Simulations of Strontium-90 Transport from the 100-N Area to the Columbia River Using VAM2DH

Prepared for the U.S. Department of Energy
Office of Environmental Restoration and
Waste Management

Westinghouse
Hanford Company Richland, Washington

Hanford Operations and Engineering Contractor for the
U.S. Department of Energy under Contract DE-AC06-87RL10930

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SIMULATIONS OF STRONTIUM-90 TRANSPORT FROM THE 100-N AREA TO THE COLUMBIA RIVER USING VAM2DH

A. H. Lu

ABSTRACT

The VAM2DH computer software was used to simulate the migration of ^{90}Sr from liquid waste disposal facilities in the 100-N Area to the Columbia River. A baseline calibration analysis was made using published concentrations of ^{90}Sr at N Springs on the south bank of the Columbia River adjacent to the 100-N Area. Because of the limitations of the two-dimensional model, data from groundwater monitoring wells were not used for the calibration.*

Excellent agreement was achieved between the published and simulated concentrations for the years 1973 through 1990. Concentrations of ^{90}Sr at N Springs were predicted for up to 20 yr based on a 350 gal/min rate of effluent discharge to the 1325-N Liquid Waste Disposal Facility.

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PREFACE

This report is part of the work supported by the U.S. Department of Energy (DOE) to provide the public with information about liquid discharges to the soil at the Hanford Site and to assess the potential for migration of contaminants from the sites receiving these discharges. The work reported here was done as part of the effort to characterize N Reactor effluent during the dry lay-up of the reactor.

The DOE, with the concurrence of the U.S. Environmental Protection Agency, agreed to assess the potential for the migration of contaminants from liquid discharges at the Hanford Site (Lawrence 1989). That assessment, of which this report is a part, is described in the *Liquid Effluent Project Plan* (Sommer et al. 1990).

SIMULATIONS OF STRONTIUM-90 TRANSPORT FROM THE 100-N AREA TO THE COLUMBIA RIVER USING VAM2DH

1.0 PURPOSE AND SCOPE

This report presents the results and conclusions of computer simulations of groundwater flow and contaminant transport from liquid waste disposal facilities (LWDF) in the 100-N Area of the Hanford Site. The VAM2DH* (Huyakorn et al. 1988) software, a 2-dimensional finite-element flow and transport model, was used.

The results stem from calibration of the VAM2DH model using published information on concentrations of ^{90}Sr at riverbank springs (N Springs) fed by artificial recharge from the LWDF. The calibrated model was then used to predict ^{90}Sr transport and concentrations during the next 20 yr.

Since the N Reactor was shut down in January 1987, the average flow rate of effluents discharged to the 1325-N LWDF has decreased. In 1986, the last full year of N Reactor operation, the average rate of effluent discharge to the 1325-N LWDF was 1,300 gal/min. The rate of discharge then decreased until, by May 1987, the rate of discharge had stabilized at approximately 270 gal/min. Except for scheduled periods of increased water usage, the rate of discharge remained at that level until March 1990. At that time, it decreased to approximately 100 gal/min. For purposes of the simulation of this report, the discharge rate was assumed to be 350 gal/min from 1990 through 2010.

Because of the limitations of the 2-dimensional model, no effort was made to calibrate the flow and transport model using data from monitoring wells.

2.0 MODEL DESCRIPTION

The geometry of the conceptual model used in the computer simulation is shown in Figure 1. The numbers in the figure identify stratigraphic units having differing hydrologic properties. The model domain encompasses an area of about 31,250 m^2. The dimensions of the model are approximately 1,250 m in a northeast-southwest direction (x-axis) and approximately 25 m vertically (y-axis). The origins of the x-y axes are at the top of the southeast end of the model domain. The cross section intersects the 1325-N LWDF and the 1301-N LWDF. The 1325-N LWDF is located between x=500 m and x=570 m; the 1301-N LWDF is located between x=940 m and x=1,010 m, or about 240 m from the Columbia River. The vertical cross section includes about 17.4 m of the

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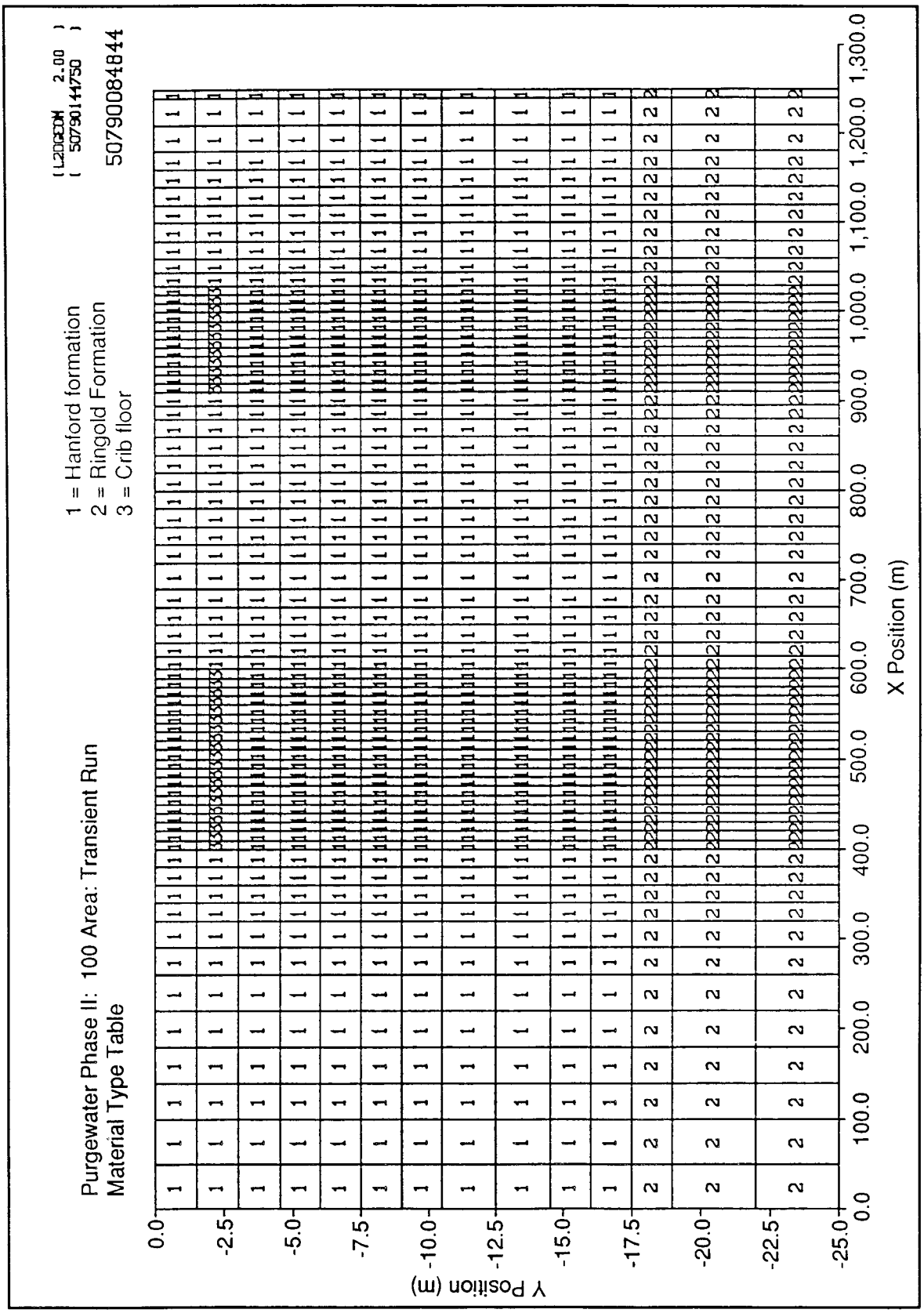

Figure 1. The Two-Dimensional Cross-Sectional Conceptual Model. Numbers depict changes in the stratigraphy.

vadose zone (Pasco gravels member of the Hanford formation) and about 7.6 m of the saturated zone (the middle unit of the Ringold Formation). The unconfined aquifer occurs in sand, gravel, and silts of the middle unit of the Ringold Formation. Each stratigraphic subdivision is assumed to be of constant thickness.

A volumetric moisture content of 0.11, or 31 percent saturation, was used as an initial condition for the vadose zone.

The 1301-N LWDF was the only facility used for the discharge of radioactive effluents from 1963 to 1983. In 1965, when the volume of effluents exceeded the capacity of the LWDF, an extension trench was added. During 1982, routine sampling of monitoring wells and seepage springs on the bank of the Columbia River adjacent to the 100-N Area indicated increasing concentrations of radionuclides (principally tritium and ^{90}Sr) reaching the river. These increases led to the hypothesis that, after 20 yr of operations, the ion-exchange adsorption and filtration capabilities of the soil underlying the 1301-N LWDF had significantly diminished. Consequently, the 1325-N LWDF was built to replace the 1301-N LWDF and became operational in 1983. However, the capacity of the new facility was only about 20 percent of the volume of the radioactive liquid waste; the remaining 80 percent of the effluent flow had to be discharged to the 1301-N LWDF. In September 1985, the 1325-N LWDF became fully operational after a 3,000-ft-long covered trench was added and discharges to the 1301-N LWDF were discontinued.

Before 1973, detailed effluent discharge data for the 1301-N LWDF were not available; therefore, the infiltration capacity of the 1301-N Crib and trench was used to estimate the rate of discharge. An average of 700,000 gal/day were discharged from 1963 to 1965; discharge increased to 2,250,000 gal/day after 1965.

3.0 FLOW MODEL CALIBRATION

Hydrogeologic parameters used in the modeling are listed in Table 1. The moisture characteristic curve was generated using Van Genuchten functions, with the parameters characterizing soil G-7, listed in Mitchell et al. (1989, Table B.6). Although better moisture characteristic curves were obtained later based on laboratory analyses of samples collected from 10 sites in the 100-N Area, the effect of using the data in Mitchell et al. (1989) is negligible because the moisture characteristic curve controls only the initial downward movement of the wetting front from the bottom of the crib to the water table.

Because sediments that comprise both the vadose zone and the unconfined aquifer are very heterogeneous, measurements of saturated hydraulic conductivities vary widely. The principal goal of the flow-model calibration was to establish a reasonable groundwater travel time by adjusting the hydraulic conductivities of the saturated zone. When Crews and Tillson (1969) calibrated their analysis, the average travel time of ^{131}I from the

Table 1. Parameters Used in the Analysis.

Model flow equation	Hanford formation	Ringold formation	Crib floors
Hydraulic conductivity	560 m/yr (H)[a] 560 m/yr (V)[b]	10,000 m/yr (H) 5,000 m/yr (V)	560 m/yr (H) 560 m/yr (V)
Effective porosity	0.35	0.26	0.35
Volumetric moisture content	0.11	0.26	0.35
Van Genuchten moisture characteristic parameters:			
Alpha	5.266/cm	N/A	5.266/cm
N	1.4419	N/A	1.4419

Model transport equation	Hanford formation	Ringold formation	Crib floors
Bulk density	1.72 g/cm^3	1.60 g/cm^3	1.72 g/cm^3
Molecular diffusivity	4.42×10^{-4} m^2/yr	4.42×10^{-4} m^2/yr	4.42×10^{-4} m^2/yr
Longitudinal dispersivity Alpha-L	1.0	1.0	1.0
Transverse dispersivity Alpha-T	0.1	0.1	0.1
Sorption coefficient ^{90}Sr	10 mL/g	10 mL/g	1,628 mL/g
Half-life ^{90}Sr	29 yr	29 yr	29 yr

[a]H = horizontal.
[b]V = vertical.

1301-N LWDF to the river was determined to be 8 to 17 days. This determination was made based on samples taken from a monitoring well and riverbank springs over a period of 30 days following two fuel-element failures. The fuel-element failures occurred 1 week apart, during the first part of July 1969. However, the results would have differed substantially if the accidental release of iodine had occurred at a different time of the year, when the elevation of the river was substantially different.

Throughout the entire time that was simulated, a constant boundary condition was used for the river elevation; fluctuations of the river were ignored.

Selected results of the simulations using the flow model are shown in Figures 2 through 8. Figures 2 and 3 show the pressure head and moisture saturation contours, respectively, a short time after the wetting front reached the water table. Figure 4 shows the pressure-head contours, indicating the rising surface of the water table beneath the LWDF. Figure 5 shows that the water table had reached the bottom of the LWDF, forming a conduit for effluent flow from the LWDF to the unconfined aquifer, then to the river. Figure 6 shows the pressure-head contours in nearly a steady-state condition after the discharged effluents reached a maximum average of 2.25 Mgal/day. Figure 7 shows the pressure-head contours during 1983, when the effluent was discharged to both the 1301-N and 1325-N LWDFs. The elevation of the water table between the cribs appears to be high from a general glance at the monitoring well data; this may be attributed to the use of a two-dimensional cross-sectional model to simulate 3-dimensional flow. However, the effect on the travel time of radionuclides migrating from the LWDF to the river is probably insignificant. Figure 8 shows the pressure-head contours when the 1325-N LWDF became fully operational and the disposal of effluent in the 1301-N LWDF was discontinued.

Figure 9 depicts the arrival time of a nonsorbed solute. The arrival time at the river of effluent from the 1301-N LWDF was estimated from this curve to be 29 days.

4.0 TRANSPORT CALIBRATION FOR STRONTIUM-90

Information on effluent discharge is summarized in Table 2. Information on average concentrations of ^{90}Sr in the cribs and at N Springs, from 1973 to 1989, is in the last two columns of Table 2. The ^{90}Sr concentrations listed in these two columns are plotted in Figure 10. No information was available from 1963 to 1972. Hence, a constant ^{90}Sr concentration of 20 nCi/L was assumed for effluent discharged to the LWDF from 1963 to 1972. The concentrations measured at N Springs were only a small fraction of the ^{90}Sr concentrations discharged to the LWDF from 1973 to 1989; this suggests that mechanisms other than retardation by sorption were present.

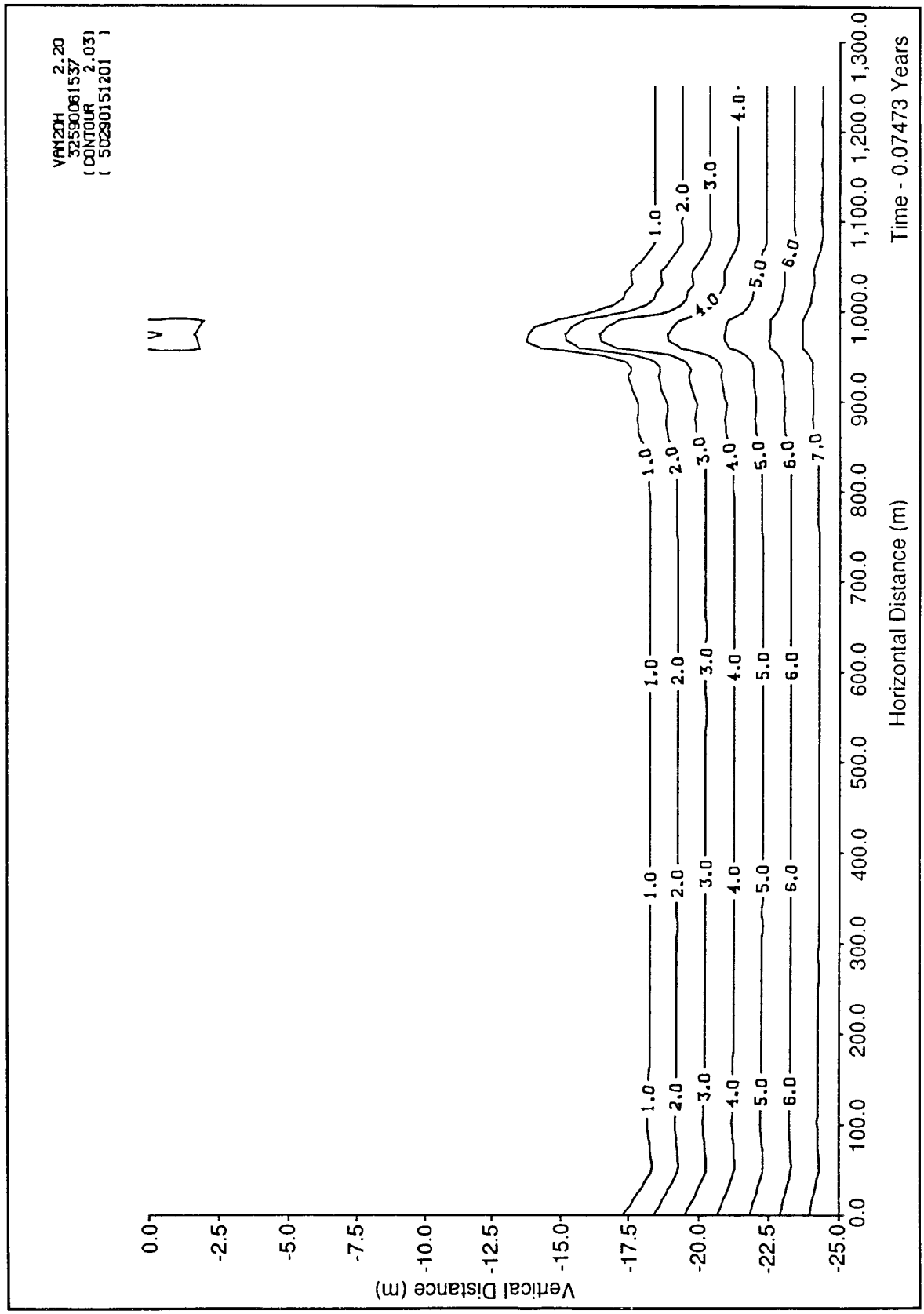

Figure 2. Pressure-Head Contours a Short Time After the Wetting Front Has Reached the Water Table.

