Lessons of the Chernobyl NPP Accident Regarding Potable Water Supply

V.M.Shestopalov, Yu.F.Rudenko, A.S.Bohuslavskiy

Radioecological Center, National Academy of Sciences of Ukraine

INTRODUCTION

The world's greatest radiation catastrophe at the Chernobyl NPP has reflected the faults in the organization of water supply for the town populations and water resources monitoring in the Ukraine. Prior to the accident, in spite of known advantages of groundwater among available sources for town water supply and the good state of groundwater prospecting, the preference was paid mainly to river water. (In Kiev, the Capital and the largest town of the Ukraine, with an existing possibility of all water being supplied by prospected groundwater of very good quality, more than two thirds of the water supply is maintained from the rivers Dnieper and Desna).

For the organization of the centralized water supply of Kiev by groundwater, of the most practical importance are the Cenomanian-Callovian (depths 100-150 m) and Middle Jurassic (Bajocian, depths 250-300 m) aquifers, which are protected by 2-3 regional aquitards with filtration coefficients of the order of 10^{-3}-10^{-4} m/day. For these two aquifers the exploitational resources are proven to exceed 700 thousand m^3/day (60% from Cenomanian-Callovian and 40% from Bajocian). Present water intake from these aquifers does not exceed 50% of this amount.

Initial composition of the radioactive contamination found in the river water formed in May 1986 was represented by several dozens of nuclides, the majority of which by their input in exposition dose for biocenoses are ^{141}Ce, ^{144}Ce, ^{103}Ru, ^{140}Ba, ^{131}I, ^{95}Zr, ^{95}Nb, ^{14}La, ^{134}Cs, ^{136}Cs, and other products of uranium decay. The input in total activity from each of these nuclides was different, but starting from 1987, the dominating in dose formation became ^{137}Cs and ^{90}Sr.

It is worth emphasizing that the maximum allowable concentration (MAC) of ^{137}Cs in potable water at that time was 37 Bq/liter ($1\ 10^{-9}$ Ci/l). By May 3, 1986 the Dnieper water exceeded the MAC for ^{137}Cs by 35 times.

DISCUSSION

Systematic observations for the content of nuclides in surface and subsurface water and analysis of their content in fish and other hydrobionts were started only in the beginning of 1987. But from May 1986, the works on surface water monitoring were performed by specialists of different organizations of the former USSR (Scientific-Industrial Union "Taifoon", USSR State Committee of Hydrometeorology, Institute of Radium, State Hydrological Institute, etc.) and Ukrainian organizations (UkrNIGMI, Institute of Nuclear Studies, Institute of Geochemistry and Physics of Minerals, Institute of Geology of Ukrainian Academy of Sciences, etc.).

Unfortunately, the majority of the observation results obtained by different monitoring groups were secret or available only "for service use". For this reason the active coordination of researches and data collection was impossible. The same reason was for the large amounts of unconditional data which entered the database created in the Institute of Cybernetics of NASU for systematization of monitoring information on the environment's state of radioactive contamination.

Based on the fact of fast radioactive contamination of water in the Dnieper, the decision was made in May 1986 by the Government of Ukraine to drill over 80 wells to deep aquifers (Cenomanian-Callovian and Bajocian) in Kiev City, and urgent construction of the water pipeline for additional transport of water from the Desna River which was contaminated to a much lesser extent than the Dnieper. The wells and pipeline were constructed over a period of two months. During this time the tendency was set for surface water quality improvement. The example is that the maximum concentration of ^{90}Sr in May 1986 in the water of the Pripyat River close to the Chernobyl NPP reached 15 Bq/l, and at the end of June the same year it dropped to 1-4 Bq/l.

Within the Kiev region, contamination of groundwater with ^{137}Cs and ^{90}Sr during the whole post-accidental period did not exceed several tens or a few hundreds of mBq/l. In spite of this fact and the proved vulnerability of surface water sources, the decision was not made or practically realized concerning the necessity of a preferable water supply on account of groundwater. The wells drilled in May-June 1986 were conserved.

The research performed after the accident has shown that notwithstanding the relatively fast penetration of initial portions of contamination into groundwater to the depth of 100-300 m within the regions of operating water intakes, the water-bearing aquifers remain much more protected than surface water.

Especially important in this research was the revealing of the pathways of nuclide penetration into groundwater. Among such pathways, the technogenic and natural ones can be considered. The technogenic are the pathways which originate in weak zones of round-wells space, cavities or breaks in wells casing. Special experiments have been done at several exploitational wells, which confirmed these suppositions. The quality of isolation of the wells from surface contamination appeared to be low.

Natural migration pathways correspond to the vertical component of infiltration within regions of groundwater recharge. The lateral flow from the Chernobyl accident epicenter is of no importance because of the general character of groundwater exchange and small horizontal flow velocities as relative to the area scale. Groundwater of the most contaminated 30-km exclusion zone area discharges into the Pripyat Valley with no access to aquifers lying north from the lower current of Uzh River.

Hence, observed contamination, besides technogenous pathways, might occur only by vertical filtration through the bulk of rock being enhanced in the central part of the water intake depression cone which provides significant pressure differences between the subsurface aquifers. In order to confirm the validity of this supposition, observations were made in drainage tunnels disposed at the Dnieper right bank slopes in Kiev, and during the Kiev subway tunnels driving in marls at depths of about 60 m. The ^{137}Cs was found in groundwater and rock samples at concentrations of 10^{-3}-10^{-2} Bq/l and 2-20 Bq/kg respectively. So, the nuclides' migration by natural pathways through the bulk of rocks is a matter of proven facts. According to these data, the vertical velocity of downward migration should be no less than 2.5 m/year, but sometimes may reach 15-20 m/year and more.

