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A Joint Russian–American Field Test at the Chelyabinsk-65 (Mayak) Site: Test Description and Preliminary Results

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A JOINT RUSSIAN – AMERICAN FIELD TEST AT THE CHELYABINSK-65 (MAYAK) SITE: TEST DESCRIPTION AND PRELIMINARY RESULTS

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ABSTRACT

In September 1994, a Russian–American team conducted hydrogeological, geochemical, geophysical, and radiometric measurements in the territory of the Mayak Production Association,13 km. southwest of Chelyabinsk-65 in the vicinity of the Mishelyak River. The primary purpose of these operations was to examine the frontal area of a groundwater plume moving from Lake Karachai toward the the river. Activities encompassed isolation of hydrologic intervals in two wells and production of water from these intervals, to compare isolated versus open-well sampling methods; surface and soil-water sampling, accompanying radiometric measurements and subsequent chemical analyses; and electrical resistivity profiling in areas of expected contrasting resistivity. Preliminary results indicate that 1) ^{60}Co and ^{137}Cs are present in small concentrations (~0.1 % of permissible levels) in water of the Mishelyak River, 2) analyses of water samples collected by a downhole sampler and of water produced from packed-off intervals agree within limits of laboratory accuracy, attesting to the efficacy of the sampling methods presently used by the Russian workers; and 3) strong contrasts occur between the electrical resistivities of soil and bedrock. Further collaborative work is strongly recommended, and should include more detailed isolation of intervals in wells by multi-packer installations, to better determine the geochemical and hydrological characteristics of the Karachai-Mishelyak system; deployment of a broader soil-water and soil sampling array; a more detailed examination of the distribution and concentration of radionuclides by high-resolution field gamma spectrometry; and a detailing of the area's electrical resistivity setting, using a mobile electromagnetic measurement system. The American and Russian scientists benefited from the collaborative exercise in that each side was able to discuss and experience first- hand the scientific rationales and methodologies used, and results obtained by their counterparts.

INTRODUCTION

This paper presents preliminary results of collaborative Russian-American hydrogeological, geophysical, and radiometric operations, conducted in September 1994 in the territory of the Mayak Production Association, 13 km southeast of Chelyabinsk-65 in the vicinity of the Mishelyak River. All activities were conducted under the "Program of Joint Russian-American Field Studies," in the framework of the Russian-American Joint Coordinating Committee for Environmental Remediation and Waste Management Agreement between the Russian Ministry of Atomic Energy (MINATOM) and the offices of Environmental Management and Technology Development of the U.S. Department of Energy (DOE). The primary purpose of this activity was to apply different methods than those previously used, to examine the frontal area of a plume of ground water moving from Lake Karachai toward the Mishelyak River (Fig.1). Activities principally encompassed: 1) surface and soil water sampling, accompanying radiometric measurements and subsequent chemical analyses; 2) isolation of specific hydrologic intervals in two wells and production of water from these intervals, to compare isolated and open-well sampling methods; and 3) surface electrical resistivity profiling in areas of expected contrasting resistivity. Surveys, instrumentation, methodologies and preliminary results are briefly described below. Detailed interpretations and evaluations are in progress.

Geological setting

The Karachai-Mishelyak area is underlain by bedrock of metamorphosed basaltic porphyrite of Silurian age. Observation of cores, walls of cuts and quarry faces indicates that the rock is ubiquitously fractured, with steeply-dipping joint sets intersected by low-angle to sub-horizontal sets. The steep joints are spaced as closely as a decimeter, while the sub-horizontal joints are generally spaced a few decimeters to a meter apart. Fracture surfaces in a roughly north-striking set were observed to be coated with manganese-oxide and iron-oxide minerals, while sub-horizontal fractures generally contain quartz and calcite. The thickness of the weathered zone ranges from nearly zero to several tens of meters and varies markedly over short horizontal distances (<100 m). Where thickness is adequate, an upper intensively weathered zone supports abundant vegetation and a lower, less weathered zone retains fractures. It has been proposed by

Russian hydrogeologists that through-going shear zones transect the area, and may be the primary flow paths for ground water moving from Lake Karachai toward the Mishelyak River (1).