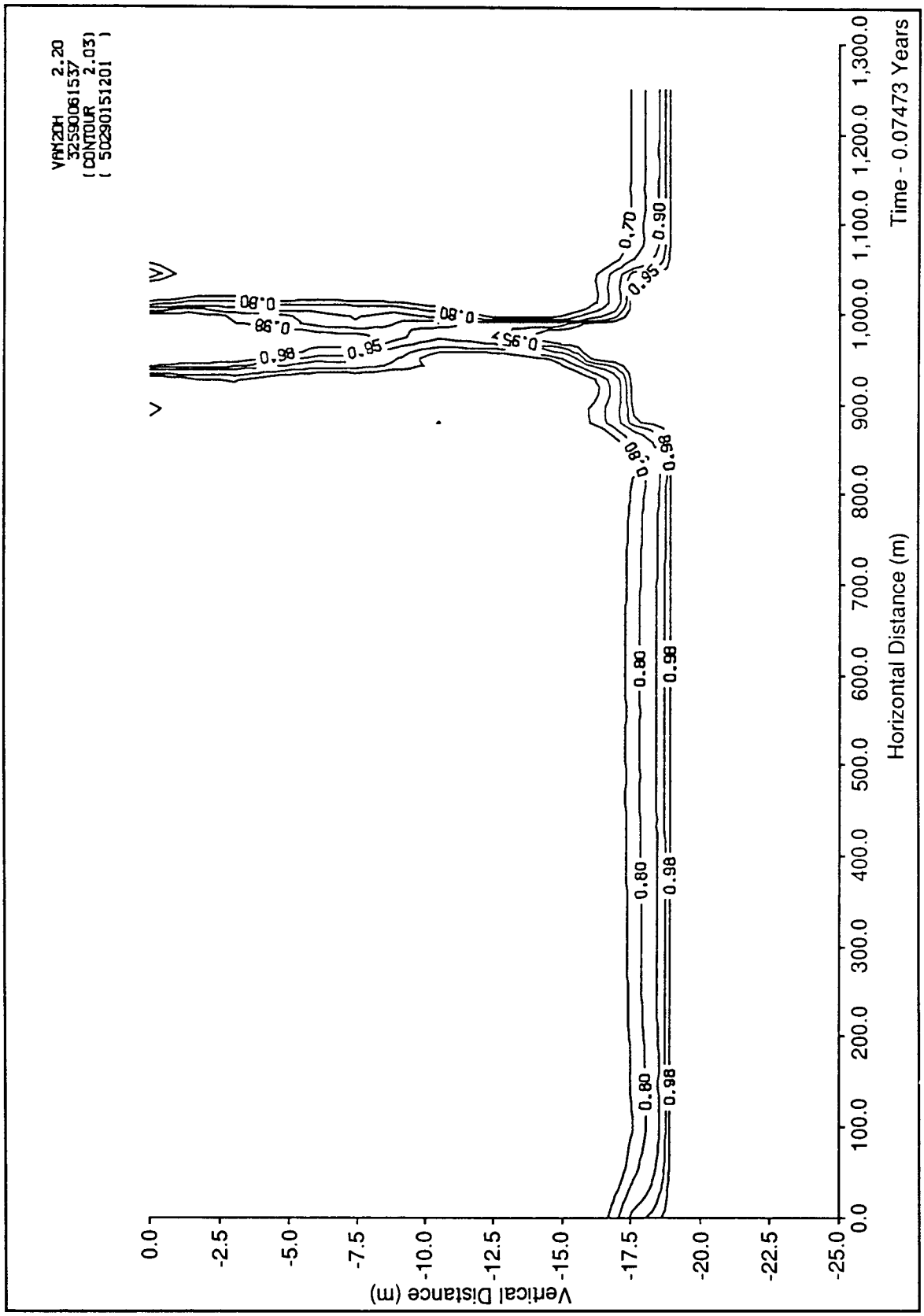

Figure 3. Moisture-Saturation Contours a Short Time After the Wetting Front Has Reached the Water Table.

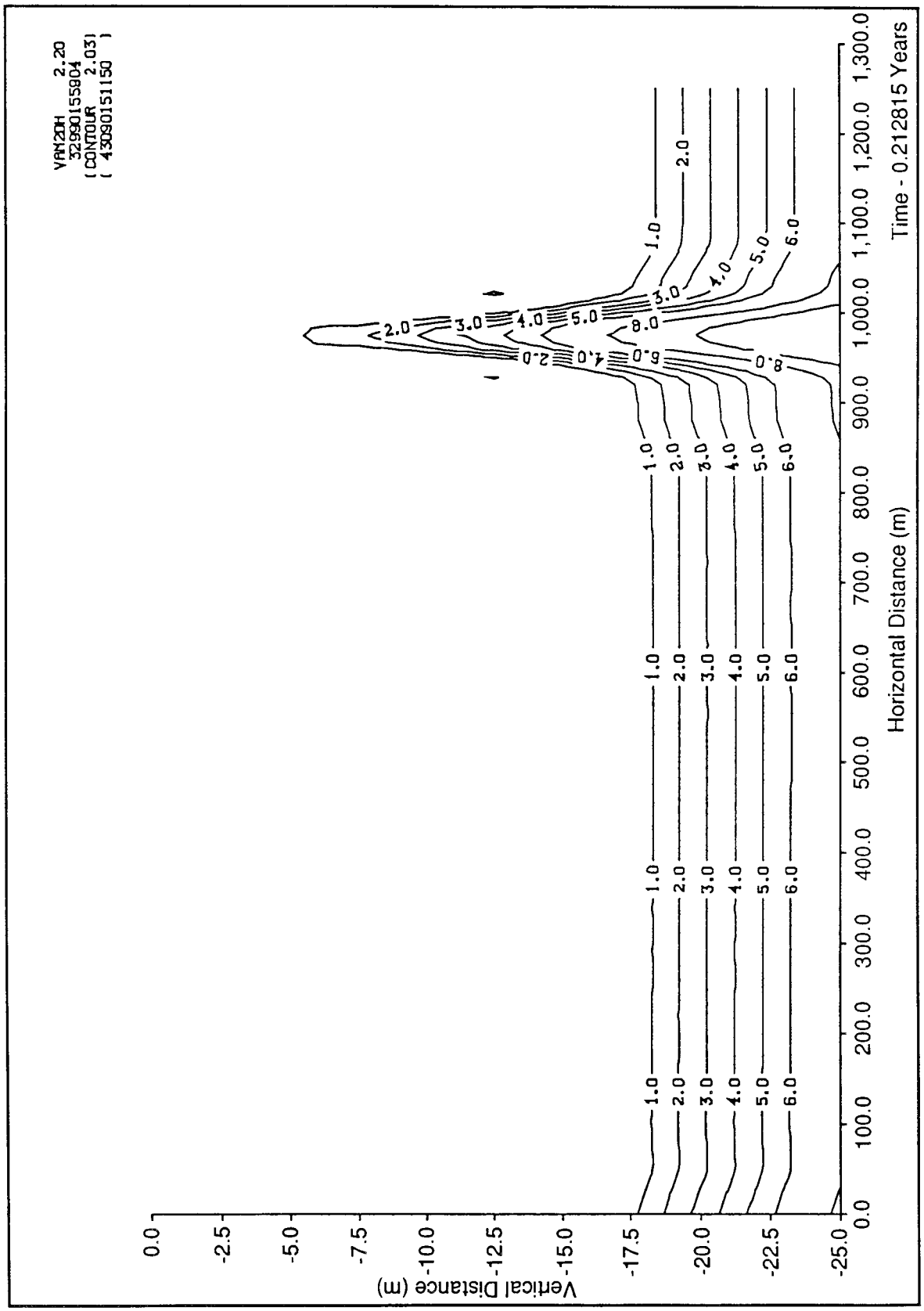

Figure 4. Pressure-Head Contours Indicating the Rising Surface of the Water Table.

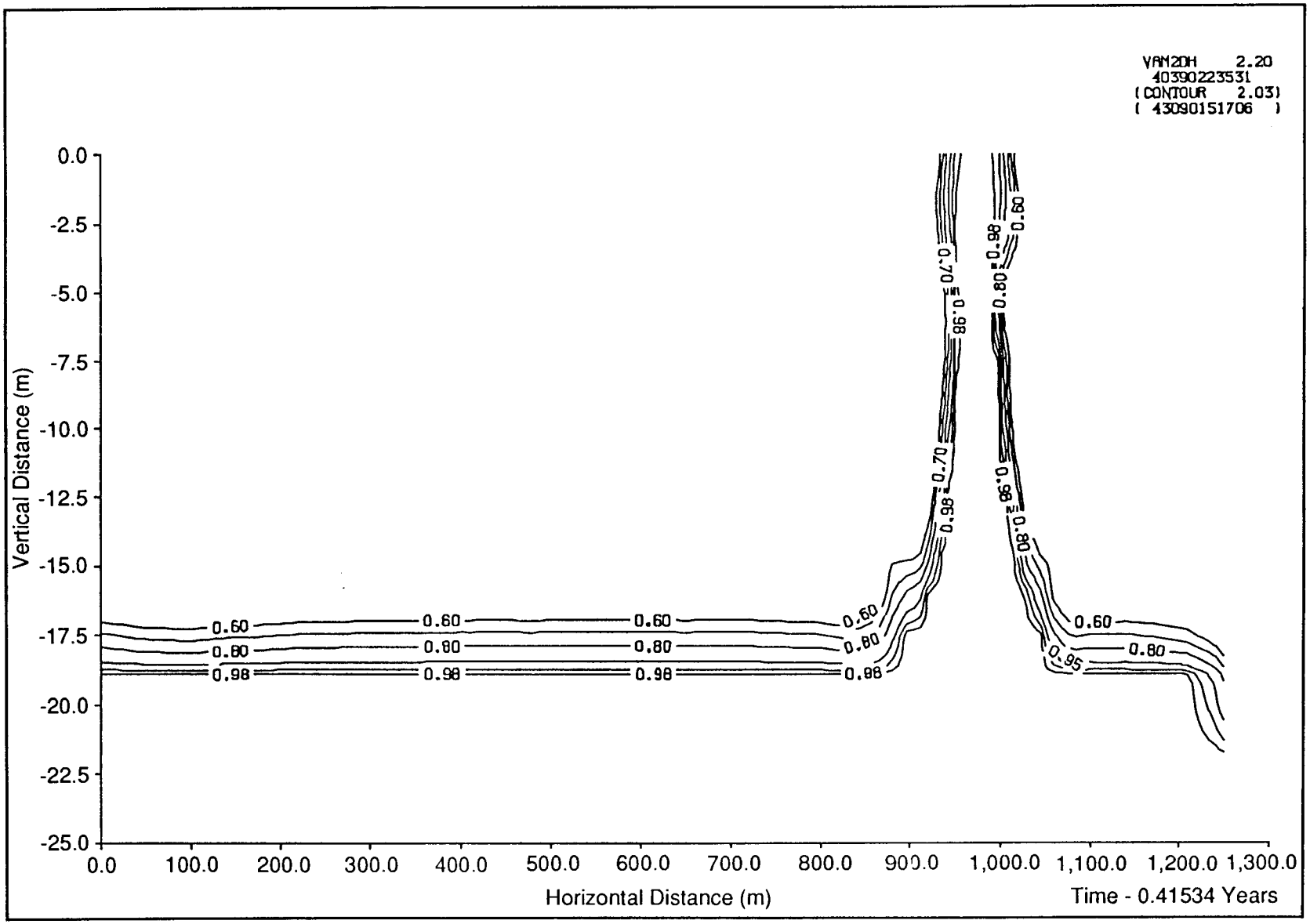

Figure 5. Moisture-Saturation Contours Indicating That a Well-Established Conduit Has Formed from the 1301-N Facility to the River.

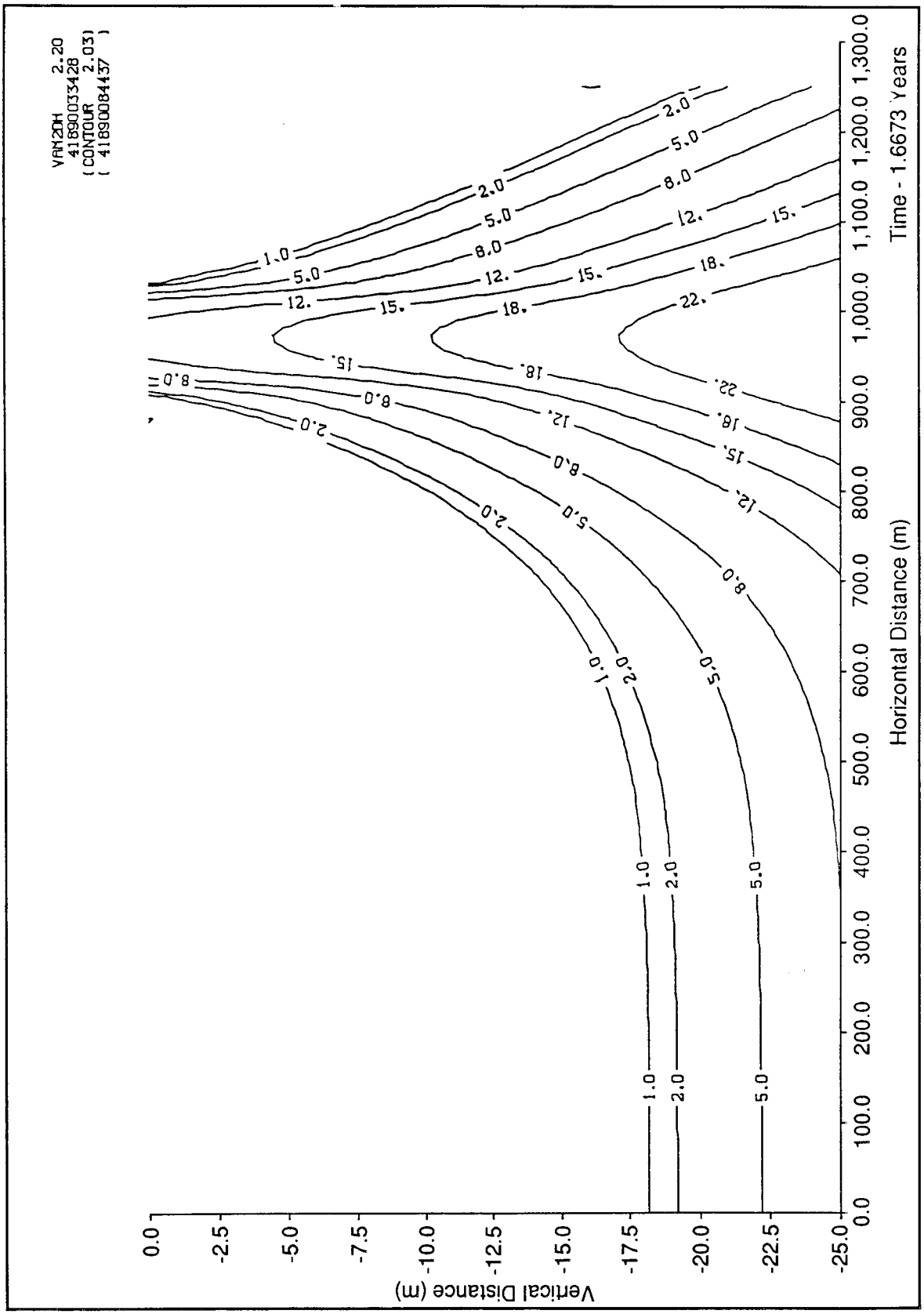

Figure 6. Pressure-Head Contours After the Effluent Discharge Rate Has Reached Its Maximum Average of 2.25 Million Gallons Per Day.

