Providing of the cooling water flow rate, necessary for the operation of Cernavodă nuclear power plant

Autors: **Prof. PHD Mihăilescu Neculai – UPB**
PHD Ghindă Theodor – INCDPM-ICIM
PHD Dan Paul – INCDPM-ICIM

1. Main data

Taking into account the completion project of Units 3 and 4 of The Nuclear Power Plant-Cernavodă, the water demand taken from the Danube river shall be increased, so that the presentation of alternative solution for providing extra water flow rates has became necessary.

Dunărea Veche channel is the main drinking water source for significant consumers located along this section and along the pathway of Danube-Black Sea Canal (DBSC). Among these consumers, a relevant weight is represented by Cernavodă nuclear power plant which draws off the water from Dunărea Veche channel through the first pool of DBSC and through the sluice. Other major consumers are the irrigation systems from Cernavodă-Hârşova section, and the ones supplied by the second pool of DBSC, as well as the industrial activities and the population. The navigation is also another main utilization given to these waterways.

DBSC has been dimensioned and built for navigation purposes and for the conveyance of the necessary water flow rates in order to fulfill the maximum water demand of the above mentioned consumers. The issue of Danube's water flow rate catchment has been analyzed based on the data concerning the water flowing rate along Dunărea Veche channel, for that period. Taking into account the flow rate state along Dunărea Veche channel, various hydrotechnical works have been considered (on Dunărea Veche, in the Bala branch area, at the water intake with DBSC, in the first pool of DBSC). The last decades brought an increase tendency of the water flow rates along Bala branch to the prejudice of Dunărea Veche branch, mostly during the seasons with low level and flow rates of Danube. The current situation and which also seems to be maintained in the future, creates shortcomings for the navigation and for the water supply of Cernavodă nuclear power plant and of the other consumers.

2. Danube water flow rates along Cernavodă section, water demand along Dunărea Veche branch and along DBSC.

The location of Cernavodă nuclear power plant is at a relatively short distance (4-5 km) from Danube, on the north side of DBSC, at about 0.5-0.8 km far from the sluice.

From Chiciu-Silistra and Călăraşi area, the Danube river is divided in two branches (see Fig.2.1-1). At 25 km downstream from this diversion, Bala branch makes the connection between Dunărea Veche and Borcea branches. Cernavodă town is located approximately in the middle of Dunărea Veche branch, at about 75 km downstream from Silistra and 62 km upstream from Giurgeni (approximately 50 km upstream from Hârşova). The water intake of DBSC is located even in the upstream area from Cernavodă.

Dunărea Veche branch, located on the eastern side of Ialomiţei moor, is laying between km 373 and 241 km along the Danube. There are proper navigation conditions up to km 346. After the detachment of Bala branch, Dunărea Veche shows a clear atrophy tendency, by slowly decreasing both its cross-section and its depth. The water flow rate alteration in the benefit of Bala branch and continuously, along the lower Borcea branch, is able to reduce the erosion and conveyance power of Dunărea Veche branch. The adobe activity is emphasized by the numerous islands which are in its near surroundings as well as by the sand layers, making up sills which are a major burden for the navigation. The morphometrical elements of the river bed are considerably different along the two sections created by the detachment of Bala branch.

The water demand for the units of Cernavodă nuclear power plant is taken from Dunărea Veche branch, through the pool 1 of DBSC and then, through the diversion channel, toward the basin from
the nuclear power plant's intake point.

The Units 3 and 4 of Cernavodă nuclear power plant which is estimated to be set into operation in 2014 and 2015, shall catch the cooling water and the service water from Dunărea Veche branch of Danube by means of the existing hydrotechnical works, just as the Units 1 and 2. The effluent of Units 3 and 4 shall be also discharged into Danube or into the second pool of DBSC (Fig.1).

