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Nuclear Power Plant Cooling Tower Steam Emission Environmental Impact

Marija Zlata Božnar, Primož Mlakar, Boštjan Grašič
MEIS d.o.o.
Mali Vrh pri Šmarju 78
1293 Šmarje-Sap, Slovenia
marija.zlata.boznar@meis.si; primoz.mlakar@meis.si; bostjan.grasic@meis.si

Luka Štrubelj, Klemen Debelak
GEN energija d.o.o.
Vrbina 17
8270, Krško, Slovenia
Luka.strubelj@gen-energija.si; klemen.debelak@gen-energija.si

Gianni Tinarelli, Daniela Barbero, Elisa Specchia
Arianet s.r.l.
Via Benigno Crespi 57
20159 Milano, Italija
g.tinarelli@aria-net.it; d.barbero@aria-net.it; e.specchia@aria-net.it

ABSTRACT

GEN energija is planning to build a new nuclear power plant in Slovenia. Due to limited heat sink capabilities of the Sava River cooling with wet cooling towers will have to be applied. A study [1] was made in order to determine the environmental impact of the steam (plume) from cooling towers to the nearby and wider surroundings. The thermal power of analysed reactor was 3500 MW, electrical power of turbine was 1200 MW and the thermal power rejected into environment by cooling tower was 2300 MW. The analysed cooling tower was 175 m high with 72 m diameter. The steam plume spread was numerically simulated for every day in 2 years of real weather conditions. When air is oversaturated, the steam is visible as fog and can have an effect to environment. The timing, amount and duration of visible plume was analysed. The shadow from the plume and the plume height were calculated. Other effect such as increase in air humidity and effect to agriculture were addressed. The simulation showed that the environmental impact is only minor and is noticeable only in the vicinity of the cooling tower. Some effects are beneficial to environment such as increased mixing of the atmosphere and reduced fog at the ground; reduced frost at the ground; and reduced vaporization of water from the soil.

1 INTRODUCTION

Nuclear energy is a key component in Slovenia's way in transition to carbon free electrical energy production. In this regard the construction of a new build nuclear power plant JEK2 is one of the most crucial projects of GEN Group. JEK2 location is upstream of the Krško Nuclear Power Plant. The presented study represents an important analysis for the integration of the new power plant into the environment.

JEK2 is expected to have one large natural draft cooling tower to dissipate heat from the condenser during normal operation. The cooling tower will be different, larger, taller and much more powerful than the existing cooling towers at the Krško Nuclear Power Plant, which only discharge part of the heat, as most of it is discharged into the Sava through cooling. The new cooling tower will be comparable to the cooling tower of Block 6 of the Šoštanj Power Plant.

The aim of this project task was the numerical analysis of the impacts of the JEK2 cooling tower discharges on the surrounding area.

A cooling tower releases water vapor into the atmosphere. This water vapour is a colourless transparent gas, but under certain conditions of the external atmosphere it is visible as a white cloud. Water vapor emanating from cooling towers can cause a visible cloud when condensate. Condensation occurs when the total humidity exceeds the amount of moisture that represents 100% relative humidity. The warmer and drier the outside air, the less likely the water vapor cloud will be visible.

The aim of the task was to numerically calculate the visibility of the cloud. According to the location of the visible cloud recorded in 3D space, we also calculated the position of its shadow on the ground. We also calculated the area under the cloud. Regardless of visibility, we also recalculated the proportion of added water vapor in the atmosphere for the layer near the ground.

Shade is important because it reduces direct solar radiation, which affects plant growth. The shade can be annoying to live under, if there is too much throughout the year, but it is desirable in the summer heat. On spring mornings, however, a cloud over the location is very welcome because it reduces the cooling of the ground and thus helps prevent frost.

2 ANALYSES

By evaporating water, we add water vapor to the atmosphere, which is transported and diluted in the same way that flue gases would be diluted. Therefore, we calculated the relative contributions of water vapor for all computational cells. If the atmospheric humidity were to be noticeably increased, this could affect the development of those plant diseases that flourish in a more humid atmosphere.

