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IMPROVING THE THERMAL EFFICIENCY OF NUCLEAR REACTORS: AN ANALYSIS OF COOLING SYSTEMS AND HEAT EXCHANGE PROCESSES

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Abstract. About two-thirds of the heat generated in a nuclear reactor is rejected to the environment through the condenser, making the type of cooling system the second major factor determining the actual efficiency achieved by the plant. This paper quantitatively evaluates the impact of the dry cooling technology selected for the nuclear power plant in the Jizzakh region on thermal efficiency. The steam cycle of a VVER-1000 unit was modelled using IAPWS-IF97 properties and twelve-month climate normals for Jizzakh. The calculations show that, in July, condenser pressure increases from 7.03 kPa under an evaporative cooling tower to 14.65 kPa under an air-cooled condenser, while gross efficiency decreases from 32.90% to 31.01%, corresponding to a loss of 1.89 percentage points. On an annual average basis, the thermodynamic penalty is 0.91 percentage points, or 27.3 MW, while the additional fan power demand is 33.9 MW. Thus, the larger share of the annual loss is attributable to parasitic fan power rather than increased condenser back-pressure. Together, these two effects reduce unit output by 6.1%. In return, two units save 31.5–47.3 million m³ of water per year. The authors recommend a hybrid configuration with seasonal wet assistance, which can recover half of the thermodynamic penalty while using only one-quarter of the corresponding water requirement.

Keywords: nuclear reactor, thermal efficiency, cooling system, heat exchange, condenser, dry cooling, VVER-1000, Jizzakh.

Annotatsiya. Yadro reaktorida hosil bo'lgan issiqlikning taxminan uchdan ikki qismi kondensator orqali atrof-muhitga chiqariladi, shu sababli sovitish tizimining turi stansiyaning haqiqiy foydali ish koeffitsiyentini belgilovchi ikkinchi asosiy omil hisoblanadi. Maqolada Jizzax viloyatida qurilayotgan yadro elektr stansiya uchun tanlangan quruq (havoli) sovitish texnologiyasining issiqlik samaradorligiga ta'siri miqdoriy baholangan. VVER-1000 blokining bug' sikli IAPWS-IF97 xossalari asosida modellashirilgan va unga Jizzax iqlimining o'n ikki oylik me'yoriy ko'rsatkichlari kiritilgan. Hisob-kitoblar shuni ko'rsatdiki, iyul oyida kondensatordagi bosim bug'latgichli minoraga nisbatan 7,03 kPa dan 14,65 kPa gacha ko'tariladi, yalpi FIK esa 32,90% dan 31,01% gacha, ya'ni 1,89 foiz punktga pasayadi. Yillik o'rtacha termodinamik yo'qotish 0,91 foiz punktni (27,3 MVt) tashkil etadi, ventilyatorlarga sarflanadigan qo'shimcha quvvat esa 33,9 MVt ni tashkil etadi. Demak, yillik yo'qotishning kattaroq qismi kondensator bosimining oshishi emas, balki ventilyatorlarning qo'shimcha quvvat sarfi hisobiga yuzaga keladi. Ikkala omil birgalikda blok quvvatining 6,1% ini tashkil etadi. Buning evaziga ikkita blok uchun yiliga 31,5–47,3 mln m³ suv tejraladi. Mualliflar mavsumiy ho'l yordamchi gibridd sxemani tavsiya etadilar: mazkur sxema termodinamik yo'qotishning yarmini suv sarfining to'rtidan bir qismi evaziga qoplash imkonini beradi.

Kalit so'zlar: yadro reaktori, issiqlik samaradorligi, sovitish tizimi, issiqlik almashinuvi, kondensator, quruq sovitish, VVER-1000, Jizzax.

Аннотация. Около двух третей тепла, вырабатываемого ядерным реактором, отводится в окружающую среду через конденсатор, поэтому тип системы охлаждения является вторым важнейшим фактором, определяющим фактический КПД станции. В статье количественно оценено влияние сухой (воздушной) системы охлаждения, выбранной для АЭС в Джизакской области, на тепловую эффективность. Паровой цикл блока ВВЭР-1000 смоделирован на основе свойств IAPWS-IF97 с использованием двенадцатимесечных климатических норм Джизака. Расчёты показывают, что в июле давление в конденсаторе возрастает с 7,03 до 14,65 кПа, а валовый КПД снижается с 32,90% до 31,01%, то есть на 1,89 процентного пункта. Среднегодовая термодинамическая потеря составляет 0,91 процентного пункта (27,3 МВт), а дополнительная мощность вентиляторов — 33,9 МВт. Таким образом, большая часть годовых потерь обусловлена не повышением противодавления, а дополнительным потреблением мощности вентиляторами. В совокупности эти два фактора снижают мощность блока на 6,1%. Взамен для двух блоков обеспечивается экономия 31,5–47,3 млн м³ воды в год. Авторы рекомендуют гибридную

схему с сезонным влажным вспомогательным охлаждением, которая позволяет компенсировать половину термодинамических потерь при использовании четверти объёма воды.

