Environmental impact of the nuclear power plants' cooling systems

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1. Introduction

The study herein is dealing with the impact of the continuous discharge of the effluent released from one ore more nuclear units into a natural receiver, that is Dunarea Veche branch of Danube, or into an artificial receiver, that is Danube-Black Sea Canal. The flow rate discharged from the cooling systems of Cernavoda nuclear power plant, that is maximum 54 m3/s, for each unit, is low as compared to the monthly mean flow rates along Dunarea Veche branch, but it is significant as compared to the flow rates running in some seasons along the second pool of Danube-Black Sea Canal. The effluent of Cernavoda nuclear power plant has similar physical-chemical characteristics with those of the water source, that is Dunarea Veche branch of Danube river, which has a temperature increase by 7-100 C and some chemical substance chargings generated by the power plant system and which are released under control. The heat density impact of the effluent of Cernavoda nuclear power plant is assessed by having in view both the influence of the effluent's temperature increase on the water supply into the receiver,and the direct and indirect effects produced on the water quality along the Danube section, downstream to the discharge point and along the second pool of Danube-Black Sea Canal. The goal was to emphasize the impact of warmer water on the physical-chemical processes deployed in the emissary, through the effects generated on the dissolved oxygen concentration and also on some biochemical processes with effects on BOD5, CCO-Mn indicators, nitrates, nitrites, ammonium, total phosphorus. The influence of the warm effluent on some biocenosis elements from the receivers is taken into account.

The water temperature variation along Dunarea Veche branch, downstream to the effluent's discharge, and also along the second pool of Danube-Black Sea Canal was estimated by means of calculus for specific hydrological and meteorological conditions, taking into account the effluent generated by one, two or four units of Cernavoda nuclear power plant. Mathematical models have been conceived in order to compute the water flow parameters and the water temperature variation which consists of the equations on movement of free surface water, as well as of the bi-variate heat transfer equation. The mathematical models have been drawn up according to the topobathymetric data on the receivers' water beds and on the specific operation conditions of Danube-Black Sea Canal. Hydrological and meteorological data surveyed for more than 40 years-long period at Cernavoda and Medgidia power stations have been also used. Surveyed data and water samples results taken from the receiver during Cernavoda nuclear power plant operation with one or two units have been used for the estimations validation, both under regular hydrological and meteorological conditions and under extreme conditions.

2. The estimated thermal impact of the effluent generated by The Units 1,2,3,4 along Dunărea Veche branch

The impact of the heat density produced by the effluent from Cernavodă Nuclear Power Plant (CNPP) is assessed by taking into account the following aspects: the impact of the effluent's temperature increase on the temperature measured into the receiver; influence of the warm water on the physical-chemical processes deployed into the emissary, with effects on the concentration of dissolved oxygen; influence of warm water on some bio-chemical processes, with effects on BOD5, CCO-Mn, nitrates, nitrites and ammonium, total phosphorus; influence on the biocoenosis'elements.

3. The thermal impact of the effluent produced by The Units 3 and 4 along Danube

The warm water flow rate of The Units 3 and 4 is low as compared to the multi-annual monthly flow rates along Dunărea Veche branch. Downstream from the outlet, the vertical mixture is produced and then, the thermal plum is quickly expanded, by decreasing its temperature difference. The water temperature distribution along Dunărea Veche branch, downstream from the effluent's outlet, was estimated by means of a calculus for the determination of characteristic hydrological and weather conditions. For estimating the effluent's thermal effect under specific conditions, monthly values for the water level, flow rates, water temperature and weather parameters have been used, as well as the effluent parameters of The Units 3 and 4. During the winter season, with a mean monthly water temperature under 50C, a re-running flow rate of 50% from the total water flow rate has been considered. The data on the effluent of Unit 1, both during periods with regular hydrological and weather conditions and during extreme conditions seasons provide results on the effluent's thermal influence in the downstream outlet area, under various conditions recorded in 2001, 2003, 2004, 2006. The extreme hydrological conditions were recorded during summer and fall seasons of 2003, when extremely low flow rates have been reached (including the minimum absolute flow rate recorded at Cernavodă Hydrometrical Station). Higher water levels as compared to the mean levels were measured in April and May 2004. Very low water temperature values were noticed in January and February 2004, and increased water and air temperature values were recorded during summer of 2001 and 2003. The results of the water temperature measurements show that the effluent water's mixture process of The Unit 1 with the river water is almost completed from the thermal effect point of view, between km 285-283. The effluent's mixture degree from a unit of Cernavodă Nuclear Power Plant (CNPP) into the Danube water was estimated by comparing the values of the water temperature measured along the branch breadth on many sections.

