THE NPP CERNAVODA USE TO ESTIMATE MAXIMUM SOLUBLE POLLUTANTS CONCENTRATION IN DANUBE BLACK SEA CHANNEL

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ABSTRACT

Tritium, routinely released as low activity liquid radioactive waste by Cernavoda nuclear power plant, was used as a radiotracer to study longitudinal dispersion of Danube Black Sea Channel. A field experiment was carried out in which, after a tritium release, water was sampled downstream from three locations along the channel at periodic intervals. Tritium was measured with a low-background liquid scintillation system and the concentration time evolution for each location was obtained. In order to obtain the channel longitudinal dispersion efficiency, the Unit Peak Attenuation (UPA) curve was plotted. The UPA slope curve was used to construct software that can estimate propagation time of soluble tracer cloud and unit peak attenuation at any location from studied area.

1 INTRODUCTION

River basins today are a foundation of economic production and ecological health, but are facing pressures from growing urban populations and agricultural and industry development. Nearly every major surface water body is at risk from pollution from a host of sources. Numerous experimental studies in hydrosphere have been carried out to study the hydrodynamic behavior of a wide type of streams. In most of these studies, chemical or fluorescent tracers are used, although they have various drawbacks, as they are usually nonperfectly conservative, their degradation products can be toxic and they are relatively expensive. The use of tritium as a tracer in river waters has several advantages [1]:
- it does not adsorb to sediments, being an ideal tracers as it forms water (HTO) molecules;
- sampling is easy and it does not require special techniques;
- small sample amounts can be used and extremely low tritium concentrations in water can be measured by low-background liquid scintillation;
- the relatively long life of tritium permits storage before measurement.

The location of NPP Cernavoda near Danube-Black Sea Canal requires the developing of a powerful program of environmental monitoring. Considering national and international regulations, interest area was founded around this important electrical energy provider. The use of tritium routinely released, as low-activity liquid radioactive waste by this CANDU type of nuclear power plant as a radiotracer, led to an extension of monitoring activity along the Danube - Black Sea Channel.

2 BACKGROUND AND TECHNIQUES

Danube-Black Sea Canal is ideal for tracers’ study, because evacuations of wastewater are occasionally due to technical operations of nuclear power plant. The possibility of a contamination agent being accidentally or intentionally spilled upstream from a water supply is a constant concern to those diverting and using water from this channel. A method of rapidly estimating traveltime or dispersion is needed for pollution control or warning the system on the channel where data are limited. Traveltime and mixing of water within a stream are basic streamflow characteristics needed in order to predict the rate of movement and dilution of pollutants that may be introduced in the stream. Tritiated water can be used to simulate the transport and dispersion of solutes in Danube-Black Sea Canal because they have the same physical characteristics as water, so understanding how tracers mix and disperse in a stream is essential to understanding their application in simulating pollution.

2.1 Theory of Transport and Dispersion for Soluble Tracer

The general procedure that use soluble tracer is to instantaneously inject a known quantity of water soluble tracer into a stream, usually in the centre of the flow, and to observe the variation in concentration of the tracer as it moves downstream. The dispersion and mixing of a tracer in a receiving stream takes place in all three dimensions of a channel. Vertical mixing is normally completed first, and lateral mixing later, depending on stream characteristics and velocity variations. Longitudinal dispersion, having no boundaries, continues indefinitely and is the dispersion component of primary interest. With time and distance, peak concentrations become attenuated and cloud lengths get longer and longer.

