATRIX

Figure 1



NOTES

(1) D. B. Chambers, Senes Consultants
(2) Includes Radon, compare to 500 mrem/yr standard
(3) Compare to 25 mrem/yr standard
(4) Based on local groundwater flow patterns, this pathway connects to surface water

RADIOLOGICAL DOSES FROM WATERBORNE & AIRBORNE RELEASES (August, 1984)

Figure 2

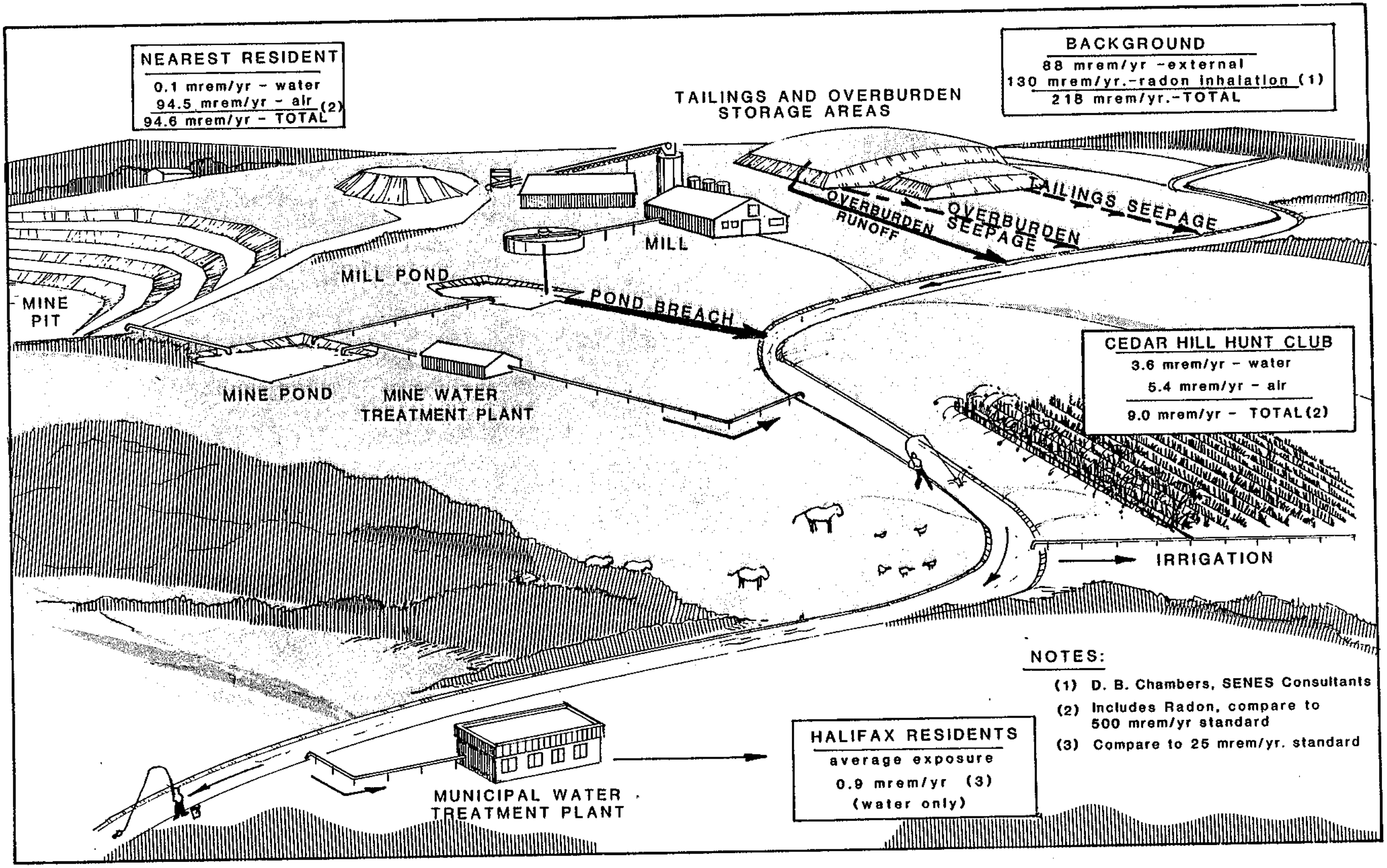


Figure 3 RADIOLOGICAL DOSES FROM WATERBORNE & AIRBORNE RELEASES

APPENDICES

1984 PABLM RADIOLOGICAL ASSESSMENT

APPENDIX A - Source: Battelle Publication PNL-SA-11937, 1984.

APPENDIX B - Calculated Individual Doses per Unit Concentration of Radionuclides Released to the Environment: Comparison of Results from Models of Pacific Northwest Laboratory (PNL) and Atomic Energy of Canada Limited (AECL). National Research Council, 1983.

APPENDIX C - Ingestion Dose Factors for Radionuclides of Interest in Assessments of High-Level Waste - Isolation System Performance. National Research Council, 1983.

APPENDIX D - PABLM Computer Output

APPENDIX A

APPENDIX A

I. EXECUTIVE SUMMARY - ENVIRONMENTAL CONSEQUENCES

The methods used for the consequence analysis of long-term radionuclide release from geologic repositories used by the DOE sites and contractors were compared with those documented by Sandia for the NRC in the three-volume report "Risk Methodology for Geologic Disposal of Radioactive Waste," NUREG/CR-1636 (Helton 1981a,b,c). Both approaches may be considered as consisting of three portions: 1) environmental transport and distribution of contamination, 2) human exposure to the contamination, and 3) human radionuclide dosimetry. The models used for the human exposure and human dosimetry are essentially the same for DOE and NRC. Only in portions of the environmental transport do the two methods differ significantly; the Sandia/NRC method allows consideration of widespread, low-level contamination in multiple "zones," while the DOE method to date has only considered individual environmental "zones" (Dove 1983). However, the NRC approach does require additional outside hydrology/sediment transport models as a data source. The DOE has a number of such models available, and if they were to be used in conjunction with the present DOE methodology, the DOE and NRC approaches would be essentially indistinguishable.

II. INTRODUCTION - ENVIRONMENTAL CONSEQUENCES

In the preparation of nuclear waste repository site selection documentation, safety analysis reports, environmental impact statements, and licensing requests, the U.S. Department of Energy (DOE) uses certain numerical models and computer programs to assess the performance of the repository. The U.S. Nuclear Regulatory Commission (NRC) uses other models to independently reassess the DOE choices. This section/report reviews and compares the models and methods used by DOE and its contractors with those developed for the NRC to calculate the consequences of long-term radionuclide release to the biosphere, including radionuclide transport in the environment, uptake by humans through various exposure models, and radiation dosimetry and human health effects.

There are presently nine field locations under consideration by DOE for the construction of the first waste repository. Investigations of these sites are being conducted for DOE by various contractors. In addition, there are several DOE offices and outside agencies involved in the assessments of the candidate sites. These include the DOE Office of Nuclear Waste Isolation (ONWI), the Office of Waste Isolation, the Office of Crystalline Repository Development, Intera Environmental Consultants, Rockwell Hanford Operations, and various national laboratories. The models presently being used or proposed for use for the environmental assessment potions of the repository performance assessment are shown in Table 1. It is fairly remarkable that essentially all of these various offices and outside contractors use the same basic models for environmental assessment. The dominant computer model is the code PABLM (Napier 1980b). This program was originally developed and documented by the AEGIS (then WISAP) program at Pacific Northwest Laboratory, under the overview of ONWI. ONWI now conducts the performance assessments for all of the candidate salt sites, both bedded and domed salt, using the PABLM code. ONWI feels that "The PABLM code represents the most up-to-date combination of detailed and broad capabilities for dose-to-man functions of all the codes reviewed. The flexibility of the PABLM code is good with numerous user options, and it is applicable to a variety of radionuclide release conditions." (ONWI 1983) PABLM incorporates the capabilities of the two earlier computer programs - ARRRG and FOOD (Napier 1980a), which were also developed for AEGIS, and used by them in early generic assessments. The AEGIS codes were transmitted to INTERA Environmental Consultants under a technology transfer agreement. The PABLM code is being used for the assessments for the tuff geology at NTS because of the generally high quality of its documentation and its ease of use (personal communication, J. P. Brannon to B. A. Napier, June 3, 1983). The Basalt Waste Isolation Project (BWIP) also identifies PABLM as the environmental assessment code of preference (BWIP 1983). BWIP personnel are also using factors calculated using the DITTY computer program (Napier 1983) in preliminary assessments (personal communication, J. C. Sonnichsen to B. A. Napier, March 1983). DITTY is a version of PABLM applicable to long-term chronic releases. The performance assessment plan for a repository in crystalline rock is not sufficiently advanced to have identified a model yet (OWI 1983).

The performance assessments completed to date do not consider extensive redistribution of radionuclides in the biosphere following initial release. The past applications of PABLM have considered either well-water scenarios,

TABLE 1. Computer Models Proposed or Used for Environmental Consequence Analysis in Nuclear Waste Depository Performance Analyses

Contractor or Site	Surface Water Transport	Environmental Accumulation	Human Uptake	Human Dosimetry	Health Effects
ONWI: Salt Domes					
Mississippi	--*	PABLM	PABLM	PABLM	--
Texas	--	PABLM	PABLM	PABLM	--
Louisiana	--	PABLM	PABLM	PABLM	--
ONWI: Bedded Salt					
Utah	--	PABLM	PABLM	PABLM	--
Texas	--	PABLM	PABLM	PABLM	--
Michigan	--	PABLM	PABLM	PABLM	--
OCRD	--	--	--	--	--
OWI	--	PABLM	PABLM	PABLM	--
BWIP: Basalt	--	PABLM/DITTY	PABLM/DITTY	PABLM/DITTY	--
INTERA	--	PABLM	PABLM	PABLM	--
AEGIS PNL					
Paradox Salt	--	--	--	--	--
Permian Salt	--	--	--	--	--
Generic Salt	--	ARRRG/FOOD	ARRRG/FOOD	ARRRG/FOOD	--
Swedish Granite	--	--	--	--	--
Gulf Coast Salt	--	PABLM	PABLM	PABLM	--
Columbia Basalt	--	--	--	--	--
NNWSI: Tuff	--	--	--	--	--
Sandia/NRC	PATH1/Other	PATH1	PATH1/DOSHEM	DOSHEM	DOSHEM

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* A dash (-) indicates that no specific models are currently in use.

A. PABLM

Purpose and Scope - PABLM calculates internal radiation doses to man from radionuclides in food products and drinking water and external radiation doses from radionuclides in the ervironment. PABLM incorporates the features of two earlier codes, FOOD and ARRRG (Napier 1980a).

Authors - The program was written by B. A. Napier, W. E. Kennedy, Jr., and J. K. Soldat of Battelle Pacific Northwest Laboratories for the Office of Nuclear Waste Isolation.

Code Functions - Radiation doses from radionuclides in the environment may be calculated from deposition on the soil or plants during an atmospheric or liquid release, or from exposure to residual radionuclides in the environment after the releases have ended. The radiation dose calculations in PABLM consider exposure to radionuclides deposited on the ground or on crops due to contaminated irrigation water, radionuclides in contaminated drinking water, radionuclides in aquatic foods raised in contaminated water, and radionuclides in bodies of water and sediments where people might fish, boat, or swim. For vegetation, the radiation dose model considers both direct deposition on leaves and uptake through roots. Doses may be calculated for either a maximally exposed individual or a population group. The calculations include both a first-year committed dose and an integrated dose for a selected number of years.

Potential Usage - This code can be used to calculate the dose to man from continuous or accidental radionuclide releases to the atmosphere during repository operation. Radionuclide concentrations in the atmosphere must, however, will be calculated by another model before input to PABLM. The code can also be used to calculate the ultimate dose to man due to radionuclide release to stream water or the use of contaminated ground water for irrigation of crops.

Availability - PABLM is available from the Radiation Shielding Information Center at Oak Ridge National Laboratory, or from the National Energy Software Center at Argonne National Laboratory.

General Critique - PABLM can be used for dose-to-man estimates once the radionuclide concentrations in air and water have been specified. Some of the options in the code, such as the use of a reconcentration factor for nuclear facility cooling water, are more applicable to a nuclear plant than to a waste repository. Furthermore, PABLM does not consider the inhalation or air submersion dose. The code was used by DOE in the Assessment of Effectiveness of Geologic Isolation Systems (AEGIS) program. The publicly available versions of the code do not allow for the simulation of long-term accumulation of radionuclides in soil, but such capabilities are being incorporated at ONI request.

Sensitivity Analysis - None. However, an analysis of the precursor code FOOD has been performed (Zach, 1980). This analysis found that the human uptake and consumption parameters, which are directly influenced by the exposure scenario analyzed, are as important as any other inputs.

Validation - No validation studies have been reported. As is the case with most of the radiological assessment codes, field measurements have been used in the development of factors used in the program equations and not as a check on the performance of the code itself.

Operating Characteristics - PABLM has been compiled under the ASCII (FTN) compiler with a region size of 65K. The code runs on a UNIVAC 1100/44 computer and requires 80,000 words of memory for execution under the EXEC 8 operating system. The sample problem required two minutes of CP time for execution by a UNIVAC 1100/44.

Inputs - The input data required for the calculations fall into four categories: general parameters, terrestrial parameters, aquatic parameters, and radionuclide release information. The general parameters include program control variables, case-specific values such as population and plant life, and reconcentration factors; the terrestrial parameters characterize the type of farming done near the area of interest; and the aquatic parameters characterize the exposure pathways from liquid releases. Most of the data required by the code are contained in the following five data libraries:

- RMDLIB

  Radionuclide decay data such as halflife, position in the decay chain, and branching ratios

- FTRANSLIB

  Factors used in relating concentrations of elements in soil to concentrations in farm products produced on that soil and relating concentrations in animal feed to concentrations in animal products

- ORGLIB

  Data used for the calculation of dose to specific organs from ingested radionuclides, including biological halflife, fraction of ingested nuclide reaching organ of interest, and effective energy absorbed per disintegration in an adult organ

- GRDFLIB

  Factors used to calculate skin and total body doses from exposure to radionuclides from contaminated ground and from immersion in contaminated water

- BIOACH

  Factors relating the concentration of nuclides in aquatic biota to the concentration of the nuclides in both fresh and salt water; also gives a factor for the cleanup of drinking water in water treatment plants.

Outputs - The following dose summary tables are produced by PABLM:

- Internal committed dose by pathway for specified organs
- Internal committed dose by radionuclide for specified organs
- External committed dose (skin and total body) by radionuclide

Committed doses are calculated for the first and final years of facility operation and for the year corresponding to the end of the user-specified dose time period. The committed dose can be calculated for a maximally exposed individual (rem) or a population (man-rem). The dose for the maximally exposed individual is based upon maximum usage parameters, while the population dose is taken to be the product of the population and the dose to an individual with average usage rates.

calculated for river water. In PABLM, the radionuclide concentration in sediments is given by the following equation:

$$C_{is} = KC_{iw}\left(1 - e^{-\lambda_i t}\right)/\lambda_i \qquad (2)$$

where C_{is} = the sediment surface concentration (pCi/m^2)
K = rate constant (liter/m^2 - yr)
C_{iw} = radionuclide concentration in river water (pCi/m^3)
$_i$ = removal constant, which, in the current version of the code, includes only radioactive decay (yr^{-1})

This sediment model is a simple approximation used when more detailed hydrological/sediment transport model results are not available. It would be possible to replace this with other model results.