Such significant velocities demonstrate the existence of fast vertical migration pathways through the bulk of alternating water-bearing and semipermeable rocks reaching great depth. These pathways may be related primarily to the zones of present tectonic fracturing of mountain rocks and disintegration of unconsolidated rocks. Also, of high importance are the facial variability, mineralogical and granulometric inhomogeneity of deposits. The openness of these pathways is registered only by rather toxic indicators such as radionuclides and pesticides.

To obtain the modeling assessment of geological rock medium contamination with ^{137}Cs in the Kiev industrial agglomeration, we performed the modeling of vertical convection/dispersion transport for typical sections of this region with downing infiltration low of about 100 mm/year rate, taking into account the equilibrium sorption process. Modeling parameters (dispersion coefficient D and partition coefficient Kd) were calibrated according to observation data for the contaminant content in liquid and solid phases at different depths. Prognostic vertical distributions until the year 2050 obtained for the concentration with its maximum values in 2005-2010 of 70-100 mBq/l for most exploited Cenomanian-Callovian, and Bajocian aquifers. So, the results of modelling confirmed that the possible groundwater contamination is significantly lower than the MPC levels.

In spite of the reliability and sufficient degree of protection of groundwater and vulnerability of surface waters, which were proven by the events during the post-accidental period and results of special research, the authorities of the former USSR, as well as of the independent Ukraine, did not perform practical measures on increasing of water supply of population by groundwater. It also is obvious that the measures are urgent but still not implemented on improvement of the protection state of ground-wells space and well casing from nuclide penetration by this way from the surface.

The assessment should be done for the possibility of potable water supply of population by groundwater during periods of surface water contamination in different accidental situations. Essentially, for each town which is partially or wholly supplied by potable water from the surface sources, the programs should be elaborated and realized of partial or entire water supply by groundwater or from other well-protected sources.

The Chernobyl disaster has shown that the pre-accidental system of surface and groundwater monitoring was insufficient with respect to the amount of observation points, data types and condition, system of analysis and forecasting of water quality. During the pre-accident period, the permanent models were not created for sites and areas of dangerous technogenous objects (NPPs, Plants, etc) and town agglomerations, and the modeling scenarios were not simulated for the consequences of possible accidents and for taking optimal administrative decisions in such situations.

In spite of a relatively low present contamination of groundwater by nuclides, further improvement of the monitoring network for surface and subsurface hydrosphere is necessary.

In particular, for substantiation of the groundwater monitoring system, the following research has been performed:

- Characterization of main origins of contamination and its state for groundwater and its neighboring media;
- Studying of the observation wells state within the depression cone of Kiev water intakes and their correspondence to the criteria of the monitoring regime network;
- Characterization of specific natural and technogenic conditions of KIA;
- Characterization of studied factors in the monitoring system;
- Elaboration of criteria for assessment of the factors of geological environment changing.

Many examples are known from groundwater exploitation practice that when operating water intake structures were fully excluded from the cycle of industrial-potable water supply because of groundwater quality deterioration first in recharging, and later in pumped aquifers. So, it is very important to register in proper time the initial stages of contamination of the elements of the water exchange system and their dynamics. In this connection, the suggested scheme of the observation network is primarily based on construction of the gungs of regime wells for each of the storey aquifers, not only for exploited ones.

Creation of a regime network should be performed gradually and should take into account the observation data during changing groundwater exploitation conditions and periodically refined information about hydrogeological conditions and technogenic loads. Substantiation for construction of each gung or separate well should be proved by modelling on the existing and periodically refined permanent hydrogeological model.

CONCLUSION

1. The world's largest technogenic radiation catastrophe at the Chernobyl NPP has reflected the faults in organization of water supply of population and monitoring of water resources in Ukraine. Notwithstanding the disaster which revealed the vulnerability of surface water

sources, the conclusions about preferable water supply on account of groundwater have not been made, nor practically realized.

2. In spite of the revealed initial contamination of groundwater by radionuclides of Chernobyl origin, the confined aquifers remain the most reliable sources of water supply within the affected regions.

3. For conditions of accidental situations leading to partial or full contamination of surface water sources, the reserve system of water supply should be elaborated and introduced, based on maximum use of groundwater, spreading of surface water intakes over the area, creation of a system of water purification, and other reserve possibilities.

4. The priority among towns requiring the accidental water supply measures implemantation should be determined taking into account:

   - existence in the neighborhood of potentially dangerous potable water contamination sources; and

   - intensive use of surface water for water supply.

5. The protection degree of groundwater water intakes should be assessed and checked with respect to technogenous pathways of fast migration of contaminants;

6. In order to perform reliable groundwater quality forecasting and, if needed, management of their state, it is necessary to create the monitoring system, which includes:

   - periodic examination of exploitation and regime wells according to developed techniques accounting for the wells conditions assessment;

   - construction of regime test sites embracing the storey system of aquifers, their interstitial semipermeable aquitards and aeration zone in different landscape-geochemical, hydrogeological and technogenic conditions;

   - creation and improvement of permanent hydrogeological models of large water intakes, other water-economy objects, regime observation sites providing reliable forecasting and, if necessary, development of variants of managerial decisions for optimization of the ecological state of water resources and their environment;

   - creation of the system of independent controls for the cases of revealing of anomalous radionuclides concentrations with guarantee for results reliability.