Ключевые слова: ядерный реактор, тепловая эффективность, система охлаждения, теплообмен, конденсатор, сухое охлаждение, ВВЭР-1000, Джизак.

INTRODUCTION

Every nuclear power plant is fundamentally a heat engine, and a substantial share of the heat generated in the reactor must ultimately be rejected to the environment. A modern pressurised water reactor converts roughly one-third of its thermal output into electricity, while most of the remaining heat is discharged through the condenser [1]. This proportion is largely determined by the thermodynamic limits of the steam cycle and the temperature conditions that the primary and secondary circuits can support. Consequently, improvements within the reactor core alone do not eliminate the thermodynamic constraints associated with heat rejection.

What can change substantially is the way in which the rejected heat is transferred to the environment. A plant located near an abundant water source can use water-based cooling with a relatively small thermal penalty. By contrast, a plant located in a water-constrained and arid region requires a different cooling solution, and that choice directly affects condenser conditions, turbine performance, and ultimately the electrical output of the plant.

In September 2025, Uzbekistan and Rosatom formalised the configuration of an integrated nuclear power plant project in the Jizzakh region. The planned facility comprises two Generation III+ VVER-1000 units with a combined capacity of 2 GW and two RITM-200N small modular reactor units of 55 MW each. The integrated site covers approximately 525 hectares and is expected to generate more than 15 billion kWh of electricity annually by 2035 [2]. Earlier, in May 2025, Uzatom and the Hungarian company MVM EGI signed a memorandum establishing cooperation that includes the implementation of advanced dry-cooling technology for Uzbekistan's first nuclear power plant [3].

The consideration of dry cooling for Uzbekistan's nuclear programme predates these agreements. In December 2023, dry-cooling technology was publicly discussed as a potential solution for reducing water consumption in nuclear power generation under the country's water-resource constraints [4]. This consideration is particularly relevant for the Jizzakh site, where climatic conditions make the reduction of water consumption an important design objective.

At the same time, dry cooling introduces a thermodynamic trade-off that requires quantitative assessment under site-specific climatic conditions. The same hot and arid climate that strengthens the case for water-saving cooling can also reduce the thermal performance of an air-cooled condenser during the hottest periods of the year. In July, the regional climate data used in this study indicate an average dry-bulb temperature of 31.3 °C and a relative humidity of 21%, corresponding to an estimated wet-bulb temperature of approximately 17.1 °C. This temperature difference provides an important advantage for evaporative cooling that cannot be fully reproduced by a purely air-cooled condenser.

The present study therefore evaluates this trade-off quantitatively for the Jizzakh site. Three principal questions are addressed. First, what is the month-by-month thermodynamic penalty associated with dry cooling? Second, how does this penalty compare with the auxiliary power required by the cooling-system fans? Third, how much water is conserved in return for the resulting reduction in electrical output? Based on these results, the study also considers whether a seasonal hybrid cooling configuration could retain most of the water-saving benefit while reducing the associated thermal penalty.

Section 2 reviews the relevant literature, Section 3 describes the modelling methodology, Section 4 presents and discusses the results, and Section 5 summarises the conclusions and provides recommendations based on the analysis.

LITERATURE REVIEW

The thermal-efficiency range of conventional water-cooled nuclear power plants is well established. Older light-water reactor units typically convert approximately 32–33% of reactor thermal power into electricity, while nuclear plants of more recent design generally achieve efficiencies in the range of 34–36% [1]. The VVER family spans this range. A VVER-1000 of the V-320 type produces approximately 1000 MWe gross from 3000 MWt, corresponding to a gross thermal efficiency of about 33.3%. With a station house load of approximately 5%, the net efficiency is close to 31.7%. By comparison, the VVER-1200 operates at a primary-circuit pressure approximately 0.5 MPa higher and a steam-generator pressure approximately 0.5 MPa higher than those of the VVER-1000, achieving about 37% gross and 34.5% net efficiency [5], [6]. This improvement is primarily associated with enhanced steam-cycle conditions. Nevertheless, both designs still reject a substantial share of their thermal output through the condenser, and this rejected heat must be handled by the cooling system.

