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THE EFFECTS OF VANDELLOS II COOLING WATER DISCHARGES

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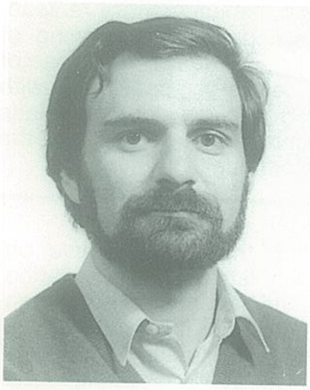

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INTRODUCTION

The main objetive of this paper is to show the effectiveness of carefully selected mathematical models for predicting and analysing the consequences of the discharges of a cooling water system. Such models are applied here to the cooling water system of Vandellós 2 Nuclear power plant. Cooling water from this plant is discharged via a coastal structure into the Gulf of Saint George in the Mediterranean Sea. The intake structure is located near a line perpendicular to the coastline at the discharge point and some 300m offshore. The present paper studies the behaviour of those discharges and discusses briefly their effects on the cooling water intake.
The technical approach adopted for applying numerical models led to the consideration of a series of domains within the receiving water. Such domains were selected in a way which was consistent with the specific physical mechanisms expected to exert dominant influences. This point, which is of major importance, will be underlined again later. Initially, three such domains were considered. However, the calculations indicated later that only two of these domains were relevant in the study. Consequently, the third domain was not studied, nor was the corresponding mathematical model utilized.
A total of fourteen scenarios were investigated, seven corresponding to summer conditions and seven representing winter conditions of operation. Each scenario was characterized by a given combination of environmental pa-

rameters and operating conditions. The values of the parameters were systematically varied to investigate the sensitivity of the predicted results.
The calculations made it possible to reach conclusions about the design and operation of the discharge concept. The analysis included the thermal effects of the cooling water discharges, as well as the transport and dispersion of contaminants potentially carried by the discharged water.

THE PROBLEM CONSIDERED

The Vandellós 2 NPP cooling water is discharged through a single outfall structure. The channel has a rectangular cross-section and is located on the coastline, as modified by the plant construction. These modifications laterally restrict the movement of the discharged waters on one side of the structure. The cooling water levels in the discharge channel and outfall structure depend both on plant operating conditions and seasonal thermal variations of the coastal waters.
The primary objective of application of the models was to predict the velocity and temperature fields resulting in the coastal waters as a consequence of the cooling discharges. Other objectives included the investigacion of the effect on the previous fields of variations, in the operating and environmental conditions, the influence of the discharges on intake water temperatures, the possibility of interaction between the discharges from the two nuclear plants at the site and the dispersion of contaminants, in order to allow a study of their effect on the environment. Finally, recommendations were prepared relative to the conceptual design of the outfall structure.

SELECTED TECHNICAL APPROACH

There are numerous mathematical models in the technical literature which allow analyzing the behaviour of a cooling water system. In a very useful study, Policastro and his coworkers (1979) presented and evaluated the capabilities of the various models. After careful consideration of these capabilities in relation to the actual conditions of application of the models in the present study, the set of models described below was finally selected.
In the "very-near field" (metres or tens of metres from the outfall structure), the discharge momentum governs the convective turbulent mechanisms which affect the velocity and temperature distributions (see Vreugdenhil and Voogt, 1975). As a result for this domain, model PM-ADEPT-2D was implemented.
Beyond that domain, in the region which extends up to several hundred metres from the outfall structure, the momentum and mixing rate of the discharge decrease by the action of ambient currents and their associated turbulence. Furthermore, vertical variations in buoyancy forces caused by density differences tend to reduce the local turbulence intensity in the neighbourhood of the discharge. Such phenomena have an influence on the mixing and entrainment rates. The resulting temperature changes heavily depend on the local turbulence and, consequently, on the distance to the shoreline. Heat losses through the exposed surface of the effluent also have an important influence on the plume temperature (Jirka *et al.* 1975; Ryan *et al.,* 1974). The flow and heat transfer mechanisms are therefore closely linked in this domain and the model must take such coupling into account. For these reasons, the model selected for analysis in this region was the model developed by Prych (1972) in the version modified and extended by Dames and Moore (1977). The model requires that the depth exceed a certain minimum value, so that the plume remains separated from the bottom, a requirement that is fulfilled in the present case. This second domain is called here the "near-field domain".
The third region to consider extends farther than the previous ones and covers a region of several square kilometres, a region that is termed here the "far-field domain". The natural movements of the coastal waters exert the dominant influences in this domain. Such movements govern the velocity at which the discharged mass in transported by ambient currents once its initial momentum is lost. During this process, mixing with ambient waters is virtually arrested and, therefore, dissolution no longer plays a dominant role in determining temperature changes. Nevertheless, the plume continues giving up heat to the atmosphere. For this reason, a model based on a shallow-water formulation (Dronkers, 1979; Leendertse *et al.,* 1973) called PM-ADEPT-SW was selected for application in the far-field. In practice, the model was never utilized, as temperature reductions in the near-field were sufficiently large as to make the far-field analysis unnecessary.