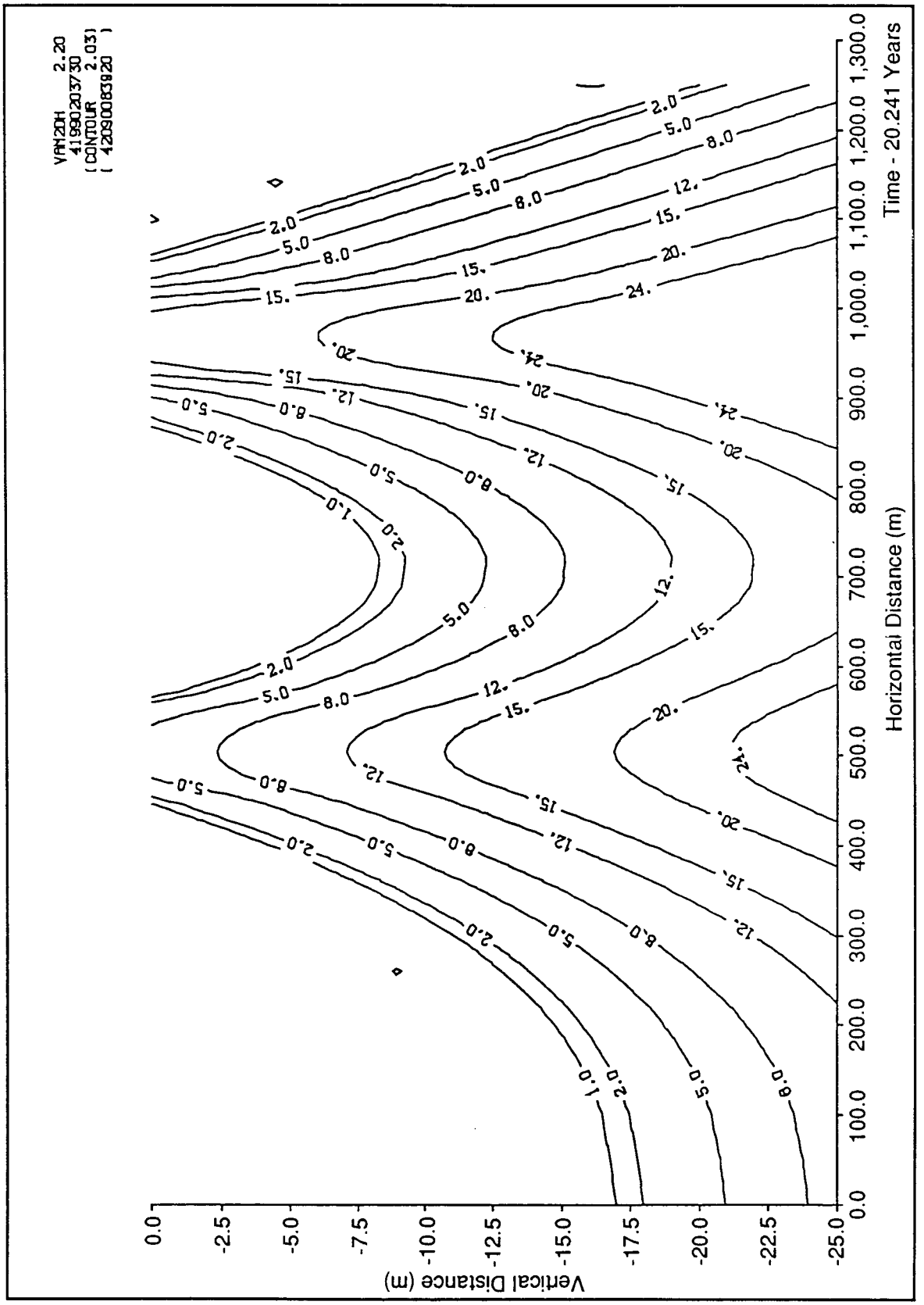

Figure 7. Pressure-Head Contours During 1983 When Effluents Were Discharged to Both the 1301-N and 1325-N Facilities.

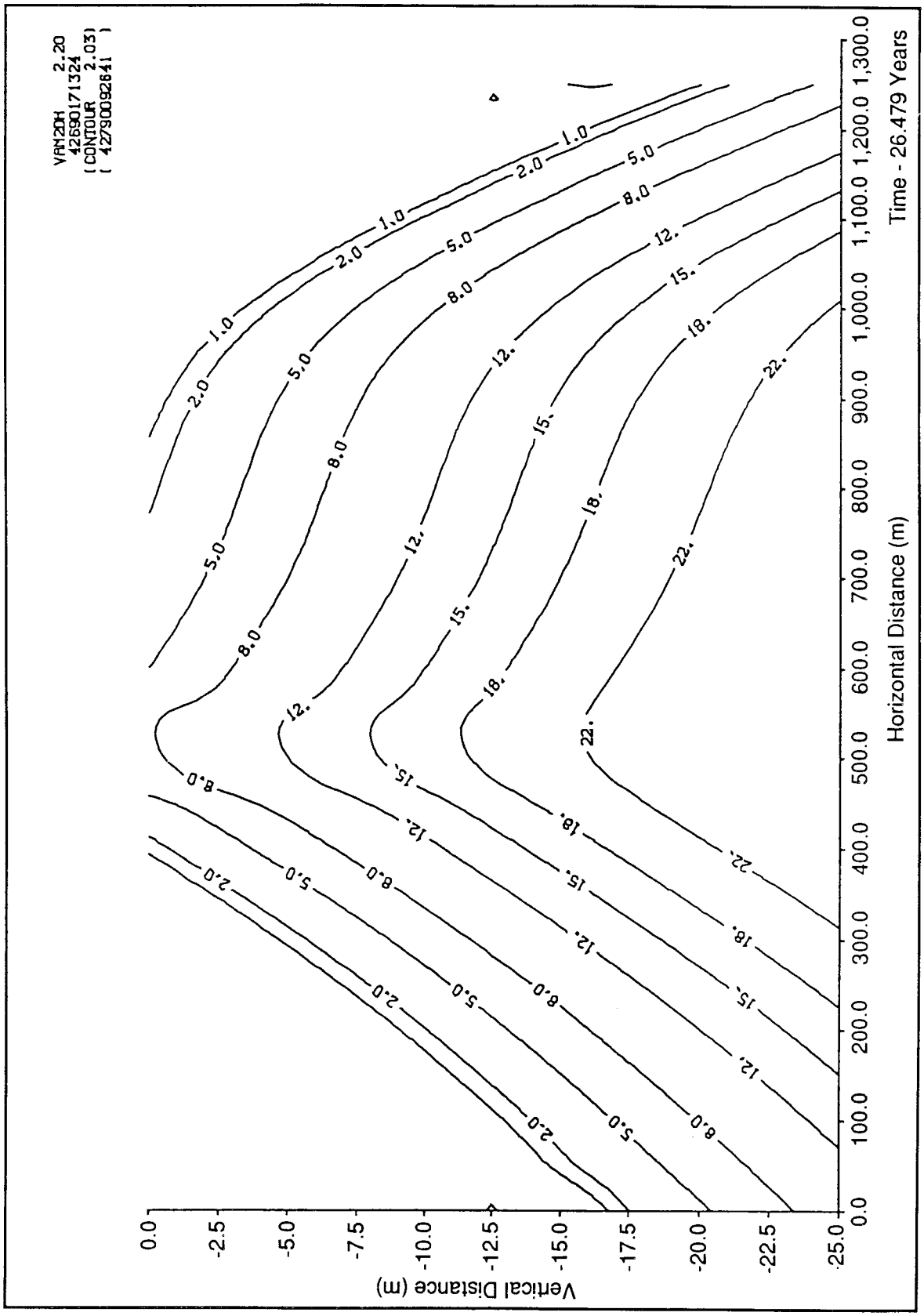

Figure 8. Pressure-Head Contours When the 1325-N Facility Became Fully Operational.

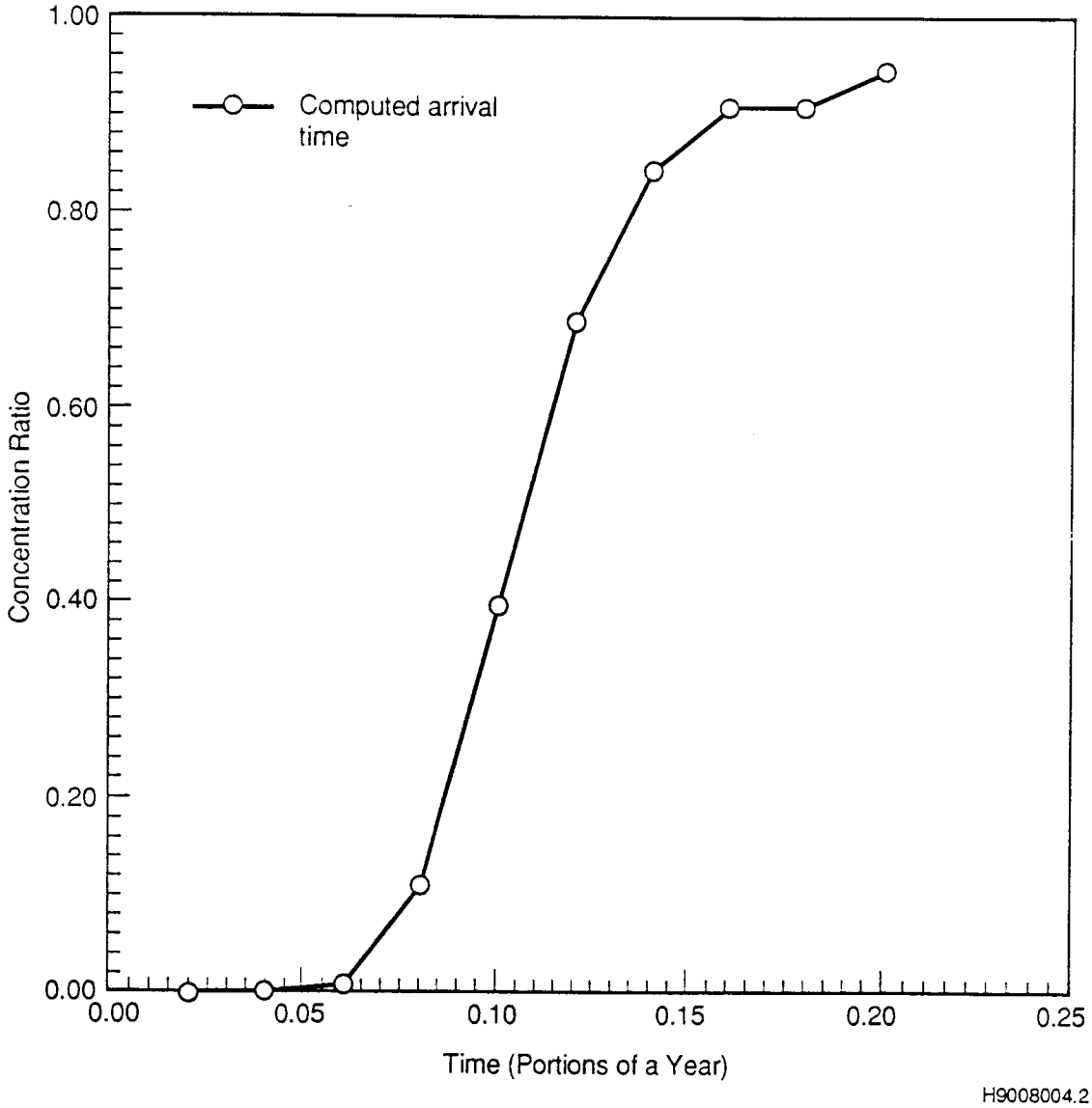

Figure 9. Arrival Time at the River of a Nonsorbed Solute.

Table 2. Effluent Discharge Information (Rokkan 1984, 1985, 1986, 1987, 1988; Perkins 1988, 1989; Fogel 1982, 1983; Greager 1979, 1980, 1981).

Year	Influx (L/day)	Outflux (L/day)	Ratio*	^{90}Sr discharged (Ci)		Annual average concentration of ^{90}Sr (nCi/L)	
				Crib	N Springs	Crib	N Springs
1973	8.70 E+06	4.35 E+06	0.500	1.60 E+01	3.00 E-01	1.50 E+01	1.70 E-01
1974	9.50 E+06	4.84 E+06	0.509	6.30 E+01	3.00 E-01	1.90 E+01	1.70 E-01
1975	9.50 E+06	4.80 E+06	0.505	9.30 E+01	4.00 E-01	2.60 E+01	2.10 E-01
1976	9.90 E+06	5.00 E+06	0.505	1.10 E+02	3.50 E-01	3.10 E+01	1.90 E-01
1977	1.45 E+07	7.30 E+06	0.503	1.20 E+02	1.00 E+00	2.30 E+01	3.70 E-01
1978	1.25 E+07	6.10 E+06	0.488	1.20 E+02	1.30 E+00	2.50 E+01	5.90 E-01
1979	1.35 E+07	6.50 E+06	0.481	1.30 E+02	1.60 E+00	2.70 E+01	6.50 E-01
1980	1.25 E+07	6.30 E+06	0.504	1.60 E+02	1.80 E+00	3.50 E+01	7.80 E-01
1981	1.05 E+07	5.00 E+06	0.476	8.40 E+01	1.80 E+00	2.30 E+01	9.40 E-01
1982	1.05 E+07	5.00 E+06	0.476	1.40 E+02	2.70 E+00	3.60 E+01	1.50 E+00
1983	8.90 E+06	4.70 E+06	0.528	1.10 E+02	4.00 E+00	3.40 E+01	2.30 E+00
1984	1.00 E+07	5.00 E+06	0.500	3.10 E+02	7.00 E+00	8.20 E+01	3.50 E+00
1985	1.00 E+07	5.00 E+06	0.500	2.40 E+02	8.40 E+00	6.50 E+01	4.50 E+00
1986	7.25 E+06	3.62 E+06	0.499	3.60 E+01	7.90 E+00	1.40 E+01	5.90 E+00
1987	2.10 E+06	1.14 E+06	0.543	1.50 E+01	2.40 E+00	1.90 E+01	6.00 E+00
1988	1.66 E+06	8.50 E+05	0.512	1.50 E+01	2.00 E+00	2.50 E+01	8.00 E+00
1989	1.66 E+06	8.70 E+05	0.524	3.90 E+01	2.00 E+00	6.20 E+01	6.20 E+00

*Ratio of influx to outflux.

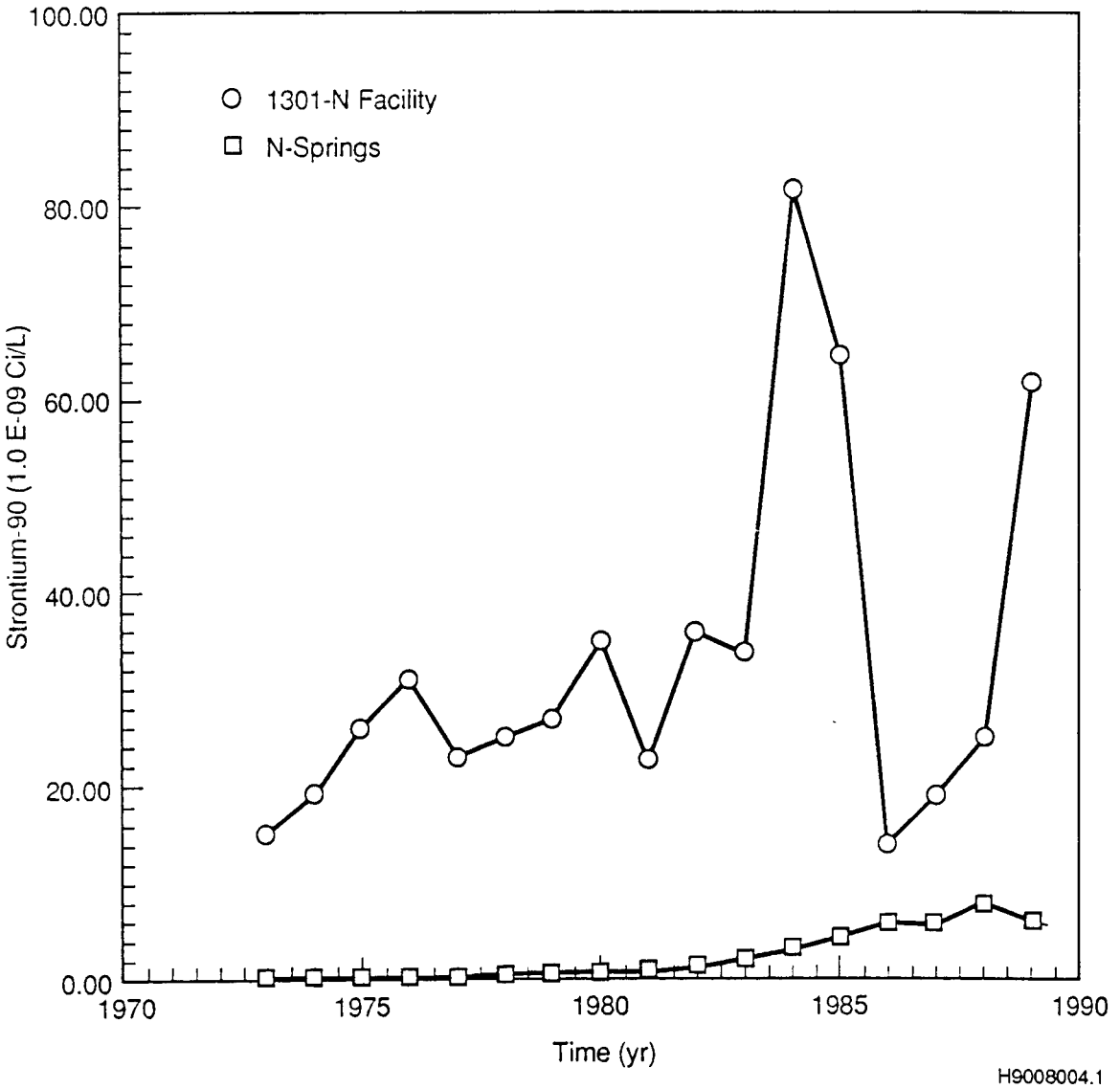

Figure 10. Annual Average Concentration of Strontium-90 at the 1301-N Facility and at N Springs.

