Groundwater Transport Modeling for BP Chemicals

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1.0 EXECUTIVE SUMMARY

The soils around BP Chemical contain varying amounts of depleted uranium that are in an insoluble condition. The option to leave the uranium material in place as a means of disposal has been investigated and found to present a minimal risk to the health and safety of the public. The USNRC has requested additional calculations to further investigate the safety of on site disposal which have been performed and take into consideration the possibility of migration of the uranium into the groundwater and to the public. This report documents that the most conservative potential pathway to the public (a well at the site boundary), presents no increase in risk to the health and safety of the public. The committed effective dose equivalent received is less than 0.0001 mrem/yr. This is well below the USNRC limit established for Below Regulatory Concern of 1 mrem/yr to large numbers of the general public.

2.0 INTRODUCTION

An application has been given to the USNRC for approval of alternative, on-site disposal of soils contaminated with residual radioactivity. This application proposes that soils containing no more 35 pCi/g depleted uranium (DU) be left on site without restrictions, and that soils containing no more than 300 pCi/g DU, and occurring at least four feet deep, be left on site also. The NRC has requested that the possibility of groundwater migration and the subsequent associated dose be investigated with the continued presence of uranium on site. This analysis is to look at the possible doses associated with the groundwater pathway from leaving the uranium contamination in the soil. The activity will be calculated at the closest offsite receptor (assumed to be a well) and the dose will be determined from ingestion at that point. The time frame covered in this analysis is 10,000 years.

The site topography is essentially flat. The soils are glacial till, with a combination of clays, silts, sands and gravels. The thickness of the till is approximately 35 - 70 feet above the groundwater. The soil strata are: surface brown clay and/or silt till unit, a gray silt and/or clay till unit , and an outwash sand unit. The aquifer layer is up to 150 feet thick.

Ground water transport modeling describes the motion of radionuclides in soils. Typically, modeling calculations assume that radionuclides are transported by both convective and dispersive components. Results from the ground water flow and source term models are used as inputs for ground water transport modeling. This analysis uses a complex conceptual model that has been developed for the USNRC for use in a variety of instances including low-level waste assessment. Steady state ground water flow may frequently be assumed, however releases from the source are intrinsically transient which requires it be necessary to model transient transport (Freeze and Cherry 1979). The number of dimensions that should be modeled depends on the conceptual model used as a basis from site data. For this analysis one dimensional modeling is appropriate which requires the basics of water flow, source term release rates, dispersivities and sorption data.

The goals of this ground water transport modeling are to: 1. estimate aquifer concentrations that may become accessible to humans through a well, and, 2. estimate the rate of radionuclide flux from the aquifer into surface water bodies. (Shipers and Harlan, 1989). Of these two pathways, the well pathway is more important because groundwater is not diluted before it is used therefore this conservative pathway was chosen for the analysis.

Three of the most common analysis techniques used to analyze groundwater transport are numerical solutions of the convective-dispersive equation, analytical solutions of the convective-dispersion equation, and the stream-tube approach (Kozak 1989). The stream-tube model is deficient in determining groundwater concentrations because it allows no mixing and gives an incorrect estimate of dispersion effects. For this analysis a steady, one dimensional aquifer flow was assumed. Solutions to this type of analytical model were developed by Codell et al. (1982). This solution was recently used by Rood et al. (1989) in a comparison with the data for radionuclide transport in the Snake River Plain Aquifer. The results, using estimated and calibrated transport parameters, were in reasonable agreement with thee field data. This analysis was a calibration exercise, not a validation of the model, but the work shows the calculational method can be used to analyze a real aquifer system.

3.0 CALCULATIONAL METHODOLOGY

The analytical Green's function (Green, 1970) was applied in this analysis as the preferred model for its ability to handle arbitrary time dependence in the source term, and allows for three dimensional dispersion and one dimensional convection. The analytical green's function must be integrated numerically for arbitrary source terms and this numerical integration can be performed by standardized models. Green's functions are available for determining aquifer concentrations and for radionuclide fluxes

into a surface-water body and have been incorporated into two numerical integration programs DISPERSE and SURFACE giving greater numerical accuracy and flexibility in the treatment of source term dispersion (Kozak, 1990). These models have been used in this analysis.

An example of a Green function is shown below:

$$G(x,y,z,t) = \frac{1}{Rn} X(x,t)\, Y(y,t)\, Z(z,t)$$

where:
G = the Green's function
R = the retardation factor
n = the effective porosity
t = time
X,Y,Z = are functions that depend of the boundary conditions and account for dispersion all three spatial directions

Transport to a well in the aquifer is modeled using the following analytical method.