SURFACE WATER SAMPLING AND RADIOMETRY

Radiometric measurements and surface water sampling were conducted in traverses on the left and right banks of the Mishelyak River. An initial reconnaissance radiometric traverse was made along the left bank. The Russian team used DBG-06t Geiger-Mueller survey meters, and the U.S. team used a SPICER pressurized argon gas ionization chamber and a "Scout" gamma-ray spectrometer. The ion chamber is calibrated with standard radium sources, with a small correction for differences in response to cosmic and typical natural gamma fields. The gamma spectrometer employs a 5 x 5 cm NaI(Tl) scintillation detector - phototube assembly coupled to a 256-channel pulse-height analyzer. Results of reconnaissance traverse measurements by both Russian and American equipment agreed within 10%, so further dosimetry measurements were done by the Russian team.

Surface water sampling was conducted at 7 locations where there was good access to the Mishelyak River (Fig. 2). At each site activities included: 1) measuring the gamma background of the river bank at the ground surface and at 1m elevation with the DBG-06t survey meter; 2) measuring gamma spectra of the water by direct immersion of the NaI detector; 3) gamma spectrometry of the bank with the detector 1m above the surface; 4) water sampling, with 10 L collected for Russian analyses and 2 L collected for American analyses.

Gamma background measurements on the surface and at 1 m were repeated at least 3 times at each site, they are summarized in Table 1. Surface measurements averaged 19.5 uR h^{-1}; at 1 m elevation the average was 18.1 uR h^{-1}. These values significantly exceed the natural background (~8 uR h^{-1}) and reflect the presence of ^{137}Cs. However, they indicate that gamma radioactivity on the traverses and at water sampling sites poses no danger to people who work there.

In-situ gamma-spectral measurements of the Mishelyak River showed qualitatively the presence in water of ^{60}Co, especially at locations 1 and 2. All gamma spectra on the bank indicated the presence of ^{137}Cs. Laboratory analyses of ^{60}Co, ^{3}H, and nitrate-ion concentrations of surface water are listed in Table 1 (analytical procedures are described below). Appreciable

concentrations of tritium occur at all 7 locations. ^{60}Co occurs at 6 of the 7 sites, with the highest value at location 2, confirming the field measurements. Earlier reports by the Russian Environmental Laboratory state that the concentrations of ^{60}Co and ^{137}Cs do not exceed 1.5 Bq/L, a level ~0.1% of the presently permissible concentrations for radiation safety in Russia. The relatively low downstream values of ^{60}Co compared to higher values at locations 1 and 2 suggest that river bottom sediments and aquatic vegetation may be helping to remove this radioelement from the river water.

SOIL WATER SAMPLING

To provide fluid sampling continuity between surface and ground water samples, two sets of samplers were installed to collect soil water from the vadose zone near wells 173 and 176. The permanent water table is expected to be 1 to 1.5 m deep at these locations. A sampler set consisted of two samplers, each at two different depths, emplaced in hand-dug holes which were then backfilled. Each sampler consisted of a PVC tube 75 cm long, with a capillary-porous tip at the bottom end and suction/pressurization and sampling tubes at the other. A hand vacuum pump provided suction for water collection. At well 176, one sampler was installed with its porous tip 1m below ground level and one at a depth of 50 cm. Because bedrock was very close to the surface at well 173, installation depths there were 75 and 50 cm.

Samples of the order of 10 to 30 mL were successfully collected from the 1 m- deep sampler at well 176 after one day, from the 50 cm - deep sampler after three days, and from the samplers at well 173 after five days. The samplers remain in place, and collection is continuing to obtain sufficient volumes for laboratory analyses.

It is suggested that nests of samplers be emplaced to provide vadose-zone soil-water samples at 10 cm intervals from depths of 20 cm to 1 to 2 m below the surface. Chemical analyses of soil samples taken from each of the 10 cm intervals could then be compared with soil-water chemistries to reveal the partitioning of contaminants between the solid and fluid phases.

GROUND WATER SAMPLING

Samples were obtained from wells 173 and 176 , initially by a downhole fluid sampler and later by pumping from packed-off intervals. Procedures and preliminary results are described below, a diagram of the wells is shown in Fig. 3.

To prepare the wells for the September samplings, the wells were washed with clean (neutral) water in July, 1994. They were then allowed to stabilize for 60 days for recovery of the natural hydrochemical balance. A downhole resistivity survey was conducted in relatively undisturbed conditions before starting the sampling sequence. This indicated to some extent the zones selected for sampling. The first sampling was then done with a plunger-type sampler developed by P.S.A. Hydrospetzgeologia; the resistivity survey was then repeated, followed by production of 330 L of water by a downhole pump to stimulate the flow of water into the well. This production was accompanied by a third resistivity survey. A second set of samples was then collected with the plunger sampler. Results of surveys before and after sampling show that after the initial pumping, there was no substantial change in the resistivity pattern.

