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E.P. NOTE 22

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Kamran Vaziri and Paul Kesich

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Author: ______________________ Date: 10/28/02
K. Vaziri

Author: ______________________ Date: 10-28-02
P. Kesich

Reviewed: ______________________ Date: 10-29-02
A. Elwyn

Approved: ______________________ Date: 10/29/02
D. Cossairt
Associate Head, Radiation Protection

Approved: ______________________ Date: 10-28-02
P. Kesich
Associate Head, Environmental Protection

Approved: ______________________ Date: 10/29/02
Bill Griffing
Head, ES&H Section

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Introduction

This note describes a calculation of the transport of the radionuclides produced in the soil, to the groundwater, for the CKM (see reference E982) experiment's target area. We have calculated the tritium concentration reduction factor for the area. This factor is based on the information obtained from geological characterizations conducted near the Meson Detector Building, from borehole S-1287 (Figure 1). This reduction factor supercedes the values given in EP-8, which are based on one site-wide average vertical seepage velocity.

We were given two locations/elevations for the CKM target pile; one near the MEast, at 741 ft, and the other near MS-4, at 743.5 ft. Since, these elevations are very near the surface, we assume there are about 3ft of gravel and other uncertainties in the elevation and construction. A harmonic average of the seepage velocities for the two locations gave 2.09 cm/yr and 2.02 cm/yr, respectively. The calculations were done for the more conservative of the two velocities; 2.09 cm/yr, the location near MEast worm.

A Brief Description of the Concentration Model

The concentration Model (Co99) is the methodology used at Fermilab to predict the production and subsequent migration of radionuclides in the soil around the beam targeting or loss areas. The predictions of this model are used in the design of new facilities and the operation of the existing facilities to keep the concentration of the radionuclides in the surface waters and the ground water, below the prescribed and regulatory limits (see reference GWR).

The concentration model uses the radiation induced star density production in the soil. This is usually obtained from a standard Monte Carlo code that simulates beam loss and the subsequent production of radionuclides in the soil in the vicinity of the enclosures. Star density, number of protons lost, the radionuclide yield, half life and leaching parameters, in conjunction with some soil parameters, are used to calculate the concentration of the radionuclides, C_0, right outside the enclosure. This concentration can be directly compared with the allowed concentration values for discharge to the surface waters.

The next step in the concentration model calculations is the transport of this initial concentration from the production location, immediately outside the enclosure walls, to the aquifer. The radionuclide plume moving through the soil will decay and expand, therefore reducing its concentration. This reduction is taken into account through the calculation of a reduction factor R. Thus the final concentration of the radionuclides, C_f, in the aquifer will be;

$$C_f = C_0 * R.$$

The radionuclide plume moves through the glacial till, the glacial till-dolomite interface, and within the dolomite, in its transport to a well. IEPA standards imply that one should assume no reduction factors due to migration through the till-dolomite interface and transport in the dolomite - both regions designated as Class I groundwater resources. Therefore, the reduction factor R, used in the calculation is only due to the transport through the glacial till.

Originally, the reduction factor was calculated based on one site-wide average vertical seepage velocity (Ma93, Co94). Further experience and investigation of the loss points at different locations at the lab showed that the use of one site-wide average velocity is neither correct nor conservative. The latest version of the concentration model (Co99) recommends the use of site-specific geological characterizations as input to transport calculations using the computer code PATCH3D (Su88).

Groundwater Transport Code PATCH3D

PATCH3D is a computer program that analytically solves a three dimensional advection-dispersion equation for the vertical transport of radionuclides in the soil (Su88). The calculations for the CKM were done by transporting a 3.7m by 3.7m-rectangular patch containing the initial radionuclide concentration in a direction perpendicular to the patch, downward to the aquifer. This code requires values for the vertical seepage velocity within the layer, the decay constant of the radionuclide, the thickness of the layer, and longitudinal and transverse dispersivities. The dispersivities were determined empirically as described in the reference Co99.

The vertical seepage velocity is calculated from the hydrogeological properties - gradient, hydraulic conductivity and effective porosity of the layer (See data on Figure 1) through which the radionuclide is transported. In cases where there are multiple layers, there are actually two methods of calculating the transport of the tritium. The first method is to calculate the reduction factor for each layer. Then the final reduction factor is the product of all of the individual ones. The second method is to use a harmonic average of velocities of all the layers (WCC93), which was used for CKM calculations (last two rows of table 1).