The conventional manner of displaying the response of a stream to a slug injection off tracer is to plot the variation of concentration with time (tracer-response curve) as observed at two or more cross sections downstream of the injection, as illustrated in figure 1. The tracer response curve, defined by the analysis of water samples taken at selected time intervals during the tracer cloud passage is the basis for determining time-of travel and dispersion characteristics of stream. The characteristics of tracer-response curves shown in figure are described in terms of elapsed time after a tracer injection: $C_p$, peak concentration of tracer cloud; $T_{lp}$, elapsed time to the arrival of leading edge of a tracer cloud at a sampling location; $T_{lp}$, elapsed time to the peak concentration of the tracer cloud; $T_{tp}$, elapsed time to the trailing edge of the tracer cloud; $T_{d}$, duration of the tracer cloud ($T_{tp}$-$T_{lp}$); $T_{10d}$, duration from leading edge until tracer concentration has reduced to within 10 percent of peak concentration; $n$, number of sampling site downstream of injection.
One of the important assumptions of the tracer dilution principle is full mixing. In this case, and also for a continuous release under stationary hydraulic conditions, the tracer activity in the river \( C_0 \) can be calculated as:

\[
C_0 = \frac{C_t}{Q} \cdot q
\]  

where \( C_t \) is the mean concentration of the tracer release, \( q \) the flow rate of the tracer discharge and \( Q \) the river discharge. This is valid for sampling points located at a distance from the source greater than the mixing length. A number of empirical formulae have been proposed to estimate the mixing length \( (L) \):

- Day [2], proposed in 1977:
  
  \[
  L = 25w
  \]  
  
  where \( w \) is the channel width.

- Guizerix and Florkovski [3], proposed in 1983:
  
  \[
  L = 10 \frac{w^3}{d}
  \]  
  
  where \( w \) and \( d \) are the stream mean width and depth, respectively.

- Killpatrick and Cobb [4], proposed in 1985:
  
  \[
  L = K \frac{vw^2}{E_z}
  \]  
  
  where \( E_z \) is the transverse mixing coefficient, \( v \) is the mean channel velocity, \( w \) is the average channel width, and \( K \) is a coefficient depending on the degree of mixing, the location of the injection and the number of injections.

The shape and magnitude of observed tracer-response curves are determined by four factors: the quantity of tracer injected, the degree to which the tracer is conservative, the magnitude of the stream discharge, and longitudinal dispersion. Observed concentrations can be adjusted for the amount of tracer injected, for tracer loss and for channel discharge by use of so called “unit concentration”. Variations in dispersion on the same flow or different flows become most apparent if the unit concentrations for the peaks, \( C_{up} \), are plotted as a function of elapsed time to the peaks. A plot of the peak concentrations (converted to unit-peak concentrations) with elapsed time for the response curves measured at four distances is shown in fig. 2.

Figure 1: Soluble tracer concentration evolution plotted with propagation time of the cloud.
Figure 2: Theoretical UPA curves as related to different mixing time.

The UPA curve, along with the travel time, provides a ready means of predicting, at any location, maximum contaminant levels that would be experienced downstream from the spill of any amount of soluble contaminant at any location in the reach after total mixing has been achieved for the range in flows tested. The final purpose of our study is to construct the UPA curve for Danube-Black Sea Canal shown in figure 2.

2.2 Studied Area

Black Sea is located in the East part of our country and it receives many surface waters, but Danube is one of the most important rivers from this area. The sea depth is very small in the Romanian coastal part and that’s why the quality of received water can have an important impact on marine ecosystem and environment. The Danube-Black Sea Canal has the length of 64.410 km and is situated between the Port of Constanta South-Agigea “0” km of the canal and the junction with the Danube river-Cernavoda 64.410 km, respectively 299.300 km on the Danube river, figure 3. The Danube-Black Sea Canal has two locks, one is located in Cernavoda and the other in Agigea and they are dividing the Canal in three sectors: sector I - between 64.410 km and 60.350 km with direct connection to the Danube; sector II - between the two locks, 59.905 km and 1.935 km with the levels characteristics to the regime of exploitation of the canal; sector III - between 1.550 km and 0.000 km of connection to the Black Sea at Constanta. The breadth of the clearways is 90 meters, and this width is getting larger by 30 meters in the curvature areas. The Channel depth, always assured in exploitation, is 7.5 meters. The Danube-Black Sea Canal monthly water discharge attend a maximum in the summer months, around 23 m$^3$/s, and a minimum in winter months, around 6m$^3$/s. The mean water velocity, assigned to the discharges, varies between 0.01 m/s and 0.047 m/s. There are no tributaries in the area, and the discharge is kept constant by the two existing locks.