One possibility is that the sludge layer on the bottom of the LWDF acted as a filter and retained many of the radionuclides that were present as fine particulates. To account for this retardation process, an unreasonably high distribution coefficient (K_d) value (1,628) was assigned to the bottom of the LWDF (Table 1). As a result, both sorption and the filtering mechanism were artificially addressed. A K_d value of 10 mL/g was chosen for both the middle unit of the Ringold Formation (unconfined aquifer) and the Pasco gravels unit of the Hanford formation (vadose zone). Parameters used in the transport model were listed in Table 1.

The simulated concentrations of ^{90}Sr for 1975, 1977, 1979, 1981, 1985, and 1988 are shown in Figures 11-17, respectively. A comparison of the simulated ^{90}Sr concentration at N Springs with the observed concentration is shown in Figure 18. Good agreement between the two curves in Figure 18 provides confidence in the calibrated model. Figures 19 through 29 show the predicted ^{90}Sr distributions for every other year from 1990 through 2010, respectively. The source term used for 1988 was also used for the 1990 through 2010 predictions (i.e., 0.5 Mgal/day of effluent discharged to the 1325-N Crib, with a ^{90}Sr concentration of 25 x 10^{-9} Ci/L). Figure 30 shows the predicted ^{90}Sr concentrations (in nanocuries) at N Springs from 1990 through 2010. The ^{90}Sr concentrations at N Springs calculated by VAM2DH are listed in Table 3.

Currently, the rate of effluent discharge to the 1325-N LWDF is less than 100 gal/min. Effluent control consistent with the Tri-Party Agreement (Ecology et al. 1989), milestone M-17-00, will be provided if needed. Milestone M-17-00 requires the completion of a liquid effluent treatment facility or elimination of the effluent discharge by June 1995. These considerations were not reflected by some of the assumptions used in the VAM2DH simulation.

5.0 CONCLUDING REMARKS

Although this analysis provides a good agreement between simulated concentrations of ^{90}Sr at the N Springs and previously published concentrations from 1973 through 1989, the reason for the agreement may not be unique; there may be more than one interpretation.

The sludge layer that accumulated in the floor of the LWDFs may have acted as a filter; consequently, much of the fine particulates containing ^{90}Sr may be retained permanently at this location. This physical mechanism for retardation was not directly accounted for in the model; instead, a high retardation factor was used for the bottom of the LWDFs. No published concentration of ^{90}Sr in the monitoring wells or in N Springs exceeds 25 percent of the average concentration in the effluent discharged to the LWDFs. This observation suggests that mechanisms other than sorption may be present.

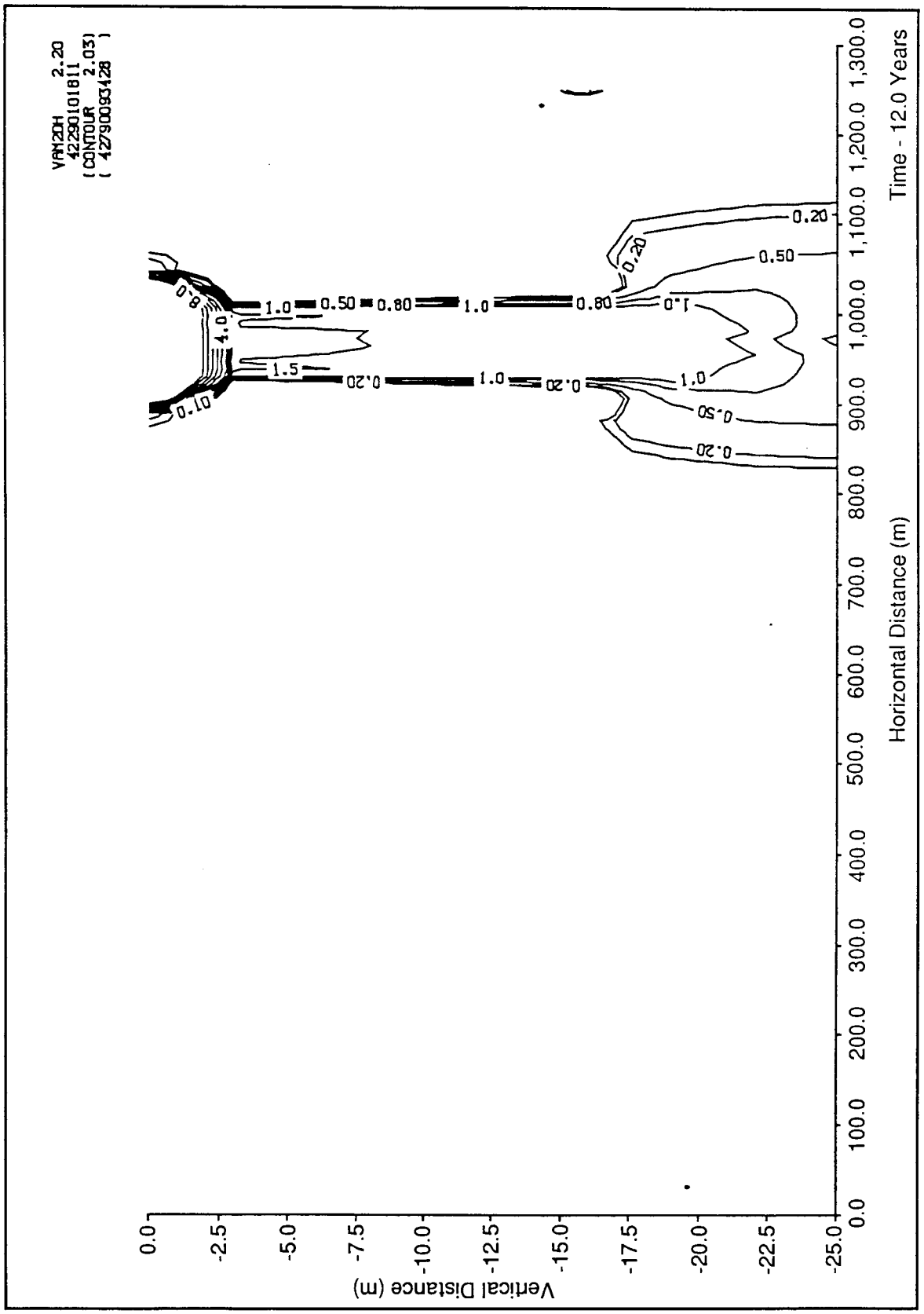

Figure 11. Concentration of Strontium-90 in 1975 (contours in nanocuries).

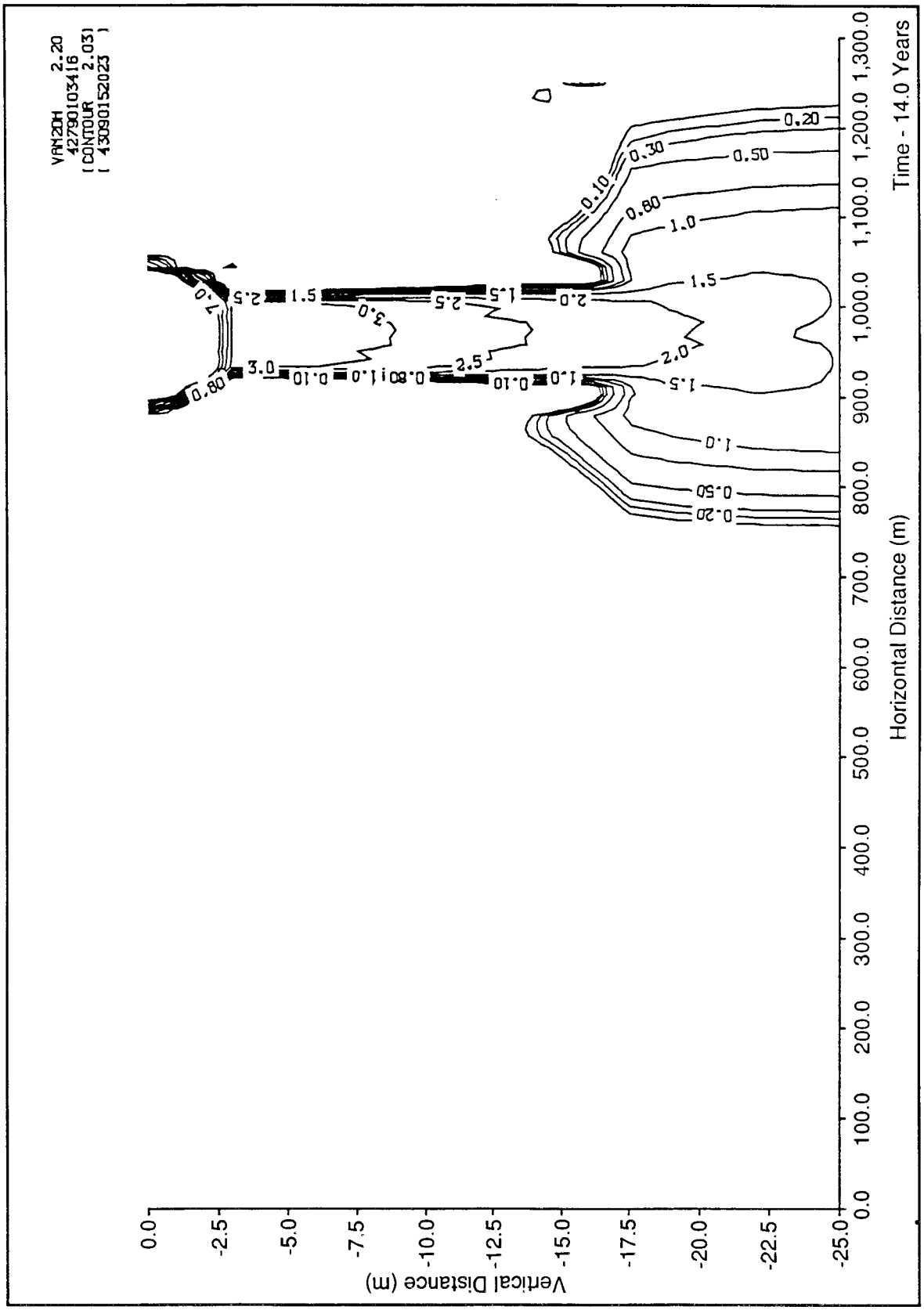

Figure 12. Concentration of Strontium-90 in 1977 (contours in nanocuries).

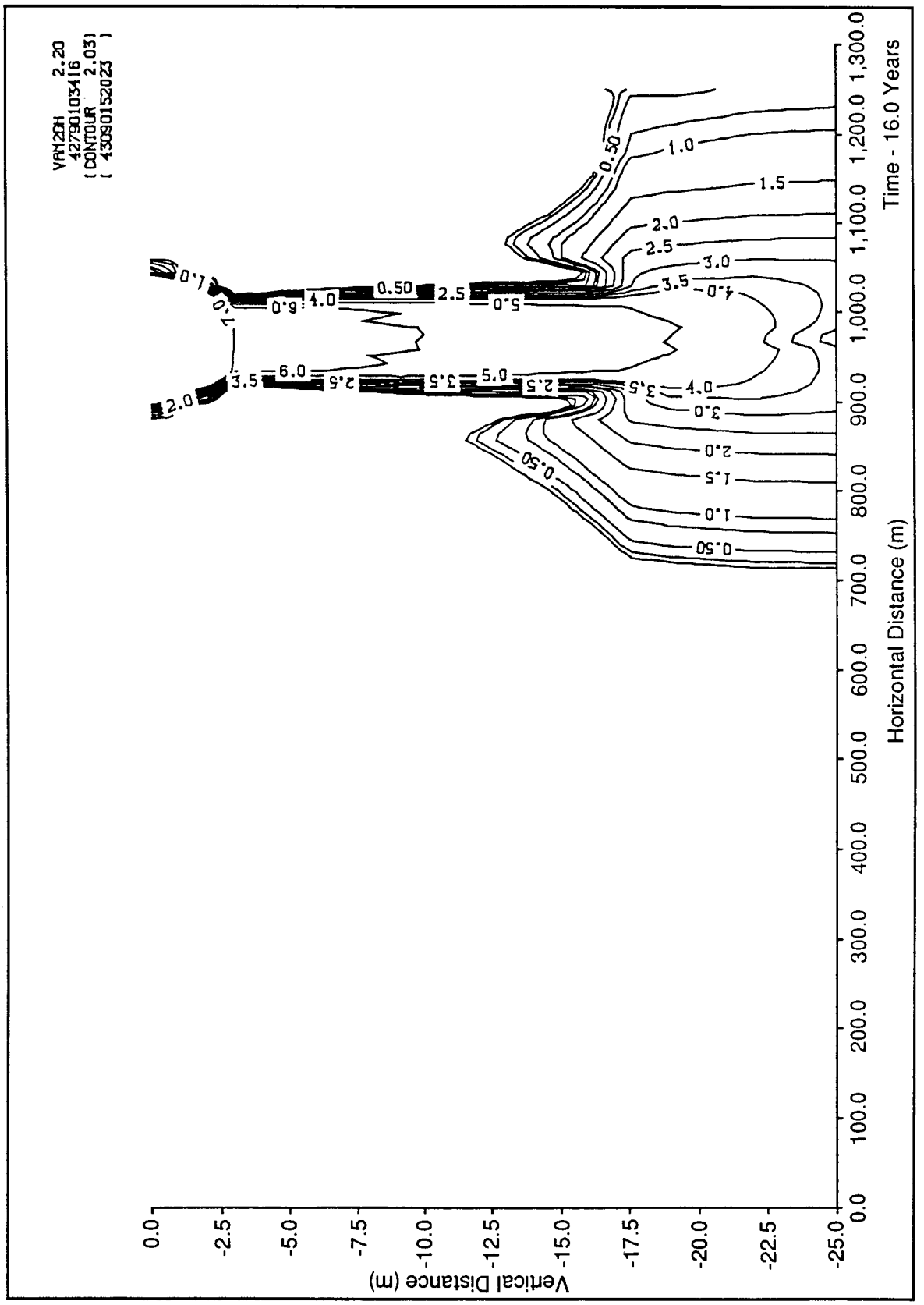

Figure 13. Concentration of Strontium-90 in 1979 (contours in nanocuries).