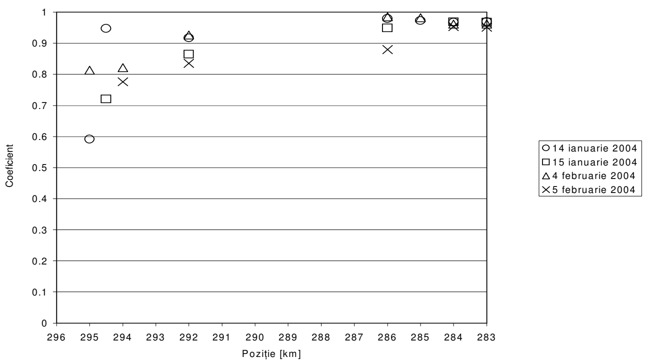

Fig. 1 . The effluent's mixture degree discharged at a unit of CNPP, with Danube water, during warm water re-running

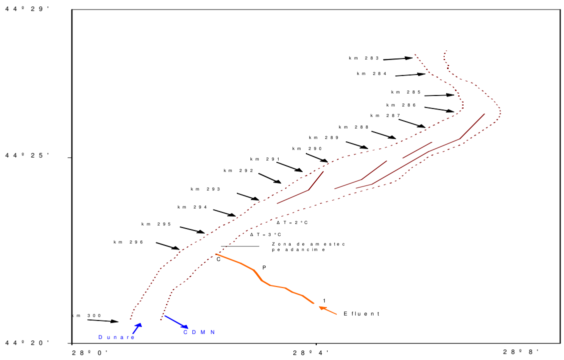

Fig. 2 Computed isotherms due to the effluent discharged from The Units 3 and 4 of CNPP, in February (re-running) under average conditions

The results recorded during all the seasons show that, as a result of the effect of the effluents generated by two units of CNPP, a water temperature increase by 3oC is expected to occur within the initial vertical mixture area and beyond that, in some circumstances, along the right side of the river. A water temperature increase by 20C is produced on the right bank on a distance greater than The Unit 1, but the influenced area is still reduced. This is a small variation as compared to the natural temperature variations recorded on the lower Danube's waterway, each year, each month. In most of the parts of each cross section along Dunărea Veche branch, downstream from this effluent, the natural thermal conditions of Danube water are not altered.

4. The joint thermal impact of the effluent discharged by The Units 1,2,3,4 on Danube river

The physical and chemical parameters of the water discharged by The Units 1,2,3,4 are similar for one unit, the differences coming from the increased effluent's flow rate. The total water flow rate, according to the draft, discharged by The Units 1, 2, 3 and 4 is 216 m3/s, as compared to 108 m3/s, generated by two units of CNPP. During the winter season, with a mean monthly water temperature under 50C, a re-running flow rate of 100 m3/s from the total cooling water flow rate has been considered. The effluent's temperature increase over the temperature of source water is expected to be similar with the one of The Unit 1.

Due to the effluent flow rate (four times higher than the flow rate recorded at one unit of CNPP), the cumulated thermal effect of the effluent discharged by The Units 1, 2, 3, 4 along Dunărea Veche branch is more extended in space, but the temperature from the discharge section is approximately the same as in the case of a single unit. Along the branch, the effluent's influence occurs along a greater distance, due to the value of the effluent's flow rate. Under the existing conditions on Danube, the expected temperature of CNPP's effluent is about 350C, settled by NTPA 001 standard (Government's Decision 352/2005). The fraction from the branch's cross section which is influenced by the effluent with an increase ratio of 30C may be in general up to a quarter, under the conditions of mean monthly flow rates recorded along Danube (flow rate values higher than 1500 m3/s).

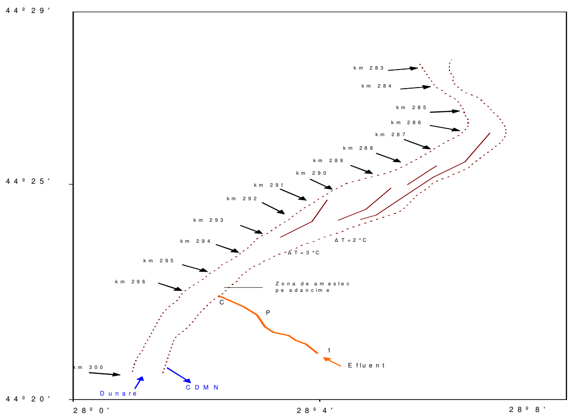

Fig. 3 Computed isotherms due to the effluent discharged by The Units 1,2,3,4 of CNPP, in January (re-running), under mean conditions