The Cernavoda nuclear power plant is situated upstream of sector II of the channel and comprises one heavy water reactor (HWR) unit. During its normal operation this unit generates low-activity radioactive waste, mainly tritium, which is released into Danube, in a controlled way, at Seimeni. Wastewater evacuations into the Canal are occasionally due to the technical operation of the nuclear power plant. The sector II is the part of the Canal that we used for our study.
2.3 Sampling and Analyses

Two main locations were established before nuclear power plant: Cochirleni is situated on the Old Danube Branch, and the second one is on the Borcea Branch. We used these two locations to compare the tritium concentration of Cernavoda water samples, upstream of NPP. Some of the other locations offer easy access to sampling, by their channel pier, Table 1. In the chosen locations, water was sampled on the 5th day of the month, during the period May 2002 – November 2002. Simultaneous sampling from centre and both sides of the channel in different location were considered, to compare the tritium concentration and to establish the mixing length.

Special attention was given to collection and preservation of the samples [5], and a total of 163 water samples of 500 ml were collected in brown glass bottles.

Table 1: Sampling locations – Danube Black Sea Channel

<table>
<thead>
<tr>
<th>Sampling location</th>
<th>Latitude (N)</th>
<th>Longitude (E)</th>
<th>Distance (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Borcea</td>
<td>44G19’03.1’’</td>
<td>27G49’47.3’’</td>
<td>-</td>
</tr>
<tr>
<td>Cochirleni</td>
<td>44G11’31.6’’</td>
<td>28G01’45.5’’</td>
<td>-</td>
</tr>
<tr>
<td>Cernavoda</td>
<td>44G18’42.4’’</td>
<td>28G02’53.7’’</td>
<td>63</td>
</tr>
<tr>
<td>Cernavoda Channel</td>
<td>44G18’16.3’’</td>
<td>28G03’05.3’’</td>
<td>60</td>
</tr>
<tr>
<td>Cernavoda Electric Plant</td>
<td>44G18’08.9’’</td>
<td>28G03’04.7’’</td>
<td>59</td>
</tr>
<tr>
<td>Faclia</td>
<td>44G15’58.8’’</td>
<td>28G08’40.3’’</td>
<td>49.4</td>
</tr>
<tr>
<td>Medgidia</td>
<td>44G15’05.3’’</td>
<td>28G15’43.7’’</td>
<td>40</td>
</tr>
<tr>
<td>Poarta Alba</td>
<td>44G13’00.1’’</td>
<td>28G23’09.6’’</td>
<td>28.8</td>
</tr>
</tbody>
</table>

As tritium is a soft beta emitter (5.72 keV mean energy), liquid scintillation is the most appropriate technique for its measurement. In this work, the low-background liquid scintillation spectrometer Quantulus 1220 (Wallac) has been used to determine tritium in channel water samples. The analytical method used to determine tritium in water samples was, briefly, the following: samples were filtered through slow depth filters; 250 ml of filtrate was distilled using ISO method [6]; 8 ml of distillate was mixed with 12 ml of scintillation cocktail OptiPhase Hisafe 3 in polyethylene vials; three background samples and three tritium standards were simultaneously prepared. Samples, backgrounds and tritium standards were counted using Quantulus 1220 during 500min/samples.
3 RESULTS

The mixing length for specific conditions of studied area recommended by equation (2) is 2.25 km. Applying equation (3) we observe another mixing length of 3.117 km. The most conservative mixing length of 8.1 km is the one obtained by equation (4). The last result is estimated using K=4 for injection of the side of the channel, and the most low discharge, 6m$^3$/s. Comparing the results obtained and applying the experimental formulas for the mixing length, we conclude that first location of the experiment will be Facilia, which is situated 10.6 km downstream of the junction of lateral Canal branch. The other two locations Medgidia (19 km downstream) and Poarta Alba (20.2 km downstream) will help to plot UPA curve, and to determine the slope, which is the efficiency of the Canal dispersion in this section. First step in obtaining basic information about studied area was to establish the base line of tritium concentration.