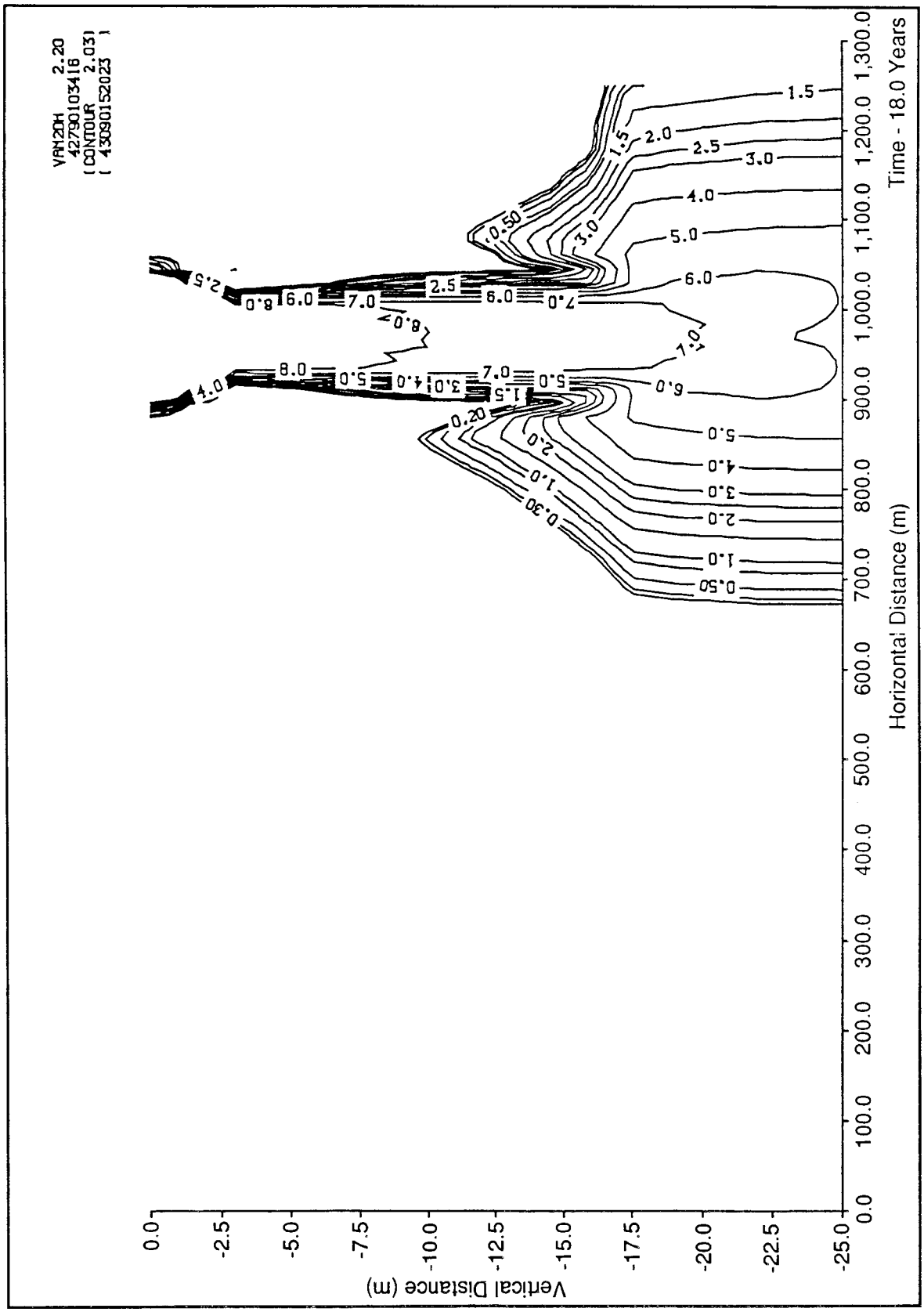

Figure 14. Concentration of Strontium-90 in 1981 (contours in nanocuries).

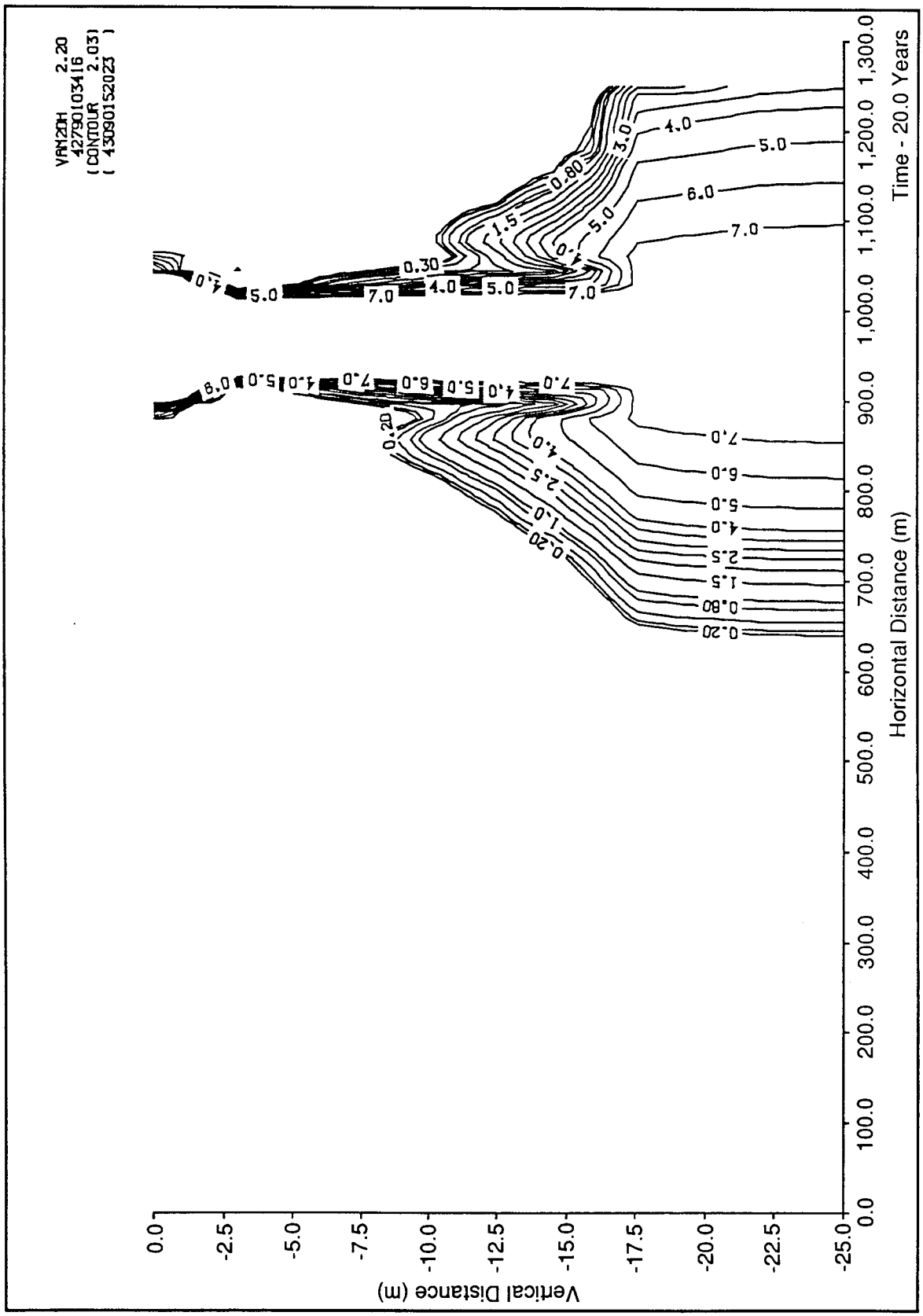

Figure 15. Concentration of Strontium-90 in 1983 (contours in nanocuries).

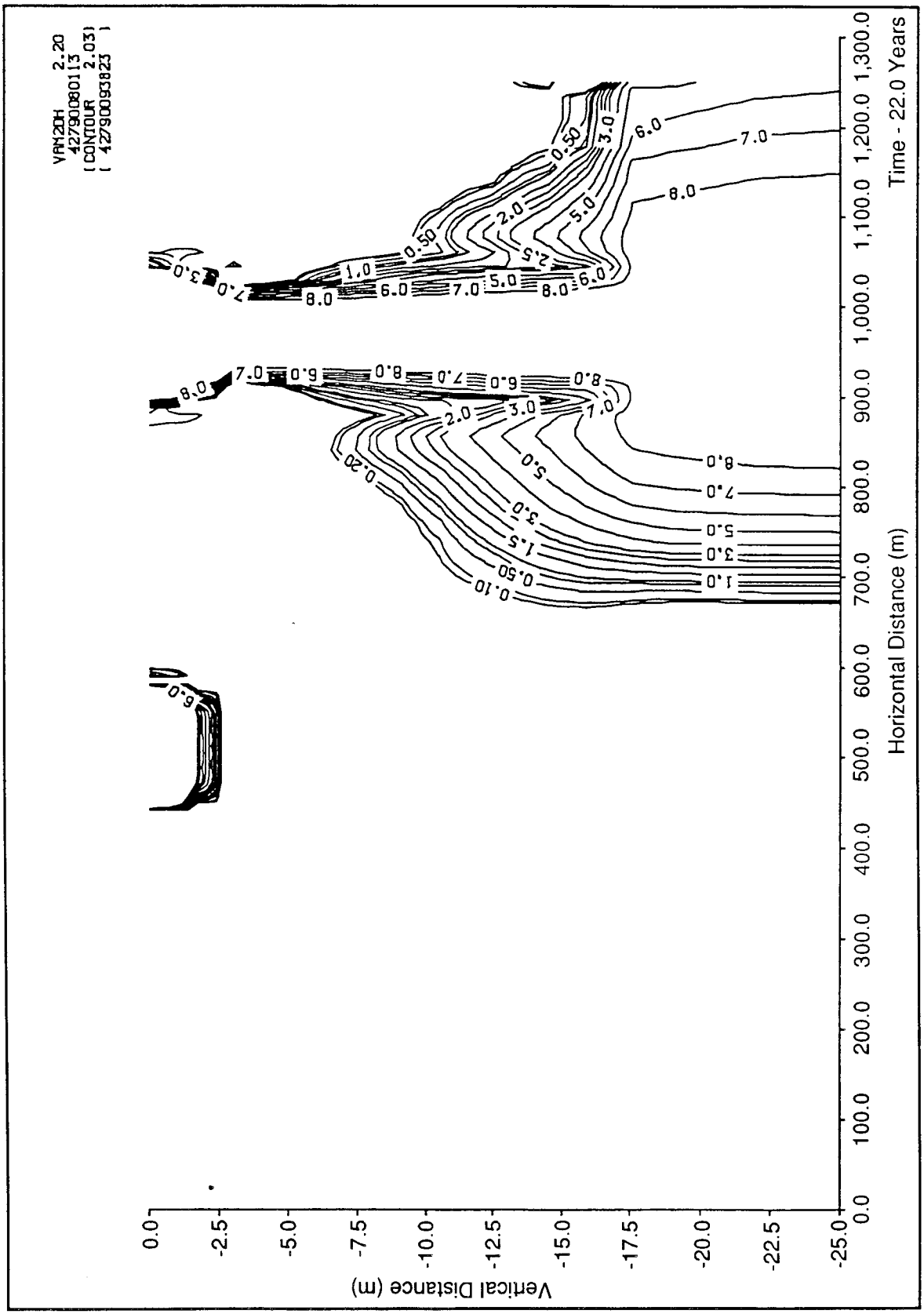

Figure 16. Concentration of Strontium-90 in 1985 (contours in nanocuries).

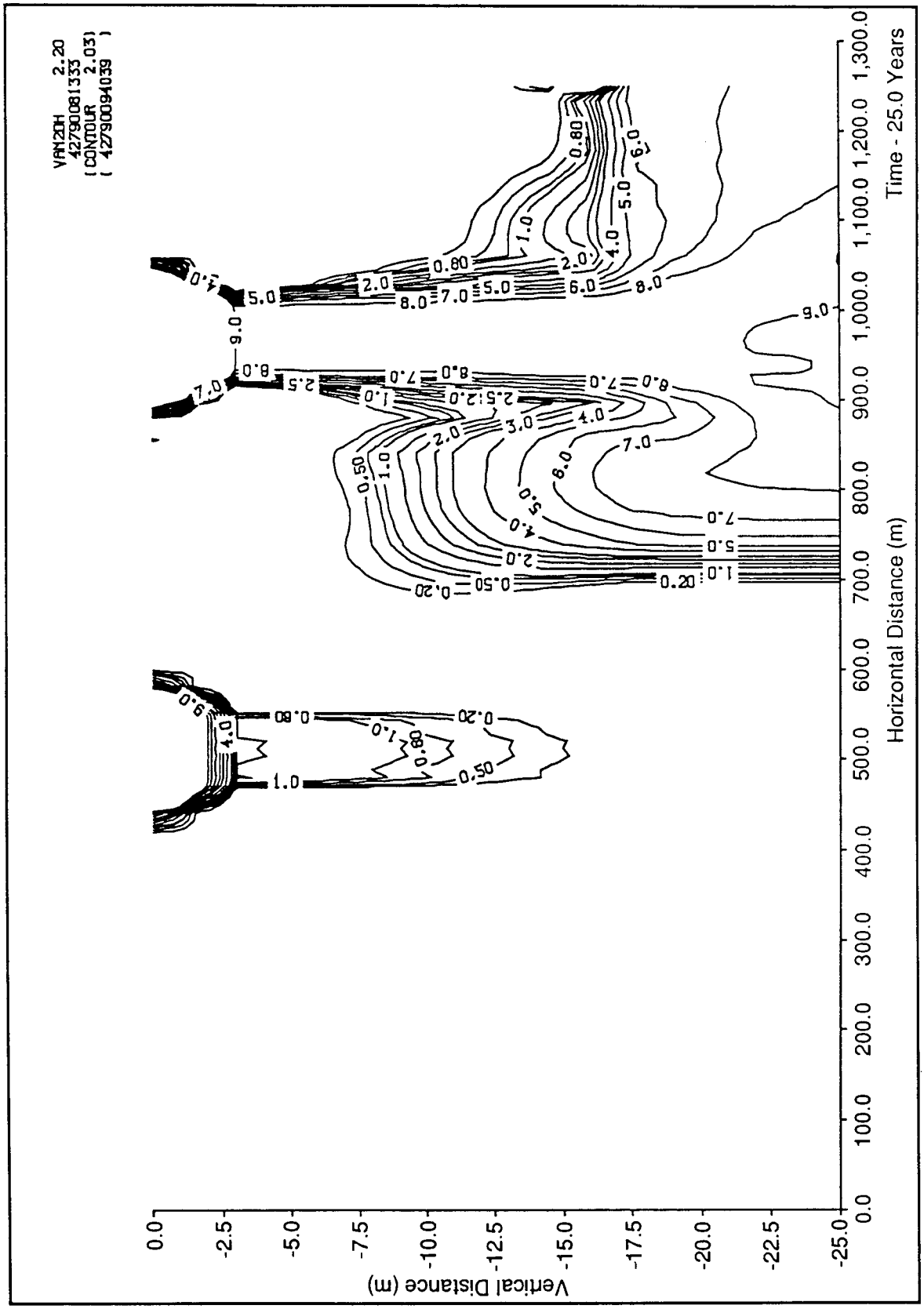

Figure 17. Concentration of Strontium-90 in 1988 (contours in nanocuries).

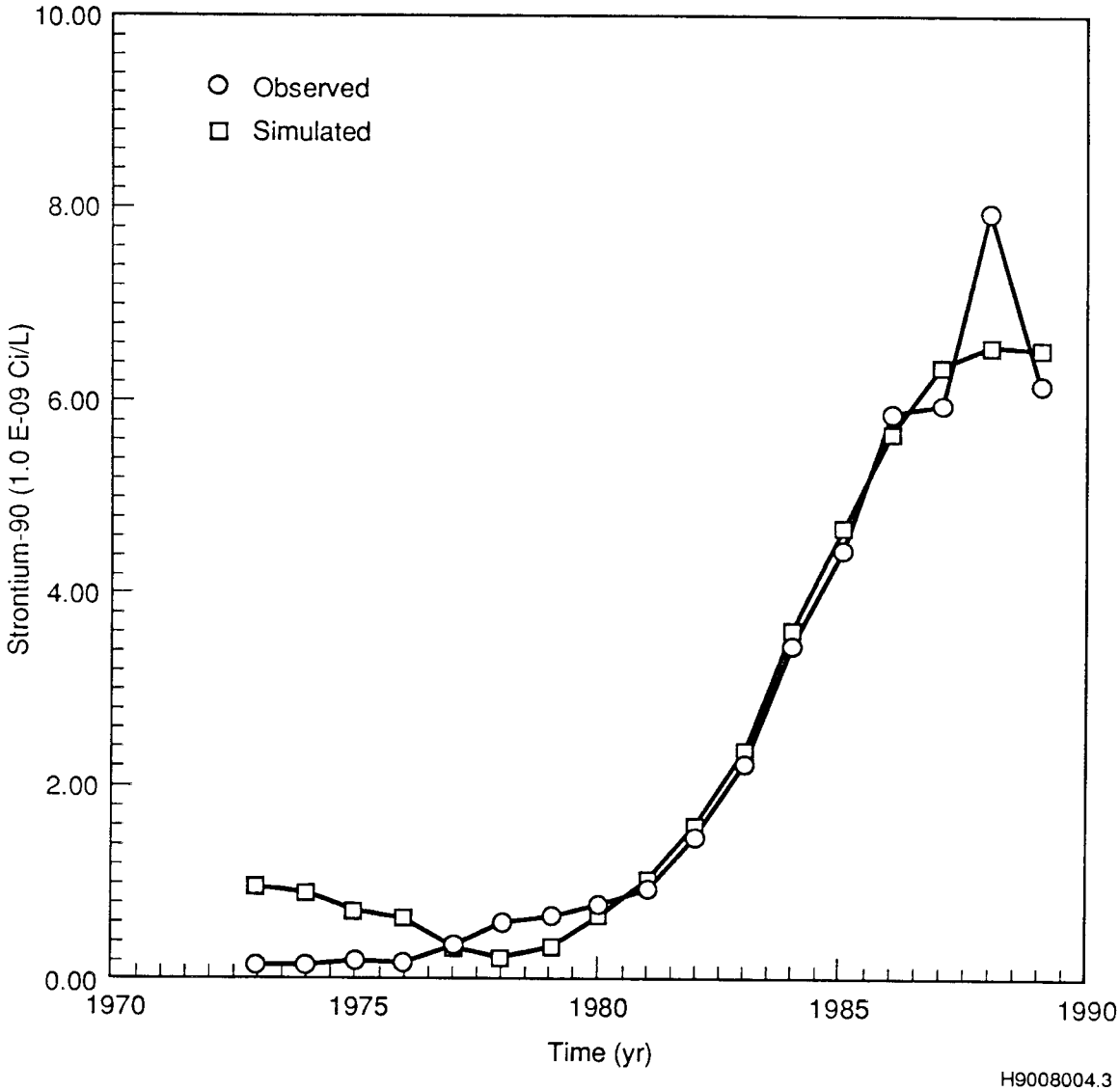

Figure 18. Comparison of Observed and Simulated Concentrations of Strontium-90 at N Springs (concentrations in nanocuries).

