

CONF-971198--

## Fractured Rock Aquifer Test in the Western Siberian Basin, Ozyorsk, Russia

by

R. L. Nichols

Westinghouse Savannah River Company  
Savannah River Site  
Aiken, South Carolina 29808

B. B. Loonev

C. A. Eddy-Dilek

E. G. Drozhko  
PA Mayak

Y. V. Glalolenko  
PA Mayak

Y. G. Mokrov  
CPL PA Mayak

I. A. Ivanov  
CPL PA Mayak

A. V. Glagolev  
PSA Hydrospetzgeologiya

N. A. Vasil'kova  
PSA Hydrospetzgeologiya

A. V. Skakov and S. A. Ter-Saakian  
PSA Hydrospetzgeologiya

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A document prepared for 1997 AMERICAN INSTITUTE OF HYDROLOGY ANNUAL MEETING at Tampa, FL, USA from 11/16/97 - 11/19/97.

DOE Contract No. **DE-AC09-96SR18500**

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**Fractured Rock Aquifer Tests in the Western Siberian Basin, Ozyorsk, Russia**

<sup>1</sup>R. L. Nichols, <sup>1</sup>B.B. Looney, <sup>1</sup>C. A. Eddy-Dilek, <sup>2</sup>E. G Drozhko, <sup>2</sup>Y. V. Glalolenko,  
<sup>3</sup>Y. G. Mokrov, <sup>3</sup>I. A. Ivanov, <sup>4</sup>A. V. Glagolev, <sup>4</sup>N. A. Vasil'kova, <sup>4</sup>A. V. Skakov, <sup>4</sup>S. A. Ter-Saakian

<sup>1</sup> Westinghouse Savannah River Company

<sup>2</sup> PA Mayak

<sup>3</sup> CPL PA Mayak

<sup>4</sup> PSA Hydrospeitzgeologiya

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*Domone Shadov*  
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Date: *mj* 7/18/97

#### ABSTRACT

A series of multi-zone pumping tests was conducted in a contaminated fractured rock aquifer in the Western Siberian Basin, Ozyorsk, Russia. The tests were conducted adjacent to the Mishelyak River floodplain in fractured Paleozoic porphyrites, tuffs, tuff breccia, and lava typical of the Ural mountain complex. Geophysical logs, borehole photography, core samples, and results from previous borehole contamination studies were used to identify the zones to be tested. A network of three uncased wells was tested using a system of inflatable packers, pressure transducers and data loggers. Seven zones were isolated and monitored in two of the uncased wells. A straddle packer assembly was used to isolate individual zones within the pumping well. Eight constant rate pumping tests were conducted.

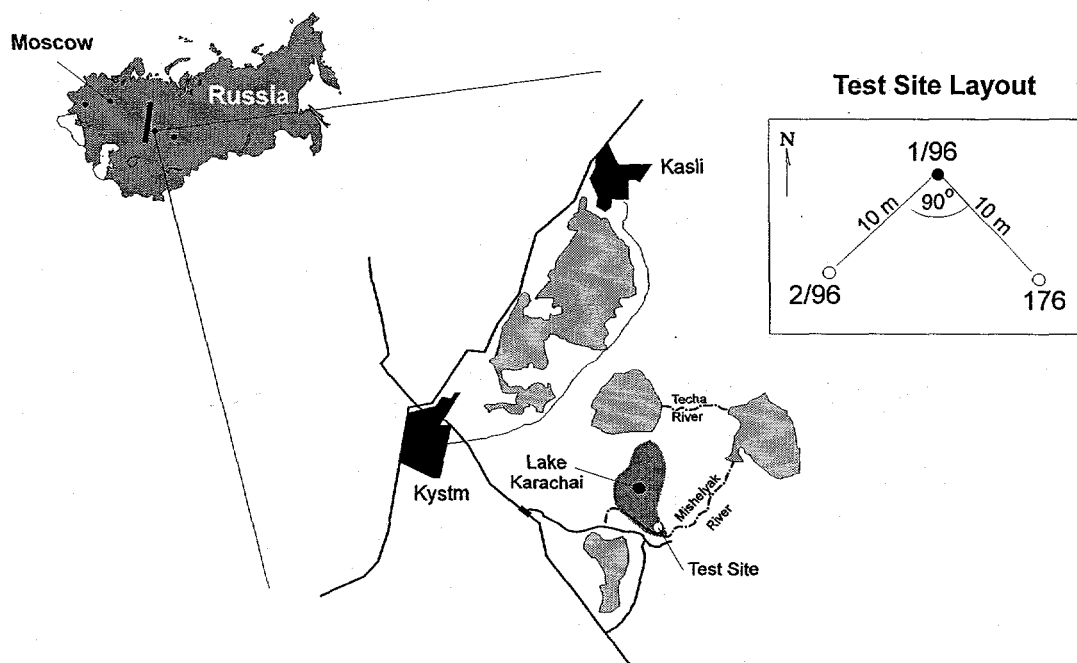
Results of the testing indicate that shallow groundwater migrates primarily in two intervals that are separated by an interval with low lateral conductivity. The water bearing intervals have moderate to high specific capacities (1.3 and 30 L/min/m). Several processes are responsible for fracturing present in the lower interval. The network of compound fractures produced a complex array of fracture intersections yielding a fractured media with hydraulic behavior similar to porous media. Models used for the analysis of pumping tests in porous media provide a good estimation of the hydraulic response of the lower interval to pumping. Future work will include more complex analysis of the data to determine hydraulic conductivity ellipses.