5. The estimated thermal impact of the effluent's discharge from The Units 1,2,3,4 in the second pool of Danube-Black Sea Canal (DBSC)

The thermal impact of the effluent from The Units 3 and 4 during its discharge into the second pool of DBSC

Taking into account the heat density of the effluent of each unit, that is similar with the effluent of Unit 1, the result is that the temperature measurements carried out for The Unit 1 and the estimates related to The Unit 1 provide a picture on the separated thermal impact of the effluent generated by Unit 3 and 4 along the second pool of DBSC. The recorded data reflect the conditions occurred in those periods (flow rates supplied from the canal, flow rates discharged into the second pool from Unit 1, supply flow rates of the second pool through The Complex Pumping Station (CPS), lockings, various weather conditions). Two water mixture techniques have been considered under cross sections and heat transfer conditions: intense mixture and high heat transfer (the results are displayed in figures, in the below-written lines) and slow mixture and low heat transfer (the above lines from the figures). The water temperature was measured in many cross sections along DBSC and Poarta Albă-Midia Năvodari Canal (PAMNC) in the absence of the effluent of Unit 1, and after a period of at least 30 days from the discharge initiation of the effluent from Unit 1 into the second pool of DBSC. The second pool of DBSC is usually supplied directly from the first pool, by means of CPS or based on the gravity technique. The flow rate depends on the demands of the water consumers which have the result of total different values in various months (mostly due to the irrigation needs). The warm effluent from CNPP is mixed with this flow rate taken directly from the first pool where the water temperature is practically the one recorded in the Danube water. The effluent from Units 3 and 4 may totally and partly supply the required water amount for the existing consumers along the second pool of DBSC. The water temperature in the upstream section of the second pool is the temperature of CNPP's effluent, or it is even lower, if the effluent is mixed with a flow rate taken directly from the first pool, through CPS.

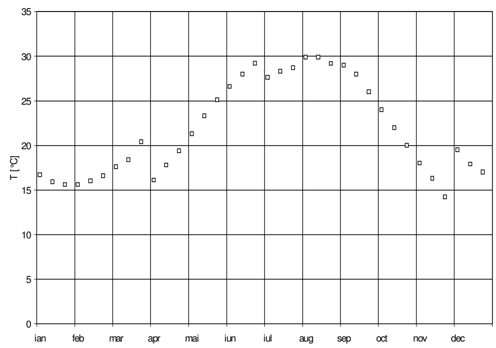

Fig. 4 Computed water temperature in the upstream section of the second pool as a result of the temperature increase into the effluent from The Units 3 and 4 of CNPP (draft water consumption in an average irrigation year)

6. The joint thermal impact of the effluent discharged by The Units 1,2,3,4 during its outlet into the second pool of DBSC

Having a similar temperature as one unit within CNPP, the effluent generated by 4 units leads to a similar water temperature under the upstream section of the second pool of DBSC during the months with no irrigation demands.

During the summer season, the effluent discharged by The Units 1,2,3,4 can cover the water demand for irrigations, without an additional flow rate. The temperature which is generated in the upstream section of the second pool is the effluent's temperature. As compared to the case of two units, the thermal impact along the second pool of the effluent generated by 4 units is given by the higher temperature values measured upstream in some months, and a shorter flowing duration along the second pool of DBSC.

The estimates regarding the thermal impact of the effluent generated by 4 units of CNPP have been carried out by taking into account the effluent's temperature increase by 70C, and a water consumption demand for irrigations in an average year, during the summer season. In case of the winter season, with a mean monthly water temperature under 50C, a re-running flow rate of 100 m3/s from the total cooling water flow rate has been considered.

7. The estimated impact of CNPP on the quality indicators in the Danube water

The effluent of Units 3 and 4 takes its chemical load from the Danube water and it has an increased water temperature as compared to the source. It also contains the waste water from CNPP which was discharged under control. The outlet water from the water treatment station discharged into the warm effluent and further on, into the receiver, does not have a significant impact. The variation of the values of some chemical indicators (such as dissolved oxygen, nitrogen, phosphorus, organic matters) also depends on the variation of the phytoplankton biomass (influenced by the water temperature). The results of the biological tests carried out on the water samples, taken during various seasons, have shown that the total phytoplankton biomass ranged within the specific limits of Danube river, just as the values of the chemical indicators. Therefore, these chemical indicators have not been altered because of the water temperature.

The tests on the chemical indicators did not reveal significant changes of their values along Dunărea Veche branch, due to the effluent from Unit 1. Therefore, it is estimated that the impact of The Units 3 and 4 on the quality indicators of Danube water shall be insignificant.

