# COOLING-TOWER TECHNOLOGIES FOR THE IFMIF-DONES HEAT REJECTION SYSTEM: TECHNICAL AND ENVIRONMENTAL CONSIDERATIONS

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*Abstract*

The International Fusion Materials Irradiation Facility-DONES (IFMIF-DONES) is a scientific infrastructure intended to test and qualify materials for fusion reactors by exposing them to intense neutron fluxes. Several auxiliary systems will ensure its continuous operation, among which the Heat Rejection System (HRS) is designed to remove and discharge to the environment the heat mainly generated by the Accelerator's primary cooling loops and the Test Cell. While open evaporative cooling towers are widely used for industrial heat rejection, alternative technologies may be more suitable depending on site-specific conditions and project priorities. Environmental factors—particularly local weather patterns and their expected evolution under climate change—play a decisive role in overall system performance. Their proper assessment is therefore essential for selecting the most appropriate cooling-tower technology. This work presents a comparative evaluation of candidate heat-rejection solutions to identify the technology that best fits the site conditions, optimises performance over the system's life cycle, and supports the project's commitment to minimising its environmental footprint.

## INTRODUCTION

Water is considered a high-value resource, particularly in regions with potential future water scarcity, such as some areas of southern Spain. Despite Granada's area is nowadays out of those areas, minimizing water consumption has been identified as a key objective in both the design and operational phases of the IFMIF-DONES project.

As part of the plant systems, Heat Rejection System (HRS) is a critical auxiliary system that ensures continuous and reliable operation by removing heat mainly from the accelerator primary cooling loops, test systems and lithium systems [1].

Although open evaporative cooling towers constitute the reference design for the HRS, their water consumption raises justified the assessment of alternatives which could reduce the demand. This paper summarises a comprehensive technical assessment of water demand, optimisation opportunities and alternative cooling-tower technologies, supporting the selection of the most appropriate solution for the IFMIF-DONES site.

## IFMIF-DONES INFRASTRUCTURE LOCATION AND WATER AVAILABILITY

### *Location*

IFMIF-DONES infrastructure is located at Metropolitan, Industrial and Technological Park of Escúzar [2], 18 km southwest of Granada city, Spain (Fig. 1).

It is an industrial area where there are several companies from different sectors already running.


Figure 1: IFMIF-DONES infrastructure location.

### *Water availability*

The water available is provided to the industrial area by underground natural sources linked to Sierra Nevada snowmelt (Fig. 2). Currently, two of the five sources available are in operation, with a combined capacity of 100 l/s (50 l/s per source), while the three remaining sources are available for future use when needed.

The total officially assigned capacity to the industrial area is 31.95 l/s (998,000 $m^3$/year), of which current industrial consumption represents approximately 20%. There is no specific consumption cap defined per consumer, and capacity upgrades can be managed if required.

Based on the first assessment of the project, make-up water for cooling towers represents about 95% of the total water demand and, therefore, dominates any optimisation strategy [2]. The assessed demand confirms the feasibility of operating the HRS within the existing water-supply framework.

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Figure 2: Scheme of snowmelting from Sierra Nevada to natural sources providing water to the industrial area. Generated using artificial intelligence.

## COOLING TOWER TECHNOLOGIES

The open evaporative cooling towers technology has been considered the reference design for the HRS during basic engineering phase of the IFMIF-DONES project [2], performed in the framework of the EUROfusion Early Neutron Source Workpackage.

Despite that operating the HRS within the existing water-supply framework is feasible, the optimisation of water consumption calculated for Open Cooling Towers is still a challenge regarding lifecycle of the project. Consequently, alternative cooling towers technologies has been identified as able to reduce total water consumption. The other two technologies considered in this comparison are: 1) Hybrid (Dry + Adiabatic) Cooling Towers; 2) Closed Circuit Cooling Towers.

### *Hybrid (Dry + Adiabatic) Cooling Towers*

This technology combines the advantages of a dry system, with no water consumption during winter conditions, with adiabatic to work during summer conditions.

In the first (dry mode), the water flows through the finned coil and air rejects the heat from the coil.

In the second, when adiabatic, the air can be cooled by either spraying water into the airstream or by using wetted pads that provide a surface for water and air to interface. In both cases, the finned coil is protected against scale and corrosion.

The best way to operate this kind of cooling system is to integrate an automatic control system to change from dry to wet mode, based on environmental conditions. Dry mode is expected to be effective when ambient T <28 ºC.

### *Closed Circuit Cooling Towers*

This technology works under the same basis than open cooling tower but using a coil to separate the water from the air. The water consumption is expected to be lower than an open cooling tower but higher than adiabatic mode, as well as the higher risk of scale and corrosion.

The closed evaporative circuit can also work as part of a hybrid system instead of adiabatic mode. This configuration still has higher risk of scale and corrosion of the finned coil (higher maintenance cost).

## HRS DESIGN CONDITIONS

The HRS shall be designed to reject 17.8 MW by supplying a flowrate of 2,186 $m^3/h$ of cooling water at 25 °C, with return of 32 °C.

The climatic conditions considered for the design shown in Table 1 are based on Granada's Airport records. A meteorological station has been installed on site for the continuous surveillance of climate parameters during the lifetime of the facility [2].