## BACKGROUND

Technology, data, models, and scientific experience developed over the last 50 years in the former Soviet Union and the United States are being applied to solve problems resulting from nuclear contamination associated with the weapons complexes. To facilitate efficient clean up, The Ministry of Atomic Energy of the Russian Federation (MINATOM) and the U. S. Department of Energy (DOE) have been exchanging characterization, clean up and waste management technologies. For groundwater contamination, early emphasis in the program has been on using innovative Russian and American technologies for detailed depth discrete characterization of the contamination and defining contaminant geochemistry. The precision of the resulting three-dimensional (3D) understanding of the contaminant plume is a key to optimizing clean up of former weapons production facilities. Research in the complex fractured rock aquifer system at the MAYAK Production Association (MAYAK) has been a successful element of the exchange. The basic geology and regional groundwater plume has been well characterized over the past thirty years. To supplement this information, the exchange program has deployed various depth discrete samplers and applied various specialized fractured rock technologies near the potential point of exposure -- the groundwater - surface water interface. A multipacker pump test provided useful data on the nature and distribution of fractures and the resulting hydraulic conductivity in this important portion of the contaminant plume. The site background, test objectives and description and initial results are discussed below

The MAYAK Production Association (MAYAK) is the site of the first production reactor complex in the former Soviet Union. MAYAK is located 15 km east of the city of Kysym, on a hilly plain, sloping down the eastern flank of the Ural Mountains, FIGURE 1. Lake Karachai at the MAYAK was a major waste disposal facility and received approximately 7% of the waste generated by the entire former Soviet Union weapons complex (Bradley, et al, 1996).

FIGURE 1 Site location map.



Mayak began using Lake Karachai for the disposal of liquid waste in 1952. When it was in service the contained a slightly alkaline radioactive sodium-nitrate brine with a dissolved salt content of 30 - 144 g/L and a density ranging from 1.016 - 1.090 g/cm<sup>3</sup> (Samsonova and Drozhko, 1996). The basin contains 120MCi of beta-active radionuclides, predominantly composed of <sup>90</sup>Sr and <sup>137</sup>Cs. Approximately 7 percent of the radioactivity is in the water and the remainder is in the silts and loams on the bottom of the lake (Drozhko et al., 1993). Through the years some of the brine infiltrated the sediments below the lake and ultimately contaminated the underlying water bearing zones which occur in fractured rock. The dense aqueous phase (DAPL) of the waste migrated to the bottom of the aquifer system and is transported along the base of the aquifer system by gravitational forces. Some of the DAPL accumulates in structural traps in the bottom of the aquifer system. A network of boreholes to monitor the regional contaminant plume was installed beginning in 1951 and systematic observations began in 1955.