MEIS d.o.o. in cooperation with the Italian partner Arianet s.r.l. set up a numerical modelling system that performed the following functions:

• calculation of the meteorological forecast for the considered area of 25 km x 25 km in fine spatial and temporal resolution,

• calculation of dispersion of water vapor from cooling towers into the surrounding atmosphere,

• calculation of water vapor cloud visibility (partner Arianet),

• analysis of the occurrence of the shadow of a visible cloud, the area under the cloud and the relative contribution of water vapor.

The numerical calculations for the output emission parameters of the cooling tower were prepared by GEN energija [2].

We made a meteorological forecast using the WRF (Weather Research and Forecasting) numerical model [3], which we extensively validated in our past research projects with SODAR (Sound Detection and Ranging) and RASS (Radio Acoustic Sounding System) measurements and ground meteorological measurements in Slovenia (Šoštanj, Trbovlje, Krško). We had to use the meteorological forecast because there are no relative humidity measurements available for the profile in the atmosphere, which is a key piece of information for our calculations.

We calculated the dispersion of water vapor in the surrounding atmosphere using the SPRAY model [4] (manufactured by Arianet), which we extensively validated in our past research projects on the data of the dedicated measurement campaign of the tracer experiment in Šoštanj.

For all other analyses, we used MEIS' own:

• research database for spatial data,

• tools for special statistical analysis and

• tools for dedicated displays of performed analyses.

We made the basic calculations for two consecutive calendar years 2020 and 2021 in half-hour increments. We used a modelling system that divided the space above the 25 km x 25 km domain centered at the JEK2 location (Figure 1) into 500 x 500 cells in the horizontal plane (a cell measures 50 m x 50 m horizontally) and into 51 layers in height. We displayed the processed results twice, first for the entire domain, and then for a section of 5 km x 5 km in the vicinity of JEK2.

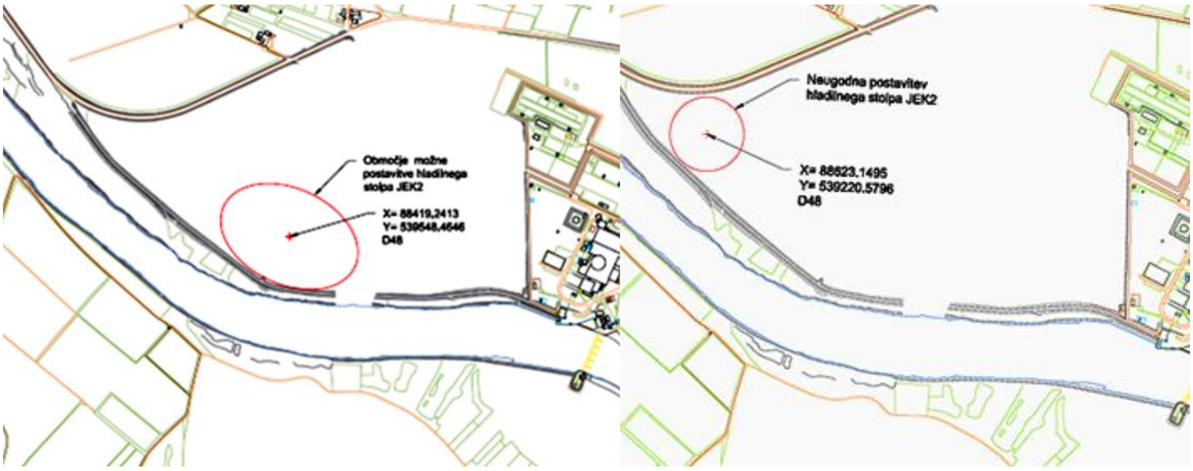

Figure 1: Location of the cooling tower (left Basic and right alternative)

The analyses carried out show that the impact of cooling towers is perceived to be relatively short-term according to all the discussed criteria. In some cases, it is even beneficial (against frost and against overheating of solar cells for electricity production).

The most shade due to steam from cooling tower is near the cooling tower only. The location with the most shade had cumulative shade for 18 days of the bright part of the day (during night there is no shade).

We did not detect significant negative impacts on agriculture, especially not in the form of a noticeable increase in air humidity near the ground, which would be important for the development of certain plant diseases.

The differences in results between two years with different meteorological conditions for the same variant of the cooling tower are greater than the differences between different heights and different locations of the cooling tower that we considered. (We considered four combinations, two locations and two heights). This means that, in terms of the considered impacts on the surroundings, there are no significant differences between the selected locations and the different heights that we have considered.