The uptake parameters, U_p, are all inputs to the code. They are directly dependent on the scenario being analyzed. The site-specific portions of the pathway analysis are largely incorporated in these factors.

The internal dose model used in PABLM is derived from that given in ICRP Publication 2 (1959) for body burden and maximum permissible concentration. The equation for committed radiation dose equivalent per picocurie per year ingested, F_{ipr} for organ r, for a period T_2 following the start of ingestion for a period T_1 is

$$F_{ipr}(T_1,T_2) = 0.0187\,\frac{f_{wir}\epsilon_{ir}}{m_r(\lambda_e^2)}\left[T_1\lambda_e + e^{-\lambda_e T_2} - e^{-\lambda_e(T_2-T_1)}\right] \qquad (3)$$

where $F_{ipr}(T_1,T_2)$ = the dose commitment for T_2 years following the start of ingestion of a radionuclide at the rate of one picocurie/yr over T_1 years, rem/pCi over T_2 years

0.0187 = a unit conversion factor =

$$\left(1.602 \times 10^{-8} \frac{\text{g-rad}}{\text{MeV}}\right)\left(\frac{0.037 \text{ dis}}{\text{sec-pCi}}\right)\left(\frac{3.15 \times 10^{7} \text{ sec}}{\text{yr}}\right)$$

f_{wir} = the fraction of nuclide i ingested reaching the organ r

$_{ir}$ = the effective decay energy of radionuclide i in organ r (MeV per disintegration)

m_r = the effective mass of organ r (grams)

T_1 = the intake time (years)

T_2 = the time over which the dose is accumulated (years)

$_{e}$ = the effective removal halftime, related to the biological halftime, T_{Bi}, and the radiological halftime, T_{Ri}, as

$$\lambda_e = \frac{0.693(T_{Ri} + T_{Bi})}{T_{Ri}T_{Bi}} \text{ years}^{-1} \qquad (4)$$

Using this formulation, the total accumulated dose over T_2 years to an organ of reference, r, from ingestion for T_1 years of food particles contaminated with radionuclides, is written as

$$D_r = \sum_{T=1}^{T_1} \sum_{P=1}^{\substack{\text{No. of Food}\\ \text{Pathways}}} \sum_{i=1}^{\substack{\text{No. of}\\ \text{Nuclides}}} C_{ip}(T)U_pF_{ipr}(1,T_2-T) \qquad (5)$$

PABLM accounts for special cases that deviate from the above equation for D_r. Since the radionuclides ^3H and ^{14}C distribute evenly in the body, the doses for all organs except bone are set equal to the dose calculated for the total body. For isotopes of sodium, all organs including the bone are set equal to the total body.

The four compartments of the GI tract - stomach, SI, ULI, and LLI - are modeled as a four-compartment system with a plug flow and no long-term storage or retention. The portions of the GI tract are assumed to be irradiated from radionuclides uniformly distributed in the material passing through each compartment. The dose factor per picocurie per year ingested is calculated as

$$F_{ipr} = 2.56 \times 10^{-5} \frac{\tau_r f^*_{ir} \varepsilon_{ir}}{m_r} e^{-\lambda_i \tau'_r} \tag{6}$$

where 2.56×10^{-5} = a unit conversion factor, equal to

$$\left(1.602 \times 10^{-8} \frac{\text{g-rad}}{\text{MeV}}\right) \left(\frac{0.037 \text{ dis}}{\text{sec pCi}}\right) \left(\frac{86,400 \text{ sec}}{\text{day}}\right) /2$$

(The factor of 1/2 accounts for the fact that the dose is calculated for the inner wall of the organs and not for the contents.)

This value, F_{ipr} must be multiplied by T_1 to make it consistent with the other ingestion dose factors.

Probabilistic or Statistical Aspects - None associated with the code.

Assumptions and Simplifications - The main assumptions and simplifications in PABLM are as follows:

- Farm and garden crops are assumed to be irrigated with sprinklers.
- Dose factors for persons swimming in water are calculated using the assumption that water is an infinite medium with respect to the range of the emitted radiation.
- The factor for translocation of externally deposited radionuclides to edible plant parts is taken to be 1 for leafy vegetables and fresh forage and 0.1 for all other produce, including grain.

- External doses from radionuclides deposited in farm fields are calculated assuming an infinite flat-plane source. The dose is divided by 2 to simulate the self-shielding effect of surface roughness.
- Removal of radioactivity from soil and sediments takes place only through radioactive decay.
- Doses are calculated for the adult population only.
- Vegetation derives all of its carbon from irrigation water.

Structure and Level of Detail - A total of 19 ingestion pathways or food products may be selected, with corresponding consumption rates, growing periods, and air or water concentrations and deposition rates. Four external exposure pathways may also be selected, with corresponding exposure times and soil or water concentrations.

B. PATH1 and DOSHEM

Unlike the unified code PABLM, the Sandia/NRC method uses two separate computer codes; PATH1 to calculate environmental transport and concentrations, and DOSHEM to calculate human dosimetry and health effects. These will be described separately.

PATH1

Purpose and Scope - PATH1 models the physical and biological processes that result in the transport of radionuclides through the earth's surface environment and man's eventual exposure to these radionuclides. PATH1 is divided into two submodels. The Environmental Transport Submodel represents the long-term distribution and accumulation of radionuclides in the environment. The Transport-To-Man Submodel simulates the movement of radionuclides from the environment to man.

Authors - PATH1 was written by J. C. Helton and P. C. Kaestner of the Sandia National Laboratory. The work was performed for the Division of Systems and Reliability Research, Office of Nuclear Regulatory Research, U. S. Nuclear Regulatory Commission.

Code Functions - The PATH1 code uses a generalized approach to the simulation of radionuclide transport from the ground water through the environment and food chain to man. The code is flexible in that it is not tied to any specific site characteristics. The Environmental Transport Submodel of PATH1 requires that the study area be divided into a number of compartments, and radionuclide movement between these compartments is represented by a system of linear differential equations. The user must specify the transfer and decay coefficients for this system of compartments. In the Transport-to-Man Submodel, radionuclide ingestion is calculated on the basis of simple food chains and concentration ratios, while the amount of each radionuclide inhaled is determined from the amount of radionuclide-containing soil suspended in the air. These calculated ingestion and inhalation rates are input to the Sandia Dose and Health Effects Model, DOSHEM.

Potential Usage - PATH1 can use as input the radionuclide concentration in aquifer discharge and the rate of aquifer discharge, both outputs of ground-water models, to calculate the transport of radionuclides through the environment to man.

Availability - PATH1 can be obtained from the NRC.

General Critique - PATH1 is one part of an overall risk methodology being developed by Sandia National Laboratory for the geologic disposal of radioactive waste. The code constitutes a general mathematical framework for modeling radionuclide transport. The generalized nature of PATH1 makes it applicable to a wide range of site configurations. By the same token, the user is required to supply most of the rate and decay constants used by the program. The code does not access standard input libraries. Also, the user must supply his own routine for the solution of the compartmental equations.

Sensitivity Analysis - None reported.

Code Verification - None reported.

Validation - None reported.

Operating Characteristics - The current version of PATH1 is written in FORTRAN and runs on Control Data computers.

Inputs - PATH1 code inputs include the following:

- Number of zones
- Characterization of the ground water, soil, surface water, and sediment subzones for each zone
    - Volume of water in the subzone
    - Mass of solids in the subzone
    - Rates of water and solid outflow to the other subzones and to a sink
    - Identification of the zone into which the surface water discharges
- Distribution coefficient for each radionuclide-subzone combination

NOTE: The following input is also required for PABLM, but is generally standardized in input libraries.

- Description of the decay chains and decay pattern
- Concentration ratios for each radionuclide:
    - Water treatment removal factor
    - Concentration ratio from water to fish
    - Concentration ratio from water to invertebrates
    - Concentration ratio from soil to plants
    - Concentration ratio from dairy cattle diet to milk
    - Concentration ratio from beef cattle diet to beef
- Radionuclide input rate for each subzone
- Control parameters for the numerical solution of the compartmental transfer equations
- Agricultural parameters
    - Fraction of radionuclides in water used for sprinkler irrigation retained on plants
    - Length of time for irrigation
    - Plant density
    - Weathering halflives for radionuclides deposited on plants by sprinkler irrigation

  - Consumption of water by dairy cattle
  - Consumption of plant material by dairy cattle
  - Consumption of water by beef cattle
  - Consumption of plant material by beef cattle

- Description of ingestion and inhalation patterns.

Outputs - PATH1 outputs include:

- Descriptive listing of the input data
- Coefficient matrix for the radionuclide transport equations
- The amount and concentration of radionuclides for both the liquid and solid phases for each subzone within each of the specified zones
- Radionuclide concentrations used for ingestion and inhalation calculations in each zone
- Radionuclide ingestion and inhalation rates for each zone

Available Documentation - PATH1 is documented in Helton (1981 a,b,c) and Campbell (1978)

Equations - PATH1 assumes that the environmental transport of radionuclides takes place between zones, each zone being more or less uniform in its physical characteristics. Each zone is divided into four subzones: sediment, ground water, surface water, and soil. All subzones have a liquid and solid phase between which the radionuclides present in the subzone are partitioned. Radionuclide input is possible into one or more of these subzones. The flows between the subzones of a given zone are shown in Figure 1. Flows between zones involve both water and solid material and are assumed to take place only from the surface-water subzone of one zone to the surface-water subzone of another zone. Water and solid material may also move from a subzone to a sink, so that the associated radionuclides are removed from the system. Flows of water and sediment are not calculated in PATH1, complete definition of the system requires input from a separate hydrology/sediment transport code. Separate compartments are defined for each nuclide in a decay chain. The physical characteristics of

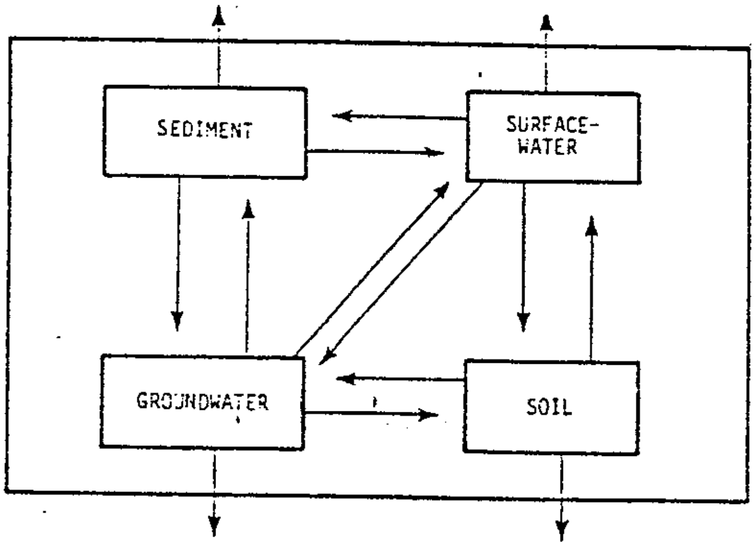

FIGURE 1. Physical Flows Out of Subzones

(Arrows represent potential directions of movement for water and solid material between the subzones of a zone and out of that zone to a sink (Helton 1981a) these compartments, such as location and flow rate, are identical, except for nuclide-specific parameters such as K_d values. Mathematically, the process may be described in terms of the following system of linear differential equations:

$$f_i'(t) = R_i(t) + \sum_{j=1}^{i-1} a_{ji}f_j(t) - k_i + \sum_{\substack{j=1 \\ j\neq i}}^{M} a_{ij} \quad f_i(t) \quad \sum_{j=i+1}^{M} a_{ji}f_j(t) \qquad (7)$$

where M = number of compartments

$f_i(t)$ = amount of radionuclide present in compartment i, at time t

$R_i(t)$ = rate of radionuclide input to compartment i

a_{ij} = coefficient of radionuclide transfer from compartment i to compartment j

k_i = decay constant for radionuclide i

The partitioning of radionuclide concentrations in each subzone between the solid and liquid phases is given by the distribution coefficient K_d.

The equations used in the Transport-to-Man Submodel are quite simple, generally involving the product of a concentration factor, a concentration in the medium such as water or soil, and an inhalation or ingestion rate. These equations are generally the same as those used in PABLM, except that the long halflives of high-level waste nuclides allow decay to be neglected in this portion of the model. Another important difference is that the concentration equations in PATH1, unlike those in PABLM, allow for the removal of radionuclides from soil due to the process of weathering. In addition, PATH1 considers the resuspension exposure pathway, while PABLM does not.

<u>Numerical Approximations</u> - None

Probabilistic or Statistical Aspects - This code can be run with the ground-water code NWFT/DVM using a Latin hypercube sampling routine. The results of such an exercise are a distribution of possible environmental contamination levels as a function of uncertainty of the ground-water transport model, of the parameters used to define the site, or of the parameters defining the nuclide distributions.

Assumptions and Simplifications - The main assumptions and simplifications in PATH1 are as follows:

- The area under study can be subdivided into discrete zones with relatively homogeneous properties in regard to sediment, ground water, surface water, and soil.
- Flows between zones are assumed to take place from one surface-water subzone to another
- Flows into and out of the ground-water subzone will involve only water
- Radionuclides are uniformly distributed through each subzone and are partitioned between the liquid and solid phases on the basis of their distribution coefficients
- The flow of water and solid material between subzones or out of the system is the only mechanism involved in the physical transport of radionuclides
- All radionuclides associated with a phase, liquid or solid, remain with that phase in movements between subzones or out of the system
- Radioactive decay is not treated in the Transport-to-Man Submodel

DOSHEM

Purpose and Scope - DOSHEM uses the radionuclide concentrations calculated by PATH1 to estimate the inhalation, ingestion, and external dose to man, along with the attendant health risks.

Authors - DOSHEM was written by G. E. Runkle and R. M. Cranwell of Sandia National Laboratories.

Code Functions - DOSHEM accounts for the following exposure pathways: ingestion, inhalation, exposure to contaminated ground and sediment, and immersion in air and water. The program combines the dose factor for each exposure pathway, radionuclide, and organ of interest and calculates the whole-body and individual-organ doses for each radionuclide of the inventory. The doses from all radionuclides in the inventory are summed to provide the total dose from the exposure to releases from geologically deposited radioactive wastes. This total dose is used to estimate the increased risk of an individual dying of cancer.

Potential Usage - DOSHEM provides a method for directly estimating health effects associated with radioactive waste disposal. The model requires input generated by the Sandia PATH1 model.

Availability - DOSHEM can be obtained through the NRC from Sandia National Laboratory.