Geology

As seen from Table 1 and Fig.1, of the five different layers, the third (Lemont formation Facies B) has the highest seepage velocity, care must be taken not to disturb or "short circuit" the integrity of the first two ("slow") layers. The second method, mentioned above, is a fast and conservative method of calculation, since it involves the total depth and one average velocity.

Table 1.Geological parameters from the borehole S-1287. First two rows shows alternate location, near Meast worm and near MS-4.

Soil Layers Elevation from the top (ft from Sealevel)	Layer type	Layer thickness (cm)	Seepage velocity (cm/year)
736-738 (1)	Lemont Formation Yorkville Member	61	1.10
736-740 (2)	Lemont Formation Yorkville Member	122	1.10
717-736	Lemont Formation Facies A	579	1.77
703-717	Lemont Formation Facies B	427	6.31
689-703	Lemont Formation Facies C	427	1.80
687-689	Batestown	61	1.09
		Average Seepage velocity (1)	2.09
		Average Seepage velocity (2)	2.02

<u>Results</u>

Measurements and calculations (Bo72 and Ma93) have shown that of all the radionuclides produced in the soil, ^{3}H and ^{22}Na are the most significant due to their yields, half lives, transportability in the soil, leachability from the soil, and the allowed concentrations in the groundwater. In usual cases at Fermilab, where the enclosure is located in the till, tritium is the main contributor to ground water contamination. ^{22}Na, due to its smaller production cross section, half life and distribution coefficient (Bo72) has a much larger reduction factor. Therefore, the following calculations were only done for the transport of tritium.

Table 2 gives the calculated reduction factors for four continuous operation scenarios; 5 year, 10 year, 15 year and 20 years. It will take between 120 to 160 years for the maximum activity produced, to get to the aquifer. It is this maximum activity that the reduction factors are based on.

Table 2. CKM reduction factors for different periods of operation.

Years of continuous operation	Tritium reduction factor
5	4E-9
10	1. E-8
15	2E-8
20	2E-8

As Table 2 shows the concentration of tritium activity produced near the target location, is reduced considerably during its transport to the aquifer. Therefore, attention must be paid to the concentration of the activity released to the surface waters. When using Table 2 the following should be considered;

1) When calculating C_0 (initial concentration of tritium as calculated using the concentration model) for the groundwater, the number of protons corresponding to the years of operation (first column of Table 1) should be used.

2) Since the transport of tritium in the surface waters is assumed to be instantaneous, for the calculation of the concentration in the surface waters the annual intensities should be used.

3) As mentioned earlier, for the cases calculated here, the reduction factors for the transport of ^{22}Na are much larger than that for tritium. Our calculations of the reduction factors for ^{22}Na, showed that even for twenty years of continuous operations, the ^{22}Na contamination does not reach further than a depth of 4.5 meters.

4) A large reduction factor for the tritium migration to the groundwater does not necessarily set the operating limit of the beam intensity/beam loss. Beside the regulatory groundwater tritium limit of 20 pCi/ml, Fermilab is also bound by a 2000 pCi/ml limit for discharge to surface water, since the surface waters limit may be reached before the groundwater limit. Therefore, the initial tritium concentration calculated using the Concentration Model should not normally be larger than the surface water discharge limit.

5) Following item 4 above, for the surface water, since there is more than one radionuclide produced in the soil, one should use the following relation to obtain the allowable beam intensity (Co94),

$$\sum_i \frac{C_i}{C_{i\text{-limit}}} \le 1.0 ,$$

where C_i is the predicted concentration of the radio-isotope i, and $C_{i\text{-limit}}$ is the regulatory of guidance concentration limit of the radio-isotope i for the surface waters.

The variation, by factors of two, of the patch size did not affect the results significantly (±13%). Experience with measurements and calculation at other location leads us to assume a conservative uncertainty of 30%-50% for these predictions.

Closing Thoughts

A comparison of the above reduction factors with that calculated using a standard parameterization for the whole site (Ma93) shows that the present results are smaller by several orders of magnitude. The main reason for this difference is that the standard model assumes 15 cm/year vertical seepage velocity. None of the cases studied so far, have such a large vertical seepage velocity. Since the velocity folds in exponentially, the difference in reduction factors becomes large.

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Co94 Cossairt, J. Donald "Use of a Concentration-Based Model for Calculating the Radioactivation of Soil and Groundwater at Fermilab" E.P. Note #8. December 1994.