In all variants, calculations were performed only for the influence from cooling towers. We did not consider other favourable or unfavourable natural or anthropogenic-like influences (for example, the shadow of a cooling tower building or the shadow of other sources of steam or hills).

We analysed the results for the effects on ground surfaces because people live there, grow agricultural and other plants and produce electricity with solar cells, which in our opinion are the most important processes affected by the visible cloud of water vapor.

The results of the analyses can generally be divided into several major sections:

- area under a cloud of visible water vapor,
- shadow of the visible vapor cloud,
- relative proportion of water vapor added,
- vertical rise of water vapor.

2.1 The area under the visible water vapor cloud

The first data processing we carried out gives an answer to when and how many times an individual ground cell (a cell is a plot of size 50 m x 50 m, in an orthogonal grid, this division is made possible by the modelling system) is located under the visible part of the cloud. Whether the plot is under a cloud is important both during the day and at night.

If the ground plot is under a visible cloud, this is beneficial for preventing spring frost, because the water vapor cloud acts as a greenhouse. An additional analysis follows.

In plots directly adjacent to the cooling tower, the worst-case location is under cloud 53% of the time. However, as soon as we move a little away from the location of the cooling tower this proportion drops significantly. Values of the counter of half-hour values above 3000 (which amounts to 62.5 days) occur only within a radius of 1 km from the location of the future reactor.

The highest value of the number of half-hourly intervals under the visible cloud occurred for the variant of the cooling tower with base height at the alternative location (Figure 1 - Right). This value amounted to 9337 half-hourly intervals, or approximately 194 full days, or 53% of all time in 2021. This occurred on the plot directly next to the cooling tower.

The maximum area of the cloud floor plan on 25 km x 25 km analysed domain

The analysis was made for the basic location and basic height of the cooling tower. We also calculated the maximum area of the cloud floor plan for each considered year. The largest area under the cloud in the area of 25 km x 25 km in 2020 is 13.7 km^2.The largest area under the cloud in the area of 25 km x 25 km in 2021 is 16.9 km^2.

2.2 Statistical processing of the cloud shadow area

We calculated how many hours an individual ground plot is located in the shadow of a visible cloud of water vapor. Shade means that there will be less direct sunlight, and scattered diffused sunlight remains or even increases. If a plot of land is in cloud shadow, it is:

• favourable for less drying of the soil on a hot sunny summer day

• and less favourable for growth in agricultural plants and

• mostly less favourable for harvesting electricity from solar panels (except on hot sunny days when it reduces cells temperature and is therefore helpful).

In the plots directly adjacent to the cooling tower, the worst-case location is in the shadow of the cloud at 447 half-hour intervals. However, as soon as we move a little away from the location of the cooling tower this proportion drops significantly.

The largest area of cloud shadow area around noon in an area of 25 km x 25 km

The analysis was made for the basic location and basic height of the cooling tower. We specifically analysed the largest area of the surface in the shadow of the visible water vapor cloud around noon in an area of 25 km x 25 km. We assume that the cloud most visibly disturbs us when the sun is at its zenith (around noon). The largest area in the cloud shadow around noon (from 11:30 a.m. to 12:30 p.m.) in an area of 25 km x 25 km in 2020 amounts to 7.1 km^2. The largest area in the shadow of the cloud around noon (from 11:30 to 12:30) in the area of 25 km x 25 km in 2021 is 10.5 km^2.

2.3 Relative proportion of added moisture in a 25 km x 25 km area

Next, we performed processing of what is the relative proportion of added moisture in the air to each floor plot. We defined the ratio - share - as a fraction of added technical versus basic natural mass of water vapor. This analysis only considers results in the ground layer. If there is a significantly increased amount of water vapor in the air above the ground plot due to the cloud from the cooling towers, it may help to develop diseases in vineyards and orchards that occur with high air humidity. Therefore, in the presentation of the results, we have shown the 99th percentile share for each floor plot separately. The 99th percentile is chosen, because the maximum value is always conditioned by the maximum modelling error (all dispersion models have some error) and therefore the 99th percentile is a more realistic indicator of what is happening. We have shown the 99th percentile relative share for:

- basic time series for each floor plot for half-hourly data,
- and then for a 72-hour moving average.

The significance of the 72-hour (three-day) moving average is that a three-day wetter atmosphere is more important for the development of plant diseases than a mere half-hourly increased value.