Following open-hole sampling, a 2-packer system was deployed in the wells, permitting isolation and subsequent sampling and pressure measurements, first of 5 intervals in well 176 and then of 3 intervals in well 173 (Fig. 3). The packer assembly consists of two packers, each 1 m in length, inflated by compressed air. Choosing the specific intervals was aided by examination of detailed borehole-wall photographs. In all intervals successful isolation was achieved, as demonstrated by the lack of response of pressure transducers located above and below the packed-off interval, compared to the response of a transducer within the interval, as water was produced from the interval by an electrically driven downhole pump.The pump was limited in depth of operation to <100 m. Pressures were regulated and recorded by a computer- controlled data acquisition system. Water samples were collected during production and were analyzed on site by the "express method," whereby the nitrate-ion concentrations of successive samples, measured by specific-ion electrode, reach a "plateau" indicating the presence of true formation water. Then the 10 liter (Russian) and 1 liter (U.S.) samples for laboratory analyses were collected. To better understand the hydrological regime, the pressure responses of the intervals to pumping are being analyzed to determine the permeabilities of the isolated intervals.

Future activities suggested include the deployment of multi-packer assemblies to depths much greater than 100 m, isolating several intervals concurrently. These, and the existing single-packer assembly could be used to examine the response of intervals in nearby wells to the production of an interval in another well, providing a broader picture of the hydrological continuity within zones.

CHEMICAL AND RADIOCHEMICAL ANALYSES OF WATER SAMPLES

Concentrations of three principal contaminants: nitrate ion, cobalt-60, and tritium, were determined by the ONIS and Central Laboratories at Chelyabinsk 65. Determination of nitrate ion concentration was by the clormetric method, whereby the intensity of coloring was compared with that of a standard; accuracy is +/-7%. Volume activity of ^{60}Co was measured by a scintillation gamma spectrometer, consisting of a 4096-channel analyzer and a 15 cm x 15 cm NaI(Tl) detector containing a 200 cubic cm well. Concentrations were determined by comparison with a ^{60}Co standard. Quality control was maintained by counting selected samples with a high-resolution germanium detector system. The sensitivity for a 1 h counting is ~0.5 Bq per sample. Tritium volume radioactivity was determined by beta- counting of a Zns liquid scintillator "cocktail" containing 40 mL of scintillator and 5 mL of water sample. Sensitivity for tritium is ~40 Bq/L.

The results of NO_3 ion, ^{3}H and ^{60}Co concentrations in wells 173 and 176 are listed in Table 2. Changes in the nitrate ion concentration are consistent when the results for samples taken by different methods are compared. For each interval in well 176, there is an increase in nitrate ion concentration for samples taken by the plunger sampler after pumping water from the well, and a relative decrease in nitrate in samples collected from the isolated intervals. This may be due to introduction of nitrate from interval 5 into the higher intervals by movement of water along the outside of the well casing. The concentrations in the packed-off interval samples compare well with the concentrations in plunger samples obtained in "natural" conditions, before pumping. This agreement is illustrated in Fig. 4, where a linear regression yields an R^2 value of 0.98, attesting to the efficacy of the ground water sampling methods presently used by the Russian workers. The largest difference between interval and plunger samples is in interval 5, the main zone of incoming

contaminated water: there the packers span a 20 m interval, while the plunger sampler was placed at one position near the center of the interval.

Table 3 compares concentrations and volume activities of contaminants in well water and Mishelyak River surface water. Average NO_3 ion concentrations of surface water are about 1/1000 those of well 176 water and 1/10 those of well 173 water. Average ^{3}H volume activities of surface water are slightly less than those!of well 176 water. Average ^{60}Co volume activities of well 176 water are ~200 times those of"surface water, and average ^{60}Co activities of well 173 and surface water are roughly equal. These results demonstrate the preponderance of contaminants in water of well 176, in contrast to nearby well 173 and to Mishelyak marsh and river water, and indicate that well 176 is definitely within the plume of contaminants moving from Lake Karachai toward the Mishelyak River. The presence of statistically-significant concentrations of ^{60}Co in the surface water suggests that some contribution from the ground water plume is reaching the surface water.