General Critique - The DOSHEM code is an integral part of the Sandia National Laboratories' assessment of long-term risks due to disposal of radioactive waste in deep geologic media. As is the case with most radiological assessment codes, however, the validity of the code depends more on the accuracy of the many input parameters than on the formulations used in the program. Whether DOSHEM will be applicable to a particular site will depend on the validity of the choices of compartments and rate coefficients for the PATH1 runs that generate input for DOSHEM.

Operating Characteristics - DOSHEM is written in FORTRAN and runs on Control Data Computers.

Inputs - The inputs to DOSHEM include:

- Identification of radionuclides to be considered
- Inhalation and ingestion dose conversion factors (rem/ Ci/yr) for each radionuclide and for each of the following organs: total body, bone, thyroid, liver, kidneys, lungs, and lower large intestine. A data base of committed dose factors for a 70-year exposure and a 70-year commitment time is provided with the code.
- Usage parameters
- Risk factor estimators

Outputs - The major outputs from DOSHEM are the following:

- Dose from ingestion, inhalation, and external exposure for each body organ, zone, and pathway as a function of time
- Total dose as a function of time
- Individual cancer risk as a function of time

Available Documentation - DOSHEM is documented in Runkle (1981 a,b; 1983)

Equations - Although the dose rate factors are input to the DOSHEM code in the form of a library, most of the theoretical significance of the code is embodied in the dose factor calculation even though it is performed externally.

The factors supplied that relate intake of radionuclide to dose to organ k from the intake (ingestion or inhalation) of radionuclide i are calculated in a method that is essentially identical to that described above for PABLM. The recent National Research Council report (National Research Council 1983) on geologic repositories compared the dose results from PABLM with those used for DOSHEM in an Appendix. The conclusion drawn was that "they are essentially identical to the PNL dose factors" (National Research Council 1983, p. 344).

The cancer risk to an individual is calculated by multiplying the individual lifetime dose by user-provided risk-per-rem factors. Those currently described with the code are taken from BEIR-II (1972).

Assumptions and Simplifications - The principal assumption in DOSHEM is that the transport of radionuclides through the food chain can be described by use of concentration factors rather than through an analysis of time-dependent compartmental transfers.

Structure and Level of Detail - DOSHEM calculates the latent cancer risk to an individual for seven different types of cancer based upon the internal and external dose received from the release of radionuclides from a waste repository site. Internal dose is calculated for the following organs: bone, thyroid, liver, kidneys, lungs, lower large intestine, and total body. Doses for air submersion, water submersion, and exposure to contaminated ground are calculated for both skin and body. Any number of radionuclides and zones can be accommodated by the model.

IV. COMPARISON OF THE DOE AND NRC MODELS

The calculational flow from model to model is given for the NRC/Sandia models in Figure 2 (Helton 1981a). The squares represent models in the risk assessment methodology. The brackets represent the output of the preceding model and the input to the next model. A similar flow scheme is given as Figure 3 for the DOE methodology. Both environmental consequence methods begin with the time-dependent discharge of radionuclides to the biosphere. In the NRC approach, the PATH1 model then can be used to determine the concentrations of radionuclides in surface water, sediments, and soils for various "zones;" i.e., for various physical locations downstream of the release points. This is really the only difference between the NRC approach and the DOE approach as used to date: the DOE method does not always require definition of multiple "zones." For the DOE assessments that have been performed, only one zone, located at the site of a well or on a nearby river, has been used. However, as shown in Figure 3, the capability to model more than one zone is available; only a hydrology/sediment/radionuclide transport code is needed. A number of these are reviewed by Onishi (1981), and several appear to be applicable. In addition, the PATH1 model does not perform the hydrology/mass transport calculations itself; these inputs are required as a driver to the code, so the DOE and NRC approaches still require equivalent input. For both approaches, once the water and soil nuclide concentrations are known, a concentration ratio method is used to determine the concentrations in foods. The food concentrations are then used with input consumption rates to determine human intake of radionuclides, from which the doses are then calculated. While in the PATH1/DOSHEM method this is performed in two separate programs, and in the PABLM code the steps are combined, the models used are essentially the same. The DOSHEM dosimetry file is in fact derived from the same background information as the PABLM libraries. The present DOE approach is to stop at individual and population dose. The NRC approach goes one

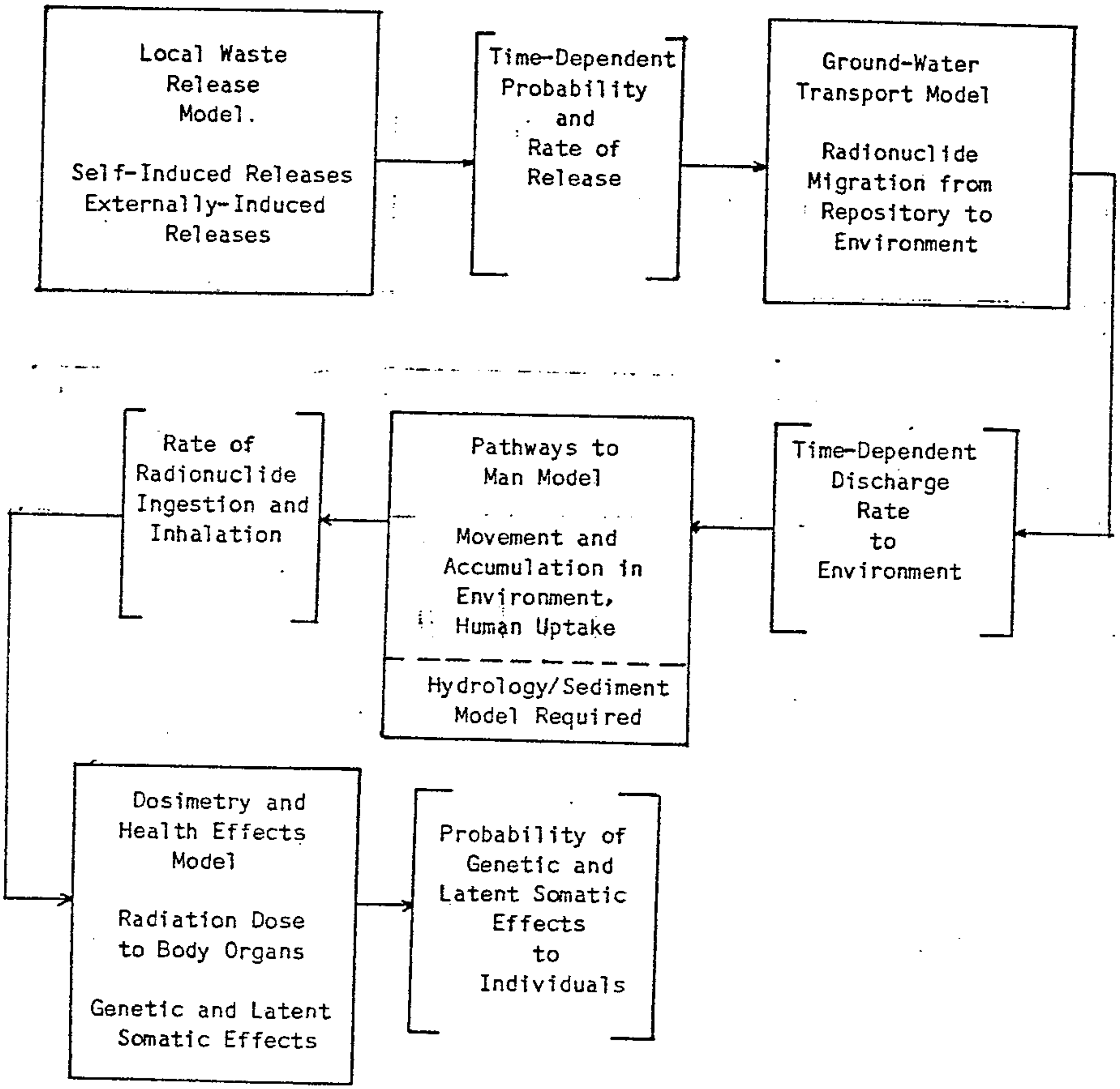

FIGURE 2. NRC/Sandia Models for Physical Processes (adapted from Helton 1981)

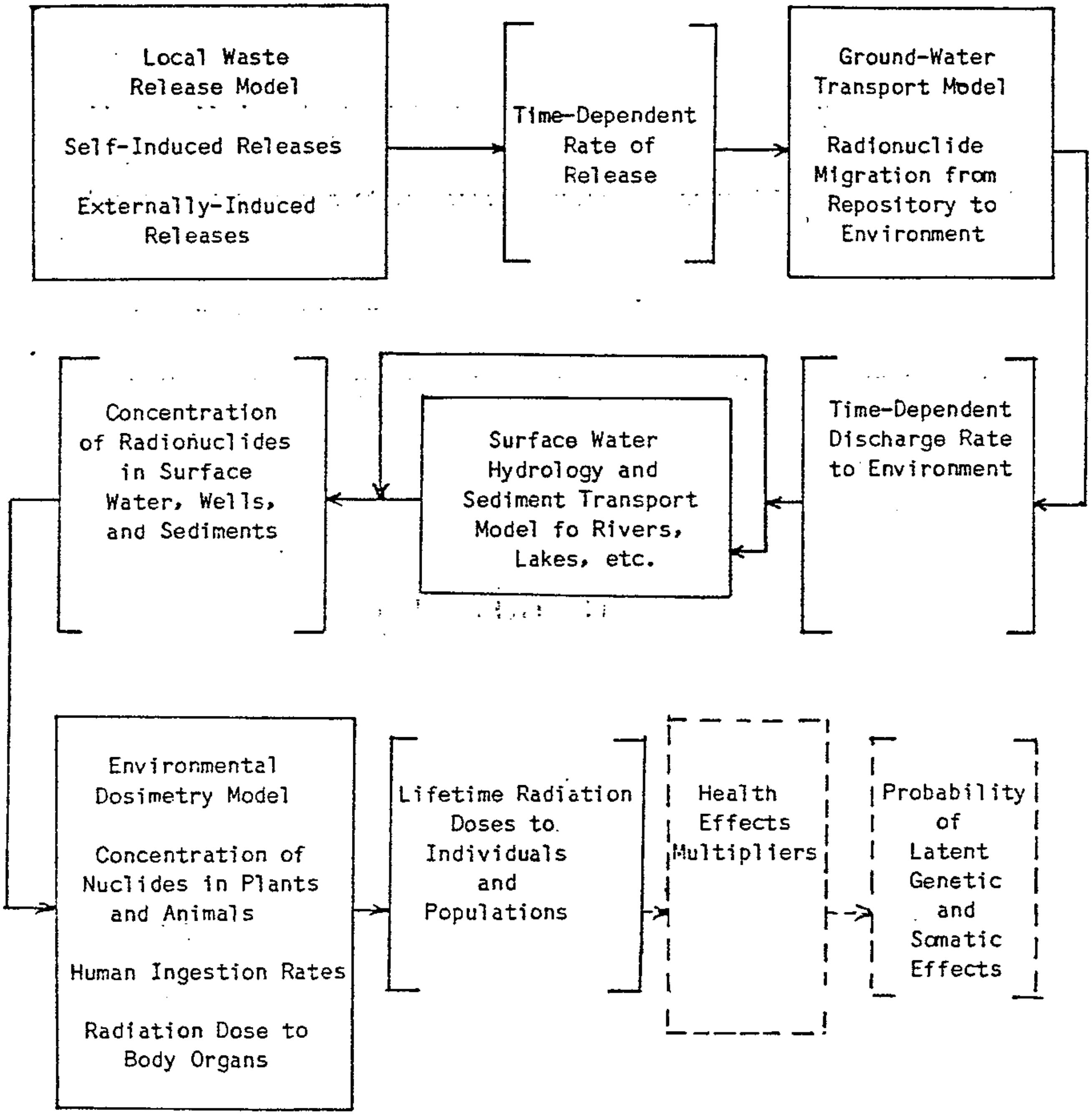

FIGURE 3. DOE Models for Physical Processes

step further and applies a dose-to-risk conversion factor to obtain risk estimates for individuals. Aside from the question of whether individual risks should be the basis of the assessment, the DOE results from PABLM could be put on the same footing with only a hand-multiplication of the doses with the same dose-to-risk factors. This is indicated in Figure 3 by the dotted boxes.

Detailed evaluation of the inputs, outputs, and models involved in each step of the evaluation are provided below.

A. Surface Radionuclide Transport

The rationale for the development of the PATH1 model for surface transport is given by Helton (1981a, pp. 18-19) as:

> "A general and adaptable model is needed to represent the transport and distribution of radionuclides through the environment. It must be possible to fit the model to the surface environment of different candidate disposal sites and to adapt it to the surface discharge patterns that are indicated by the Ground-Water Transport Model. Further, the capability must exist to incorporate areas into the model which are not initially affected by a radionuclide release but which may eventually be affected because of surface transport."

The DOE assessments to date have only looked at the zone including the discharge point, mostly because the source of contamination is most concentrated at that point (personal communication, F. H. Dove to B. A. Napier, July 1983), and also because the presently proposed EPA and NRC regulations do not require a detailed analysis of public dose over long time periods from repository leakage (EPA 1982, NRC 1982).

The NRC approach to multiple zones is illustrated in Figure 4, which is an elaboration of the "Environmental Transport" model shown in Figure 1. All exposure pathways within each zone are assumed to originate from within homogeneously mixed compartments.

The "Transport-to-Man" and "Dose-to-Man" portions of the calculation are superimposed on each of these zones, following the environmental transport calculation. The DOE approach is shown as Figure 5. Within the one zone, the pathways may have differing concentrations depending on the exposure scenario. It can be seen that if the DOE approach were to be sequentially applied to more than one zone, the result would be equivalent to the NRC approach. This could be done by using an independent hydrology/mass transport code to determine the input water concentrations. Equivalently, the NRC approach could be limited to one zone.

Onishi (1981) reviewed several models for surface water transport. He identified five models that perform not only the hydrology/sediment transport, as required for the PATH1 input, but that also fill the requirements for PABLM in calculating nuclide transport. When long-term radionuclide migration and accumulation are under consideration, dissolved and particulate forms of a radionuclide must be solved simultaneously by including full sediment-radionuclide interactions. Sediment-radionuclide interactions involve radionuclide adsorption/desorption, and transport, deposition and scouring of radionuclides sorbed by sediment. For these cases, the following five models can be used:

One-dimensional model for rivers developed by Shull and Gloyna (1968)

One-dimensional model (TODAM) for rivers and well-mixed estuaries developed by Onishi et al. (1978)

Two-dimensional model (SERATRA) for rivers and river-run reservoirs developed by Onishi et al. (1979a)

Two-dimensional model (FETRA) for coastal waters and well mixed estuaries developed by Onishi et al. (1979b)

One-dimensional model for rivers developed by Fields (1976).

All of the above five models have been applied to actual sites, and some of them were partially verified with field data. However, more complete model verification is needed. Because the input necessary to run these models is required for either the NRC or DOE approach, if surface water modeling is applied, no further evaluation of differences is given.