The highest 99th percentile of the calculated fraction in the air at the ground is 0.21% for the half-hourly data and 0.094% for the 72-hour averages, both of which are practically negligible. The highest value for the half-hourly data occurred for the cooling tower variant with a base height at an alternative location in 2020 east of the cooling tower location at a distance of 11.2 km from the planned JEK2 cooling tower. The highest value for the 72-hour averages occurred for the variant of the cooling tower with a base height at an alternative location in 2020 south-west of the location of the cooling tower at a distance of 10.5 km from the future reactor.

The differences between the results for the basic and elevated height and the basic and alternative location are, even with this processing, in the order of magnitude of the differences that occur between the first and second year under consideration due to meteorological differences, and are therefore not typical.

2.4 Area of cloud ground plan on region 25 km x 25 km

The analysis was made for the basic location and basic height of the cooling tower. We made an analysis of the total area under the cloud for every half hour in the two years in question, which is a measure of the area of the cloud's floor plan. We calculated for both considered years for daytime and nighttime. The largest area is 16.9 km^2. The entire area under consideration is 25 km x 25 km, which is 625 km^2. Therefore, the maximum floor plan is 2.7% of the total area under consideration. The analyses clearly show that the large area of the ground plan is mainly in the evening, night and early morning hours. This is when the visible cloud will be the least disturbing.

2.5 A cloud shadow area in a 25 km x 25 km area

The analysis was made for the basic location and basic height of the cooling tower. We made an analysis of the total area in the shadow of the cloud for every half hour in the two years under consideration, which is a measure of the area of the shadow of the cloud. We calculated for both considered years for all intervals during the day. At night, the value is zero.

The maximum value of the shadow area of the visible water vapor cloud is 35.4 km^2. The entire area under consideration is 25 km x 25 km, which is 625 km^2. Therefore, the maximum area in the shadow of the cloud is 5.7% of the total considered area. The analyses clearly show that there are large areas of shadow mainly in the morning and evening hours. During the day, around noon, there are significantly fewer of them. This means that when the sun is at its strongest (around noon), there are relatively few shadows. This is favourable for plant growth.

2.6 Occurrence of water vapor cloud over selected locations

The analysis was made for the basic location and basic height of the cooling tower. We created graphs that show the statistical distribution by hours of the day when the ground location is under the cloud for the selected plot. We have shown the distribution for the location with the maximum value of the variable "Under the cloud" and for the location "Sadovnjak", which is located at the junction of the Evrosad orchard and the Krka pharmaceutical factory, d.d. and also represents the location of the former (original) AMP Krško (Vipap).

The maximum value of the variable "Under the cloud" occurred on the plot, which was determined from the picture (Figure 2) and marked with the mark "max" on the graphs.

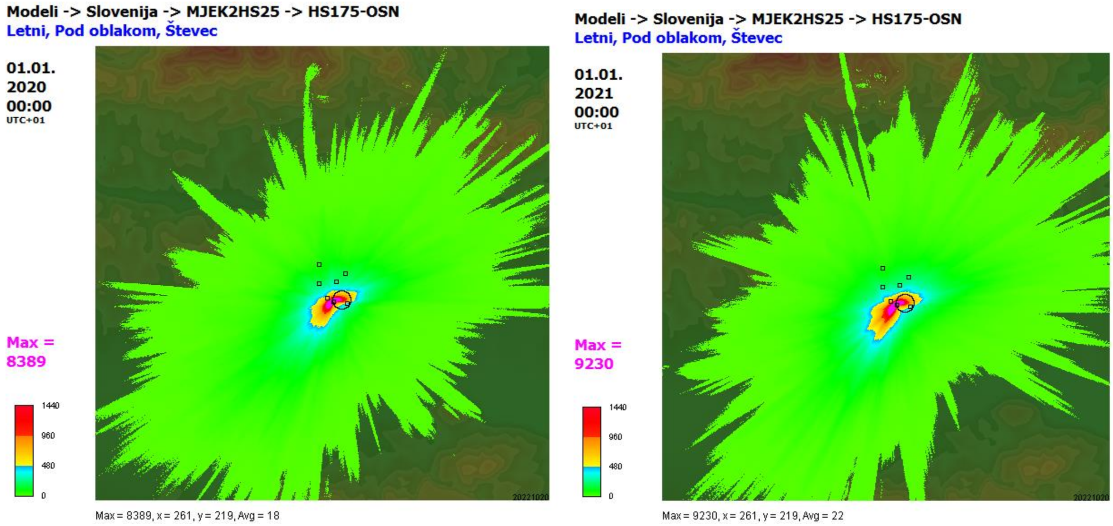

Figure 2: The number of half-hour intervals under cloud in an area of 25 km x 25 km