GEOPHYSICAL SURVEYS

Surface geophysical methods may help to determine the location of contaminated ground water at less cost, but with lower resolution than direct drillhole techniques. In this respect, an electrical resistivity and induced polarization (IP) survey was conducted; the locations of the survey lines are shown in Fig. 2. A dipole-dipole resistivity array was deployed because it permitted both vertical sounding and lateral profiling. Lightweight equipment brought from the U.S. included a stable-oscillator based phase-measuring IP set, a low-power current-controlled transmitter, and a set of non-polarizing measuring electrodes. A dipole spacing of 20 m provided good resolution between depths of 5 and 40 m. Traverses encompassed ~1.8 line km; including profiles through wells 173 and 176, a parallel profile south of the Mishelyak River and its marsh, and two profiles roughly orthogonal to these: one to the north and one south of the Mishelyak (Fig. 2).

An example of a resistivity profile is shown in Fig. 5. The profile is oriented S 37° E and passes through the location of well 176 (Fig. 2). It indicates the presence of an electrically conductive sequence of soil and weathered rock overlying a resistive bedrock basement, which appears closer to the surface to the southeast in the direction of well 173. Estimates of the

overburden thickness from the resistivity surveys range from nil in the area of well 173 to over 10 m near the northwest end of the westernmost line. Work is underway to interpret other observed variations of resistivity.

Induced polarization properties vary strongly along the observed lines. The highest apparent IP effects occur south of the Mishelyak River and the lowest are to the east, near well 173. The significance of these differences is under consideration.

Preliminary results do not show definitive evidence of the presence of a contaminant plume, but do indicate that there are electrical resistivity contrasts that require more detailed, as well as broader investigation. Therefore, it is suggested that electromagnetic methods, which permit rapid determination of resistivity, be used in future work. Electromagnetic methods are quite mobile, and have the advantage of being deployed over frozen surfaces, which would allow a comprehensive survey of the Mishelyak marshes during winter months.

CONCLUSION

Though this is essentially a progress report, there are some important preliminary results:

1) ^{60}Co and ^{137}Cs are present in small concentrations (~0.1 % of permissible levels) in water of the Mishelyak River; ^{3}H is present in appreciable abundance in both river and ground water;
2) analyses of water samples collected by a downhole sampler and of water produced from packed-off intervals agree within limits of laboratory accuracy, attesting to the efficacy of the sampling methods presently used by the Russian workers;
3) The strong differences in contaminant concentrations between wells 173 and 176 support the concept (1) that the orientation of the plume between Lake Karachai and the Mishelyak River is controlled primarily by fractures and/or shear zones; and
4) strong contrasts occur between the electrical resistivities of soil and bedrock.

Further collaborative work is strongly recommended, and should include: 1) more detailed isolation of intervals in wells by multi-packer installations, to better determine the geochemical and hydrological characteristics of the Karachai - Mishelyak system; 2) deployment of a broader and

more vertically detailed soil-water and soil sampling array; 3) a more detailed examination of the distribution and concentration of radionuclides by high-resolution field gamma spectrometry; and 4) a detailing of the area's electrical resistivity setting, using a mobile electromagnetic measurement system.

The American and Russian scientists benefited from the collaborative exercise in that each side was able to discuss and experience first- hand the scientific rationales and methodologies used, and results obtained by their counterparts.

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1. E. Z. Drozhko, Yu. G. Mokrov, Yu. V. Glagolenko and L. M. Samsonova, "Determination of Hydrodynamic Parameters of a Cleaved Rock Mass According to Regime Examination Data in the Lake Karachai Area," report in preparation, Chelyabinsk, Russia (1993).

Captions:

Table 1. Concentrations and radioactivities at surface water sampling sites.

Table 2. Concentrations at different stages of sampling at wells 173 and 176.

Table 3. Comparison of concentrations of surface and ground waters.

Figure 1. Location map, Chelyabinsk 65 area.

Figure 2. More detailed map of Lake Karachai - Mishelyak River area.

Figure 3. Diagrams of wells 176 (3a) and 173 (3b). Striped zones indicate packed-off intervals. Heavy dots indicate fluid sampler positions.

Figure 4. Comparison of nitrate-ion values, packer and plunger samples.

Figure 5. Electrical resistivity and induced polarization profiles through well 176 site. Electrode spacing is 20 m and the vertical and horizontal scales are the same.

