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THE RECHARGE AREA CONCEPT - A STRATEGY FOR SITING NUCLEAR WASTE REPOSITORIES

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Abstract

The Recharge Area Concept is the proposition that in Canadian-Shield type natural environments recharge areas of regional groundwater flow systems are superior for high-level nuclear waste repositories to other types of groundwater flow regimes, especially to areas of groundwater discharge. This conclusion is reached from an analysis of basinal groundwater flow models. The calculations were made for a two-dimensional flank of a fully saturated topographic basin, 20 km long and 4 km deep, in which groundwater is driven by gravity. Variants of hydraulic-conductivity distributions were considered: 1) homogeneous; 2) stratified; and 3) stratified-faulted. The faults attitudes were changed by steps from vertical to horizontal for different variants. The model is assumed conceptually to represent the crystalline-rock environment of the Canadian Shield. The hydrogeologic performances of hypothetical repositories placed 500 m deep in the recharge and discharge areas were characterized by thirteen parameters. The principal advantages of recharge- over discharge-area locations are: 1) longer travel paths and return-flow times from repository to surface; 2) robustness of predicted values of performance parameters; 3) field-verifiability of favourable hydrogeologic conditions (amounting to an implicit validation of the calculated minimum values of return-flow times); 4) site acceptance based on quantifiable and observable flow-controlling parameters; and 5) simple logistics and favourable economics of site selection and screening. As a by-product of modeling, it is demonstrated that the presence of old water is not an indication of stagnancy.

1. INTRODUCTION

The basic objective of nuclear waste disposal is to ensure that toxic contaminants from the wastes do not harm humans and the environment. In the present plan of disposal in terrestrial geologic media adopted by all countries, this effectively means that the possible escape of contaminants from an underground vault must be prevented or at least retarded for a sufficiently long period of time in the geosphere so as to render the radionuclides harmless if and when they surface.

It is almost axiomatic in nuclear waste disposal to regard groundwater as always the negative agent by which radioactive contaminants escaping from an underground vault is brought up to the surface. Due to this view, the major focus in the geologic work worldwide has been on studying and characterizing all aspects of fractures (e.g. density, orientation, width, etc.) and associated features (e.g. fracture fillings, matrix diffusion, etc.). However, many years of research in this direction has shown that there are numerous intractable problems with the characterization and prediction of behaviour of fractures, fracture-associated features and processes. In this paper, we advance the view that hydrogeology (more specifically, a clear understanding of regional groundwater flow patterns) can be exploited so as to have groundwater delay the transport of contaminants to the surface and thereby add another "barrier" to the planned system of engineered/geologic multi-barriers. We make the propositions that such an understanding is the single-most crucial technical factor to be addressed in ensuring the safety of geologic disposal, that a hydrogeologic model based on this understanding is robust, and that such a model is amenable to meaningful assessment.

The two basic arguments upon which the Recharge Area Concept has been developed, are: 1) that a position in a regional recharge area ensures the maximum degree of dilution and maximum possible travel times back to the land surface (as compared with other positions in a basin of similar hydrogeologic properties) for contaminants possibly escaping from a repository, and 2) that it is recharge environments where the groundwater flow-characteristics are sufficiently insensitive to discrepancies between actual hydrogeologic conditions and conditions assumed for purposes of calculations, to allow the construction of adequately robust flow models and their validation.

2. MODEL CALCULATIONS

Four key characteristics of basinal groundwater flow have been calculated by numerical modelling. Tóth and Sheng (1996) [1] gives complete details of model calculations and results. The calculations were performed for hypothetical repositories located at depths of 500 m, and 1000 m in both recharge- and discharge-areas of topographically defined basins which are underlain by a geologic framework of varying permeability distributions. The four flow characteristics are: 1) "return time", t_s, or the travel time of water from a repository to the land surface; 2) "repository-age of water", t_r, or the travel time of water from the land surface to the repository; 3) "return route", l_s, i.e., the length of flow line leading from the repository to the land surface in the direction of flow; and 4) "fault route", l_f, or the total length of that flow line inside of a highly conductive fault which passes also through a repository. These characteristics were determined with reference to a point 500 m below the land surface and 1 km distant from the lateral boundaries of the basin (Figure 1). The point is considered to represent the upper edge of a repository. The repository extends over a surface area of 2x2 km and its centre coincides with the basin's lateral boundaries at both the water divide (recharge side) and valley bottom (discharge side).

3. DISCUSSION OF MODELLING RESULTS

The most fundamental advantage of a repository location in a regional groundwater recharge area as opposed to that in a discharge area is summed up in the first four items in Table I. Collectively they indicate that in a recharge area groundwater flows downward with respect to the land surface, at decreasing velocities which may approach zero in the direction of flow and beneath the water divide. Conditions are opposite, on the other hand, in discharge areas: water moves from depth toward the land surface with increasing intensity in the directions of flow and the thalweg boundary. In the field, the sense of flow directions can be readily determined by measurements of fluid pressures and/or water levels in wells.