Then we carried out the same analysis for the three spring months, when dew or frost conditions can occur that have impact on agriculture. The analysis shows that the location is under a cloud several times in the morning hours, which is a favourable influence for agriculture, both for the location of the maximum and for the location of the Evrosad orchard.

2.7 Occurrence and density of vapor cloud shadows at selected locations

The analysis was made for the basic location and basic height of the cooling tower. Due to the geometry of the daily course of the sun and the prevailing wind directions at high altitudes, every location that is a little further from JEK2 is in the shade, especially during a certain part of the day, depending on its position in relation to the position of the cooling tower.

We calculated the annual integral of the shadow density due to the visible vapor cloud in an area of 5 km x 5 km for the year 2020. The spatial distribution showed that the most heavily shadowed locations will be up to one kilometer west or northwest of the location of the future reactor. Areas of dense population in Krško and Videm will be less burdened. The more congested areas are only areas up to 2 km from the location of the new reactor. Outside this area, the shadow occurs less than 150 hours per year. Shade means more diffused light and less direct sunlight.

2.8 Vertical rise of water vapor from a cooling tower

The analysis was made for the basic location and basic height of the cooling tower. The vertical rise of water vapor is defined as the average vertical rise of water vapor above the discharge point. From the analysis for both considered years, it can be seen that the minimum vertical rise of water vapor is high and amounts to 186 m above the top of the cooling tower (in total, 361 m above the terrain), while the average vertical rise of water vapor in 2020 is 867 m and in 2021 is 899 m.

2.9 Visual display of visible water vapor for three selected periods

For the following three selected days, we have shown the visible and invisible part of the water vapor cloud from the cooling tower for the base location and base height of the cooling tower for:

- 28/12/2021, when the air temperature was low (Figure 3),
- 25/05/2021, when the air temperature was moderate and
- 14/07/2021, when the air temperature was high.

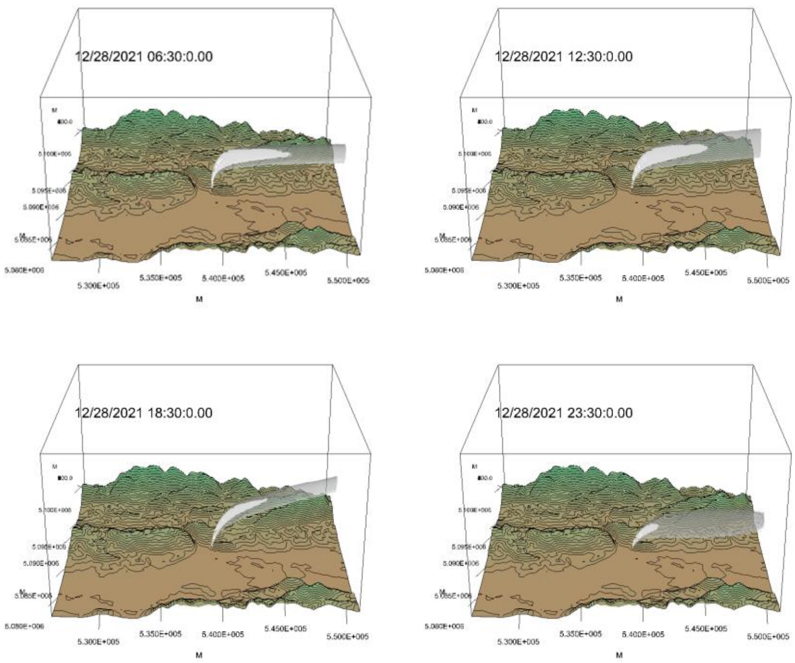

Figure 3: 3D display of water vapor cloud visibility for four time intervals for the weather situation 28/12/2021 (white color represents visible cloud, gray represents invisible cloud due to water vapor)

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