$$C = \frac{1}{nLWR} \int_0^t Q(\tau)\; X(x, t-\tau)\, Y(t-\tau)\, Z(t-\tau)\; d\tau$$

where:
C = the concentration in the aquifer
Q = the time dependent source rate,
τ = the time at which the inventory is exhausted
n = the effective porosity,
L = the length of the unit of interest
W = the width of the unit of interest
R = the retardation factor in the aquifer
t = time

and

$$X = \frac{1}{2}\left[erf\left(\frac{x+L/2 - u(t-\tau)/R}{\alpha_L}\right) - erf\left(\frac{x-L/2 - u(t-\tau)/R}{\alpha_L}\right)\right]$$

$$Y = erf\left(\frac{W/2}{\alpha_T}\right)$$

$$Z = \frac{1}{b}\left[1 + 2\sum_{m=1}^{\infty} \exp\left(\frac{-m^2\pi^2 D_T(t-\tau)}{b^2 R}\right)\right]$$

where:
- b = the aquifer thickness, assumed constant
- x = the downgradient distance
- u = the pore velocity (the Darcy velocity divided by the effective porosity)
- erf = error function
- m = total inventory of the radionuclide

$$\alpha_L = \sqrt{[4D_L(t-\tau)/R]}$$

$$\alpha_T = \sqrt{[4D_T(t-\tau)/R]}$$

where:
- D_T = the transverse dispersion coefficient
- D_L = the longitudinal dispersion coefficient

A one dimensional vertical flow can often be justified if the soil is relatively homogeneous. The soil around BP is predominantly glacial till and was assumed to be homogeneous with respect to transport of water for conservatism. There is the presence of clay and fractured bedrock around the site but these present further restrictions to groundwater flow then a homogeneous till. The travel time to the water table for a non-dispersing solute can then be determined by straightforward methods for one-dimensional flow. Once travel time has been determined radioactive decay of the nuclide is performed.

4.0 CALCULATIONS

The calculations using the above methodology were done using data that was available from previous work at the BP Chemicals site. Previously, analysis was done to determine the distribution coefficient with actual site material (Enwright 1990). This was used to calculate a retardation factor for the migration of the depleted uranium. In the calculations for this analysis a sensitivity analysis approach was used which allowed different orders of magnitude of variables to be entered to observe the

effects on the activity migration. This type of approach allows the investigator use a wide range of assumptions to evaluate items and their contribution in the model that may affect the conclusion. This gives a conservative approach to the problem.

Once radionuclide concentrations have been determined in the environmental medium the dose to an individual can be calculated using dosimetry models. Dose models estimate the effect of the radionuclide intake on human tissues. NRC guidance exists for appropriate models and assumptions for pathways models (NRC, 1977). Internationally accepted dosimetry models have been developed from a model of the human body, as described by the International Commission on Radiological Protection (ICRP), ICRP 26, 1987. The result of the ICRP models is a data base of dose-conversion factors that convert radionuclide intake to doses, and these have been published in ICRP 30. The recommended NRC pathways models and the recommended ICRP dosimetry models are implemented in this analysis.

5.0 ASSUMPTIONS

The quantity of uranium available for transport to the groundwater was calculated previously (Daily and Schmidt, 1990). The quantity calculated represents the total quantity of uranium on site prior to any remediation. This analysis uses all of that uranium as the source term and takes no credit for disposal of material as presented in the Decommissioning Plan. The total quantity of uranium is assumed to be concentrated in a form and physical location that represents the easiest pathway to the groundwater. This activity is available for migration to the groundwater for a period of 10,000 years.

The calculated retardation coefficient was 1.32 X 10^5 when the distribution coefficient of 33,000 ml/g which was measured from actual site material was used (Daily and Schmidt, 1990). This calculation assumed an effective porosity of 0.4. Typical retardation coefficients for uranium are in the range of 10^4, therefore the number calculated from physical data from the site is within the expected values. This high retardation factor becomes the controlling factor in the analysis and when other conservative factors are applied to the models the total dose equivalent received by the public is below 0.0001 mrem/yr. Upon varying this variable 3 decades to determine the dose received again at a smaller retention coefficient the total dose equivalent was still less than 0.0001 mrem/yr.

T . following constants were used:

- Facility length 120 meters
- Facility width 120 meters
- Aquifer thickness 80 meters
- Distance to groundwater 8 meters
- No delay in the unsaturated zone

Variations in the following variables of up to 3 decades were calculated in the sensitivity analysis and used to determine the total activity and therefore the dose equivalent:

- Longitudinal dispersivity: model default 0.05 m^2/yr, varied from 0.1 to 0.0005 m^2/yr
- Transverse dispersivity: model default 0.005 m^2/yr, varied from 0.01 to 5 X 10^{-6} m^2/yr
- Pore velocity: initial 0.1 m/yr, varied from 1 to 0.01 m/yr
- Effective porosity: initial 0.4, varied from 0.1 to 0.8
- Retardation coefficient: initial 1.32 X 10^5, varied from 132 to 1.32 X 10^5

6.0 CONCLUSIONS

The inherent insolubility of uranium in soil make its probability for migration very small. This can be seen from the soil characterization for uranium that has been done which shows distinct lines of contamination without subsequent migration through the soil on the site through the last several years. This characteristic has a profound affect on the assessment of the migration into the groundwater either through surface action or absorption through the soil. The activity levels at the end of 10,000 years are less than 1 X 10^{-5} Ci/m3. The analysis performed shows a total committed effective dose equivalent contribution of less than 0.0001 mrem/yr to the population at the end of a 10,000 year time of interest. This dose represents a risk several orders of magnitude below the guidance established by the NRC for Below Regulatory Concern. Therefore, the safety of the public is not compromised by the on-site disposal of soils containing slight amounts of depleted uranium and the total dose equivalent is well below regulatory guidelines of 1 mrem/yr for large numbers of the general public.

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