BORIS (Russia)

Description: Three sites have been used for the deep injection of liquid radioactive wastes in the Russian Federation: Dimitrovgrad, Krasnoyarsk-26 and Tomsk-7 (Rybal'chenko et. al., 1998).

Krasnoyarsk-26 and the similar site at Tomsk-7 were studied between 2000-2002 as anthropological analogues under the EC-funded BORIS [BORhole Injection Sites] project (Knight et. al., 2002; Wickham et. al., 2003a; b). The sites provided unique opportunities to study the migration of man-made radionuclides under in-situ deep geosphere conditions. Compilation of historical data was dominated by data from Krasnoyarsk-26, but due to national security restrictions it was only feasible to take in-situ groundwater samples from Tomsk-7 and then only from the less highly contaminated parts of the plumes. Thus there is merit in considering the two sites together.

Both sites are similar in consisting of several hundreds of metres of alternating high porosity sandstones and low permeability mudstones overlying a pre-Cambrian crystalline basement. At both sites liquid waste injection took place into two sandstone aquifers, the lower for ILW and HLW and the upper for LLW, see Figure 1. Injection commenced in 1963 at Tomsk-7 and 1967 at Krasnoyarsk-26. Some details of the sites are given below.

	Krasnoyarsk-26	Tomsk-7
Total injected volume	$6.1\ 10^6\ m^3$	$4.2\ 10^6\ m^3$
Present day activity	$17\ 10^6$ TBq	$37\ 10^6$ TBq
Depth of LLW injection horizon	180-280 m	180-280 m
Depth of ILW/HLW injection horizon	370-465 m	314-386 m
Number injection/extraction/monitoring wells	11/12/132	28/25/149

Some of the key findings are set-out below.

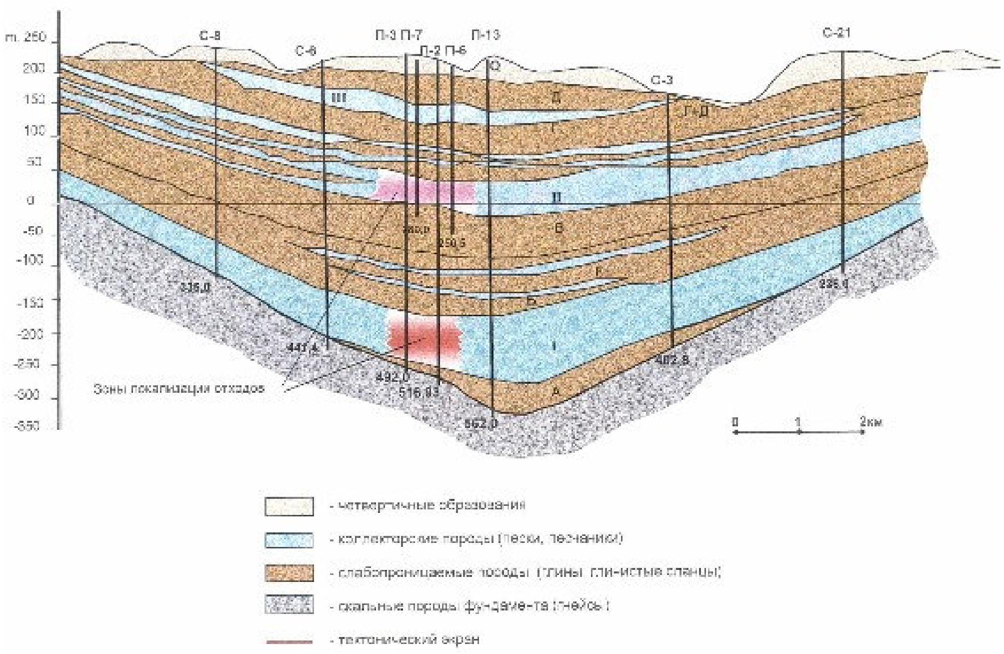

Figure 1 Cross-section at Krasnoyarsk-26 showing injection horizons for ILW/HLW (lower) and LLW (upper). Red colour indicates injection areas

<u>Rocks as radiation shields</u>

The repeated measurement of gamma activity in monitoring boreholes over a 30-40 year period demonstrated that natural rocks provide a very effective radiation barrier. Despite the very high activity of the HLW/ILW wastes, gamma logs do not detect the presence of the plume at distances more than 5 m above the plume, see Figure 2.