E982 http://www.fnal.gov/projects/ckm/Welcome.html

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Illinois EPA Regulations (35 IAC 620)

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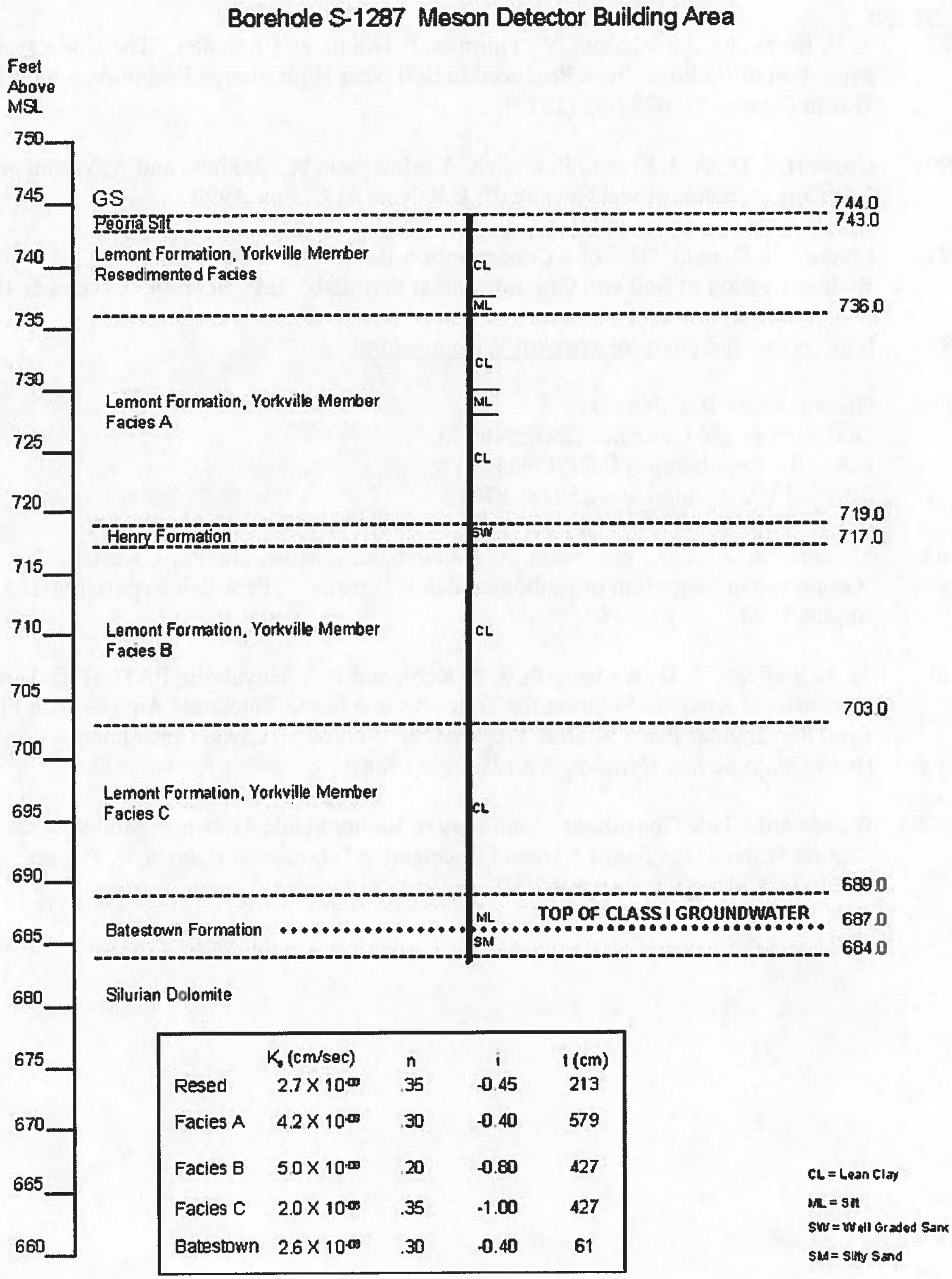

	K_s (cm/sec)	n	i	l (cm)
Resed	2.7×10^{-08}	.35	-0.45	213
Facies A	4.2×10^{-08}	.30	-0.40	579
Facies B	5.0×10^{-08}	.20	-0.80	427
Facies C	2.0×10^{-06}	.35	-1.00	427
Batestown	2.6×10^{-08}	.30	-0.40	61

Fig. 1: Cross sectional geological map of CKM target area from borehole S-1248 (not to scale)