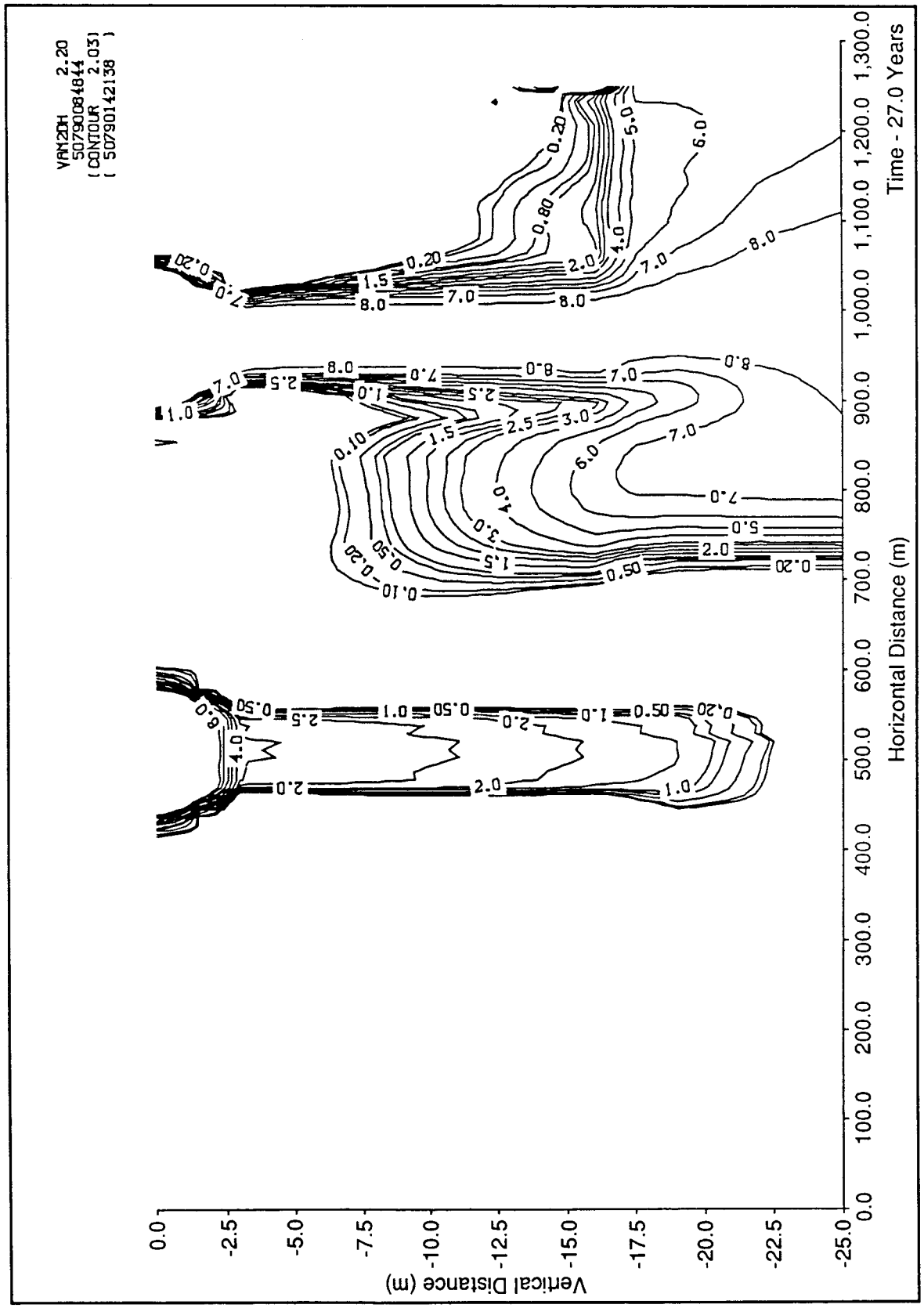

Figure 19. Predicted Concentration of Strontium-90 in 1990 (contours in nanocuries).

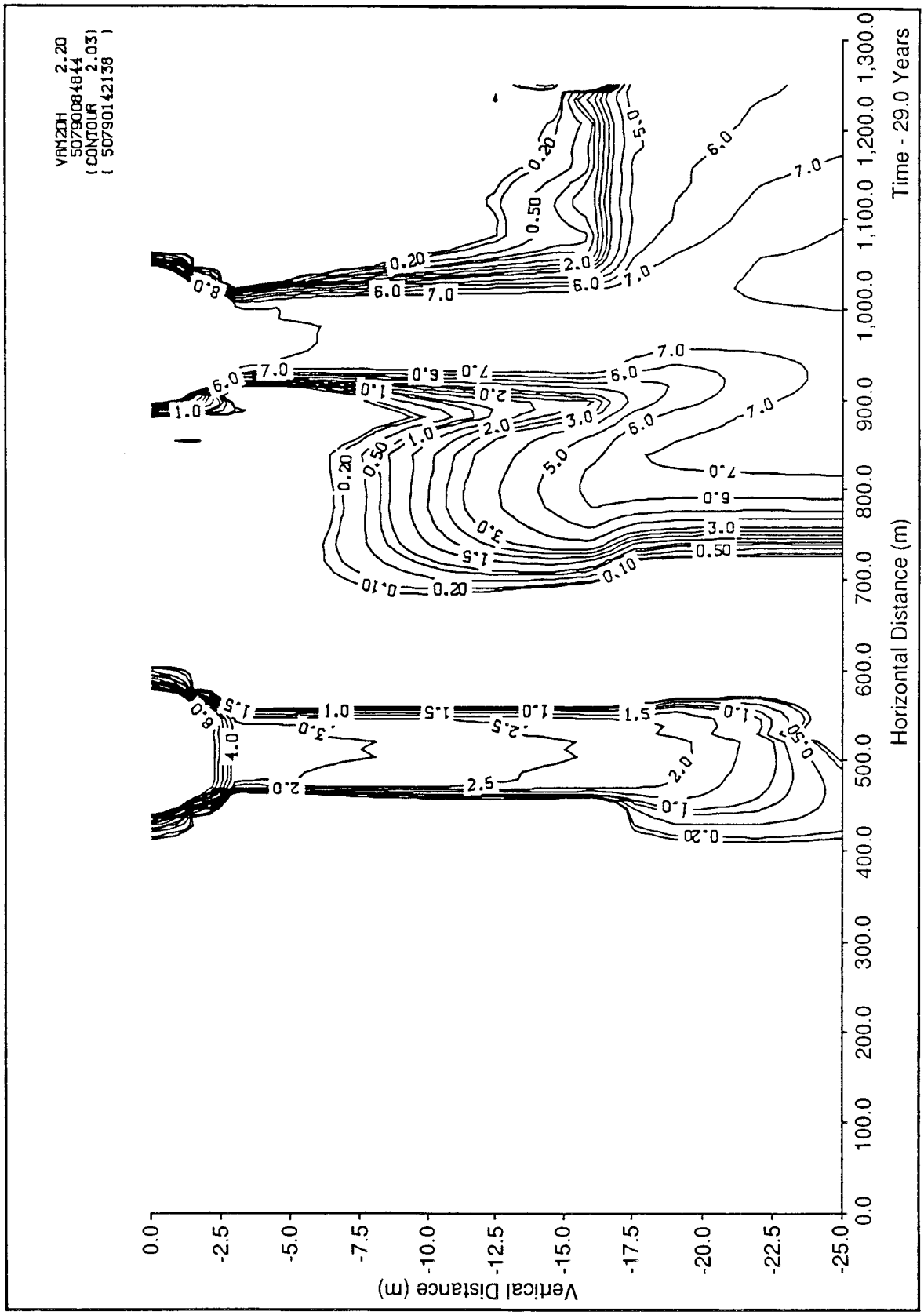

Figure 20. Predicted Concentration of Strontium-90 in 1992 (contours in nanocuries).

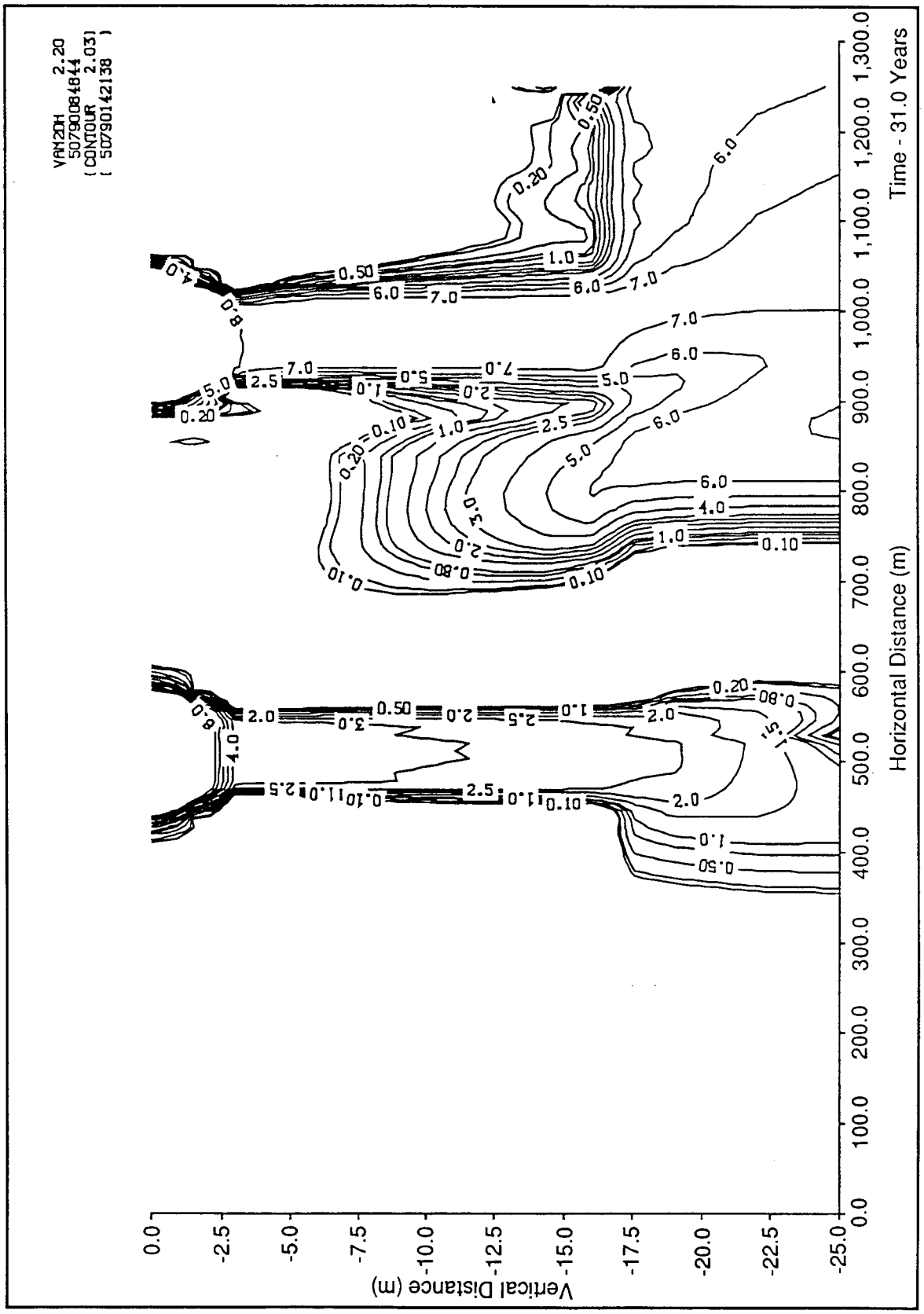

Figure 21. Predicted Concentration of Strontium-90 in 1994 (contours in nanocuries).

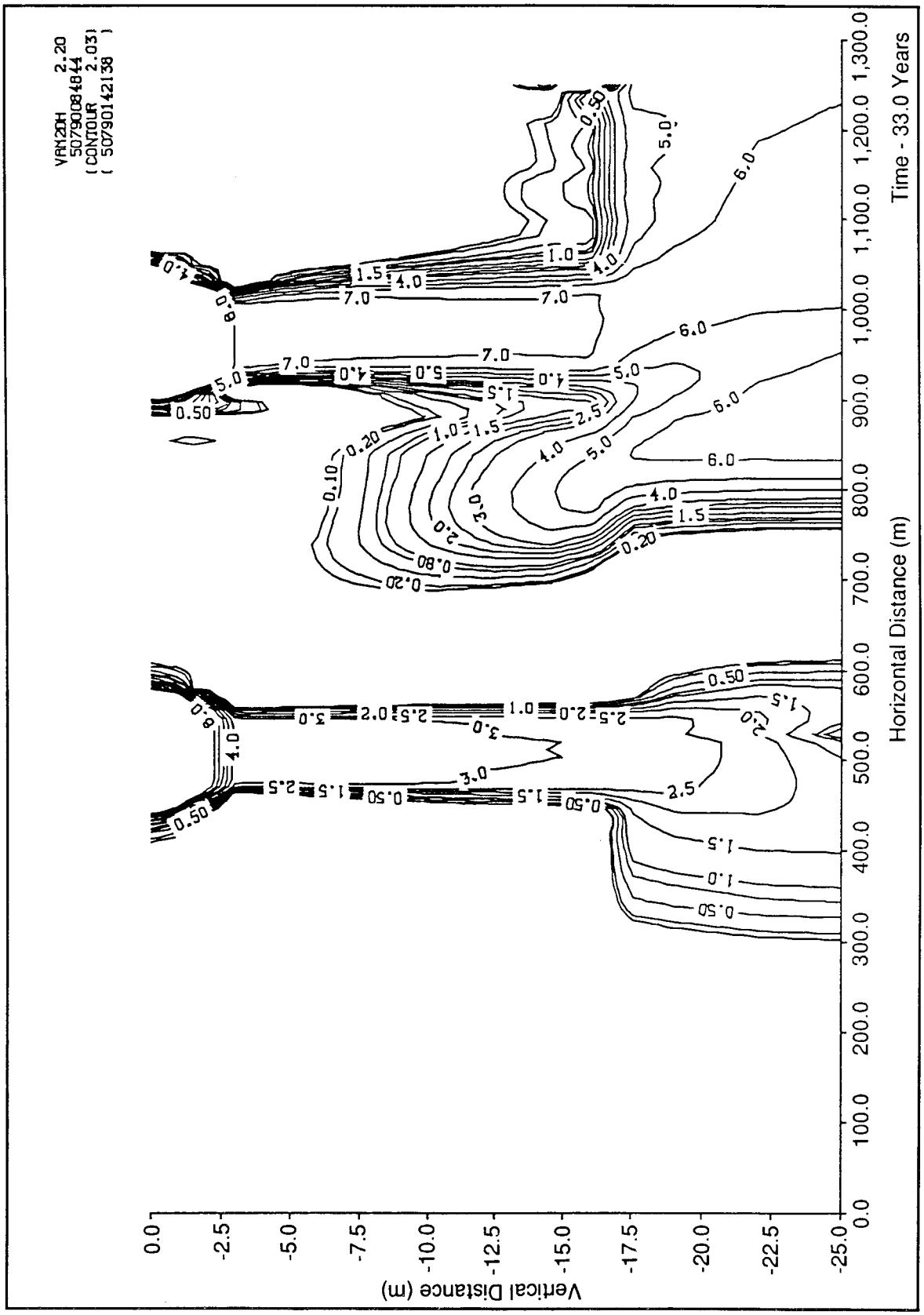

Figure 22. Predicted Concentration of Strontium-90 in 1996 (contours in nanocuries).