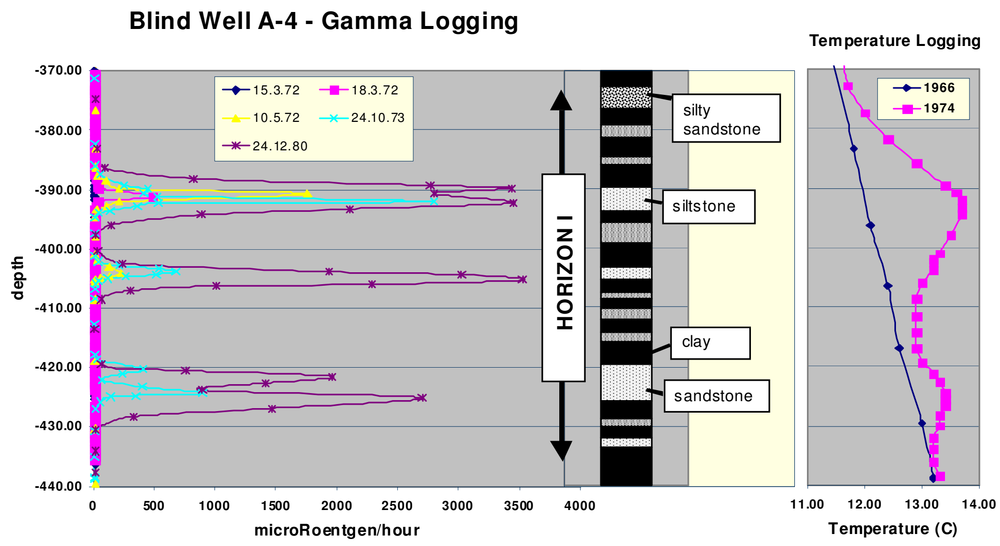

Figure 2 Repeat gamma and temperature logging of the HLW injection horizon in well A-4, Krasnoyarsk-26. The gamma log is measuring total gamma activity in the rock and groundwater, reduced by shielding effects of the well casing, cement and water. The gamma logs clearly show the plume confined to three sandstone layers within the injection horizon.

Mudrocks as seals

Fine details of plume development in space and time are available from repeat wireline gamma logs. These show that plume migration follows specific high porosity pathways and that an understanding of the 3D geometry of the sedimentary architecture is required to model plume development in detail, see Figure 2. Mudrocks provide effective barriers to vertical advective plume migration over the 40 year period studied, see Figure 2. On very much longer timescales diffusive migration into the mudrocks may occur.

Colloids and micro-organisms

Groundwater analyses at Krasnoyarsk-26 showed evidence of complex plume development and water–rock-colloid-microbe interactions. Figure 3 shows the evolution of groundwater chemistry in well P-3 at Krasnoyarsk. Breakthrough curves for total activity and activity of Ru^{106}, Sr^{90} and Cs^{137} show classical breakthrough behaviour albeit somewhat spiky due to the multiple injection events. However, the nitrate content repeatedly spikes (due to injection) but then rapidly falls back to background level. Since nitrate is normally considered a non-reactive tracer, this behaviour may be due to microbial-mediated nitrate reduction.

Complex and diverse populations of micro-organisms were found in uncontaminated groundwaters from the injection horizons at Tomsk-7. These included a large number of new lineages. Micro-organisms capable of interacting with uranium and other heavy metals were recorded which suggests that micro-organisms could play a part in radionuclide transport under deep geosphere conditions. Denitrifying bacteria capable of degrading nitrates to nitrogen gas were found which could explain the fate of nitrates noted above. Other groups capable of generating methane, hydrogen and hydrogen sulphide were recorded. In this context the only serious accident reported from the injection sites was a gas blow-out attributed to in-situ bio-mediated nitrogen gas production from the wastes.