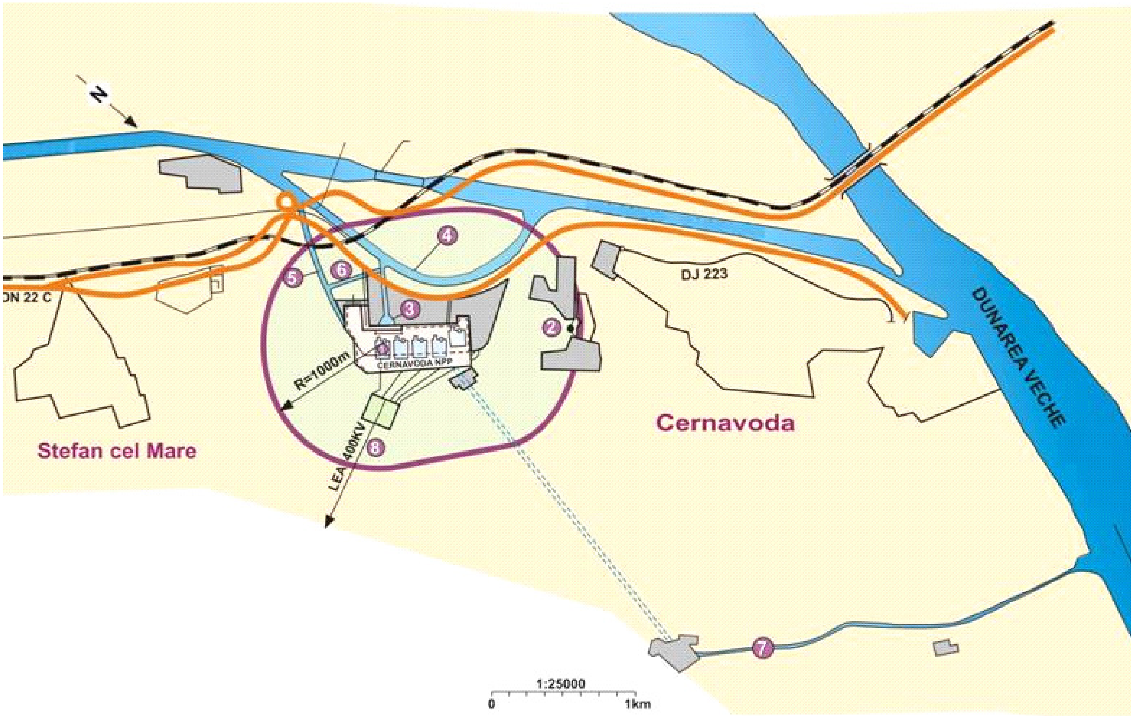

Figure 1. The scheme of cooling water circuit at Cernavodă nuclear power plant-

The multi-annual mean values of the monthly and yearly water flow rates, computed at The Hydrometer Station- Cernavodă during 1961-2002 period are presented in table 1. The values of the minimum annual water flow rates with various exceeding ratios, determined according to the statistical series from 1961-2002 period, are presented in table 2.

Table 1. Monthly and multi-annual mean water flow rates (m^3/s) recorded at The Hydrometer Station- Cernavodă (HSC)

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Module flow rate
Q_{mean}	2300	2340	2810	3620	3540	2970	2380	1720	1470	1490	1670	2170	2370

Table 2. Annual minimum flow rates (m^3/s) with different exceeding probability ratios

p%	90	95	97
$Q_{min.p(\%)}$	355	315	290

The minimum and maximum values of the monthly and annual mean levels determined according to the data measured at HSC are presented in table 3. Figure 2 shows the multiannual water level gauge at HSC and the altered water level gauge, according to the data measured in 2003.

Table 3. The minimum and maximum values of the monthly and annual water level (cm)

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	I - XII
$(H_{med.})_{min.}$	-16	-49	26	74	122	-3	-33	-139	-178	-109	-84	-106	-178
Anul	1964	1989	1993	1972	1990	1993	1993	1990	1990	1961	1969	1986	1990
$(H_{med.})_{max.}$	519	472	572	622	674	657	588	361	374	368	513	428	674
Anul	1982	1979	1977	1981	1970	1970	1965	1965	1966	1972	1974	1974	1970