As a consequence of the opposite nature of conditions in these hydraulic environments, two associated key characteristics, namely the return-route length and the return time also are more favourable for recharge area locations (Table I, Items 5, 7). Contaminants, possibly escaping from a recharge-area repository would have to travel virtually the full width of the basin plus twice the depth to which regional flow would take them. If originating from areas within one kilometre of the divide boundary, this flow penetrates into the low permeability basement thereby delaying contaminant return both by adding distance and reducing velocity; the route length is significantly greater than 20 km. From a discharge area position, on the other hand, the contaminants would only have to travel 500 m, mostly through the high permeability weathered zone, to reach the land surface. The different conditions are amply reflected by the difference in return times (Table I, Item 7): 8×10^6 a for the recharge area repository and 1.1×10^5 a for the discharge area repository. Both the return-route length and the return time have significant bearings on the safety of a nuclear waste facility. The longer the route, the greater a proportion of the contaminants is adsorbed on the rock matrix's minerals; the longer the travel time the larger proportion of the radioactivity decays.

The age of the water in the recharge and discharge areas (Table I, Item 12) are noteworthy from two standpoints. During the 1.3×10^5 years that descending meteoric waters take to reach a repository in a recharge area they will be largely depleted in free or dissolved oxygen and will not be an oxidizing agent. In the discharge area, on the other hand, by virtue of its high age, an 8×10^6 year old water could be mistaken to indicate stagnancy, yet it is only 1.1×10^5 years away from the surface.

4. CONCLUSIONS

The conclusions drawn from the analysis of the Recharge Area Concept as supported by model calculations may be summarized as follows:

1. Recharge areas are superior to discharge areas for the siting of high level nuclear waste repositories. Recharge area locations assure considerably greater minimum travel-path lengths and return-flow times than do discharge area locations, and their effectiveness can be evaluated and purposefully modified; this type of control is not possible for discharge area locations.
2. The possible presence of, even undetected, faults does not negate or compromise the theoretical superiority or the suitability of recharge areas.
3. The hydrogeologic conditions required for the suitability of a recharge area location can be recognized and verified from field observations and, to the extent needed for safety, evaluated and critically assessed by modelling. This is not possible for discharge-area positions: the sensitivity of regional hydrogeological conditions to changes in their controlling factors is low as compared with that of the local conditions. Consequently, regional model estimates are robust relative to those from local models.
4. Regional groundwater flow can be exploited to enhance the role (utility) of the geosphere as a barrier to radioactive waste transport by judiciously selecting the basin and locating the repository near the basin's crest. Such deliberate exploitation, as it were engineering, of natural conditions is not possible for discharge-area repository-positions.

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Reference

[1] TÓTH J., SHENG, G., Enhancing nuclear waste disposal safety by exploiting regional groundwater flow: the recharge area concept, Hydrogeology Journal 4, 4, (1996) 4-25.

Item Number	HYDROGEOLOGIC CHARACTERISTICS	GROUNDWATER REGION	
		RECHARGE AREA	DISCHARGE AREA
1 *	hydraulic head gradient	upward	downward
2 *	vertical pressure gradient	less than hydrostatic	greater than hydrostatic
3 *	vertical component of flow	downward	upward
4 *	driving-force past the repository in direction of flow and toward divide	downward weak, decreasing to zero	upward strong and increasing
5 **	minimum return route from repository to surface (unfaulted stratified basin)	greater than 20 km	500 m
6	effect of faults on minimum return route (unfaulted)	reduce to ~20 km	nil
7 **	return-time from repository to surface t_s (unfaulted stratified basin)	8×10^6 a t_{sR}	$1{,}1 \times 10^5$ a t_{sD}
8	effect of dipping faults on minimum return time from repository	reduce to: (3 to 0,83) $\times 10^6$ a	possibly increase up to $1{,}8 \times 10^5$ a, mostly reduce to $0{,}23 \times 10^5$ a
9	effect of horizontal fault on minimum return time from repository	reduce to: (1,83 to 5,0) $\times 10^5$ a	reduce to: $2{,}5 \times 10^4$ a
10 **	minimum flow-path length from surface to repository (unfaulted stratified basin)	500 m	greater than 20 km
11	effect of faults on minimum flow-path length to repository (unfaulted)	nil	reduce to ~20 km
12 **	age of water at repository t_r (unfaulted stratified basin)	$\sim 1{,}3 \times 10^5$ a t_{rR}	$\sim 8{,}0 \times 10^6$ a t_{rD}
13	effect of faults on age of water at repository	reduce to: ~(2,7 to 3,2) $\times 10^4$ a	reduce to: ~(0,42 to 2,6) $\times 10^6$ a

* general conditions
** conditions in reference (unfaulted and stratified) basin