![Baseline of tritium level in studied area](image)

During the monitoring period, May 2002- November 2002, there weren’t wastewater releases from the Nuclear Power Plant, only the water necessary for basic technical operations. Locations Cochirleni and Bratul Borcea were used to determine a mean tritium concentration in places without influences of NPP. A mean of 16.82 ± 2.7 TU for Cochirleni, against 19.02 ± 2.7 TU for Cernavoda town, fig.4, proves that upstream of NPP the influences of gaseous evacuation in water channel are minim (1TU=1T atom to $10^{18}$ protium atoms). The tritium concentrations behaviour along the Channel is similarly like that of Facilia location, fig.4. There isn’t a seasonal variation, and a mean of 30 TU is the significant value for edge and tail of tracer cloud.

At the end of May 2003, it began the evacuation of tritiated water from NPP-Cernavoda in Danube-Black Sea Channel. We settled three observation locations: Facilia, Medgidia and Poarta Alba. The behavior of tritiated liquid effluents is similar to the tracer and it is illustrated in fig. 5. The water channel flow was around 30 m$^3$/s. We made simultaneous sampling on three streamlines (center and both side of the flow) in Medgidia location. The values confirm a behavior like a tracer at a distance greater than the mixing length, and relatively homogenous mixture of the tracer in the body water. From recorded values, the elapsed time for the edge of the tracer cloud was after 34 hours for Facilia location. The unit
peak of concentration in this location was $62.72 \text{ s}^{-1}$. The elapsed time for the edge of the cloud in Medgidia location was 62 hours, with unit peak of concentration of $40.44 \text{ s}^{-1}$. The elapsed time for the edge of tritiated water in Poarta Alba location was 93 hours from the evacuation beginning, with a unit peak of concentration of $32.72 \text{ s}^{-1}$.

![Graph showing the behavior of tritiated liquid effluents in three locations of Danube – Black Sea Channel](image)

**Fig. 5** The behaviour of tritiated liquid effluents in three locations of Danube – Black Sea Channel

Drawing the UPA curve, fig. 6, we determined a mean of slope of 0.62 which indicate a lower efficiency of dispersion.

![Graph showing the UPA curve for three locations of Danube-Black Sea Channel](image)

**Fig. 6** UPA curve for three locations of Danube-Black Sea Channel

Using experimental data obtained during this experiment we developed software that can evaluate the unit concentration in any location of observed area. In this way it can be predicted any maximum concentration of soluble pollutants that would be experienced downstream of a spill along the observed area of the Channel.

All data obtained during this experiment offer a global evaluation of the flow along Danube-Black Sea Channel. It must be emphasized again that, the studied water has a very
slow flow, the discharge is imposed by agricultural, human and dams consumption. In order to make a real evaluation of all the possibilities, it will be necessary to develop an experiment during the autumn-winter conditions.

4 CONCLUSION

The theory of the soluble tracers can be applied in the case of tritiated wastewater of NPP Cernavoda, for Danube-Black Sea Canal. In order to plan the sampling campaign we established the proper mixing length for the Canal flow, and the locations with easy access for tracer experiments. In these locations we established significant tritium concentrations for the edge and the tail of tritiated wastewater evacuations. During the evacuations of tritiated liquid effluents we determined the slope of the UPA curve, that help us to model the water movement in observed area of Danube-Black Sea Channel. In this way with specific software we can predict maximum concentration of soluble pollutant accidental spills in studied area.

ACKNOWLEDGMENTS

This work was supported by National Program for Research and Development MENER, contract number 004/2001. The authors gratefully acknowledge the Administration of Navigable Canals –S.H. Constanta Agigea, for their full collaboration and provided data, and Nuclear Power Plant Cernavoda for logistic support.

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