### HYDROGEOLOGIC SETTING

The study area is located 2.5km south of Lake Karachai along the banks of the Misheyak river. Water from Lake Karachai migrates down along major geologic structures and discharges locally into the Mishelyak and Techa rivers. The bedrock in this region is composed primarily of lava and tuffaceous lava of Silurian to Early Devonian age. A complex internal structure produced by the thinning and pinching of various volcanic and volcanoclastic facies has been documented (Velichkin et al., 1996). A network of fractures is present in the bedrock: these fractures are associated with multiple processes including cooling of the volcanic rocks, regional tectonics associated with the formation of the Kyshtash Synclinorium, and regional unloading of the overburden due to erosion (Velichkin et al., 1996). In general, the frequency of fractures decreases with depth. Bedrock below 80 to 100 m has extremely low permeability and does not function as part of the hydrologic system.

In the study area, an overlying sedimentary section that ranges in thickness from 0.5 m to 12 m is composed of loam and sandy loam with gravel and rock fragments. The underlying bedrock to several hundred meters is composed of porphyrites, tuffs, brecciated tuff, and lava. The rocks are massive; locally foliated or fractured; with quartz, calcite, and chlorite-filled veins.

Analysis of the distribution of fractures present in each of the boreholes was done using fracture orientations measured from borehole pictures. Several different populations of fractures are present in the section including NS-trending subhorizontal fractures, NNW-trending NE-dipping at 45° fractures, and NNW-trending NW-dipping at 45° fractures. The density of fractures decreases with depth from approximately 3 fractures/meter in the upper part of the section, 1.5 fractures/m for the intermediate depths (Zones E and F), to less than 1 fracture/m (Zone G).