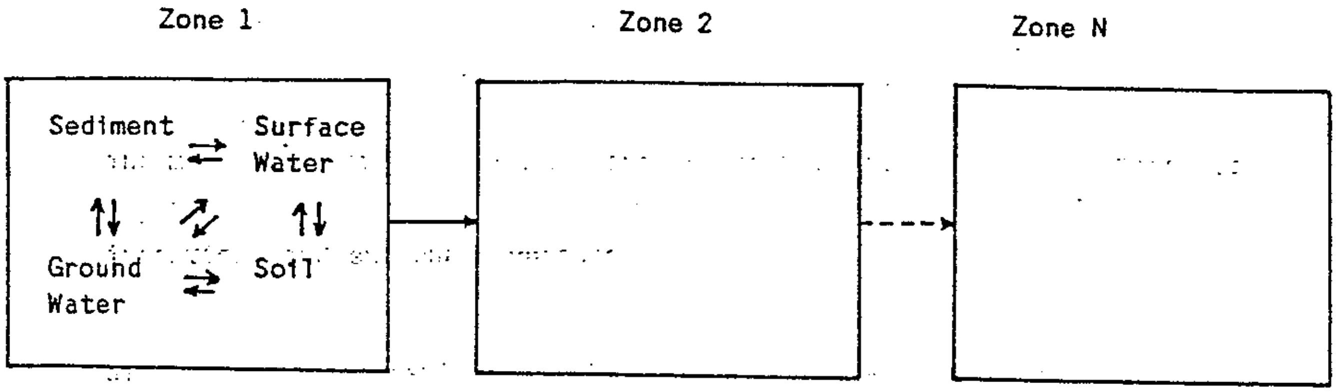

FIGURE 4. The PATH1 Approach to Multiple Zones of Contamination, All Exposure Pathways See the Same Contamination

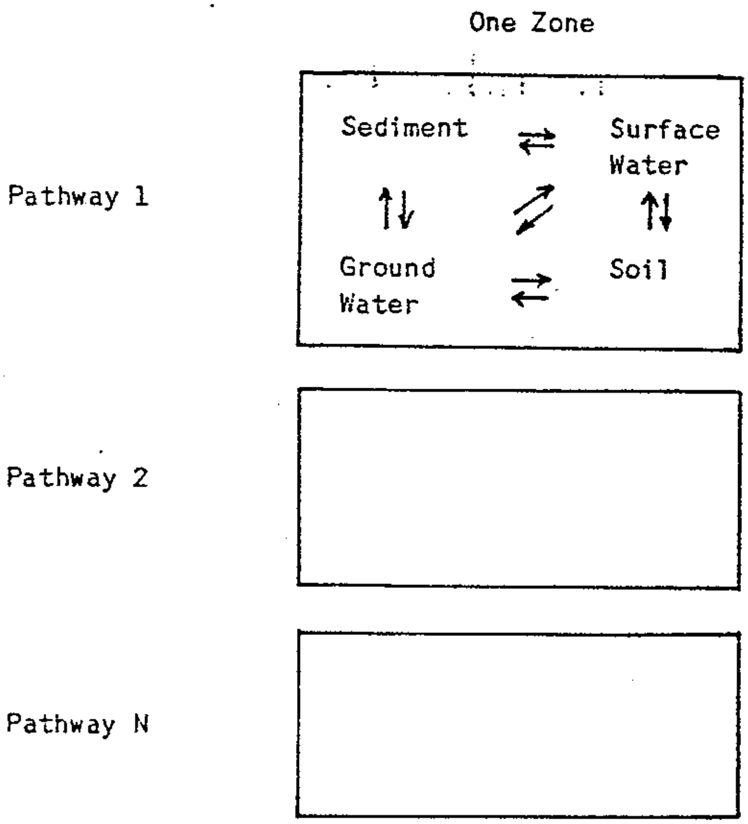

FIGURE 5. The PABLM Approach to Multiple Exposure Pathways Within One Zone

B. Radionuclide Transport-to-Man

Once the environmental distribution of radionuclides is determined, using either the NRC/Sandia PATH1 models or the early subroutines in PABLM, it is necessary to determine the quantity of radionuclides reaching man, using either the NRC Transport-to-Man model or the intermediate portions of PABLM. The various routes of exposure are inhalation, ingestion, and external exposure.

The NRC model includes a term for suspension of contaminated soil in air, to obtain an estimate of inhalation dose. A simple resuspension factor model is incorporated. The DOE PABLM model does not include a term for inhalation. The Sandia documentation states that "since nuclides must reach the surface and then be suspended before inhalation, this probably will not be an important pathway." Previous PNL studies for the NRC have shown this to be the case. A study of long-term public doses for low-level waste burial grounds, performed using a computer code derived from PABLM, showed that even for concentrated wastes in surface soils, the inhalation contribution was generally a minimum of two orders of magnitude lower than the ingestion contribution (Murphy and Holter 1980).

In the NRC model, no allowance is made for radioactive decay in the quantity of radionuclides in the Transport-to-Man model during production or storage of foods. While the PABLM models do allow for decay during holdup, this should be a negligible difference in simulating repository impacts. The long halflives of the materials involved results in minimal reduction during the short food-handling and storage periods. This omission, however, does preclude the use of the general NRC methodology for determining impacts from any other source that might have shorter-lived materials, such as the repository during the operational period. PABLM can be used for analyzing the safety of the operation as well as the long-term acceptability of the repository.

Concentration of nuclides in plants is a function of foliar deposition and root uptake. Both PATH1 and PABLM assume foliar deposition from overhead sprinkler irrigation, with an interception fraction of 0.25. Both codes also incorporate a weathering halftime of 14 days.

For root uptake, both codes rely on concentration factors. The factors used by PATH1 are taken from U.S. NRC Regulatory Guide 1.109 (NRC 1976). The PABLM factors deviate only slightly from the 1.109 values. PABLM will handle more discrete pathways than will PATH1, but the level of detail is generally superfluous and not used.

Calculation of radionuclide concentrations in aquatic food products in also done using concentration ratios. Again, PATH1 factors are taken from Regulatory Guide 1.109, and the PABLM factors are similar. Both PABLM and PATH1 account for cleanup of drinking water by water treatment plants; both codes use a removal factor based on work by Soldat (1976).

Finally, both codes require definition of human ingestion rates of the various crops. These are in general scenario and site-specific, depending on what crops are grown locally. The PATH1 documentation suggests default values taken from Regulatory Guide 1.109 (NRC 1976); these could be used in PABLM as well. Work done to date with PABLM has often used the default parameters for the Hanford Site (Napier 1981).

C. Human Dosimetry and Health Effects

The general equation for calculating dose per unit intake are presented in Section III.A. for PABLM. The same equation was used to develop the DOSHEM dose factors. The results are essentially identical (National Research Council 1983). The application of the dose factors differs only slightly between PABLM and DOSHEM. Both codes consider a 70-year lifetime exposure. In DOSHEM, this exposure is assumed to be constant, but in PABLM the exposure varies from year to year as the radionuclides accumulate in the soil from continuous irrigation. The net result in either case will generally not be too dissimilar. Schreckhise (1980) has compared soil accumulation results of a simple model like PABLM with a more sophisticated compartment model like PATH1. This comparison showed that, for the case of 10% overwatering (good farming practice to avoid salt buildup in soil), the PABLM-like model tended to slightly overpredict the soil concentration of nuclides that are only slightly sorbed by soils (i.e., those that are likely to be seen leaching from the repository) at the end of the accumulation period. Since the PABLM approach has an initial soil concentration of zero, the early underprediction and the later overprediction would tend to cancel out. The root uptake is only a portion of the total plant concentration (usually dominated by the foliar deposition from irrigation), so the dose results will be comparable.

The PATH1/DOSHEM combination is written to automatically consider variable time steps between dose calculations, and to calculate individual doses at certain points in time. Past applications of PABLM have only looked at selected times of peak nuclide concentration. A recent simplified simulator has incorporated PABLM to automatically calculate doses at many time periods, and to select the highest period (Petrie 1983). Thus, the DOE approach is evolving into one similar to that of NRC.

The calculation of health effects from the dose values is performed in DOSHEM as a simple multiple of dose with dose-to-risk factors. These factors are required input to the code. The factors presently being used are derived from BEIR-II (Ruhkle 1981a,b), with corrections for the fraction of a lifetime falling within each of the BEIR age groups. The PABLM code does not perform health effects calculations.

The DOSHEM output consists of a table of increased probabilities of cancer to an individual as a function of time. This does not relate to either the existing NRC/DOE/EPA regulations on individual dose, nor to the proposed EPA standards (EPA 1982) that are loosely based on total numbers of health effects in populations. At this time, it is not apparent what use the NRC will make of the DOSHEM results in evaluating performance assessments.

D. Probabilistic Analyses and Model Accuracy

The PATH1 environmental transport portions have been run with the NRC/Sandia ground-water code using Latin hypercube sampling of a range of parameters. The ostensible reasons for this were to 1) develop a capability to perform sensitivity analyses, and 2) to acquire insight into the variables which influence the predictions made by the transport model. No calculations were applied to the Transport-to-Man or

Dosimetry portions of the model. This author concurs with the observation made by Stevens et al. (1982) in their review of the work, that:

> "...the question remains as to how effective the proposed methodology is in predicting actual radionuclide concentration in soil and in surface water. In other words, a test of the model's validity has not been performed to date. The work that has been the might best be classified as a demonstration of the methodology. Little is said about the difficulties that are anticipated when applying the methodology to actual geophysical problems or release scenarios."

A similar study was performed by Zach (1980) on a model similar to PABLM. The results again were most useful in providing insight with regard to the controlling variables. This was, however, also only a method demonstration and not a test of the model validity.

In regard to model accuracy in general, the general consensus of an international workshop on accuracy in dose calculations, which included a session on "imprecision analysis" similar to the Sandia study, is relevant (Brussermann 1980):

> "The current calculational models allow an estimation of radiation exposure in the surroundings of nuclear facilities as a consequence of the emission of radioactive substances during normal operation and the resulting annual equivalent doses. Here, all relevant exposure pathways, including food chains can be considered, eventually by implementing site-specific modifications.
>
> "An exhaustive validation of the entire site-specific model is at present not possible because due to the low level of emissions intermediate values in the chain emission - radiation exposure e.g. the concentration in specific environmental media or food types, can not be correlated with their origin, the emission of the nuclear facility. Thus, the model prediction can not be verified. Furthermore, metabolic data of the exposed organisms can not be investigated for obvious reasons. Therefore, statements can only be based on a reasonable generalization. The 'reference man' is a example for this limitation. This situation, namely that the

specified conditions do not exactly apply to every case or person being considered and that the calculational model can not precisely consider all of the diverse distributing factors, must be accepted, at least for the time being. In the opinion of the workshop participants, these uncertainties can be tolerated against the background of the very small emissions."

V. SUMMARY

Both DOE and NRC require the capability to analyze the environmental consequences of radionuclide release from a geologic repository to the biosphere. The DOE approach has evolved over a period of several years' effort by the AEGIS program, the Office of Nuclear Waste Isolation, the various field sites, and DOE Headquarters. The NRC approach, developed by Sandia National Laboratories, has relied on much of the same data. Therefore, it is not surprising that the two approaches are internally very similar. The NRC method includes a model for environmental transport via surface waters, although that model requires additional simulations to provide input. The DOE to date has not analyzed beyond the point of entry of the radionuclides to the biosphere; however, models combining surface water/sediment transport and radionuclide transport are available, and, if used, the DOE and NRC methods would be both conceptually and numerically similar.

REFERENCES

BEIR-II, 1972. The Effects on Populations of Exposure to Low Levels of Ionizing Radiation, Advisory Committee on the Biological Effects of Ionizing Radiation, National Research Council, Washington D.C.

BEIR-III, 1980. The Effects on Populations of Exposure to Low Levels of Ionizing Radiation, Advisory Committie on the Biological Effects of Ionizing Radiation, National Research Council, Washington D.C.

Brussermann, K., Ed., 1983. Proceedings of a Workshop on "Accuracy in Dose Calculations for Radionuclides Released to the Environment", Aachen, Federal Republic of Germany

BWIP, 1983. Basalt Waste Isolation Project Performance Assessment Plan, SD-BWI-PAP-001, Rev 0.0, Rockwell Hanford Operations, Richland, Washington

Campbell, J.E., et al., 1978. Risk Methodology for Geologic Disposal of Radioactive Waste: Interim Report, NUREG/CR-0458, Sandia Laboratories, Albequerque, N.M.

Dove, F.H., 1983. Modeling Long-term Aspects of Nuclear Waste Disposal: The AEGIS Experience, PNL-SA-10694, Pacific Northwest Laboratory, Richland, Washington

EPA, 1982. 40 CFR Part 191, "Environmental Standards and Federal Radiation Protection Guidance for Management and Disposal of Spent Fuel, HLW, and TRU Wastes (Draft)"

Fields, D.E., 1976. LINSED: A One-Dimensional Multireach Sediment Transport Code, ORNL/CSD-15, Oak Ridge National Laboratory, Oak Ridge, Tennessee

Helton, J.C., and P.C. Kaestner, 1981a. Risk Methodology For Geologic Disposal of Radioactive Waste: Model Description and User Manual for Pathways Model, NUREG/CR-1636, Vol 1., Sandia Laboratories, Albequerque, New Mexico

Helton, J.C., and R.L. Iman, 1981b. Risk Methodology For Geologic Disposal of Radioactive Waste: Sensitivity Analysis of the Environmental Transport Model , NUREG/CR-1636, Vol 2., Sandia Laboratories, Albequerque, New Mexico

Helton, J.C., J.B. Brown, and R.L. Iman, 1981c. Risk Methodology For Geologic Disposal of Radioactive Waste: Asmyptotic Properties of the Environmental Transport Model , NUREG/CR-1636, Vol 3., Sandia Laboratories, Albequerque, New Mexico

ICRP-2, 1959. Report of Committee II on Permissible Dose for Internal Radiation, Publication 2, International Commission on Radiological Protection, Pergamon Press, Oxford

ICRP-26, 1977. Reccomendations of the International Commission on Radiological Protection, Publication 26, International Commission on Radiological Protection, Pergamon Press, Oxford

Mills, M. and D. Vogt, 1983. A Summary of Computer Codes for Radiological Assessment, NUREG/CR-3209, Teknekron Research, Inc., Bethesda, MD

Murphy, E.S., and G.M. Holter, 1980. Technology, Safety, and Costs of Decommissioning a Reference Low-Level Waste Burial Ground, Vol. 2, Appendix C, NUREG/CR-0570, Pacific Northwest Laboratory, Richland, WA

Napier, B.A., R.L. Roswell, W.E. Kennedy, Jr., and D.L. Strenge, 1980a. ARRRG and FOOD - Computer Programs For Calculating Radiation Dose To Man From Radionuclides in the Environment, PNL-3180, Pacific Northwest Laboratory, Richland, WA

Napier, B.A., W.E. Kennedy, Jr., and J.K. Soldat, 1980b. PABLM - A Computer Program to Calculate Accumulate Radiation Doses From Radionuclides in the Environment, PNL-3209, Pacific Northwest Laboratory, Richland, WA

Napier, B.A., 1981. Standardized Input For Hanford Evironmental Impact Statements, Part 1, PNL-3509 PT1, Pacific Northwest Laboratory, Richland, WA

Napier, B.A., A.E. Reisenauer, and D.L. Strenge, 1983. Collective Dose Over Long Time Periods Following Radionuclide Release To Ground-Water Systems, PNL-SA-11278, Pacific Northwest Laboratory, Richland, WA

National Research Council, 1983. A Study of the Isolation System for Geologic Disposal of Radioactive Wastes, National Research Council, National Academy of Sciences, Washington, D.C.