If the effluent is generated by four units, its temperature variation over the Danube water temperature and its chemical substances loads are expected to be similar with the case of a unit from CNPP. The substances' concentration into the effluent is at the same level as into the Danube water. Only the flow rate shall be four times higher. Therefore, the thermal impact shall occur along a greater distance, but this impact shall be local, along the river's right bank. Based on the results of thermal effect estimates and according to the studies performed along the Danube river, it is expected that the joint impact on the water's quality indicators, discharged by the effluent from The Units 1,2,3 and 4 would not be relevant.

8. The estimated impact of CNPP effluent on the quality indicators from the DBSC'water

The water quality into DBSC and PAMNC is under the effect of the chemical loads carried by the Danube and it is also influenced by the waste water received. The specific situation of water movement generates a long period of water standstill which is important for the physical and chemical processes deployed into the aquatic ecosystem and also for their relation with the biocoenosis'elements. Moreover, as compared to the physical indicators, the relevant chemical indicators for the assessment of the potential effects produced by the CNPP's effluent into the aquatic environment from the second pool of DBSC are the indicators of oxygen, nutrients and dissolved ions.

The effluent discharge from two or more units of CNPP into the second pool shall alter the water flowing status, from a quasi-standing water body to a slow flowing water stream. This change helps the water replacement into DBSC, by reducing for a long period of time the water's standstill time. It is estimated that the increased water flowing would be favorable for the water quality. Based on the above mentioned data concerning the direct impact and according to the estimated thermal effects, it may be expected that the separate impact of the effluent discharged by The Units 3 and 4, would mainly influence the water temperature distribution. It is not expected that the effluent to change the water's quality class regarding the dissolved oxygen or to have a direct significant effect on other quality indicators. Some indirect temporary effects are sometimes likely to occur during the warm season, because of the algae growth.

The joint effect of the effluents from The Units 1,2,3,4 is higher on the water temperature. The values of the dissolved oxygen are expected to be maintained into the second quality class. The chemical substances'concentrations shall be similar, so that no direct effects are expected to be produced on the chemical indicators of water quality. During the warm season, the thermal effect may produce more increased temperature values which would encourage the algae growth and the biochemical reactions from the aquatic environment, which are able to influence some of the water's quality indicators. Therefore, the joint impact of the effluent on the water quality into DBSC is more intense during some periods. However, the effluent generates a more rapid movement and replacement of water into the second pool, with shorter standstill periods which are favorable for the water quality.

9. The influence of the specific chemical substances from CNPP's effluent on the water quality from Danube or DBSC

The hydrazine is used as a reducing agent in order to prevent the corrosion induced by the dissolved oxygen. The hydrazine reacts with the oxygen, resulting nitrogen, and in some conditions, the hydrazine is decomposed, resulting ammonia and nitrogen.

The morpholine is used in order to control pH value in some parts of the cooling system running with de-mineralized water in order to reduce the corrosion effect.

Another substance used under normal operation conditions is the cyclohexylamine.

The chemical tests of the water samples taken from CNPP's effluent, from Danube and DBSC, carried out by ICIM and by CNE PROD (regular tests) within their own monitoring program did not show detectable values for hydrazine, morpholine and cyclohexylamine into the effluent of The Unit 1 or into the receiver's water. Taking into account that the hydrazine dissolved in water may lead to the increase of the ammonia content by means of chemical processes, the ammonium concentration and its equilibrium with ammonia have been studied within the studies performed on Danube river and on DBSC. The results have shown that the ammonium values were in compliance with the regular limits recorded in Danube and DBSC, without noticing an increase due to the possible hydrazine's decay.

Taking into consideration the concentrations of these substances into the effluent from Units 3 and 4, similar with the ones generated by the effluent from Unit 1 and the above mentioned results, it is estimated that the influence of these substances shall be similar, with no effects on the water's quality indicators. The total amount of the substances generated by The Units 1,2,3,4 is much higher, but the concentrations into the effluent are the same because the total flow rate is four times higher. Therefore, the concentrations coming from the receiver shall still be under the detection limits, just as in the case of one unit.

By maintaining the concentration of these substances under the admitted limits and by making a monitoring on them, the compliance with the regulations settled for the surface water protection shall be achieved.