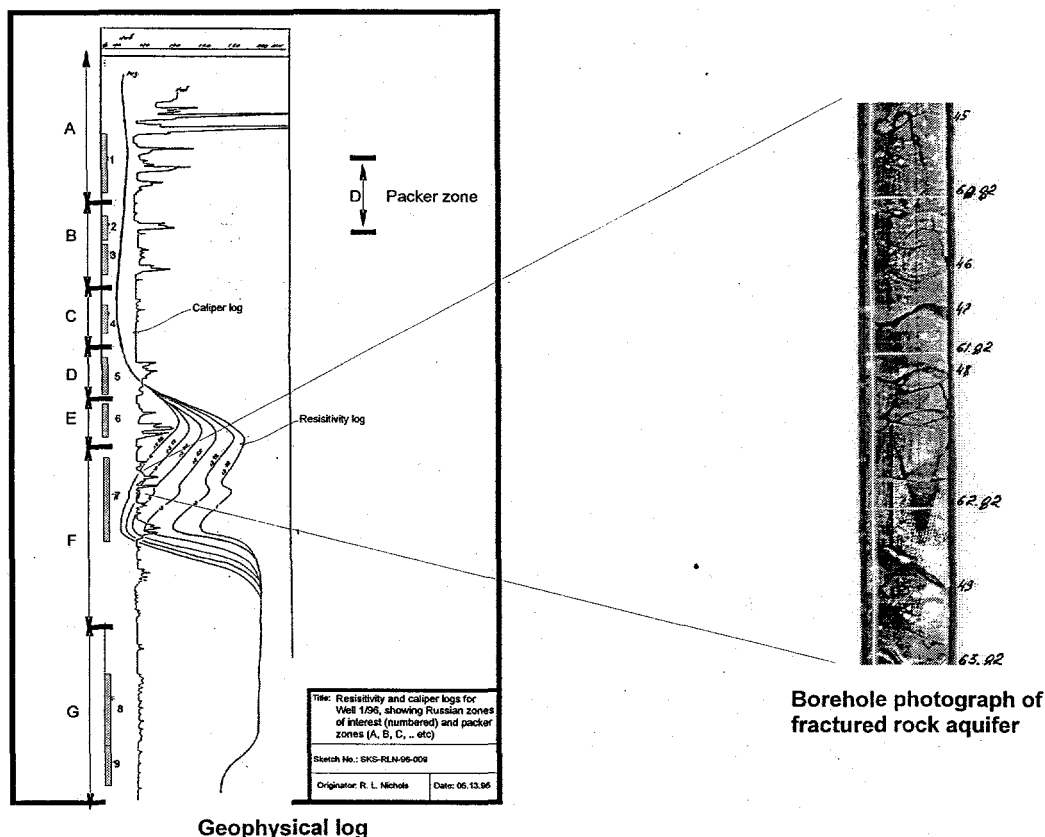
### AQUIFER TESTING

Three 110 mm diameter wells, 1/96, 2/96, and 176 were used to conduct the pumping test. Each of the wells had 10 m of surface casing and the rest of the well was open to the underlying fractured rock aquifer system. The objective of the test was to measure the transmissivity of individual zones within the aquifer system. The zones were selected using geophysical logs (e.g., resistivity and caliper logs), borehole photography, and results from previous pumping and borehole contaminant distribution studies, FIGURE 2. Based on these criteria seven zones of interest were identified with particular emphasis on active hydrologic zones and depths where contaminant transport has been observed.

A system of six medium duty packers, in-line adapters, pipe, tubing (for packer inflation and pressure transfer) and pressure transducers was used to isolate and monitor individual zones within each observation well, 2/96 and 176. A straddle packer assembly was used for the pumping well, 1/96. This assembly allowed isolation of a pumping zone from the zones above and below as needed. The length of the assembly was adjusted for each pumping zone to match the agreed depths (Nichols et al., 1996).

A constant rate pumping test was run on each zone until the water level in the pumping and observation wells approached steady state. Water levels were monitored for 30 minutes prior to each pumping test, during the pumping test, and during the recovery period following termination of the pumping test. Water levels were monitored and recorded using pressure transducers and data loggers. Water samples were collected on a periodic basis during each pumping test. The nitrate-ion content of each sample was measured immediately after collection in the field using an ion-selective electrode. Water samples for chemical and radiochemical analysis were given to the MAYAK Central Processing Laboratory for additional analysis.

FIGURE 2 Geophysical log and borehole photograph from well 1/96.



## RESULTS

The specific capacity for each zone in the pumping well was calculated using the final drawdown in the pumping zone, TABLE 1. The lack of well screen in the well and the relatively low pumping rates minimize the head loss due to the entry of water into the well and as a result the specific capacity of each zone can be used to estimate the relative hydraulic conductivity of the zones. The highest specific capacities (39.5 L/min/m) are found in zones E and F. Above and below these high capacity zones, in zone D and in the deepest zone (G), the lowest specific capacities were measured, 0.047 and <0.003 L/min/m, respectively. Overlying zone D, the rock exhibited intermediate specific capacities, 1.3 L/min/m (Zones A



and B) and 0.32 L/min/m (Zone C). As a check on quality and consistency, the sum of the specific capacities in the individual zones (82 L/min/m) should approximately equal the specific capacity measured when all zones were pumped simultaneously (84.7 L/min/m). The close agreement indicates high quality and consistent results.

Similarly, the sum of the nitrate concentrations weighted using the specific capacity (4903 mg/L) should approximately equal the nitrate concentration measured when pumping all zones simultaneously (4624 mg/L). This provides evidence that the chemical analysis was also of high quality and consistency. Structural analysis of the boehle fractures are consistent with these results. The zones (E and F) with relatively high specific capacities are dominated by the horizontal fractures that are intersected by more steeply dipping fractures. Zone D, which is relatively impermeable, is cut by only one population of subparallel fractures while Zone G is relatively impermeable due to the very low fracture density.

Drawdown data collected during the pumping tests of zone E and F were analyzed to calculate estimates of transmissivity. The data was analyzed using the Hantush method for leaky aquifers with correction for partial penetration by observation and pumping wells Hantush 1955, 1961a, and 1961b. This method was chosen based on the following assumptions:

- The complex array of fractures produced a system that behaves hydraulically similar to a porous media.
- Zones E and F are within the same water bearing unit.
- Zone D responds to pumping similar to a leaky aquitard, based on its low specific capacity.
- Zone G is effectively a no flow boundary due to its very low permeability.

TABLE 1 Results from interval pumping of well 1/96.