Surface water concentrations and shoreline measurements

	Constituents			Gamma Radioactivity	
Sample point	Cobalt-60	Tritium	Nitrate ion	On soil surf.	1m above surf.
	(Bq/l)	(Bq/l)	(mg/l)	(uR/h)	(uR/h)
1	0.9	132	<0.45	-	17
2	1.3	198	<0.45	14 *	21 *
3	0.4	264	2.8	20	13
4	0.42	198	<0.45	28	29
5	0.89	264	<0.45	25	20
6	<0.4	176	8.8	13	13
7	0.75	176	3.1	17	14
				* over water surface	

Table 1

Concentrations at different stages of sampling at wells 173 and 176

	A	B	C	D	E	F	G	H	I	J
1	Well No.	Interval No.	Nitrate-ion concentration (g/l)			Tritium concentration (Bq/l)			Cobalt-60 concentratic	
2		(sampler								
3		depth (m))	Before pumping	After pumping	Packer sample	Before pumping	After pumping	Packer sample	Before pumping	After pumping
4	176	1 (24)	1.1/1.0	1.6/1.69	1.09	286	527	286	114	204
5		2 (31.5)	0.9	1.8	0.9	286	616	264	116	242
6		3 (40)	1.03	2.04	0.94	330	748	330	121	277
7		4 (50)	1.3	1.4	1.15	396	573	264	158	196
8		5 (63)	2.5/3.0	4.6	3.17	814	1474	1320	318	564
9		6 (137)	1.4	1.6	-	462	616	-	109	124
10		7 (162)	2.4	-	-	638	-	-	133	-
11		8 (190)	2	-	-	748	-	-	167	-
12										
13	173	1 (8)	0.021	-	0.021	<70	-	<70	0.54	-
14		2 (31)	0.022	-	0.015	<70	-	<70	0.6	-
15		3 (43)	0.019	-	0.016	<70	-	<70	0.6	-

Table 2

Summary of concentrations, surface and well water

	Nitrate ion (mg/l)	Tritium (Bq/l)	Cobalt-60 (Bq/l)
Well 173 (3)	21	<70	0.6
Well 176 (8)	1600	495	155
	(s.d. 700)	(s.d. 211)	(s.d. 61)
Surface water (7)	2.3	201	0.7
	(s.d. 3.1)	(s.d. 48)	(s.d. 0.4)
Ratio, surf./well 176 water	1.4x10^-3	4.5x10^-1	4.5x10^-3

Table 3

Chelyabinsk - 65 area

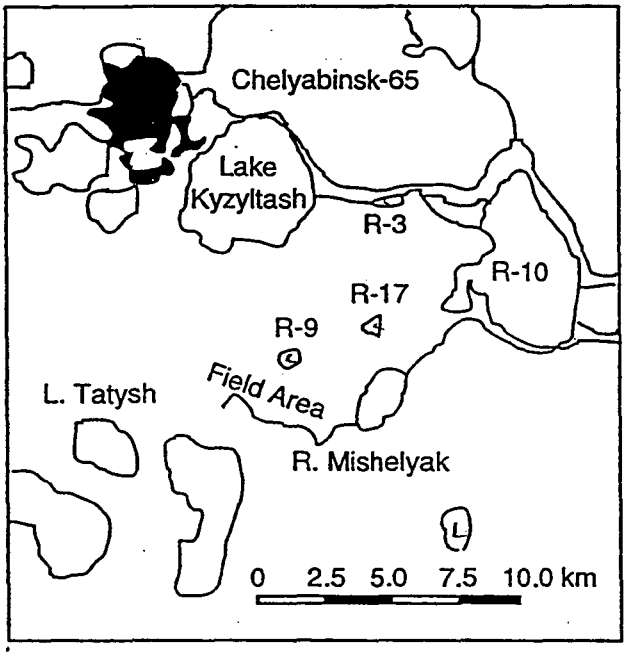
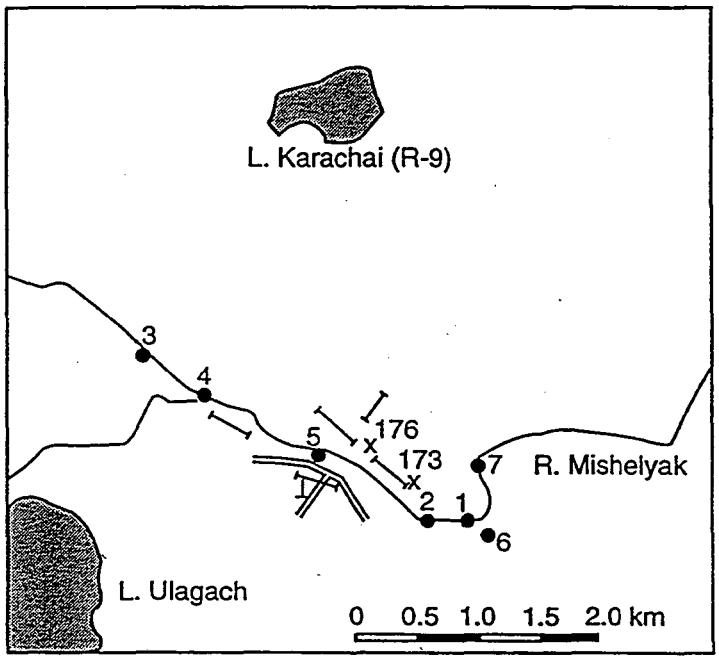