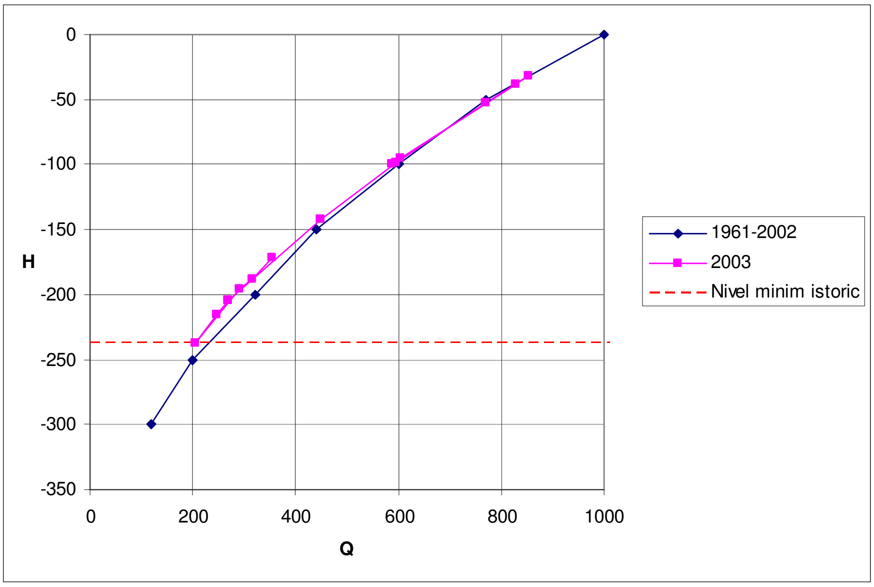

Figure 2. The multiannual water level gauge (1961-2002) at HSC, for shallow water, amended according to the data recorded in 2003

2003 was a special hydrological year, with very shallow water level, the hydrological drought phenomenon being noticed. A very low water level maintained on long periods has been recorded by HSC. The high spring water levels missed, and in October and December, the monthly mean water level have been under the 0 quota of the hydrometer. In September 2003, the lowest level since 1961-2003 period has been recorded. The level measured in 2003 is the lowest level from the entire operational period of the Cernavodă hydrometer (set into operation in 1896). The corresponding water flow rate had a value of 205 m^3/s. This situation led to the shutting down of The Unit 1 from Cernavodă nuclear power plant (CNPP) for about one month.

The continuous operation of the hydro-technical system was planned to be achieved at CNPP. The maximum flow rate for one unit is 53.8 m^3/s, that is a flow rate made from the cooling water of the capacitors (46 m^3/s) and from service water (7.8 m^3/s). The Units 1 and 2 are currently set into operation at CNPP. The maximum water flow rate for two units, under normal operation conditions, at a nominal output, is 107.6 m^3/s. It is foreseen that Units 3 and 4 to be set into operation in 2014 and 2015. The maximum flow rate processed by the four units, under normal operational conditions, at a nominal output, is 215.2 m^3/s. In case of the cooling of two units, when the nuclear power plant is shut-down, a water flow rate of about 14 m^3/s is required. In case of the cooling of four units, when the nuclear power plant is shut-down, a water flow rate of about 28 m^3/s is required. During the cold season, a water flow rate fraction is re-circulated into the distribution tank of the nuclear power plant. Accordingly, the water flow rate caught from Danube is lower. If the combined rotation cooling technique (water-cooling towers) would be selected for one or more units within CNPP, the water demand for this kind of equipment shall be decreased by the value of the cooling and re-circulated water flow rate.

The water demand for the irrigation systems which are supplied from Danube via the Danube-Black Sea Canal may reach values of about 148 m^3/s in an average year and about 189 m^3/s in a draught season.

The main water consumers for industrial purposes and for treatment meant for drinking water supply are Rompetrol Refining - Petromidia company with a maximum flow rate of 2.5 m^3/s, RAJA Constanța, with a mean drinkability flow rate of 3.5 m^3/s and Fertilchim Năvodari with a mean flow rate of 2.5 m^3/s.

The balance of the water flow rates into Cernavodă section must also take into consideration the values of the flow rates which can be caught from Danube at the DBSC intake. These values depend on the levels and on the flow rates from Dunărea Veche branch along Cernavodă section. In case of very shallow water, with flow rates under 300-400 m^3/s along Dunărea Veche branch, it is clear the difficulty to supply the flow rates needed for the above mentioned consumers.