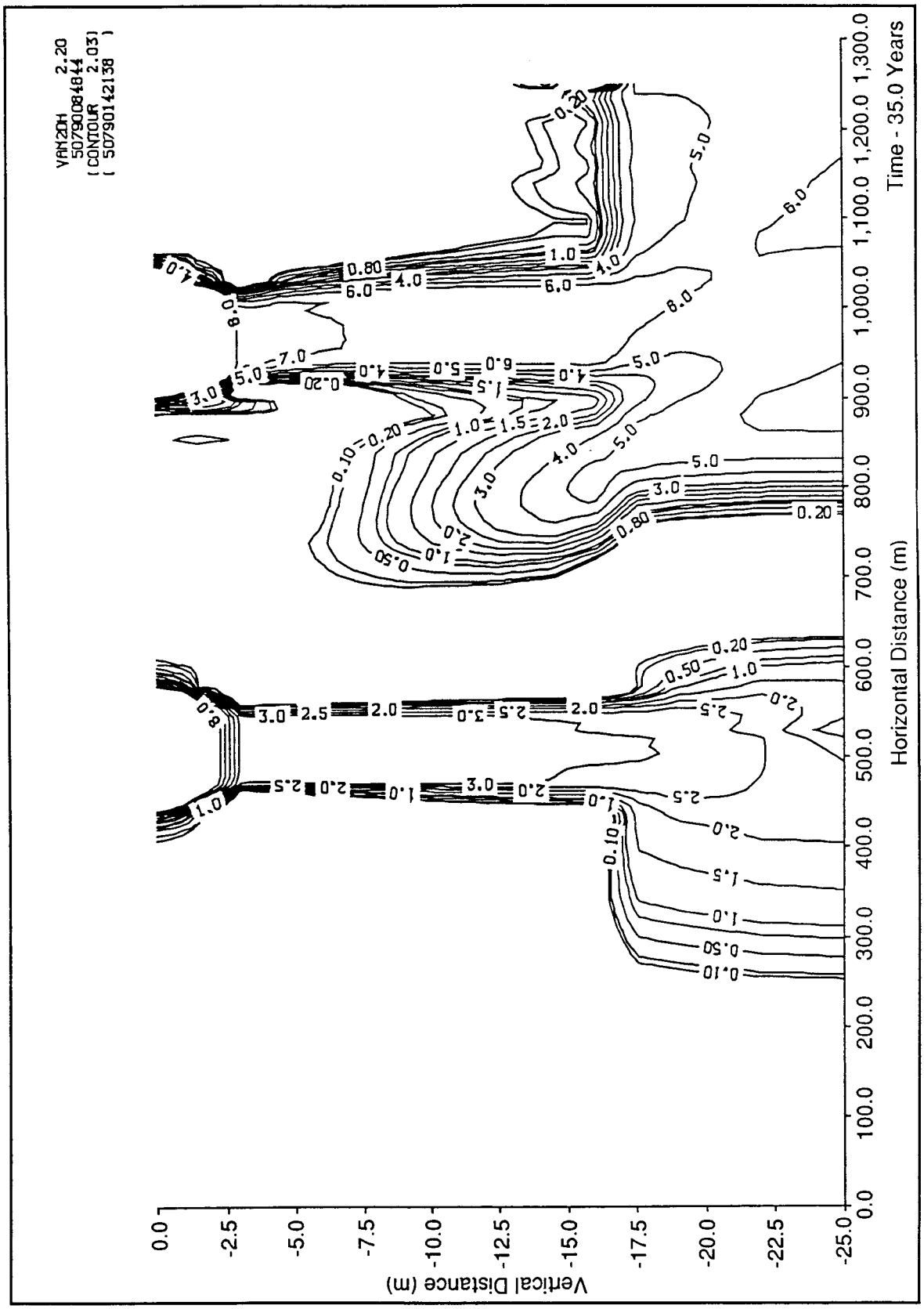

Figure 23. Predicted Concentrations of Strontium-90 for 1998 (contours in nanocuries).

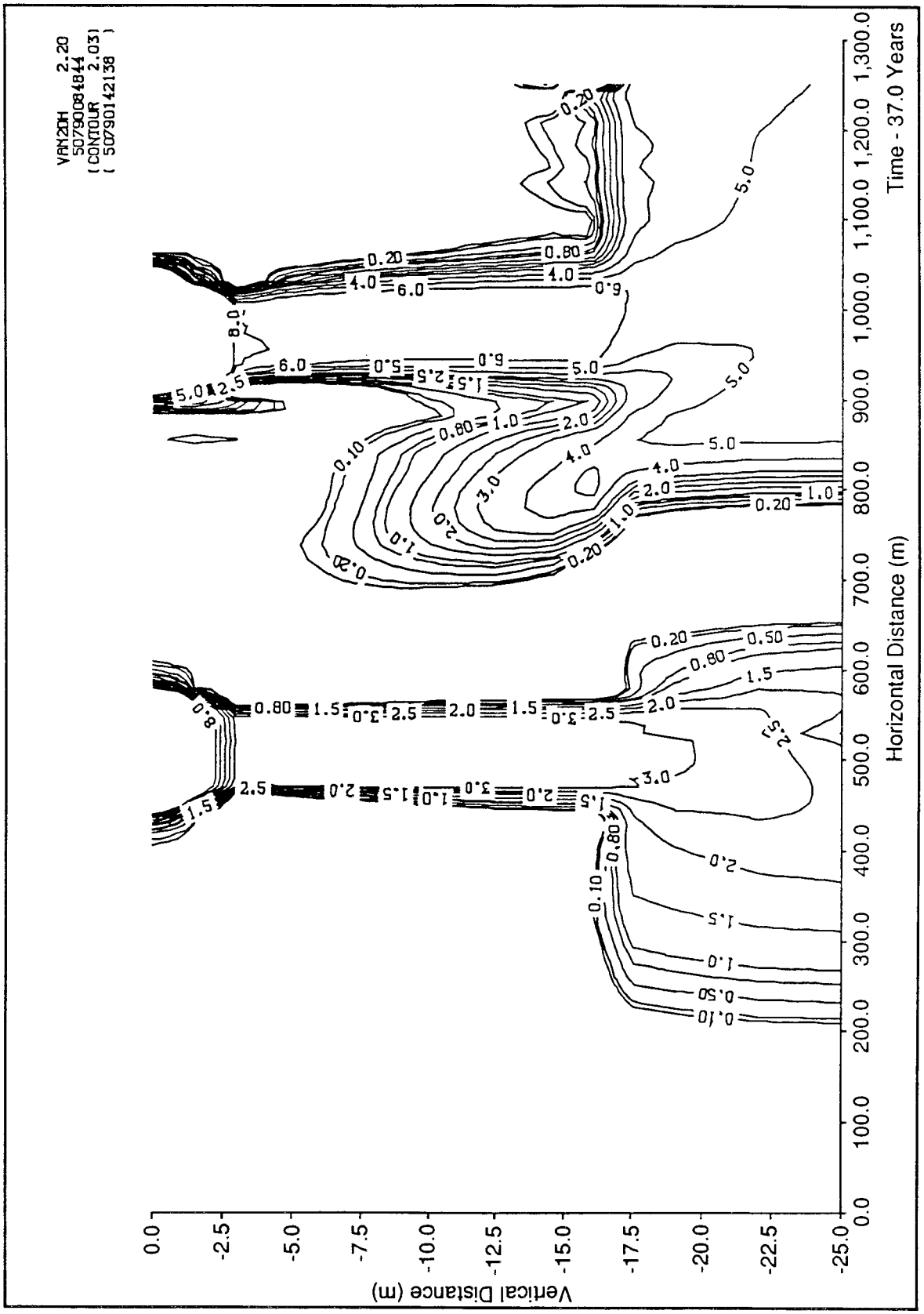

Figure 24. Predicted Concentrations of Strontium-90 for 2000 (contours in nanocuries).

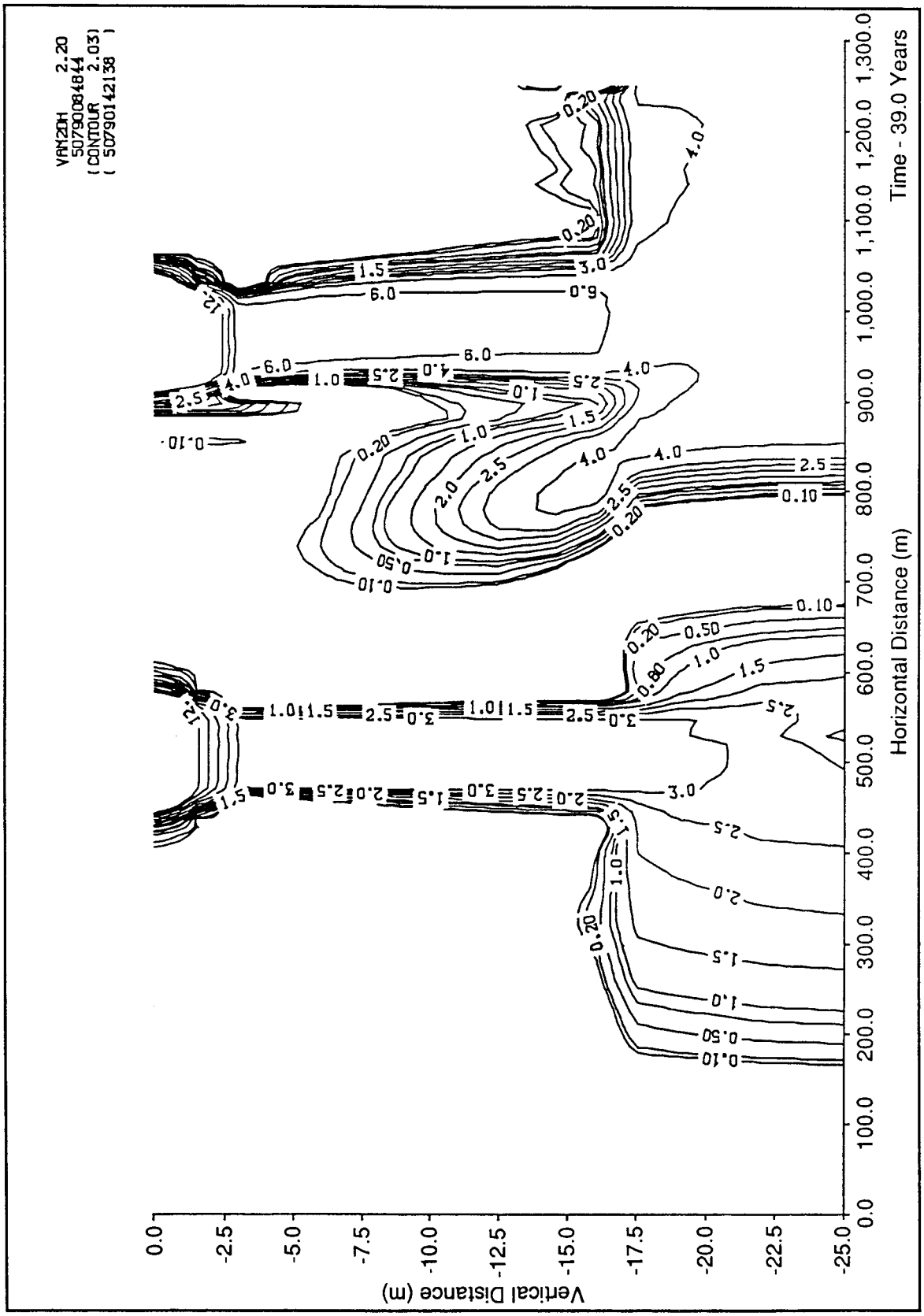

Figure 25. Predicted Concentrations of Strontium-90 for 2002 (contours in nanocuries).

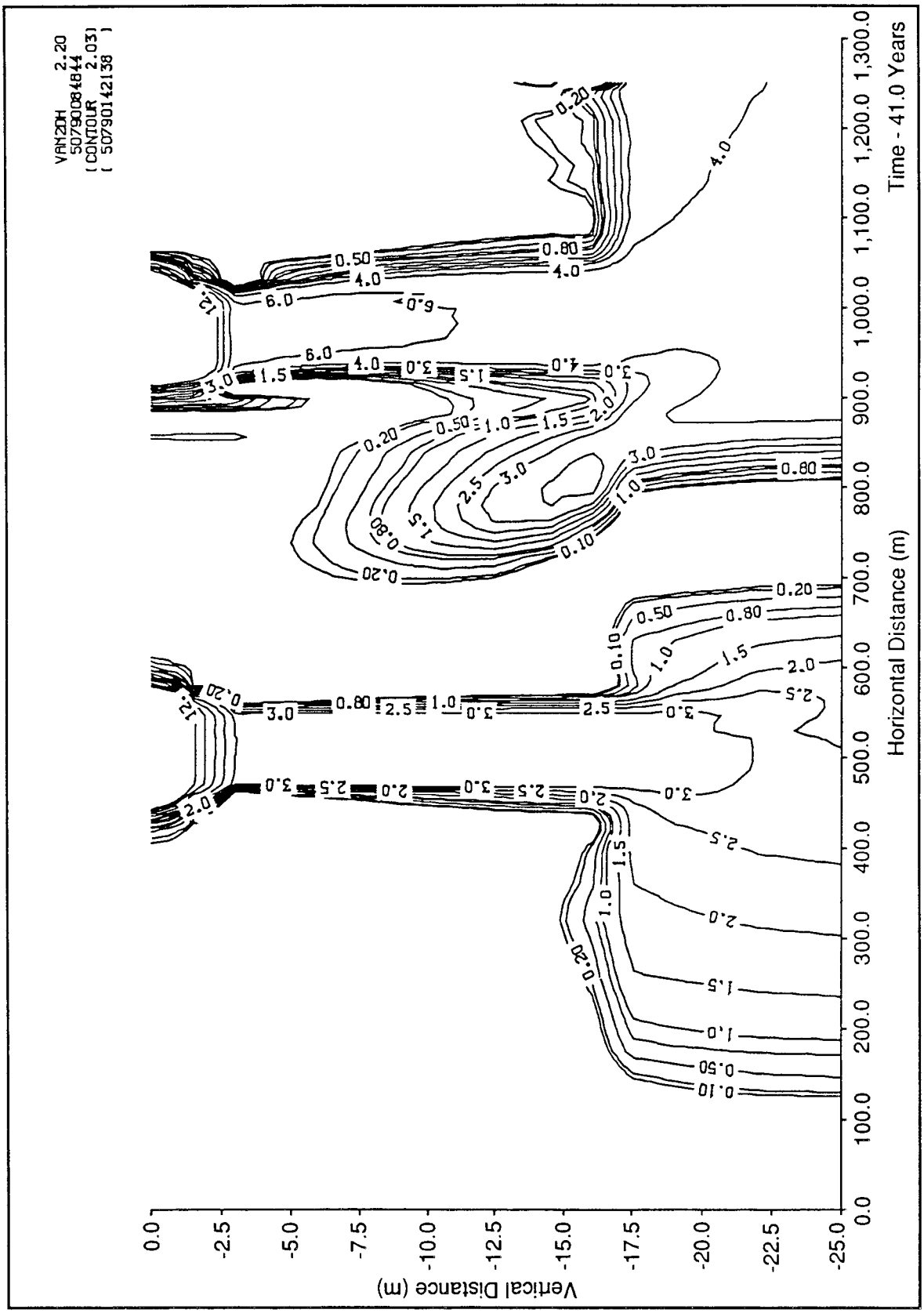

Figure 26. Predicted Concentration of Strontium-90 in 2004 (contours in nanocuries).