10. The estimated impact of CNPP's effluent on the flora and wild life from Dunărea Veche branch

The impact of CNPP's effluent coming from The Units 1,2,3,4 on the biocoenosis from Dunărea Veche branch is estimated by considering the studies concerning the influence of the effluent from The Unit 1. The phytoplankton and zooplankton bodies from Danube, either upstream or downstream from the effluent's outlet section were recorded with values which are naturally variable, depending on the season conditions. Both inside and outside of the thermal plum, the values of the water sample tests are comparable. A set of similar values with the ones recorded in the upstream of Danube has been also found downstream from the effluent. Therefore, the results of the phytoplankton and zoo-plankton tests carried-out by ICIM do not reveal an influence produced bt the effluent.

It may be estimated that the effluent generated by two units of CNPP does not have a negative impact on the water quality and on the bioconeosis from Dunărea Veche branch.
Taking into acount the estimated impact of CNPP's effluent (after the setting into operation of The Units 3 and 4) on the water temperature and on the physical and chemical indicators of the water quality, as well as the low level of the specific substances into the effluent and by also considering a much more higher Danube's flow rate, it is expected that the effluent influence on the biocoenosis elements would not be significantly different.

11. The estimated impact of CNPP's effluent on the flora and wild life from the second pool of DBSC

The effects on the water quality and biocoenosis produced by the CNPP's effluent outlet from a unit into the second pool of DBSC, within one month, have been studied by ICIM (during spring and fall) in 1999, 2004 and 2005.

For estimating the biological water quality in all the control sections, the correlation of the test results of biota element with the non-biota element was taken into account. Most of the bio-indicator species found into the water of DBSC and PAMNC has belong to the beta-mesosaprobic area, and few species have belong to the alpha-mesosaprobic area. Depending on the values of biological quantitative indicators (such as density and phytoplanktonic biomass), on the presence of bio-indicator species and on the structure of the entire biocoenosis, and biologically speaking, the water from DBSC and PAMNC belong to the beta-mesosaprobic area.

Due to water temperature increase conditions at DBSC intake and due to an extra low flow rate on the canal, and by taking into account the natural nourishing factor available into the second pool, the increase of the water temperature may lead to algae growth. If occur, the large algae structures may lead, throughout time, to consequences on some chemical elements of the biotope (such as high oxygen demand) and on some quality indicators which are important for various purposes (mainly as a source of water treatment for drinking purposes). After returning to normal values of the water temperature (during the fall season), the biocoenosis shall be gradually recovered.

12. The estimated impact of CNPP's effluent on the utilization of Danube water and on the utilization of DBSC water

The surface water from CNPP is used for navigation, industrial water supply, as a water treatment source in order to produce drinking water, as an irrigation source, as well as for commercial and entertaining fishing.

The Danube river is used as a raw water source for drinking water supply of Cernavodă town, the catchment point being in an area located upstream from the effluent's outlet point. The localities which are downstream from Cernavodă are far away, beyond the influence of the thermal plum from the CNPP's effluent. Along Danube, between the outlet section of the effluent from CNPP and Hârşova, there are the water intakes of three irrigation systems. Only Seimeni irrigation system is supplied from an area relatively influenced by the warm water plum. The effluent's impact on the water temperature in that area is quite low and a negative impact of the thermal factor on the irrigated plants is unlikely to occur. The fog's occurrence frequency in Cernavodă area has been analyzed based on the data obtained from the meteorological stations. This phenomenon has been described in the specialized literature, in relation to the main relevant factors, including the temperature of the underlying surface.

As for the area from the proximity of the effluent's outlet into Dunărea Veche branch, an increase by 10% of the annual frequency of the fog phenomenon in the discharge area of the warm water has been estimated, due to one or more units of CNPP. The water temperature increase is produced in a relatively small area, on the right side of the river, so that the influence of the effluent on the fog occurence is not too significant. After setting into operation of The Unit 2 and of The Units 3 and 4, the fog occurence conditions into the effluent's outlet area and its frequency shall be practically the same, but on a longer downstream section. The area from Dunărea Veche subjected to a potential impact is relatively narrow, on the right side, and the effluent effect is low. Within the hydrotechnical system of DBSC, the intake of the water treatment station from PAMNC is far from Cernavodă town, along a slow flowing canal, and the water temperature increase,which is less than in the upstream section of the second pool, shall be reduced by means of the underground cold water.

As for the impact on the water catchment for the irrigation systems operating along the second pool, the long water conveyance distances significantly reduce the impact of the thermal factor on the systems.

It was estimated that the effluent would lead to an annual frequency increase by 10% of the fog (with some season variations) in the upstream end of the second pool. During the stage of effluent outlet from The Units 1,2,3,4 into DBSC, the water temperature increase could produce the fog occurence on a longer downstream section. The effluent's effect on the fog phenomenon is decreased once with the increase of the distance from the warm water's outlet section, in any season.

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