Groundwater monitoring at Well P-3

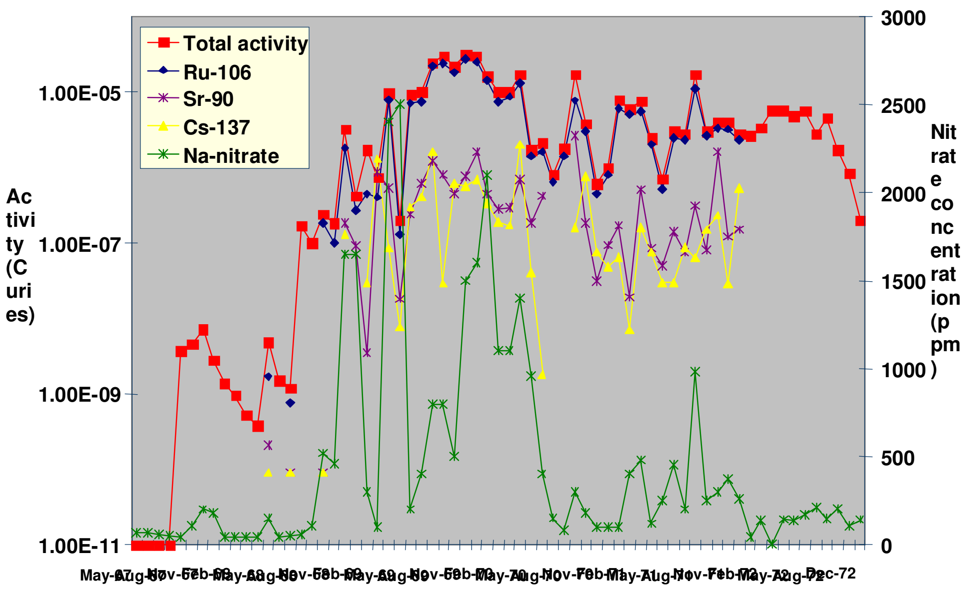

Figure 3 Evolution of groundwater chemistry in well P-3 close to the injection wells N-3 and N-4. Note that the total activity and that for individual radionuclides behaves as a typical breakthrough curve. In sharp contrast the nitrate concentrations repeatedly peak and rapidly return to background levels. This behaviour has been attributed to in-situ microbial degradation of nitrate.