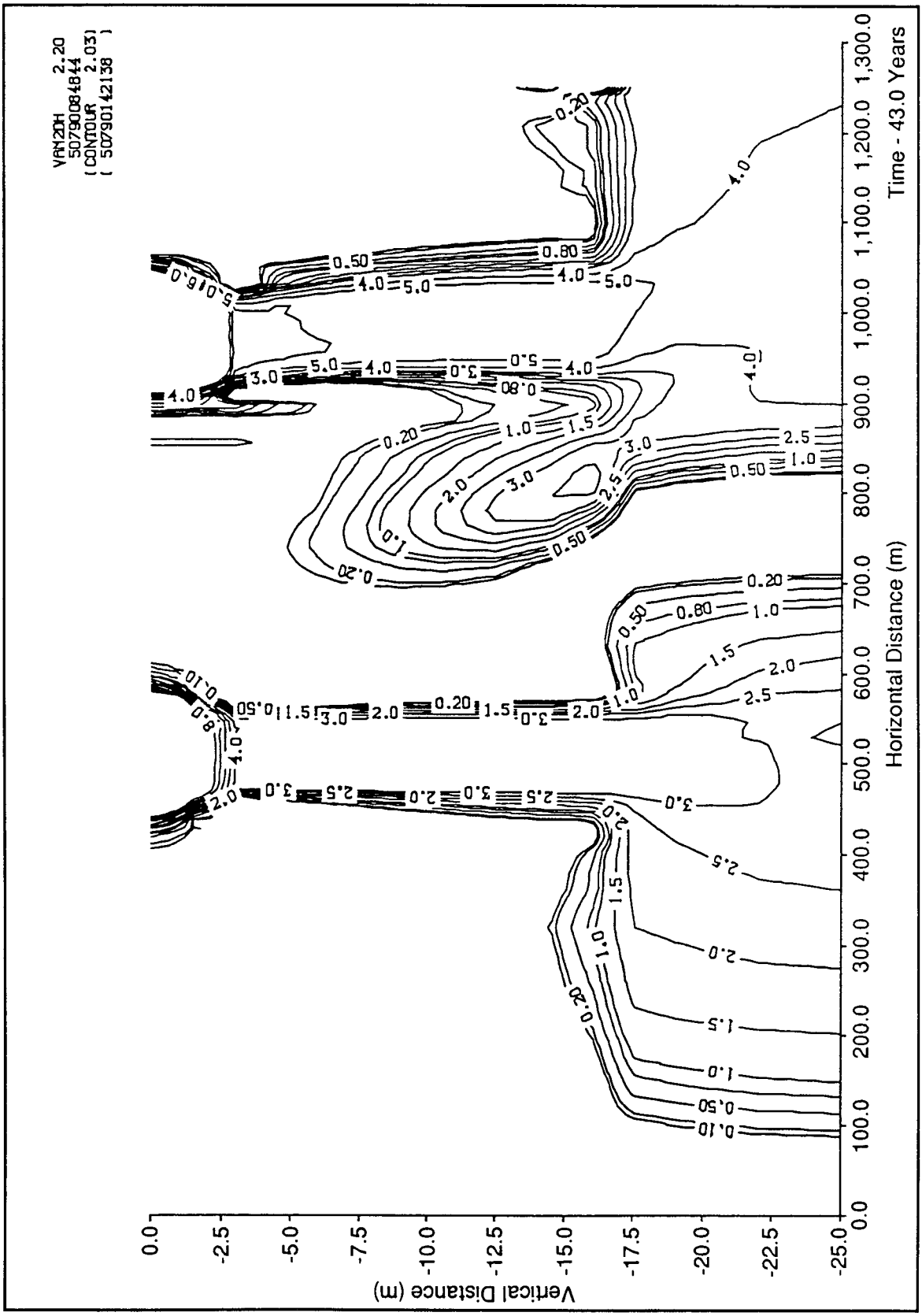

Figure 27. Predicted Concentrations of Strontium-90 for 2006 (contours in nanocuries).

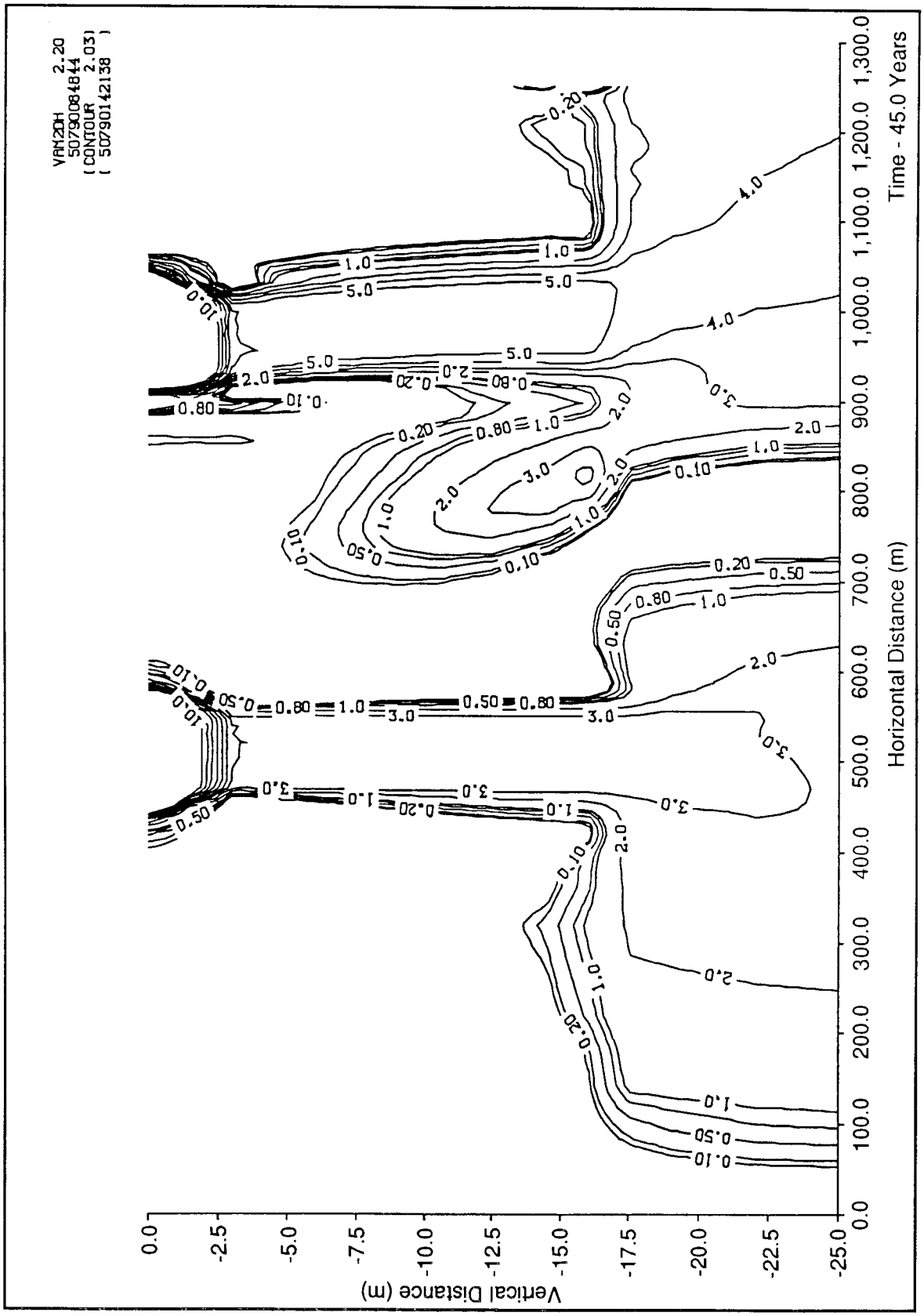

Figure 28. Predicted Concentrations of Strontium-90 for 2008 (contours in nanocuries).

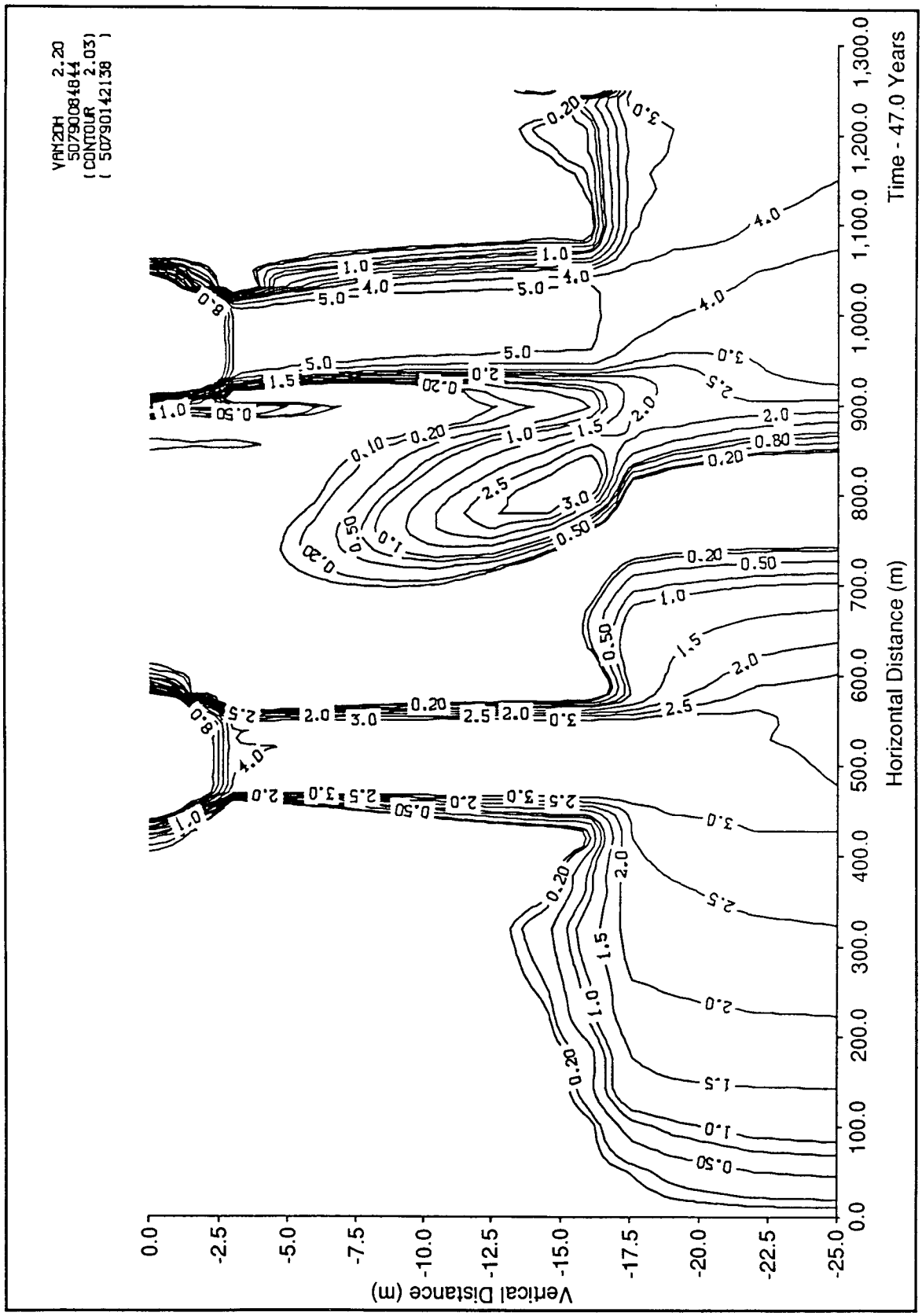

Figure 29. Predicted Concentrations of Strontium-90 for 2010 (contours in nanocuries).

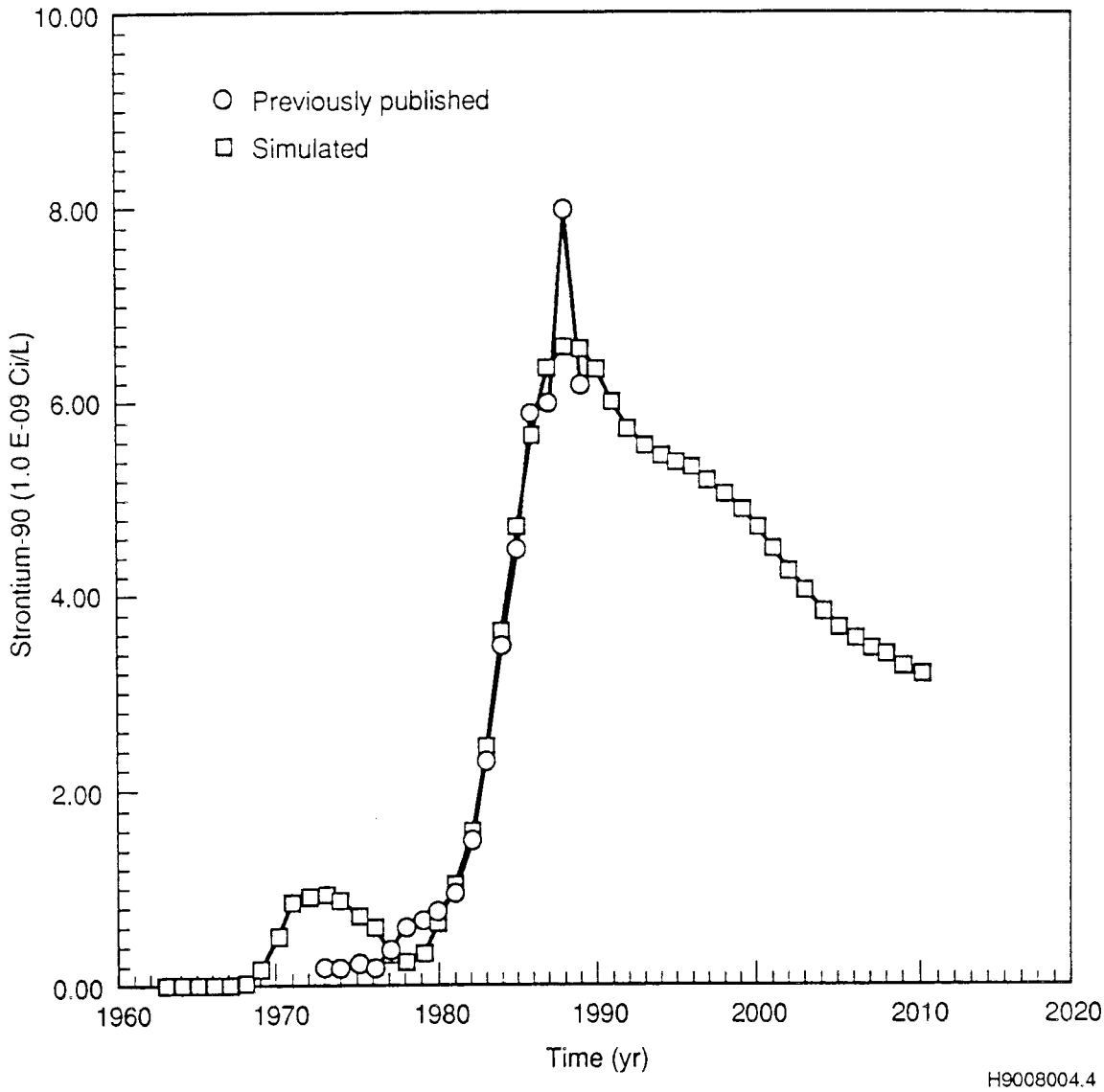

Figure 30. Predicted Concentrations of Strontium-90 at N Springs from 1990 to 2010, Using a Model Calibrated for 1973-1989.

Table 3. Simulated Concentrations of Strontium-90 at N Springs.

Year	Simulated concentration (nCi/L)	Year	Simulated concentration (nCi/L)	Year	Simulated concentration (nCi/L)
1964	7.59 E-12	1980	6.70 E-01	1996	5.34 E+00
1965	1.70 E-08	1981	1.02 E+00	1997	5.22 E+00
1966	3.90 E-06	1982	1.55 E+00	1998	5.08 E+00
1967	1.40 E-04	1983	2.42 E+00	1999	4.92 E+00
1968	2.17 E-02	1984	3.66 E+00	2000	4.74 E+00
1969	1.80 E-01	1985	4.72 E+00	2001	4.53 E+00
1970	5.10 E-01	1986	5.70 E+00	2002	2.30 E+00
1971	8.60 E-01	1987	6.38 E+00	2003	4.07 E+00
1972	9.00 E-01	1988	6.59 E+00	2004	3.88 E+00
1973	9.40 E-01	1989	6.58 E+00	2005	3.72 E+00
1974	9.00 E-01	1990	6.36 E+00	2006	3.59 E+00
1975	7.20 E-01	1991	6.01 E+00	2007	3.49 E+00
1976	6.10 E-01	1992	5.73 E+00	2008	3.40 E+00
1977	3.20 E-01	1993	5.56 E+00	2009	3.31 E+00
1978	2.30 E-01	1994	5.48 E+00	2010	3.23 E+00
1979	3.30 E-01	1995	5.42 E+00		

The 2-dimensional cross-sectional model can provide a good approximation only of the average flux of groundwater and the average rate of migration of radionuclides from the LWDFs to the river. The predicted lateral movement will be addressed by 3-dimensional simulation using the PORFLO-3 (Runchal and Sagar 1989) computer software.

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