Table 1: Design Climatic Conditions

| Factor | Design Value |
|---|---|
| Dry-bulb temperature | 39 ºC |
| Wet-bulb temperature | 22.4 ºC |
| Maximum temperature | 41 ºC |
| Minimum temperature | –4.7 ºC |
| Average relative humidity | 57% |

In addition, the main requirements imposed to the system are a system availability above 95 %, minimum noise impact, reduced water consumption and fitting in available space.

## COMPARISON AMONG COOLING TECHNOLOGIES

To confirm the results expected of those technologies, the updated design conditions has been sent to several cooling tower suppliers.

Based on the feedback the main point extracted from the comparison among those technologies are:

- A hybrid cooling solution represents the most favourable option in terms of water demand reduction. However, although the average water consumption is approximately five times lower, peak water demand still requires a water storage capacity and hardness treatment system comparable to, or potentially larger than, those required for conventional evaporative technology.
- Water consumption of closed cooling circuit could be even higher than open evaporative cooling towers in IFMIF-DONES design conditions. The use of hybrid technology integrating closed cooling circuits would reduce this consumption, but still worse than hybrid integrating adiabatic solution.
- An increase in water cost would improve the economic competitiveness of adiabatic solutions; however, the expected impact on overall OPEX remains limited.
- Power consumption is significantly higher for both hybrid and closed-circuit cooling towers compared with conventional evaporative systems. The implementation of photovoltaic panels in the cooling tower area could partially offset the additional fan power demand.
- All evaluated technologies comply with the available cooling tower space allocation. Nevertheless,

additional reserved space for future redundancy is strongly recommended to ensure the required system availability. Due to its larger footprint, adiabatic technology provides the lowest margin for additional units beyond the installed capacity.

- Maintenance data are not yet fully consolidated; however, the expected deviations are not considered significant enough to offset the higher CAPEX and power consumption associated with alternative technologies.
- Both alternative technologies contribute to reducing the risk of legionella proliferation, thereby decreasing the need for biocide treatment. Nevertheless, legionella control is considered a mature and well-established process, with no major technological or operational challenges identified.

Table 2 is the summary of the best scenario received compared with the Evaporative Open Cooling Towers Technology.

Based on the analysis done, at least one of the alternatives to the open cooling tower design allows to reduce the water consumption at IFMIF-DONES facility, but it will increase the total cost considering complete lifecycle. Best scenario of Hybrid technology will cost about 54% more than open cooling towers offered by the same supplier.

Table 2: Comparison of alternatives cooling technologies: (Hybrid or Closed) vs Open Cooling Towers (reference)

| Factor | Hybrid (Dry + Adiabatic) | Closed Circuit |
|---|---|---|
| Water demand | 22% | 107% |
| Power Consumption | 530% | 444% |
| Footprint | 162% | 115% |
| CAPEX | 321% | 292% |
| OPEX | 117% | 170% |
| Maintenance | Low | Medium |
| Risk of Legionella | Very low | Medium |

## OPEN COOLING TOWER OPTIMISATION

There are potential improvements that would result in a reduction of the water consumption, related with different design and operating factors.

### *Increase of Cycles of Concentration (N)*

Cycles of Concentration (N) is a parameter related to water hardness and to the protection of the system against corrosion and scaling. The current design includes chemical dosing of corrosion and scale inhibitors. During the basic engineering phase, the design value was set to N = 3 [2]. The comparison presented in this paper is based on N = 5; however, during operation, this value could be increased up to N = 7, potentially resulting in a 7% reduction in blowdown flow rate compared with operation at N = 5.

This optimization would require a reduction in water hardness, allowing an increase in N without increasing either the risk of corrosion or the required chemical dosing. A target hardness level of 60–90 ppm as $CaCO_3$ is currently being considered in the design of the water hardness treatment plant.

### *Blow down recovering by recirculation*

The blowdown generated during operation of an open cooling tower contains higher conductivity and organic carbon (TOC) than make-up water; however, the remaining water quality parameters are expected to be similar to those of the stored water. Therefore, reusing the blowdown water in the water stored tank instead of discharging it could potentially reduce overall water demand [3].

Additional water treatment step may be required to mitigate the impact of the blowdown water on the quality and stability of the stored water.

In addition, the blowdown water may contain residual traces of biocides and biodispersant products. A long-term impact assessment of these substances on the system shall be performed to determine whether any additional water treatment would be required.

The balance between the expected water savings and the required investment will drive the final decision during the plant design process and will be confirmed during the final design phase.

## CONCLUSION

The assessment confirms that:

- The water consumption of IFMIF-DONES is fully compatible with the industrial area water-supply capacity.
- Open evaporative cooling towers remain the most balanced solution in terms of performance, robustness and life-cycle cost.
- Optimisation of design parameters can reduce makeup water demand by up to 40%, significantly improving sustainability.
- Alternative cooling technologies can further reduce water use but do so at the expense of substantially higher CAPEX, OPEX and energy consumption.

Based on these results, optimised open evaporative cooling towers are currently the option considered as the reference technology for the IFMIF-DONES Heat Rejection System.

## REFERENCES


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