NRC, 1976. "Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating compliance with 10 CFR part 50, Appendix I", Regulatory Guide 1.109, U.S. Nuclear Regulatory Commission, Washington D.C.

NRC, 1982. 10 CFR Part 60, "Disposal of High-Level Radioactive Wastes In Geologic Repositories: Technical Criteria" (Draft), U.S. Nuclear Regulatory Commission

Onishi, Y., and S.E. Wise, 1978. Mathematical Modeling of Transport of Sediment and Kepone in the James River Estuary, PNL-2731, Pacific Northwest Laboratory, Richland, WA

Onishi, Y. and S.E. Wise, 1979a. "Finite Element Model for Sediment and Toxic Contaminant Transport in Streams', Proceedings of Hydraulics and Energy Divisions Special Conference of ASCE on Conservation and Utilization of Water and Energy+Sources, San Fransisco, CA pp. 144-150

Onishi, Y., E.M. Arnold, and D.W. Mayer, 1979b. Modified Finite Element Transport Model, FETRA, for Sediment and Radionuclide Migration in Open Coastal Waters, NUREG/CR-1026, Pacific Northwest Laboratory, Richland, WA

Onishi, Y., R.J. Serne, E.M. Arnold, C.E. Cowan, and F.L. Thompson, 1981. Critical Review: Radionuclide Transport, Sediment Transport, and Water Quality Modeling; and Radionuclide Adsorption/ Desorption Mechanisms, NUREG/CR-1322, Pacific Northwest Laboratory, Richland, WA

ONWI, 1983. Preliminary Performance Assessment Plan for a Nuclear Waste Repository in Salt, Office of Nuclear Waste Isolation, Columbus, Ohio

OWI, 1983. National Waste Terminal Storage Program: NWTS Performance Assessment Plan, Office of Waste Isolation, U.S. Department of Energy, Washington, D.C.

Petrie, G.M., S.C. Sceider, B.A. Napier, and J.C. Barnard, 1983. Simplified Codes for Performance Evaluation (SCOPE) of Radionuclide Transport, Version 1.0, PNL-4737, Pacific Northwest Laboratory, Richland, WA

Runkle, G.E., R.M. Cramwell, and J.D. Johnson, 1981a. "A Method for Estimating the Dose and Health Effects from Geologic Waste Disposal", SAND81-0003C, in CONF-810372--6. Sandia Labortaries, Albequerque, N.M.

Runkle, G.E., R.M. Cranwell, and J.D. Johnson, 1981b. Risk Methodology For Geologic Disposal of Radioactive Waste: Dosimetry and Health Effects, NUREG/CR-2166, Sandia Laboratories, Albequerque, N.M.

Runkle, G.E., and N.C. Finley, 1983. Dosimetry and Health Effects Self-Teaching Curriculum, NUREG/CR-2422, Sandia Laboratories, Albequerque, N.M.

Schreckhise, R.G., 1980. Simulation of the Long-Term Accumulation of Radiocontaminants in Crop Plants, PNL-2636, Pacific Northwest Laboratory, Richland, WA

Soldat, J.K., 1976. "Aquatic Exposure Pathways - Potential Exposure of Man from Environmental Transport of Waste Nuclides", International Symposium on the Management of Wastes from the LWR Fuel Cycle, pp 539-553

Shull, R.D., and E.F. Gloyna, 1968. Radioactivity Transport in Water-- Simulation of Sustained Releases to Selected River Environments, EHE-04-6801, Technical Report No. 15 to the U.S. Atomic Energy Commission, University of Texas, Austin TX

Stevens, C.A., R.R. Fullwood, B. Amirijafari, S.L. Basin, J. Cohen, and D. Kaul, 1982. Risk Assessment Methodology Development for Waste Isolation in Geologic Media, NUREG/CR-1672, Science Applications, Inc., Palo Alto, CA

Zach, R., 1980. Sensitivity Analysis of the Terrestrial Food Chain Model FOOD III, AECL-6794, Whiteshell Nuclear Research Establishment, Pinawa, Manitoba

APPENDIX B

APPENDIX B

CALCULATED INDIVIDUAL DOSES PER UNIT CONCENTRATION OF RADIONUCLIDES RELEASED TO THE ENVIRONMENT: COMPARISON OF RESULTS FROM MODELS OF PACIFIC NORTHWEST LABORATORY (PNL) AND ATOMIC ENERGY OF CANADA LIMITED (AECL)

Table B-1 compares results from two different environmental pathways and dosimetry modeling computer codes that have been used to assess radioactivity releases to the environment from conceptual high-level waste repositories. It is of interest to examine results of independent calculations to gain understanding of the sensitivity of calculated results to assumptions and parameters used to characterize environmental transport and human exposure. As a first step toward this objective, we have used data from results of preliminary calculations performed by the Canadian National Nuclear Fuel Waste Management Program, as reported by Wuschke et al. (1981), for several radionuclides. These are compared with the Battelle Pacific Northwest Laboratory (PNL) data used in the waste-isolation system performance calculations described in Chapter 9.

The most useful comparison, consistent with the performance assessment approach described in Chapter 9, examines dose rates to an individual that result from a unit concentration (1 Bq/m^3) of a radionuclide reaching the environment. In this discussion, "environment" refers to a location or an environmental medium where radionuclides calculated to have been released from a repository are available for causing radiation exposure to humans. However, because of the somewhat different approaches used by the PNL and AECL groups in calculating environmental transport and doses, and because only limited data were available from the AECL calculations (Wuschke et al. 1981), the bases for the comparison in Table B-1 are not completely consistent.

The Table B-1 data taken from Table 9-1 of Chapter 9 give the average yearly dose to an individual calculated from an assumed continuous 70-year intake of contaminated water and food grown from this water. The PNL computer code PABLM, from which these data are derived, calculates an individual's intake as a time-dependent function of the radionuclide concentration in environmental media (Napier et al. 1980). For the comparison in Table B-1, only those pathways to man initiated by contaminated surface water are considered. In the calculation used here, it is assumed that a constant-unit concentration (1 Bq/m^3) of a radionuclide is in the surface water during the 70-year lifetime of an individual. The PABLM code calculates the committed dose equivalent for each year's intake of radioactivity and adds it to the cumulative committed dose from previous yearly incremental intakes. That is, for the first year of the individual's life, the 70-year committed dose that

TABLE B-1 Average Annual dose to an Individual per Unit Concentration of Radioactivity in Water

Radionuclide	Average Annual Dose per Unit Concentration ($Sv-m^3/Bq-yr$) Table 9-1[a]	Wuschke et al.[b]
^{79}Se	1.6×10^{-7}	7.9×10^{-9}
^{99}Tc	7.0×10^{-10}	6.1×10^{-10}
^{129}I	2.0×10^{-8}	9.1×10^{-11}
^{135}Cs	5.3×10^{-8}	1.6×10^{-8}
^{210}Pb	7.7×10^{-6} [c]	4.9×10^{-6}
^{225}Ra	1.4×10^{-6}	1.7×10^{-7}
^{226}Ra	2.4×10^{-6} [d]	4.1×10^{-6}
^{229}Th	5.6×10^{-7}	6.4×10^{-6}
^{230}Th	8.0×10^{-8}	3.4×10^{-4}
^{233}U	3.8×10^{-8}	4.8×10^{-8}
^{234}U	3.8×10^{-8}	4.8×10^{-8}
^{238}U	2.9×10^{-8}	4.2×10^{-8}
^{237}Np	1.3×10^{-5} [e]	6.5×10^{-6}
^{239}Pu	9.8×10^{-9}	6.1×10^{-8}

NOTE: All data rounded to two significant digits.

[a] Average annual "total-body" dose resulting from 1 Bq/m^3 in water (constant concentration over 70 years); derived from data of B. A. Napier (Battelle Pacific Northwest Laboratory, personal communication to T. H. Pigford, 1982) for 70-year committed dose from 70-year intake of water and food.

[b] Fifty-year committed effective dose equivalent from water and food taken in during first year; derived from data of Wuschke et al. (1981).

[c] Increased by a factor of 4.4 above data of B. A. Napier (Battelle Pacific Northwest Laboratory, personal communication to T. H. Pigford, 1982) to allow for ICRP-30 corrections (Runkle and Soldat 1982).

[d] Reduced by factor of 90 below data of B. A. Napier (Battelle Pacific Northwest Laboratory, personal communication to T. H. Pigford, 1982) to allow for ICRP-30 corrections (Runkle and Soldat 1982).

[e] Increased by a factor of 200 above data of B. A. Napier (Battelle Pacific Northwest Laboratory, personal communication to T. H. Pigford, 1982) to allow for ICRP-30 corrections (Runkle and Soldat 1982).

results from the intake is calculated; for the second year's intake, the 69-year committed dose is calculated and added to the result from the first year's intake; and so on to obtain the total 70-year lifetime dose. To obtain the average yearly contribution to the committed dose per unit concentration in water (Table 9-1 data in Table B-1), the 70-year lifetime dose per unit concentration of each radionuclide in surface water is divided by 70.

As explained in Appendix C, the doses calculated by the PABLM code for internally deposited radionuclides are based on the physical dosimetry models of the International Commission on Radiological Protection (1959) Publication 2, hereafter referred to as ICRP-2. The ICRP-2 model for the whole body or total body assumes that the internally deposited radionuclide is concentrated at the center of a 70-kg sphere of tissue. The time-dependent metabolic behavior of each radionuclide is characterized by an "effective biological half-life" representative of the body in its entirety (B. A. Napier, Battelle Pacific Northwest Laboratory, personal communication to T. H. Pigford, 1982). It should be noted that in this instance the effective biological half-life is distinguished from the "effective half-life" used in the ICRP-2 dosimetry system, as the latter term includes radioactive decay. The data for lead-210, radium-226, and neptunium-237 from B. A. Napier (Battelle Pacific Northwest Laboratory, personal communication to T. H. Pigford, 1982) have been adjusted to account for ICRP-30 corrections (International Commission on Radiological Protection 1979) according to the method of Runkle and Soldat (1982). The numerical adjustment to each is shown in the footnotes of Table B-1.

The AECL models (Wuschke et al. 1981) calculate 50-year committed dose equivalents to an individual in the form of effective dose equivalent, defined by International Commission on Radiological Protection (1977), Publication 26, as opposed to the total body dose calculated by the PABLM code (Napier et al. 1980), which is used to obtain the PNL doses. The doses from Wuschke et al. in Table B-1 represent the 50-year dose commitment to an individual that results from a unit concentration (1 Bq/m^3) of a radionuclide reaching the "environment" from a repository. These values are, in effect, the maximum annual dose commitment rates to an individual from 1 Bq/m^3 (average annual concentration) in water.

The Canadian models calculate dose to man from terrestrial and aquatic food chains from radionuclides released to groundwater, soil pore water, and surface water. The distribution of radioactivity between the solid and liquid phases in the soil compartment is characterized by the equilibrium distribution coefficient K_d. The value selected for K_d affects the transfer of radioactivity from the soil compartment to the water compartments and to plants. The data from Wuschke et al. in Table B-1 are for a case where the concentrations in all the water compartments are equal. The results given here are for values of K_d selected at the low end of the range of K_d values given for each radionuclide (Wuschke et al. 1981).

The doses shown in Table B-1 from both data sources are calculated for an individual who obtains all his drinking water from the contaminated water and all his food from plants and animals whose water is obtained from the same contaminated water sources. The individual is thus, in effect, the maximally exposed individual at the site characterized by the respective environmental pathway and dosimetry models.

REFERENCES

International Commission on Radiological Protection. 1959. Report of Committee II on Permissible Dose for Internal Radiation. Publication 2. New York: Pergamon.

International Commission on Radiological Protection. 1977. Recommendations of the International Commission on Radiological Protection. Publication 26. New York: Pergamon.

International Commission on Radiological Protection. 1979. Limits for Intakes of Radionuclides by Workers. Publication 30, Part 1. New York: Pergamon.

Napier, B. A., W. E. Kennedy, and J. K. Soldat. 1980. PABLM--A Computer Program for Calculating Accumulated Radiation Doses from Radionuclides in the Environment. PNL-3209. Pacific Northwest Laboratory, Battelle Memorial Institute, Richland, Wash.

Runkle, G. E., and J. K. Soldat. 1982. Comparison of ICRP-2 and ICRP-30 for estimating the dose and adverse health effects from potential radionuclide releases from a geologic waste repository. Proceedings of the Waste Management 1982 Symposium. SAND81-2163C. Sandia National Laboratories, Albuquerque, N.Mex.

Wuschke, D. M., K. K. Mehta, K. W. Dormuth, T. Andres, G. R. Sherman, E. L. J. Rosinger, B. W. Goodwin, J. A. K. Reid, and R. B. Lyon. 1981. Environmental and Safety Assessment Studies for Nuclear Fuel Waste Managèment, Vol. 3: Post-Closure Assessment. TR-127-3. Atomic Energy of Canada Ltd., Ottawa.

APPENDIX C

APPENDIX C

INGESTION DOSE FACTORS FOR RADIONUCLIDES OF INTEREST IN ASSESSMENTS OF HIGH-LEVEL WASTE-ISOLATION SYSTEM PERFORMANCE

Table C-1 contains ingestion dose factors from four separate sources for 30 long-lived radionuclides contained in high-level radioactive waste. The factors give the committed dose equivalent to an individual resulting from the intake in food, liquids, or drinking water of a unit amount of a radionuclide. The table is arrayed to allow comparisons of dose factors from the four sources for each organ-nuclide combination of interest. Each dose factor is given in units of sieverts per becquerel and, immediately beneath, in units of rem per curie.

The first row of dose factors, identified as EPA, are from Appendix F of the report by Smith et al. (1981), which was prepared as part of the supporting analysis for the proposed Environmental Protection Agency (EPA) high-level waste standard. The eight organs included are those used by EPA for calculating the number of fatal cancers in the derivation of the 10,000-year release limits as contained in the proposed standard (U.S. Environmental Protection Agency 1982, Table 2). Not included in this comparison are the dose factors for reproductive organs used by EPA to estimate "first generation" genetic effects. The EPA dose factors are 50-year committed dose equivalents from an initial intake at time zero. The principal source for the EPA dose factors is an early compilation prepared at Oak Ridge National Laboratory of the INREM II internal dosimetry model (Killough et al. 1978; G. G. Killough, Oak Ridge National Laboratory, personal communication to B. J. Mann, 1982). The EPA report by Smith et al. (1981) contains detailed explanations of adjustments to the INREM dose factors made by EPA and identifies other sources of dose factor data used by EPA. The EPA entry in Table C-1 under the total body column heading is identified as the dose to "other organs" in the EPA report (Smith et al. 1981). It is essentially the sum of the dose contributions to a volume equivalent to the "whole body" from the radionuclide deposited in the 22 source organs of the INREM II model (Killough et al. 1978). Care should be taken to distinguish this entry in the table from the total body entries of the other data sources.