The literature generally classifies heat-rejection systems into four principal categories: once-through cooling, wet recirculating cooling towers, dry cooling systems, and hybrid wet–dry configurations. Wet cooling towers rely substantially on evaporation and therefore operate in relation to ambient wet-bulb temperature, whereas dry systems reject heat through finned heat-transfer surfaces to an air stream and are governed primarily by dry-bulb temperature [7]. Their water requirements consequently differ considerably. A recirculating wet cooling tower may evaporate up to approximately 3.0 litres of water per kilowatt-hour generated, with additional make-up water required for blowdown, whereas dry cooling can reduce water consumption substantially. This reduction, however, is accompanied by higher auxiliary power requirements and a greater sensitivity of condenser performance to ambient air temperature [1].

For nuclear power plants, a detailed engineering assessment of dry cooling was conducted for the AP1000 configuration considered at the Vogtle site [8]. The cited study indicates that practical air-cooled condenser (ACC) design requires a substantial initial temperature difference (ITD) between ambient air and condensing steam. Lower ITD values improve turbine back-pressure conditions but require significantly larger heat-transfer surfaces and higher capital expenditure. According to the assessment reported in [8], application of an ACC to an approximately 1100 MWe-class unit would impose a significant net-output penalty when turbine back-pressure, duct losses, and fan power are considered together. The study also reports substantially higher station-service demand, capital cost, equipment dimensions, and annual maintenance expenditure relative to the wet-cooling alternative. These findings demonstrate the scale of the engineering trade-off associated with applying dry cooling to gigawatt-class nuclear units.

On the steam-cycle side, the principal methods for improving efficiency are well established. Regenerative feedwater heating extracts steam at intermediate turbine stages to preheat the feedwater, thereby increasing the mean temperature of heat addition and reducing the heat input required in the steam generator. Thermodynamic modelling of configurations with different numbers of feedwater heaters confirms a progressive increase in cycle efficiency as regenerative heating is expanded [9]. Reheat provides a more moderate contribution to thermal efficiency but plays an important role in reducing exhaust-steam moisture and protecting the final turbine stages.

Another efficiency-related factor is condenser condition. Fouling increases thermal resistance, reduces the overall heat-transfer coefficient, and can raise condenser pressure. A 2024 study using a PSO-LSTM model to predict fouling resistance and optimise condenser-cleaning intervals found that, for a 300-day annual operating period, optimisation of the cleaning schedule could reduce operating costs by approximately USD 0.45 million per year for the analysed unit [10].

In the longer term, advanced reactor concepts may substantially increase thermal efficiency. Supercritical water-cooled reactor (SCWR) concepts operate above the thermodynamic critical point of water and are designed to achieve thermal efficiencies of approximately 44–48%, compared with roughly 34–36% for current water-cooled reactor technologies [11].

The reviewed literature, however, provides limited site-specific evidence for Central Asian climatic conditions. The AP1000 assessment considered conditions at the Vogtle site, while general cooling-system studies typically report water-consumption and auxiliary-power characteristics without direct application to the climate of Jizzakh. The thermodynamic environment of Jizzakh therefore requires separate quantitative assessment.

Bilibino is frequently cited as an important nuclear dry-cooling precedent [3]. Its four EGP-6 units entered commercial operation between 1974 and 1977. Each unit had a thermal capacity of approximately 62 MWt and a gross electrical output of 12 MWe [12]. The scale and climatic conditions of this installation differ fundamentally from those of a VVER-1000. A 1000 MWe VVER unit is more than 80 times larger in gross electrical output and approximately 48 times larger in thermal capacity than a single EGP-6 unit. In addition, Bilibino is located in an Arctic environment, whereas Jizzakh is characterised by a hot and arid continental climate. Consequently, the direct transfer of operational experience from Bilibino to a gigawatt-class VVER installation in Uzbekistan is limited. This difference provides the principal rationale for a site-specific assessment of dry-cooling performance under Jizzakh climatic conditions.

RESEARCH METHODOLOGY

The study employs a model-based comparative analysis. A steam-cycle model representing the reference unit was developed, after which two alternative heat-sink models were coupled to the cycle and evaluated using twelve months of local climatic data. The analysis is deterministic and reproducible; no proprietary vendor data were used, and all input parameters were either obtained from published sources or derived from published values according to the procedures described below. In preparing the article text, artificial intelligence tools were used to an extent not exceeding 10%.