3. Solutions and options for meeting the water demand of CNPP

The variations of Danube level at the canal's intake point are high, with values recorded along a range of over 9 metres. These level values are spread toward the first pool and along the diversion channel. Therefore, the water drawing off with variable flow rates, depending on the users'demands, is carried out under various water levels. In case of a low water level along Dunărea Veche branch, the catchment capacity of the canal's intake is decreased. The water flow rate demand, currently considered, shall be provided at a greater extent by means of some works which are proposed to be performed along Bala and Dunărea Veche branches. This kind of works have been reviewed and studied under many stages.

The flow rates in Cernavodă section depend on the total Danube's flow rate, as well as on its distribution along Dunărea Veche and Borcea branches. According to the available data, the result is that, in the event of high flow rates, the distribution along branches is more balanced than in case of the low flow rates (Fig.3), which means that Dunărea Veche branch is disfavoured. The current trend, of increasing the flow rates toward Borcea branch, to the prejudice of Dunărea Veche, is due to the configuration of the Danube'd river bed in Bala area and to the flowing conditions along Dunărea Veche, with many secondary branches.

The hydrological data from 1965-1982 shows a flow rate's decrease tendency along Dunărea Veche. The mean flow rate which was considered at Cernavodă when designing DBSC was 2600 m^3/s, and during 1961-2000 period, it was 2390 m^3/s. The works which have been commenced at Bala in order to balance the flow rate's distribution have been interrupted and the evolution of this situation was not positive.

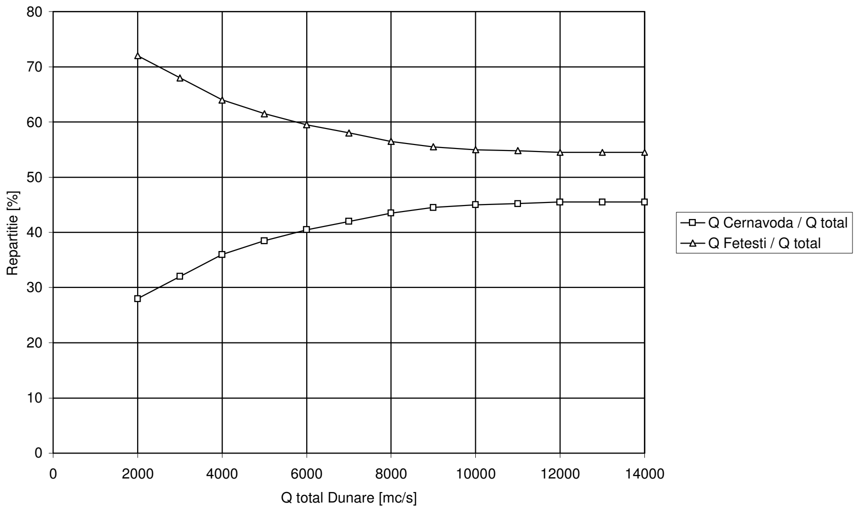

Figure 3. Estimates of flow rate's distribution along Dunărea Veche and Borcea branches.

For solving the problems related to the catchment of Danube's flow rates inside DBSC for various utilizations, hydro-technical works were proposed for performance on Danube and in the first pool of the canal. A breakdown threshold and a training wall were designed along Bala branch, as well as rock blasting works at Pârjoaia rock.

Based on the performance drafts, the works from Gura Bala area have been partly executed: the embankments of Turcescu island, the closure and training walls (80 % completed), bottom sill (about 10% performed). Because of the works non-completion, the hydro-morphological effects from Gura Bala area have been amplified, resulting an increase of the shallow water toward this branch, to the prejudice of Dunărea Veche branch, and a major deepening of the river bed, downstream from the bottom sill. The local alteration works of the section within the first pool of DBSC have not been initiated, but dredging works have been performed so far.

Within the project entitled „The technical assistance for the improvement of navigation conditions along the Danube- Improvement of navigation conditions along Danube between Călăraşi and Brăila section(km 375-170) and additional measures" (EUROPEAID/114893/D/SV/RO), the state of Danube was studied in 2005 and hydro-technical work versions were assessed for this Danube section. The project's goal is that the works carried out on the river bed to be only the strictly necessary ones so that the impact on the aquatic ecosystem to be as low as possible.

The project proposes the reconstruction and completion of the works from the entrance point on Bala branch, so that the flow rates distribution between Danube and Bala to return to a more convenient situation. This is the most significant element of the project consisting of the construction of a training wall, of a bottom sill and of the related embankments, so that the local increase of the flow rates to not affect the nearby lands and to not jeopardize the works, as a whole.