The INREM II results in Table C-1 are from a recent update (Dunning et al. 1981) that includes results of some modifications in the INREM II dosimetry and metabolic models, as well as changes in metabolic data for some elements. The total body data entries here are effective dose equivalents, based on the International Commission on Radiological

TABLE C-1 Ingestion Dose Factor Compilation

Nuclide	Bone[a]	Red Marrow[a]	Lung	Liver	GI-LLI	Thyroid	Kidney	Total Body[b]
^{14}C								
EPA[c]	3.2×10^{-10}	9.2×10^{-10}	2.3×10^{-10}	3.2×10^{-10}	4.0×10^{-10}	2.4×10^{-10}	3.0×10^{-10}	5.1×10^{-10}
	1.2×10^{3}	3.4×10^{3}	8.5×10^{2}	1.2×10^{3}	1.5×10^{3}	8.9×10^{2}	1.1×10^{3}	1.9×10^{3}
INREM II[c]	3.2×10^{-10}	9.2×10^{-10}	2.3×10^{-10}	3.2×10^{-10}	4.0×10^{-10}	2.4×10^{-10}	3.0×10^{-10}	4.2×10^{-10}
	1.2×10^{3}	3.4×10^{3}	8.5×10^{2}	1.2×10^{3}	1.5×10^{3}	8.9×10^{2}	1.1×10^{3}	1.5×10^{3}
ICRP-30[c]	5.6×10^{-10}	5.6×10^{-10}	5.6×10^{-10}	5.6×10^{-10}	5.6×10^{-10}	5.6×10^{-10}	5.6×10^{-10}	5.6×10^{-10}
	2.1×10^{3}	2.1×10^{3}	2.1×10^{3}	2.1×10^{3}	2.1×10^{3}	2.1×10^{3}	2.1×10^{3}	2.1×10^{3}
PNL[d]	7.8×10^{-10}	—	1.5×10^{-10}	1.5×10^{-10}	1.5×10^{-10}	1.5×10^{-10}	1.5×10^{-10}	1.5×10^{-10}
	2.9×10^{3}	—	5.7×10^{2}	5.7×10^{2}	5.7×10^{2}	5.7×10^{2}	5.7×10^{2}	5.7×10^{2}
^{90}Sr								
EPA	3.2×10^{-7}	1.2×10^{-7}	4.3×10^{-15}	1.5×10^{-9}	5.4×10^{-8}	1.6×10^{-9}	1.6×10^{-9}	2.6×10^{-8}
	1.2×10^{6}	4.3×10^{5}	1.6×10^{-2}	5.7×10^{3}	2.0×10^{5}	6.0×10^{3}	6.0×10^{3}	9.5×10^{4}
INREM II	3.2×10^{-7}	1.2×10^{-7}	1.6×10^{-9}	1.5×10^{-9}	2.1×10^{-8}	1.6×10^{-9}	1.6×10^{-9}	2.3×10^{-8}
	1.2×10^{6}	4.3×10^{5}	6.0×10^{3}	5.7×10^{3}	7.8×10^{4}	6.0×10^{3}	6.0×10^{3}	8.7×10^{4}
ICRP-30	4.2×10^{-7}	1.9×10^{-7}	1.5×10^{-9}	1.5×10^{-9}	2.0×10^{-8}	1.5×10^{-9}	1.5×10^{-9}	3.9×10^{-8}
	1.5×10^{6}	7.2×10^{5}	5.6×10^{3}	5.6×10^{3}	7.3×10^{4}	5.6×10^{3}	5.6×10^{3}	1.4×10^{5}
PNL	1.0×10^{-6}	—	0.0	0.0	2.1×10^{-8}	0.0	0.0	2.7×10^{-7}
	3.9×10^{6}	—	0.0	0.0	7.7×10^{4}	0.0	0.0	1.0×10^{6}
^{93}ZR								
EPA	5.4×10^{-11}	8.9×10^{-11}	1.0×10^{-11}	3.8×10^{-10}	4.6×10^{-9}	4.6×10^{-9}	5.4×10^{-11}	6.8×10^{-11}
	2.0×10^{2}	3.3×10^{2}	3.9×10	1.4×10^{3}	1.7×10^{4}	1.7×10	2.0×10^{2}	2.5×10^{2}
INREM II	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—
ICRP-30	9.1×10^{-9}	7.4×10^{-10}	1.2×10^{-13}	8.3×10^{-14}	1.0×10^{-9}	7.3×10^{-14}	1.1×10^{-13}	3.6×10^{-10}
	3.4×10^{4}	2.7×10^{3}	4.3×10^{-1}	3.0×10^{-1}	3.7×10^{3}	2.7×10^{-1}	4.0×10^{-1}	1.3×10^{3}
PNL	1.1×10^{-11}	—	0.0	5.9×10^{-13}	7.3×10^{-10}	0.0	2.3×10^{-12}	3.0×10^{-13}
	4.2×10	—	0.0	2.2	2.7×10^{3}	0.0	8.6	1.1
^{99}Tc								
EPA	9.7×10^{-11}	8.7×10^{-11}	0.0	1.7×10^{-10}	8.7×10^{-11}	3.8×10^{-9}	1.2×10^{-10}	5.7×10^{-11}
	3.6×10^{2}	3.2×10^{2}	0.0	6.3×10^{2}	3.2×10^{3}	1.4×10^{4}	4.6×10^{2}	2.1×10^{2}
INREM II	9.7×10^{-11}	8.7×10^{-11}	8.7×10^{-11}	1.7×10^{-10}	8.7×10^{-10}	3.8×10^{-9}	1.2×10^{-10}	2.7×10^{-10}
	3.6×10^{2}	3.2×10^{2}	3.2×10^{2}	6.3×10^{2}	3.2×10^{3}	1.4×10^{4}	4.6×10^{2}	1.0×10^{3}
ICRP-30	6.0×10^{-11}	6.0×10^{-11}	6.0×10^{-11}	8.2×10^{-11}	1.1×10^{-9}	1.6×10^{-9}	6.0×10^{-11}	3.7×10^{-10}
	2.2×10^{2}	2.2×10^{2}	2.2×10^{2}	3.0×10^{2}	4.1×10^{3}	6.0×10^{3}	2.2×10^{2}	1.5×10^{3}
PNL	3.5×10^{-11}	—	4.3×10^{-12}	4.9×10^{-11}	1.8×10^{-12}	0.0	6.2×10^{-13}	1.3×10^{-11}
	1.3×10^{2}	—	1.6×10	1.8×10^{2}	6.8×10^{3}	0.0	2.3×10^{3}	5.0×10
^{126}Sn								
EPA	2.3×10^{-8}	2.3×10^{-8}	8.4×10^{-10}	4.6×10^{-10}	3.2×10^{-8}	1.3×10^{-10}	7.6×10^{-10}	7.6×10^{-10}
	8.6×10^{4}	8.6×10^{4}	3.1×10^{3}	1.7×10^{3}	1.2×10^{5}	5.0×10^{2}	2.8×10^{3}	2.8×10^{3}
INREM II	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—
ICRP-30	5.1×10^{-9}	2.7×10^{-9}	6.0×10^{-10}	6.9×10^{-10}	4.3×10^{-8}	5.5×10^{-10}	8.2×10^{-10}	6.2×10^{-9}
	1.9×10^{4}	1.0×10^{4}	2.2×10^{3}	2.5×10^{3}	1.6×10^{5}	2.0×10^{3}	3.0×10^{3}	2.3×10^{4}
PNL	2.3×10^{-8}	—	0.0	4.3×10^{-10}	7.3×10^{-9}	1.3×10^{-10}	0.0	6.5×10^{-10}
	8.4×10^{4}	—	0.0	1.6×10^{3}	2.7×10^{4}	4.9×10^{2}	0.0	2.4×10^{3}
^{151}Sm								
EPA	1.3×10^{-12}	8.7×10^{-13}	3.0×10^{-14}	4.6×10^{-12}	1.6×10^{-9}	2.7×10^{-14}	1.5×10^{-12}	6.2×10^{-12}
	4.9	3.2	1.1×10^{-1}	1.7×10	5.9×10^{3}	1.0×10^{-1}	5.5	2.3×10
INREM II	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—
ICRP-30	3.5×10^{-10}	2.8×10^{-11}	6.5×10^{-16}	9.2×10^{-11}	1.0×10^{-9}	3.3×10^{-17}	5.2×10^{-16}	9.1×10^{-11}
	1.3×10^{3}	1.0×10^{2}	2.4×10^{3}	3.4×10^{2}	3.7×10^{3}	1.2×10^{4}	1.9×10^{3}	3.4×10^{2}
PNL	1.9×10^{-11}	—	0.0	3.0×10^{-12}	1.6×10^{-9}	0.0	3.5×10^{-12}	7.8×10^{-13}
	6.9×10	—	0.0	1.1×10	5.8×10^{3}	0.0	1.3×10	2.9

TABLE C-1 *(continued)*

Nuclide	Bone[a]	Red Marrow[a]	Lung	Liver	GI-LLI	Thyroid	Kidney	Total Body[b]
^{225}Ra								
EPA	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—
INREM II	3.0×10^{-7}	3.0×10^{-7}	7.0×10^{-8}	7.0×10^{-8}	2.6×10^{-8}	7.0×10^{-8}	7.0×10^{-8}	1.7×10^{-7}
	1.1×10^{6}	1.1×10^{6}	2.6×10^{5}	2.6×10^{5}	9.7×10^{4}	2.6×10^{5}	2.6×10^{5}	6.2×10^{5}
ICRP-30	1.8×10^{-6}	1.7×10^{-7}	3.4×10^{-8}	3.4×10^{-8}	6.4×10^{-8}	3.4×10^{-8}	3.4×10^{-8}	1.0×10^{-7}
	6.6×10^{6}	6.2×10^{5}	1.3×10^{5}	1.3×10^{5}	2.4×10^{5}	1.3×10^{5}	1.3×10^{5}	3.7×10^{5}
PNL	1.8×10^{-6}	—	0.0	2.0×10^{-9}	9.2×10^{-8}	0.0	5.7×10^{-8}	3.5×10^{-7}
	6.6×10^{6}	—	0.0	7.4×10^{3}	3.4×10^{5}	0.0	2.1×10^{5}	1.3×10^{6}
^{226}Ra								
EPA	1.7×10^{-5}	5.7×10^{-7}	7.3×10^{-11}	5.1×10^{-7}	2.2×10^{-7}	2.2×10^{-7}	1.6×10^{-6}	2.1×10^{-6}
	6.3×10^{7}	2.1×10^{6}	2.7×10^{2}	1.9×10^{6}	8.2×10^{5}	8.0×10^{5}	5.8×10^{6}	7.8×10^{6}
INREM II	1.2×10^{-5}	5.9×10^{-7}	1.6×10^{-7}	1.6×10^{-7}	8.9×10^{-8}	1.6×10^{-7}	1.6×10^{-7}	3.8×10^{-7}
	4.3×10^{7}	2.2×10^{6}	5.9×10^{5}	5.9×10^{5}	3.3×10^{5}	5.9×10^{5}	5.9×10^{5}	1.4×10^{6}
ICRP-30	6.8×10^{-6}	6.0×10^{-7}	9.2×10^{-8}	9.1×10^{-8}	1.3×10^{-7}	9.1×10^{-8}	9.2×10^{-8}	3.6×10^{-7}
	3.4×10^{5}	2.2×10^{6}	3.4×10^{5}	4.9×10^{5}	3.4×10^{5}	3.4×10^{5}	3.4×10^{5}	1.3×10^{6}
PNL	1.0×10^{-4}	—	0.0	0.0	1.0×10^{-7}	0.0	0.0	6.8×10^{-5}
	3.7×10^{8}	—	0.0	0.0	3.7×10^{5}	0.0	0.0	2.5×10^{8}
^{229}Th								
EPA	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—
INREM II	8.7×10^{-7}	7.0×10^{-7}	2.7×10^{-9}	9.7×10^{-9}	5.7×10^{-8}	2.5×10^{-9}	2.5×10^{-9}	3.5×10^{-7}
	3.2×10^{6}	2.6×10^{6}	1.0×10^{4}	3.6×10^{4}	2.1×10^{5}	9.4×10^{3}	9.4×10^{3}	1.3×10^{6}
ICRP-30	2.4×10^{-5}	1.9×10^{-6}	4.6×10^{-9}	4.0×10^{-8}	6.3×10^{-8}	4.5×10^{-8}	4.6×10^{-9}	9.5×10^{-7}
	8.8×10^{7}	7.1×10^{6}	1.7×10^{4}	1.5×10^{5}	2.3×10^{5}	1.7×10^{4}	1.7×10^{4}	3.5×10^{6}
ICRP-2	3.0×10^{-6}	—	0.0	4.1×10^{-8}	1.5×10^{-7}	0.0	1.9×10^{-7}	1.4×10^{-7}
	1.1×10^{7}	—	0.0	1.5×10^{5}	5.7×10^{5}	0.0	7.1×10^{5}	5.3×10^{5}
^{230}Th								
EPA	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—
INREM II	3.2×10^{-7}	2.7×10^{-7}	1.2×10^{-8}	5.9×10^{-9}	4.9×10^{-8}	1.2×10^{-9}	1.2×10^{-9}	1.7×10^{-7}
	1.2×10^{6}	1.0×10^{6}	4.6×10^{3}	2.2×10^{4}	1.8×10^{5}	4.6×10^{3}	4.3×10^{3}	6.3×10^{5}
ICRP-30	3.6×10^{-6}	2.9×10^{-7}	6.8×10^{-10}	5.9×10^{-9}	4.9×10^{-8}	6.8×10^{-10}	6.8×10^{-10}	1.5×10^{-7}
	1.3×10^{7}	1.1×10^{6}	2.5×10^{3}	2.2×10^{4}	1.8×10^{5}	2.5×10^{3}	2.5×10^{3}	5.5×10^{5}
PNL	6.8×10^{-7}	—	0.0	4.1×10^{-8}	1.8×10^{-8}	0.0	1.9×10^{-7}	2.1×10^{-8}
	2.5×10^{6}	—	0.0	1.5×10^{5}	6.7×10^{4}	0.0	6.9×10^{5}	7.7×10^{4}
^{231}Pa								
EPA	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—
INREM II	4.9×10^{-6}	4.1×10^{-6}	5.9×10^{-8}	7.6×10^{-6}	5.1×10^{-8}	5.9×10^{-8}	9.7×10^{-7}	2.6×10^{-6}
	1.8×10^{7}	1.5×10^{7}	2.2×10^{5}	2.8×10^{7}	1.9×10^{5}	2.2×10^{5}	3.6×10^{6}	9.5×10^{6}
ICRP-30	7.2×10^{-5}	5.8×10^{-6}	6.8×10^{-11}	4.4×10^{-9}	5.3×10^{-8}	6.3×10^{-11}	6.8×10^{-9}	2.9×10^{-6}
	2.7×10^{8}	2.1×10^{7}	2.5×10^{2}	1.6×10^{4}	2.0×10^{5}	2.3×10^{2}	2.5×10^{4}	1.1×10^{7}
ICRP-2	1.3×10^{-6}	—	0.0	5.4×10^{-8}	2.2×10^{-8}	0.0	3.0×10^{-7}	5.7×10^{-8}
	5.0×10^{6}	—	0.0	2.0×10^{5}	8.0×10^{4}	0.0	1.1×10^{6}	2.1×10^{5}
^{223}U								
EPA	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—
INREM II	2.1×10^{-6}	6.5×10^{-8}	4.6×10^{-9}	4.1×10^{-9}	4.6×10^{-8}	4.3×10^{-9}	4.6×10^{-7}	7.0×10^{-8}
	7.9×10^{6}	2.4×10^{5}	1.7×10^{4}	1.5×10^{4}	1.7×10^{5}	1.6×10^{4}	1.7×10^{6}	2.6×10^{5}
ICRP-30	1.2×10^{-6}	7.4×10^{-8}	2.6×10^{-9}	2.6×10^{-9}	5.0×10^{-8}	2.6×10^{-9}	4.7×10^{-7}	7.8×10^{-8}
	4.3×10^{6}	2.7×10^{5}	9.7×10^{3}	9.7×10^{3}	1.8×10^{5}	9.7×10^{3}	1.7×10^{6}	2.9×10^{5}
PNL	2.3×10^{-7}	—	0.0	0.0	1.9×10^{-8}	0.0	5.4×10^{-8}	1.4×10^{-8}
	8.7×10^{5}	—	0.0	0.0	6.9×10^{4}	0.0	2.0×10^{5}	5.3×10^{4}