Zone	Depth to Interval (m)		Pumping Rate (L/min)	Specific Capacity (L/min/m)	NO3 (mg/L)
	Top	Bottom			
1/96 A	0.0	19.0	8.82	1.3	536
1/96 B	20.9	32.2	12.5	1.3	1096
1/96 C	32.3	41.5	7.5	0.32	1380
1/96 D	42.5	47.5	0.63	0.05	1928
1/96 E	49.0	54.0	75	39.5	4217
1/96 F	55.4	75.0	75	39.5	5888
1/96 G	79	99.6	<0.1	<0.003	no sample
1/96 All			75	84.7	4624

The Hantush method produced an excellent fit to the drawdown data for Zones E and F as shown in FIGURE 3. The results from both tests are very similar as would be expected since both tests were conducted on the same water bearing unit. However, the transmissivity estimates from the Zone E test are slightly higher than for Zone F, TABLE 2. These variations may be due to anisotropy since the transmissivities were measured along different flowpaths.

FIGURE 3 Field data (symbols) and type curve fit (lines) for pumping test of Zone F.

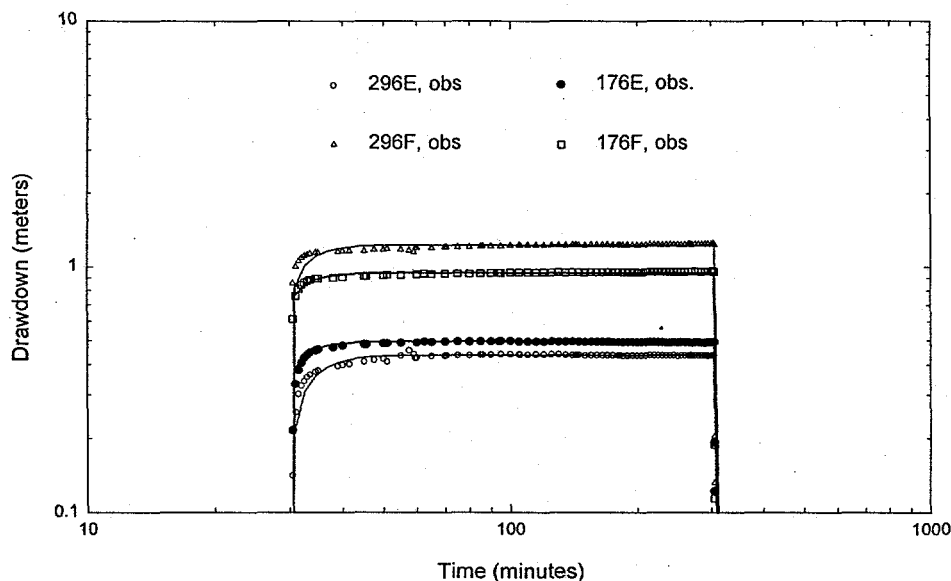


TABLE 2 Results from Hantush type curve analysis of data from pumping tests of Zones E and F.

Well/Zone	T (m <sup>2</sup> /min)	S	r/B
Pumping Zone 196E			
176/E	0.061	1.3E-4	0.198
176/F	0.067	4.5E-5	0.096
296/E	0.110	1.5E-6	0.008
296/F	0.068	1.3E-5	0.053
Pumping Zone 196F			
176/E	0.032	2.1E-5	0.096
176/F	0.055	3.6E-6	0.096
296/E	0.025	3.7E-4	0.442
296/F	0.014	9.4E-5	0.320

### CONCLUSION

The fractured igneous and metamorphic rock aquifer at the site behaves as a layered system of water bearing units when subjected to pumping. The good match between the field data and analytical models for leaky aquifers show that groundwater flow in Zones E and F can be simulated using porous media models. Additional field studies should be studied to expand the areal extent over which this approach can be applied. A more rigorous analysis of the test data using methods that incorporate anisotropy similar to those developed by Hsieh and Nueman, 1985 may yield additional insight about the

hydraulic conductivity field at the test site. Data from the pumping test, combined with inorganic and radiochemical measurements are the basis for Russian and American scientists to define the behavior and rate of release of radionuclide to the regional surface water system from lake Karachai.

### ACKNOWLEDGMENTS

The Joint Coordinating Committee for Environmental Remediation and Waste Management (JCCEM) sponsored the field research and is composed of the United States Department of Energy (USDOE) Office of Science and Technology Development and the Russia Ministry of Atomic Energy (MINATOM).

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