The estimated duration for the performance of the hydrotechnical works is no more than three years. It is expected therefore that their effects to be generated before the completion of Units 3 and 4 of CNPP.

According to the calculus made by the designer, by using sections of Danube's river bed which were measured in 2005, the water level along Cernavodă section will increase with about 130 cm in case of low Danube's flow rates (2000 m^3/s in Silistra section).

In case of mean flow rates, the water level in Cernavodă section will increase with about 30 cm, and the water level increase in case of very high flow rates will be less than 5 cm.

As a result of the above-mentioned hydrotechnical works, the flow rates along Dunărea Veche branch, downstream from Bala will be considerably increased during Danube's shallow water season.

It is estimated that the water flow rate along Dunărea Veche, downstream from Bala (and also at Cernavodă) would be over 800 m^3/s, at a total Danube's flow rate of 2000 m^3/s in Silistra section, that is over 40% from the flow rate measured in Silistra area. It is expected that in case of total flow rates which are lower at Silistra, the ratio will be higher because of the bottom sill along Bala branch. It is also expected that the minimum flow rate along Dunărea Veche branch at Cernavodă to be at least 700 m^3/s, even in case of shallow water of Danube, similar with the level from 2003 (with a minimum flow rate of about 1800 m^3/s in Silistra section). In case of medium water level, a less flow rate increase along Cernavodă section would be produced. As for the high and very high water level of Danube, the flow rate increase on Dunărea Veche section, at Cernavodă, will have an insignificant effect on the maximum water level.

4. Water catchment and conveyance along DBSC

The water's flowing conditions in the area of DBSC intake point produce significant alterations of the river bed and of the flowing section throughout the time. The keeping of proper conditions in that area requires periodical maintenance works. These mainly consists of dredging works carried out on the Danube's navigation channel and toward DBSC.

The local alluvial deposits are monitored in the intake point of DBSC and they are also adjusted by means of dredging works in order to maintain the navigation conditions along Dunărea Veche and at DBSC intake. In fact, the alongshore drift has been considerably reduced because of various works which were performed in the Danube basin, but the alluvial deposition process into the river bed and into the first pool of DBSC did not stop because of the configuration of the water streams. Since the setting into operation of Danube-Black Sea Canal and by now, at the junction point of the canal with Danube and in the first pool of the canal, significant alluvial depositions have been accumulated. Based on the topo-hydrographical surveys carried out in October 2002, the depositions amount has been assessed, which was at the end of that year in amount of roughly 1.300 thousand m^3, out of which, 679 thousand m^3 into the Danube's river bed (between the canal's intake and the Danube's navigation channel), 457 thousand m^3 along the navigation channel (first pool) and 164 thousand m^3 along the diversion channel. In the junction point of DBSC with Danube, the alluvial deppositions were in amount of 1.5-4.5 m, much more higher than the depositions admitted by The Operation and Maintenance Regulation of the Canal. As a result, dredging works have been performed both at the DBSC intake and in the first pool, and in the diversion channel. This kind of dredging works shall also be necessary in the future.

Previous to the period designed for the performance of the above mentioned works in Bala section, the water supply conditions of DBSC during shallow water season of Danube can be improved by means of local works carried out at DBSC intake and in its first pool.

The dredging works performed along these sections have been already done in some periods, resulting the improvement of the catchment capacity during shallow water seasons of Danube. These works do not have an impact on the flow rate distribution between Borcea and Dunărea Veche branches.

5. Conclusions

The outcome of the pilot studies and of the hydraulic calculus made possible the indication of the gauges of the flow rates which can be caught depending on the Danube's water level at

Cernavodă. These results have emphasized the values of the catchment coefficient at DBSC intake, ranging from 0.25 to 0.31, in case of the shallow water level of Danube. These values can be reached if the level and flow rate conditions are met along Dunărea Veche according to the data considered when the study was drawn up. For instance, in case of a flow rate of 270 m^3/s, a flow rate of over 1000 m^3/s is necessary to be recorded along Dunărea Veche, and a level of at least 3.50 mMB, and for a caught flow rate of 400 m^3/s, a flow rate higher than 1200 m^3/s is required on Dunărea Veche and a level higher than 4.50 mMB (Hydraulic studies on the providing of navigation conditions on Danube, between Călăraşi-Cernavodă-Galați sections, ICIM 1992).