Figure. 1

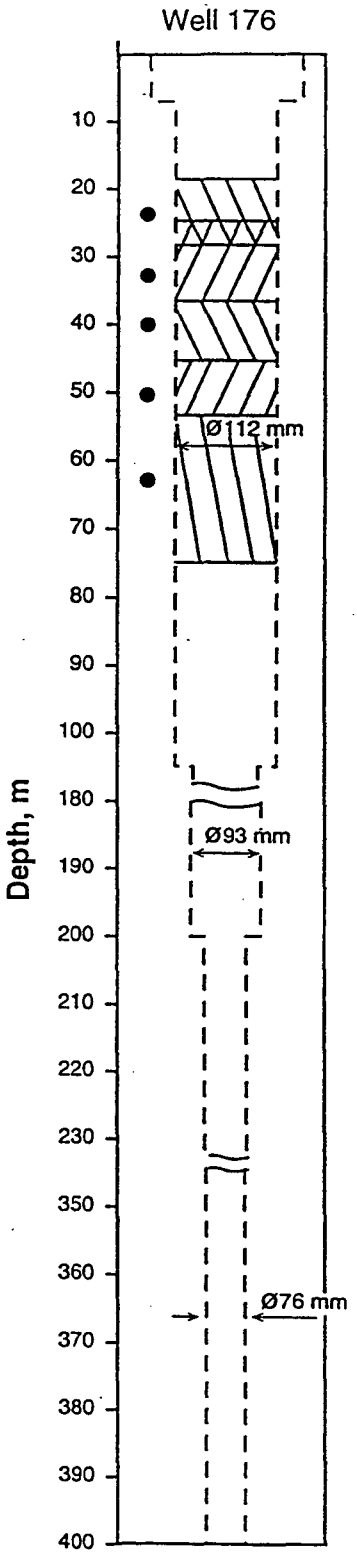
R. Mishelyak field area



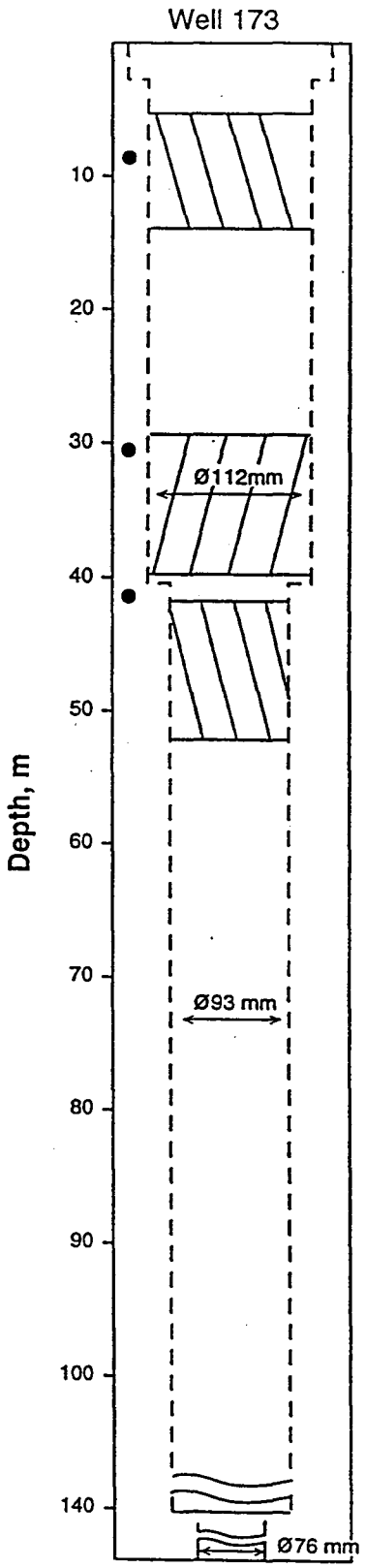
3
● surface water site
x 173, 176 wells
⊢⊣ resistivity survey line