TABLE C-1 *(continued)*

Nuclide	Bone[a]	Red Marrow[a]	Lung	Liver	GI-LLI	Thyroid	Kidney	Total Body[b]
^{234}U								
EPA	5.4×10^{-6}	2.2×10^{-7}	2.2×10^{-10}	1.6×10^{-7}	2.4×10^{-8}	1.6×10^{-7}	1.6×10^{-7}	4.6×10^{-7}
	2.0×10^{7}	8.0×10^{5}	8.2×10^{2}	5.8×10^{5}	8.9×10^{4}	5.8×10^{5}	8.5×10^{5}	1.7×10^{6}
INREM II	2.1×10^{-6}	6.2×10^{-8}	4.6×10^{-9}	4.3×10^{-9}	4.6×10^{-8}	4.3×10^{-9}	4.6×10^{-7}	7.0×10^{-9}
	7.8×10^{6}	2.3×10^{5}	1.7×10^{4}	1.6×10^{4}	1.7×10^{5}	1.6×10^{4}	1.7×10^{6}	2.6×10^{5}
ICRP-30	1.1×10^{-6}	7.2×10^{-8}	2.6×10^{-9}	2.6×10^{-9}	4.9×10^{-8}	2.6×10^{-9}	4.7×10^{-7}	7.7×10^{-8}
	4.2×10^{6}	2.7×10^{5}	9.5×10^{3}	9.5×10^{3}	1.8×10^{5}	9.5×10^{3}	1.7×10^{6}	2.9×10^{5}
PNL	2.3×10^{-7}	—	0.0	0.0	1.8×10^{-8}	0.0	5.1×10^{-8}	1.4×10^{-8}
	8.4×10^{5}	—	0.0	0.0	6.8×10^{4}	0.0	1.9×10^{5}	5.2×10^{4}
^{235}U								
EPA	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—
INREM II	1.9×10^{-6}	4.9×10^{-8}	4.3×10^{-9}	3.2×10^{-10}	4.9×10^{-8}	4.1×10^{-9}	4.1×10^{-7}	5.9×10^{-8}
	7.1×10^{6}	1.8×10^{5}	1.6×10^{4}	1.4×10^{4}	1.8×10^{5}	1.5×10^{4}	1.5×10^{6}	2.2×10^{5}
ICRP-30	1.1×10^{-6}	5.8×10^{-8}	2.5×10^{-9}	2.5×10^{-9}	5.3×10^{-8}	2.5×10^{-9}	4.3×10^{-7}	7.2×10^{-8}
	4.1×10^{6}	2.5×10^{5}	9.1×10^{3}	9.1×10^{3}	2.0×10^{5}	9.1×10^{3}	1.6×10^{6}	2.7×10^{5}
PNL	2.2×10^{-7}	—	0.0	0.0	2.3×10^{-8}	0.0	4.9×10^{-8}	1.3×10^{-8}
	8.0×10^{5}	—	0.0	0.0	8.6×10^{4}	0.0	1.8×10^{5}	4.9×10^{4}
^{238}U								
EPA	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—
INREM II	1.9×10^{-6}	5.1×10^{-8}	4.1×10^{-9}	3.2×10^{-10}	4.0×10^{-10}	3.8×10^{-9}	4.1×10^{-7}	5.9×10^{-8}
	7.0×10^{6}	1.9×10^{5}	1.5×10^{4}	1.3×10^{4}	1.6×10^{5}	1.4×10^{4}	1.5×10^{6}	2.2×10^{5}
ICRP-30	1.0×10^{-6}	6.8×10^{-8}	2.3×10^{-9}	2.3×10^{-9}	4.6×10^{-8}	2.3×10^{-9}	4.1×10^{-7}	6.9×10^{-8}
	3.7×10^{6}	2.5×10^{5}	8.5×10^{3}	8.5×10^{3}	1.7×10^{5}	8.5×10^{3}	1.5×10^{6}	2.5×10^{5}
PNL	2.1×10^{-7}	—	0.0	0.0	1.7×10^{-8}	0.0	4.6×10^{-8}	1.2×10^{-8}
	7.7×10^{5}	—	0.0	0.0	6.1×10^{4}	0.0	1.7×10^{5}	4.5×10^{4}
^{237}Np								
EPA	5.1×10^{-6}	1.7×10^{-6}	2.4×10^{-10}	2.2×10^{-6}	4.1×10^{-8}	1.7×10^{-8}	3.0×10^{-7}	4.3×10^{-7}
	1.9×10^{7}	6.2×10^{6}	8.9×10^{2}	8.2×10^{6}	1.5×10^{5}	6.1×10^{4}	1.1×10^{6}	1.6×10^{6}
INREM II	2.0×10^{-6}	1.7×10^{-6}	3.2×10^{-8}	4.3×10^{-6}	6.2×10^{-8}	3.2×10^{-8}	3.7×10^{-7}	1.3×10^{-6}
	7.3×10^{6}	6.1×10^{6}	1.2×10^{5}	1.6×10^{7}	2.0×10^{5}	1.2×10^{5}	2.1×10^{6}	4.7×10^{6}
ICRP-30	1.9×10^{-4}	1.5×10^{-5}	2.4×10^{-9}	4.1×10^{-5}	5.4×10^{-8}	8.2×10^{-10}	3.1×10^{-9}	8.5×10^{-6}
	7.1×10^{8}	5.6×10^{7}	8.8×10^{3}	1.5×10^{8}	2.0×10^{5}	3.0×10^{3}	1.1×10^{4}	3.1×10^{7}
PNL	4.6×10^{-7}	—	0.0	2.5×10^{-7}	2.4×10^{-8}	0.0	1.5×10^{-7}	2.0×10^{-8}
	1.7×10^{6}	—	0.0	9.3×10^{5}	8.8×10^{4}	0.0	5.4×10^{5}	7.3×10^{4}
^{238}Pu								
EPA	1.3×10^{-7}	4.6×10^{-8}	2.1×10^{-14}	5.9×10^{-8}	3.0×10^{-8}	4.3×10^{-10}	7.8×10^{-9}	1.2×10^{-12}
	5.0×10^{5}	1.7×10^{5}	7.9×10^{2}	2.2×10^{5}	1.1×10^{5}	1.6×10^{3}	2.9×10^{4}	4.3×10^{4}
INREM II	5.4×10^{-8}	4.6×10^{-8}	8.7×10^{-10}	1.2×10^{-7}	5.7×10^{-8}	8.7×10^{-10}	1.5×10^{-8}	3.8×10^{-8}
	2.0×10^{5}	1.7×10^{5}	3.2×10^{3}	4.4×10^{5}	2.1×10^{5}	3.2×10^{3}	5.7×10^{4}	1.4×10^{5}
ICRP-30	1.8×10^{-6}	1.5×10^{-8}	8.7×10^{-15}	4.0×10^{-8}	5.7×10^{-8}	3.9×10^{-16}	1.2×10^{-14}	1.1×10^{-7}
	6.8×10^{5}	5.4×10^{4}	3.2×10^{2}	1.5×10^{5}	2.1×10^{5}	1.5×10^{-3}	4.4×10^{-2}	4.1×10^{5}
PNL	1.2×10^{-7}	—	0.0	7.0×10^{-8}	2.2×10^{-8}	0.0	2.3×10^{-8}	5.9×10^{-9}
	4.4×10^{5}	—	0.0	2.6×10^{5}	8.1×10^{4}	0.0	8.7×10^{4}	2.2×10^{4}
^{239}Pu								
EPA	1.5×10^{-7}	5.1×10^{-8}	1.7×10^{-14}	6.8×10^{-8}	2.7×10^{-8}	5.1×10^{-10}	8.7×10^{-9}	1.3×10^{-8}
	5.7×10^{5}	1.9×10^{5}	6.1×10^{-2}	2.5×10^{5}	9.9×10^{4}	1.9×10^{3}	3.2×10^{4}	4.8×10^{4}
INREM II	5.9×10^{-8}	5.1×10^{-8}	9.7×10^{-10}	1.3×10^{-7}	5.4×10^{-8}	9.7×10^{-10}	1.7×10^{-8}	4.3×10^{-8}
	2.2×10^{5}	1.9×10^{5}	3.6×10^{3}	4.9×10^{5}	2.0×10^{5}	3.6×10^{3}	6.3×10^{4}	1.6×10^{5}
ICRP-30	2.1×10^{-6}	1.7×10^{-8}	5.3×10^{-15}	4.4×10^{-8}	5.3×10^{-8}	4.4×10^{-16}	1.4×10^{-14}	1.2×10^{-7}
	6.5×10^{5}	6.1×10^{4}	2.1×10^{-2}	1.6×10^{5}	2.0×10^{5}	1.6×10^{-3}	5.1×10^{-2}	4.4×10^{5}
PNL	1.5×10^{-7}	—	0.0	8.1×10^{-8}	2.0×10^{-8}	0.0	2.7×10^{-8}	7.0×10^{-9}
	5.4×10^{5}	—	0.0	3.0×10^{5}	7.4×10^{4}	0.0	1.0×10^{5}	2.6×10^{4}