Taking into account the flow rate values with an exceeding probability of 90%, 95% and 97%, respectively, 355 m^3/s, 315 m^3/s and 290 m^3/s, the result is that the flow rates necessary for the 4 units represent 46-56% from the flow rate recorded on Dunărea Veche branch, much higher than the above mentioned catchment coefficient.

It is found therefore, that the flow rate which can be caught at DBSC intake, is only a small fraction from the flow rate measured on Dunărea Veche branch, so that, without performing hydrotechnical works in Bala section, the intake is under-supplied in case of shallow water, in relation to the total flow rate required, including for the simultaneous operation of 4 units of Cernavodă nuclear power plant.

Under the current cross-sections of the first pool, an increased water level would be necessary (as compared to the draft specifications) on Danube at DBSC intake, in order to take the flow rate required for the running of CNPP with four operational units. The level differences are presented in figure 4. Both for the period previous to the performance of hydrotechnical works at Bala and after their completion, it is important that the sections from the first pool of DBSC to be adjusted to the values considered during the layout stage.

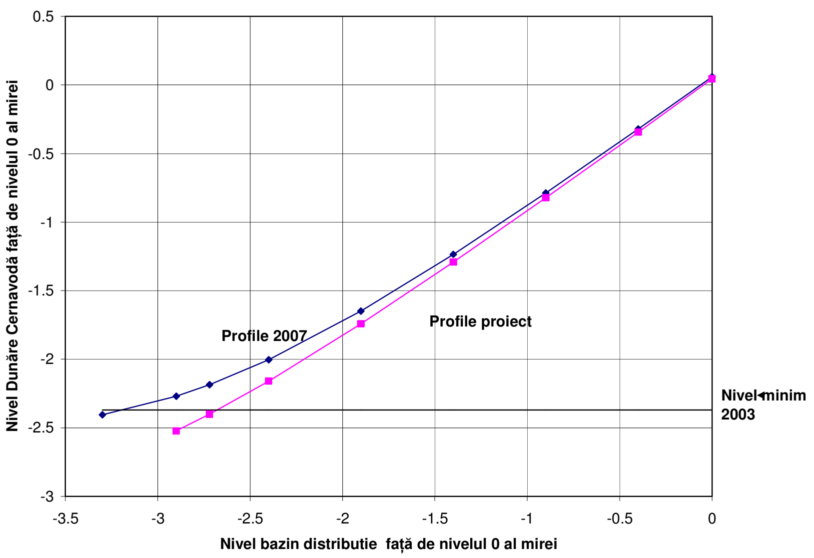

Figure 4. Correlation of the water level at The Hydrometer Station-Cernavodă with the levels reached in the distribution tank of CNPP.

The holder of the completion project of Units 3 and 4 from CNPP has also reviewed the technique of combined rotation cooling. Some cooling towers have been designed for one of the units of CNPP.

The cooling towers shall be used only in some periods of time, mostly during the minimum flow rates recorded on Danube. Their impact will not be continuous and it will be reduced by the project's solutions and by means of the operation techniques.

According to the combined rotation cooling technique, the flow rate necessary for CNPP is decreased with about 53 m^3/s.

References:

- **ICIM, 2007.** *Studiu privind asigurarea cerinței de apă în secțiunea Cernavodă în condițiile realizării grupurilor 3 şi 4 de la CNE Cernavodă.*
- **ICIM, 2007.** *Raport la studiul de evaluare a impactului asupra mediului pentru CNE Cernavodă Unitățile 3 şi 4.*
- **ICIM, 2006.** *Raport la studiul de evaluare a impactului asupra mediului pentru proiectul „Asistență tehnică pentru îmbunătățirea condițiilor de navigație pe Dunăre, Măsura 1: Îmbunătățirea condițiilor de navigație pe Dunăre între Călăraşi şi Brăila (km 375 - km 170) şi măsuri complementare.*
- **INHGA, 2004.** *Studiu hidrologic pe fluviul Dunărea, în zona Cernavodă - Hârşova.*
- **INHGA, 2003.** *Studiu hidrologic pe Dunăre în zona Cernavodă - Hârşova.*