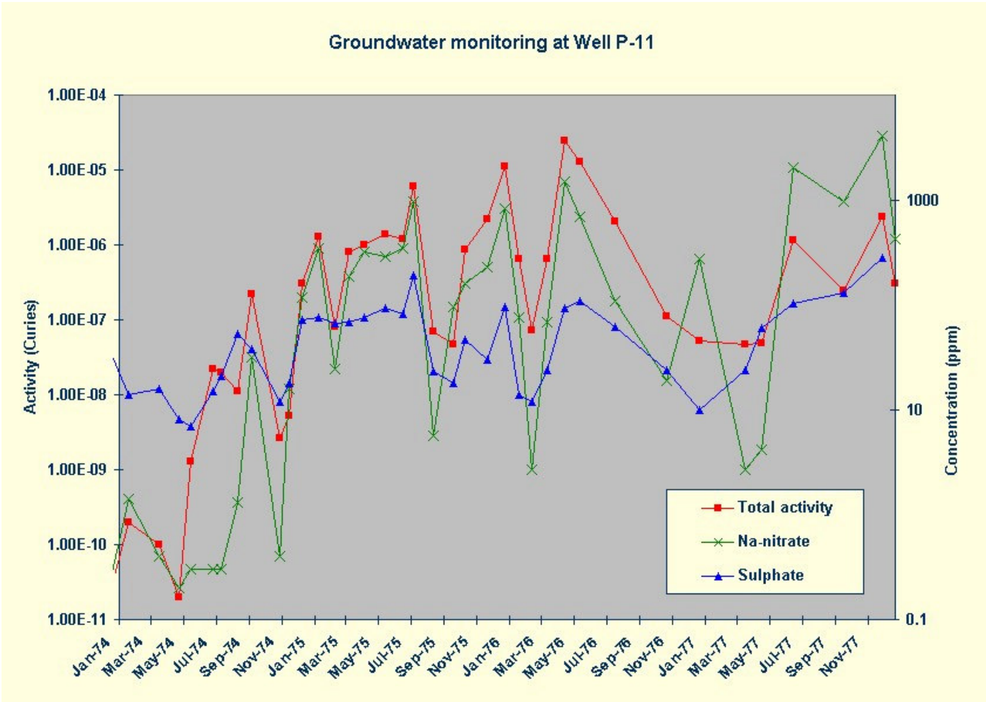

Figure 4 Groundwater chemistry at well P-11, Krasnagarsk. In contrast to Figure 3 nitrate and sulphate follow the curve for total activity. This suggests that part of the activity is acting as a 'conservative' tracer which has been interpreted as evidence for activity associated with colloids or micro-organisms.

In contrast groundwater monitoring in Krasnoyarsk-26 Well P-11, close to injection well N-11, shows a completely different behaviour, see Figure 4. Here the total activity shows a classic breakthrough curve as above, however, the nitrate and sulphate concentrations broadly follow fluctuations in total activity, albeit in a more exaggerated way. Since nitrate and sulphate are generally considered non-reactive it follows that some of the activity is behaving analogously to a 'conservative' tracer. This might be attributed to attachment to colloids or micro-organisms. In this context, goethite-like and clay colloids were found in the uncontaminated groundwaters from the injection horizons at Tomsk-7. Concentrations of lanthanides and actinides fell with progressive ultrafiltration, suggesting an association with the colloidal component, however, the possibility of sampling-induced artefacts could not be discounted.

Relevance: Krasnoyarsk-26 and Tomsk-7 provide analogues for the later stages of a repository once near field physical and chemical containment has broken down and radionuclides are free to migrate through the geosphere. These sites are some of the few places in the world where the long-term (30-40 year) migration of man-made radionuclides can be studied in-situ at repository-relevant depths.

Position(s) in the matrix tables: The study illustrates the far-field process of RN-migration and chemical RN-retardation in sandstones at low temperature - in particular impact of colloids and microbes.

Limitations: The injection history of wastes is complex and incompletely quantified. This comes about due to the very large number of injection events (more than 8000 at Krasnoyarsk-26), the incomplete characterisation of the wastes in terms of volumes and radionuclide content due to poor data recording and national security restrictions, and the operation of extraction wells to control the plume development. Thus the value of these sites to 'validate' models of radionuclide migration is limited.

Quantitative information: There is quantitative data for the dimensions of the plumes that developed at the sites, however, wastes were injected under pressure and extraction of uncontaminated groundwaters were undertaken to make room for the wastes.

Uncertainties: The key uncertainties relating to the sites are the complex and incomplete injection histories.

Time-scale: The sites provide data on the development of a plume over 30-40 year timescale (human timescale), but the conditions when such a plume will develop in a repository context will be far into the future once the physical and chemical containment barriers have failed.

PA/safety case applications: There are no known uses of these sites in a PA context.

Communication applications: There are no known uses of these sites in a communications context.

References:

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Added value comments: This analogue provides very clear examples of how rocks act as radiation barriers and that mudrocks can act as seals under repository-relevant in-situ conditions. They also show the need to consider the role of micro-organisms and colloids in radionuclide transport.

Potential follow-up work: Initially this was proposed to be a 3 year task. In the event only the first 21 month phase was funded and so there is considerable scope for further analysis of the Krasnoyarsk-26 data obtained and a large amount of additional data from Tomsk-7 is available in the Russian Federation.

Keywords: Krasnoyarsk-26, Tomsk-7, liquid HLW injection, mudrocks as seals, micro-organisms, colloids

Reviewers and dates: Les Knight, Nirex (December 2003).