TABLE C-1 *(continued)*

Nuclide	Bone[a]	Red Marrow[a]	Lung	Liver	GI-LLI	Thyroid	Kidney	Total Body[b]
^{240}Pu								
EPA	1.5×10^{-7}	5.1×10^{-8}	2.2×10^{-14}	6.8×10^{-8}	2.7×10^{-8}	4.9×10^{-10}	8.7×10^{-9}	1.3×10^{-8}
	5.7×10^{5}	1.9×10^{5}	8.3×10^{-2}	2.5×10^{5}	9.9×10^{4}	1.8×10^{3}	3.2×10^{4}	4.8×10^{4}
INREM II	5.9×10^{-8}	5.1×10^{-8}	9.7×10^{-10}	1.3×10^{-7}	5.4×10^{-8}	9.7×10^{-10}	1.7×10^{-8}	4.3×10^{-8}
	2.2×10^{5}	1.9×10^{5}	3.6×10^{3}	4.9×10^{5}	2.0×10^{5}	3.6×10^{3}	6.3×10^{4}	1.6×10^{5}
ICRP-30	2.1×10^{-7}	1.7×10^{-8}	9.7×10^{-15}	4.4×10^{-8}	5.3×10^{-8}	4.8×10^{-16}	1.3×10^{-14}	1.2×10^{-7}
	7.6×10^{5}	6.1×10^{4}	3.6×10^{3}	1.6×10^{5}	2.0×10^{5}	1.8×10^{-3}	5.0×10^{2}	4.4×10^{5}
PNL	1.5×10^{-7}	—	0.0	8.1×10^{-8}	2.0×10^{-8}	0.0	2.7×10^{-8}	7.0×10^{-9}
	5.4×10^{5}	—	0.0	3.0×10^{5}	7.5×10^{4}	0.0	1.0×10^{5}	2.6×10^{4}
^{241}Pu								
EPA	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—
INREM II	1.2×10^{-9}	1.0×10^{-9}	2.0×10^{-11}	2.6×10^{-9}	2.7×10^{-10}	2.0×10^{-11}	3.2×10^{-10}	7.6×10^{-10}
	4.6×10^{3}	3.9×10^{3}	7.5×10	9.5×10^{3}	9.9×10^{2}	7.5×10	1.3×10^{3}	2.8×10^{3}
ICRP-30	4.2×10^{-9}	3.4×10^{-10}	6.5×10^{-15}	8.6×10^{-10}	2.7×10^{-10}	1.2×10^{-15}	7.6×10^{-15}	2.4×10^{-9}
	1.6×10^{4}	1.3×10^{3}	2.4×10^{-2}	3.2×10^{3}	1.0×10^{3}	4.6×10^{3}	2.8×10^{-2}	8.9×10^{3}
PNL	2.4×10^{-9}	—	0.0	5.7×10^{-10}	4.3×10^{-10}	0.0	4.1×10^{-10}	9.2×10^{-11}
	9.0×10^{3}	—	0.0	2.1×10^{3}	1.6×10^{3}	0.0	1.5×10^{3}	3.4×10^{2}
^{242}Pu								
EPA	1.5×10^{-7}	4.9×10^{-8}	4.3×10^{-14}	6.5×10^{-8}	2.5×10^{-8}	4.9×10^{-10}	8.4×10^{-9}	1.2×10^{-8}
	5.4×10^{5}	1.8×10^{5}	1.6×10^{-1}	2.4×10^{5}	9.4×10^{4}	1.8×10^{3}	3.1×10^{4}	4.6×10^{4}
INREM II	5.7×10^{-8}	4.9×10^{-8}	9.5×10^{-10}	1.3×10^{-7}	5.1×10^{-8}	9.5×10^{-10}	1.6×10^{-8}	4.1×10^{-8}
	2.1×10^{5}	1.8×10^{5}	3.5×10^{3}	4.7×10^{5}	1.9×10^{5}	3.5×10^{3}	6.0×10^{4}	1.5×10^{5}
ICRP-30	2.0×10^{-7}	1.6×10^{-8}	2.4×10^{-14}	4.2×10^{-8}	5.1×10^{-8}	3.3×10^{-15}	1.1×10^{-13}	1.1×10^{-7}
	7.3×10^{5}	5.8×10^{4}	8.7×10^{2}	1.6×10^{5}	1.9×10^{5}	1.2×10^{-2}	4.0×10^{-1}	4.1×10^{5}
PNL	1.4×10^{-7}	—	0.0	7.8×10^{-8}	2.0×10^{-8}	0.0	2.7×10^{-8}	6.8×10^{-9}
	5.0×10^{5}	—	0.0	2.9×10^{5}	7.3×10^{4}	0.0	9.9×10^{4}	2.5×10^{4}
^{241}Am								
EPA	5.1×10^{-6}	1.7×10^{-6}	3.5×10^{-11}	2.3×10^{-6}	3.0×10^{-8}	1.7×10^{-8}	3.0×10^{-7}	4.3×10^{-7}
	1.9×10^{7}	6.4×10^{6}	1.3×10^{2}	8.5×10^{6}	1.1×10^{5}	6.3×10^{4}	1.1×10^{6}	1.6×10^{6}
INREM II	2.1×10^{-6}	1.7×10^{-6}	3.2×10^{-8}	4.6×10^{-6}	5.7×10^{-8}	3.2×10^{-8}	5.9×10^{-7}	1.2×10^{-6}
	7.6×10^{6}	6.4×10^{6}	1.2×10^{5}	1.7×10^{7}	2.1×10^{5}	1.2×10^{5}	2.2×10^{6}	4.6×10^{6}
ICRP-30	1.0×10^{-5}	8.4×10^{-7}	1.7×10^{-11}	2.3×10^{-6}	5.8×10^{-8}	3.1×10^{-12}	2.3×10^{-11}	5.9×10^{-7}
	3.9×10^{7}	3.1×10^{6}	6.4×10	8.4×10^{6}	2.1×10^{5}	1.1×10	8.4×10	2.2×10^{6}
PNL	4.9×10^{-7}	—	0.0	2.7×10^{-7}	2.2×10^{-8}	0.0	1.4×10^{-7}	1.8×10^{-8}
	1.8×10^{6}	—	0.0	1.0×10^{6}	8.2×10^{4}	0.0	5.0×10^{5}	6.7×10^{4}
^{242}Am								
EPA	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—
INREM II	2.0×10^{-6}	1.7×10^{-12}	3.2×10^{-8}	4.3×10^{-6}	9.2×10^{-9}	3.2×10^{-8}	5.7×10^{-7}	1.1×10^{-6}
	7.5×10^{6}	6.3×10^{6}	1.2×10^{5}	1.6×10^{7}	3.4×10^{4}	1.2×10^{5}	2.1×10^{6}	4.1×10^{6}
ICRP-30	1.0×10^{-5}	8.3×10^{-7}	1.1×10^{-11}	2.2×10^{-6}	9.7×10^{-9}	2.2×10^{-12}	1.3×10^{-11}	5.7×10^{-7}
	3.8×10^{7}	3.1×10^{6}	4.0×10	8.1×10^{6}	3.6×10^{4}	8.1	4.9×10	2.1×10^{6}
PNL	4.6×10^{-7}	—	0.0	2.6×10^{-7}	2.7×10^{-8}	0.0	1.3×10^{-7}	1.8×10^{-8}
	1.7×10^{6}	—	0.0	9.5×10^{5}	1.0×10^{5}	0.0	4.9×10^{5}	6.6×10^{4}
^{243}Am								
EPA	5.1×10^{-6}	8.6×10^{-6}	2.6×10^{-10}	2.3×10^{-6}	4.1×10^{-8}	1.7×10^{-8}	3.0×10^{-8}	4.3×10^{-7}
	1.9×10^{7}	3.2×10^{7}	9.6×10^{2}	8.5×10^{6}	1.5×10^{5}	6.3×10^{4}	1.1×10^{6}	1.6×10^{6}
INREM II	2.1×10^{-6}	1.7×10^{-6}	3.5×10^{-8}	4.6×10^{-6}	5.9×10^{-8}	3.5×10^{-8}	5.9×10^{-7}	1.3×10^{-6}
	7.6×10^{6}	6.4×10^{6}	1.3×10^{5}	1.7×10^{7}	2.2×10^{5}	1.3×10^{5}	2.2×10^{6}	4.7×10^{6}
ICRP-30	1.0×10^{-5}	8.4×10^{-7}	1.2×10^{-10}	2.3×10^{-6}	6.0×10^{-8}	3.6×10^{-11}	1.7×10^{-10}	5.9×10^{-7}
	3.9×10^{7}	3.1×10^{6}	4.6×10^{2}	8.4×10^{6}	2.2×10^{5}	1.3×10^{2}	6.4×10^{2}	2.2×10^{6}
PNL	4.9×10^{-7}	—	0.0	2.7×10^{-7}	2.6×10^{-8}	0.0	1.3×10^{-7}	1.8×10^{-8}
	1.8×10^{6}	—	0.0	1.0×10^{6}	9.7×10^{4}	0.0	5.0×10^{5}	6.7×10^{4}

TABLE C-1 *(continued)*

Nuclide	Bone[a]	Red Marrow[a]	Lung	Liver	GI-LLI	Thyroid	Kidney	Total Body[b]
^{242}Cm								
EPA	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—
INREM II	4.6×10^{-8}	3.8×10^{-8}	7.3×10^{-10}	1.2×10^{-7}	6.2×10^{-8}	7.3×10^{-10}	1.5×10^{-8}	1.9×10^{-7}
	1.7×10^{5}	1.4×10^{5}	2.7×10^{3}	4.4×10^{5}	2.3×10^{5}	2.7×10^{3}	5.7×10^{4}	7.2×10^{5}
ICRP-30	2.3×10^{-7}	1.8×10^{-8}	1.3×10^{-14}	6.0×10^{-8}	6.3×10^{-8}	5.3×10^{-16}	1.7×10^{-14}	1.9×10^{-8}
	8.5×10^{5}	6.8×10^{4}	4.8×10^{-2}	2.2×10^{5}	2.3×10^{5}	2.0×10^{-3}	6.4×10^{-2}	7.0×10^{4}
PNL	8.4×10^{-9}	—	0.0	6.2×10^{-9}	2.4×10^{-8}	0.0	1.6×10^{-9}	3.8×10^{-10}
	3.1×10^{4}	—	0.0	2.3×10^{4}	8.8×10^{4}	0.0	6.0×10^{3}	1.4×10^{3}
^{243}Cm								
EPA	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—
INREM II	1.4×10^{-6}	1.1×10^{-6}	2.2×10^{-8}	3.2×10^{-6}	6.8×10^{-8}	2.2×10^{-8}	4.1×10^{-7}	7.8×10^{-7}
	5.0×10^{6}	4.2×10^{6}	8.3×10^{4}	1.2×10^{7}	2.5×10^{5}	8.2×10^{4}	1.5×10^{6}	2.9×10^{6}
ICRP-30	7.0×10^{-6}	5.6×10^{-7}	4.4×10^{-11}	1.6×10^{-6}	6.7×10^{-8}	1.3×10^{-11}	7.5×10^{-11}	4.0×10^{-7}
	3.0×10^{7}	2.1×10^{6}	1.6×10^{2}	5.8×10^{6}	2.5×10^{5}	5.0×10	2.8×10^{2}	1.5×10^{6}
PNL	2.7×10^{-7}	—	0.0	1.7×10^{-7}	2.4×10^{-8}	0.0	5.1×10^{-8}	1.1×10^{-8}
	1.0×10^{6}	—	0.0	6.4×10^{5}	8.7×10^{4}	0.0	1.9×10^{5}	4.2×10^{4}
^{244}Cm								
EPA	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—
INREM II	1.1×10^{-6}	8.9×10^{-7}	1.7×10^{-8}	2.5×10^{-6}	5.9×10^{-8}	1.7×10^{-8}	3.2×10^{-8}	6.2×10^{-7}
	3.9×10^{6}	3.3×10^{6}	6.4×10^{4}	9.3×10^{6}	2.2×10^{5}	6.4×10^{4}	1.2×10^{6}	2.3×10^{6}
ICRP-30	5.5×10^{-6}	4.4×10^{-7}	2.6×10^{-13}	1.3×10^{-6}	6.0×10^{-8}	2.6×10^{-14}	2.3×10^{-13}	3.1×10^{-7}
	2.0×10^{7}	1.6×10^{6}	9.5×10^{-1}	4.7×10^{6}	2.2×10^{5}	9.5×10^{-2}	8.4×10^{-1}	1.1×10^{6}
PNL	2.0×10^{-7}	—	0.0	1.3×10^{-7}	2.3×10^{-8}	0.0	3.8×10^{-8}	8.4×10^{-9}
	7.4×10^{5}	—	0.0	4.8×10^{5}	8.4×10^{4}	0.0	1.4×10^{5}	3.1×10^{4}

NOTE: First row of entries for each data source is in units of Sv/Bq; the second row is in units of rem/Ci. Dashes indicate no data available. A value of 0.0 indicates dose factor not calculated for particular organ. PNL's PABLM dose factors are based upon the ICRP-2 critical organ model, which does not yield doses from "cross irradiation" due to radionuclides deposited in other organs.

[a] EPA, INREM II, and ICRP-30 entries for bone are for bone surface. Portion of bone considered in PNL model (ICRP-2 bone dosimetry model) for bone dose is nuclide dependent. Nuclides are classified as surface seekers or volume seekers.

[b] EPA and PNL entries in "Total Body" column are for dose equivalents to a tissue volume equivalent to the whole body. The EPA dose factors (based on early INREM results) are the sums of dose contributions from a radionuclide deposited in 22 "source" organs. The PNL dose factors are the doses from a radionuclide deposited at the center of an equivalent sphere. The INREM II and ICRP-30 entries are effective dose equivalents.

[c] Values for EPA, INREM II, and ICRP-30 throughout table are for 50-year committed dose equivalents from initial intake.

[d] Values for PNL throughout table are for 70-year committed dose equivalents from intake at constant rate during first year.

Protection (1977) Publication 26 dose limitation system and described by Dunning and Killough (1981). The effective dose equivalents are from Dunning and Killough (1981). The recent INREM II data have been included in the table to enable a comparison with the EPA data.

The ICRP-30 dose factors in Table C-1 are from the recently revised recommendations of the International Commission on Radiological Protection on limits for intake of radionuclides by radiation workers. These were provided by K. Eckerman (Oak Ridge National Laboratory, personal communication to B. J. Mann, 1982) from the data developed in support of the International Commission on Radiological Protection

(1979) Publication 30 and supplements. As with the EPA and INREM II dose factors, the ICRP-30 factors are 50-year committed dose equivalents from an initial intake. Data in the total body column are effective dose equivalents.

The PNL entries in Table C-1 consist of dose factors calculated by the PABLM computer code at Battelle Pacific Northwest Laboratory (Napier et al. 1980). The data were provided by B. A. Napier (Battelle Pacific Northwest Laboratory, personal communication to B. J. Mann, 1982). The PABLM code is largely based on the physical dosimetry and metabolic models of the International Commission on Radiological Protection (1959) Publication 2. The PNL dose factors are defined as 70-year committed dose equivalents per unit (becquerels) intake, taken in at a constant rate during the first year. The total body entry is the dose equivalent to an equivalent sphere from an amount of radionuclide assumed to be concentrated at the center (Napier et al. 1980). PABLM is a fairly general environmental pathway transport and dosimetry modeling code. For high-level waste performance assessments, PABLM is usually used to calculate cumulative 70-year dose commitments to individuals from a 70-year lifetime of intake (Cloninger and Cole 1981). Dose factors calculated on this latter basis are presented in Table 9-1.

Computer codes developed at Sandia National Laboratories for assessment of high-level waste isolation use environmental pathway and dosimetry models that are derived from the PNL methods (Runkle et al. 1981). Seventy-year dose factors provided by G. E. Runkle (Sandia National Laboratories, personal communication to B. J. Mann, 1982) are not included here because they are essentially identical to the PNL dose factors.

For strontium-90 and the isotopes of uranium, neptunium, and plutonium, dose factors have been calculated for chemical compounds of differing solubility and, hence, differing metabolism and resultant dose per unit amount ingested. The effects of solubility in the ingestion dose models are described by the fractional uptake from the gut to the blood stream, designated by the parameter f_1. Dose factors shown in Table C-1 from INREM II, ICRP-30, and PNL were selected to correspond to the values of f_1 used by EPA (Smith et al. 1981). All data have been rounded to two significant digits.

REFERENCES

Cloninger, M. O., and C. R. Cole. 1981. A Reference Analysis on the Use of Engineered Barriers for Isolation of Spent Nuclear Fuel in Granite and Basalt. PNL-3530. Pacific Northwest Laboratory, Battelle Memorial Institute, Richland, Wash.

Dunning, D. E., and G. G. Killough. 1981. A comparison of effective dose equivalents from three major internal dose compilations. Radiation Protection Dosimetry (Nuclear Technology Publishing) 1(1):3-9.

Dunning, D. E., G. G. Killough, S. R. Bernard, J. C. Pleasant, and P. J. Walsh. 1981. Estimates of Internal Dose Equivalent to 22 Target Organs for Radionuclides Occurring in Routine Releases from

Nuclear Fuel-Cycle Facilities, Vol. III. ORNL/NUREG/TM-190/V3. Oak Ridge National Laboratory, Oak Ridge, Tenn.

International Commission on Radiological Protection. 1959. Report of Committee II on Permissible Dose for Internal Radiation. Publication 2. New York: Pergamon.

International Commission on Radiological Protection. 1977. Radiation Protection. Publication 26. New York: Pergamon.

International Commission on Radiological Protection. 1979. Limits for Intakes of Radionuclides by Workers. Publication 30, Part 1. New York: Pergamon.

Killough, G. G., D. E. Dunning, Jr., S. R. Bernard, and J. C. Pleasant. 1978. Estimates of Internal Dose Equivalent to 22 Target Organs for Radionuclides Occurring in Routine Releases from Nuclear Fuel Cycle Facilities, Vol. I. ORNL/NUREG/TM-190. Oak Ridge National Laboratory, Oak Ridge, Tenn.

Napier, B. A., W. E. Kennedy, and J. K. Soldat. 1980. PABLM--A Computer Program to Calculate Accumulated Radiation Doses from Radionuclides in the Environment. PNL-3209. Pacific Northwest Laboratory, Battelle Memorial Institute, Richland, Wash.

Runkle, G. E., R. M. Cranwell, and J. D. Johnson. 1981. Risk Methodology for Geologic Disposal of Radioactive Waste: Dosimetry and Health Effects. NUREG/CR-2166, SAND80-1372. Sandia National Laboratories, Albuquerque, N.Mex.

Smith, J. M., T. W. Fowler, and A. S. Goldin. 1981. Environmental Pathway Models for Estimating Population Health Effects from Disposal of High-Level Radioactive Waste in Geologic Repositories. EPA 520/5-80-002. U.S. Environmental Protection Agency, Washington, D.C.

U.S. Environmental Protection Agency. 1982. Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes. 40 CFR 191. Federal Register 47(250):58196-58206.