Figure. 2

Well profiles



3a



3b

Figure. 3

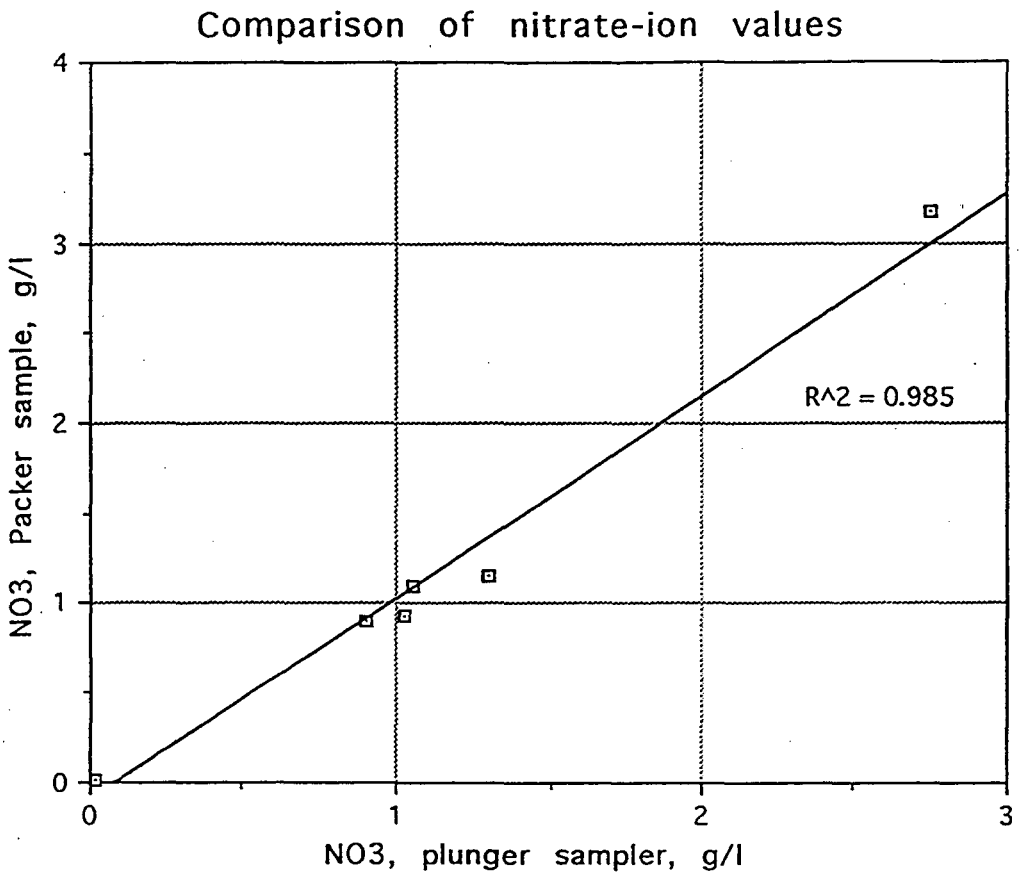
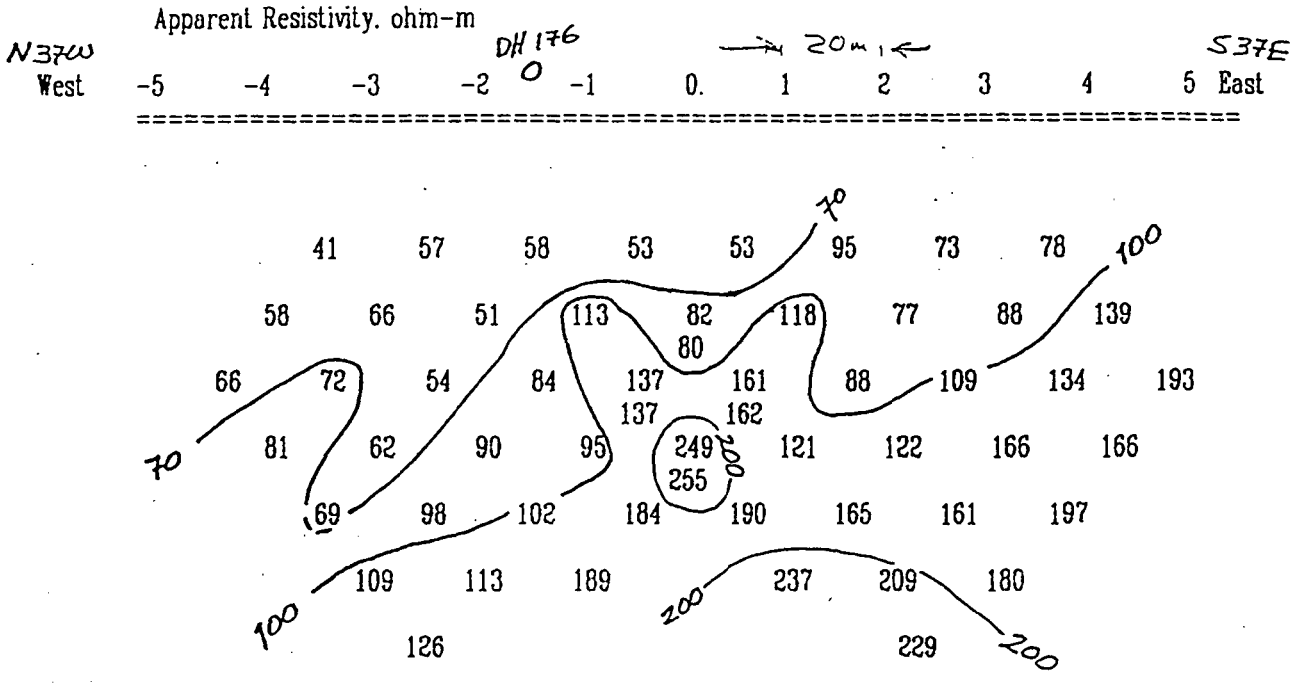
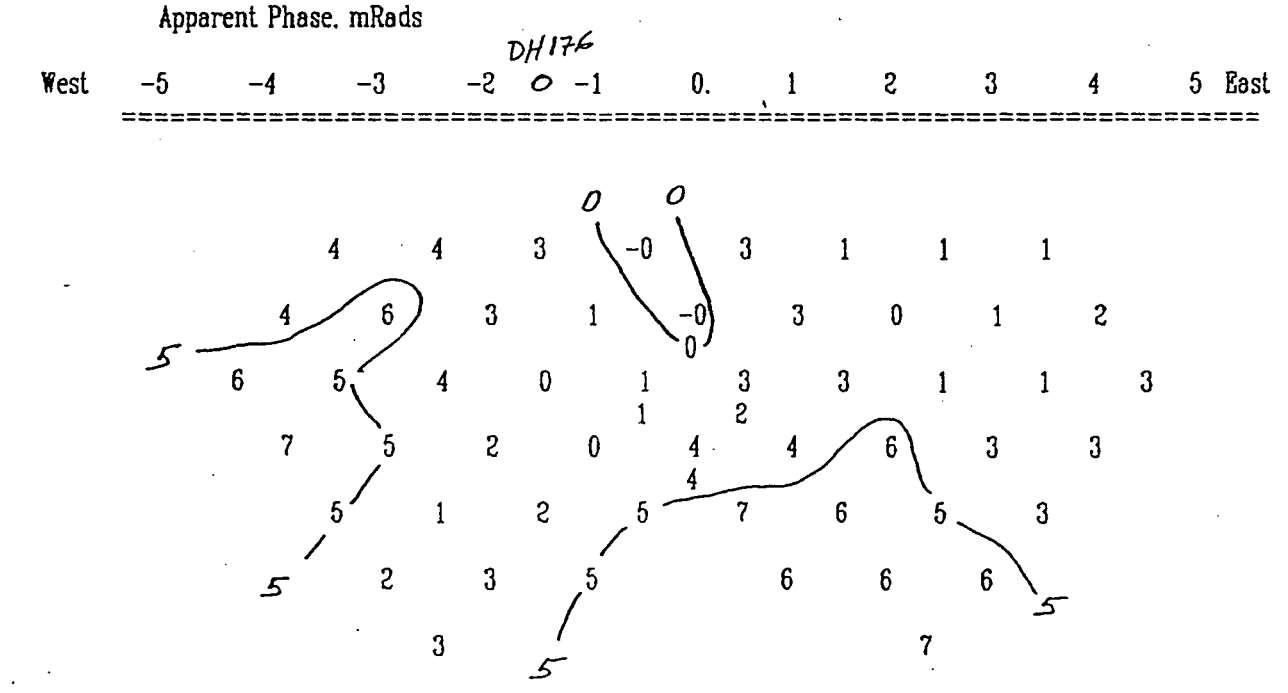

Comparison of nitrate-ion values
NO3, Packer sample, g/l
NO3, plunger sampler, g/l
R^2 = 0.985
0
1
2
3
4
0
1
2
3

Figure. 4

Electrical Resistivity Profile

Line 7 Mayak Area, Russia





a = 20 meters freq = 1 Hz Data by: WF Date: 19ix94

Figure. 5

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