STRATEGY FOR APPLICATION OF THE MODELS

The strategy for applying the models in order to evaluate the cooling system included the following six steps:

– Compiling information about the cooling system characteristics, the plant operating parameters and the oceanographic and meteorological conditions. Table I presents the set of parameters used in application of the models. Such parameters included:

- Geometrical parameters, such as the shape and orientation of the outfall structure, as well as the local bathymetry.
- Discharge parameters, such as flow-rates, thermal jumps and densities.
- Oceanographic parameters, such as ambient water temperatures and speed and direction of the currents.
- Atmospheric parameters, such as air temperature, wind direction and speed, relative humidity, etc.

– Deciding on a series of scenarios, represented by the corresponding sets of parameters, for eventual processing. Seven such scenarios were selected for more thorough analysis for each of the seasonal extremes, that is summer and winter. Tables II and III identify both these scenarios.

– Constructing a mesh for modelling the very-near field and applying PM-ADEPT-2D for predicting the turbulent

T I
DISCHARGE PARAMETERS

PARAMETER	WINTER	SUMMER
Flow-rate (m^3/sec)	40	53
Width of the discharge channel (m)	15.7	15.7
Height of the discharge channel (m)	4	4
Water level in the discharge channel (m)	1.50 to 2.55	1.47 to 2.42
Discharge velocity (m/sec)	1.0 to 1.7	1.4 to 2.3
Thermal jump (°C)	11.9	8.9

T II
SUMMER CONDITIONS ANALYZED

PARAMETER	CASES						
	S1	S2	S3	S4	S5	S6	S7
Flow-rate (m^3/sec)	53	53	53	53	53	53	53
Thermal jump (°C)	8.9	8.9	8.9	8.9	8.9	8.9	8.9
Discharge velocity (m/sec)	2.3	2.3	2.3	2.3	2.3	2.3	1.4
Current velocity (m/sec)	0.10	0.0	0.25	0.10	0.10	0.10	0.10
Current direction	SW	SW	SW	SW	SW	SW	SW
Depth at the discharge point (m)	4	4	4	3	2	4	4
Heat transfer coefficient	L	L	L	L	L	M	L

L: low; M: medium; H: high

T III
WINTER CONDITIONS ANALYZED

PARAMETER	CASES						
	W1	W2	W3	W4	W5	W6	W7
Flow-rate (m^3/sec)	40	40	40	40	40	40	40
Thermal jump (°C)	11.9	11.9	11.9	11.9	11.9	11.9	11.9
Discharge velocity (m/sec)	1.0	1.0	1.0	1.0	1.0	1.0	1.7
Current velocity (m/sec)	0.25	0.00	0.10	0.25	0.25	0.25	0.25
Current direction	SW	SW	SW	SW	SW	SW	SW
Depth at the discharge point (m)	4	4	4	3	2	4	4
Heat transfer coefficient	M	M	M	M	M	H	M

L: low; M: medium; H: high

transient flow and the heat transfer associated to the cooling discharges. The results obtained from this model have clear implications in implementation of the near-field model.

– Selecting a space discretization interval adequate for near-field analysis of all the scnarios of interest. Applying the modified Prych model to each of these scenarios and representing the results obtained.

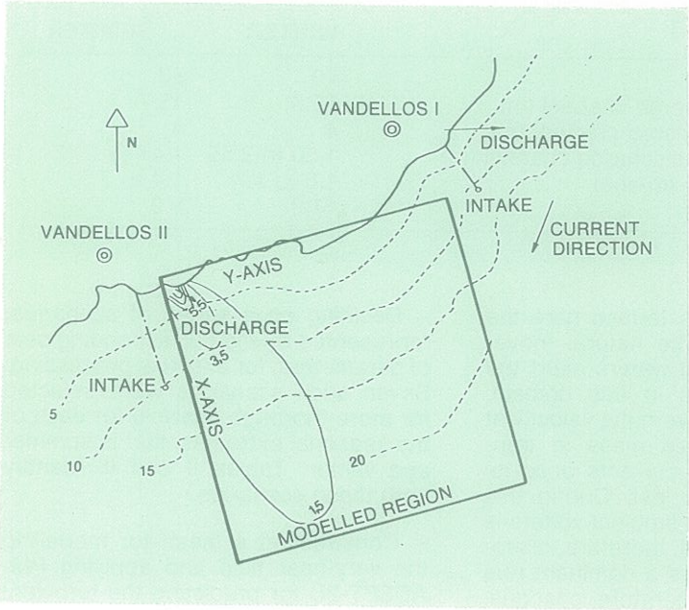
– Interpreting the near-field results in order to establish the possible need for a farfield model. In case the latter is unnecessary, directly employing the results to evaluate the effectiveness of the cooling system design under the conditions investigated.

– Proposing conclusions and recommendations based on the application of the models.

RESULTS

The results obtained with the very-near field model were very instructive in several respects. Firstly, the analyses indicated that the plume reaches an essentially stationary regime over a relatively short time period following any change in the discharge parameters. This period is generally on the order of two hours, after which all transient effects practically disappear. Second, the same analyses showed that for all modelled discharge conditions, the plume comes into contact with the seabottom if the depth of the receiving water is less than 3.5m. In this case, mixing across the lower surface of the plume is no longer possible and the tempera-

F I *Surface isotherms (case W1)*



F II *Surface isotherms (case W4)*