Reference unit. The large units planned for the Jizzakh site are Generation III+ VVER-1000 reactors [2]. Accordingly, the secondary-side characteristics of the VVER-1000/V-320 were adopted as the reference basis:

3000 MWt reactor thermal power, 1000 MWe gross electrical output, saturated steam leaving the steam generators at approximately 6.3 MPa, and main steam reaching the turbine at approximately 5.9–6.0 MPa after steam-line pressure losses [5], [6]. Table 1 summarises the parameters used in the analysis, with the VVER-1200 included for comparison.

Steam-cycle model. Thermodynamic properties of water and steam were calculated using the IAPWS-IF97 industrial formulation [13]. Expansion from the saturated turbine-inlet state to the condenser pressure was first treated as isentropic and subsequently corrected using an assumed overall internal turbine efficiency of 0.84. This value was adopted as a modelling assumption to represent wet-steam expansion in a saturated-cycle nuclear turbine equipped with moisture separator reheaters. Mechanical and generator losses were represented by an efficiency factor of 0.98, while feedwater-pump work was calculated using the specific volume of saturated liquid. Gross cycle efficiency was then determined as follows:

$$\eta = [(h_1 - h_2) \cdot \eta_m - w_p] / (h_1 - h_4), (1)$$

where h_1 is the enthalpy of saturated steam at the turbine inlet, h_2 is the actual turbine-exhaust enthalpy, h_4 is the enthalpy after the feed pump, w_p is the pump work, and η_m is the mechanical and electrical efficiency.

The model reliably reproduces differences between operating states; however, its absolute efficiency level depends on assumptions regarding regenerative feedwater heating that cannot be fully represented by a single-expansion model. The model was therefore calibrated against the rated parameters of the reference unit. The calibration constant was selected so that, at the design condenser back-pressure of 5.9 kPa, the model reproduces a gross efficiency of 33.3%, corresponding to the ratio of 1000 MWe to 3000 MWt. Accordingly, only differences between the cooling-system options are interpreted as primary results, while absolute efficiency values are reported for reference.

Two validation checks were performed on the thermodynamic and psychrometric property calculations before the results were accepted. Calculated saturation pressures reproduce standard steam-table values to within 0.001 kPa over the temperature range of 20–60 °C, while the psychrometric routine reproduces standard-chart wet-bulb temperatures to within 1 K over the range of relative humidity considered in this study.

Heat-sink models. For the evaporative cooling tower, the condensing temperature was calculated from the ambient wet-bulb temperature using a tower approach of 8 K, a condenser range of 11 K, and a terminal temperature difference of 3 K:

$$T_{evet} = T_v^b + \delta_a + \Delta t_r + \delta_t, (2)$$

and for the air-cooled condenser directly from the dry-bulb temperature and the initial temperature difference,

$$T_{ev,ry}^d = T^{db} + ITD, (3)$$

For the dry-cooling option, the condensing temperature was determined using an initial temperature difference (ITD) of 22.2 K, corresponding to 40 °F and representing the lower end of the range commonly used in practical air-cooled condenser design [8]. Wet-bulb temperatures were calculated from dry-bulb temperature and relative humidity using the empirical relation proposed by Stull [14]. Over its stated range of applicability, the relation reproduces wet-bulb temperature with errors generally within approximately 1 K.

A minimum condenser pressure of 3.5 kPa was imposed on both cooling configurations as a modelling constraint representing the practical lower limit beyond which further reductions in turbine back-pressure were assumed not to produce additional useful output. This constraint becomes active in January, February, and December. Applying the same lower-pressure limit to both cooling options also makes the comparison conservative by removing the small winter advantage that the air-cooled system would otherwise exhibit.

Climate input. Twelve-month climate normals for Jizzakh were used, including monthly mean dry-bulb temperature and mean relative humidity [15]. July represents the most demanding month, with a mean temperature of 31.3 °C and relative humidity of 21.1%, while the annual mean values are 16.6 °C and 44.0%, respectively. The use of monthly averages is a deliberate simplification of short-term weather variability, and the implications of this assumption are discussed in Section 5.

Auxiliary power and water consumption. Auxiliary-power requirements for the two cooling configurations were estimated by scaling the station-service values reported in the AP1000 assessment [8] according to the ratio of reference-unit capacities, 1000/1100. This proportional scaling was adopted as a modelling assumption rather than as a vendor-specific design value.

Water consumption for the evaporative-cooling option was calculated using published evaporation rates of 2.0–3.0 L/kWh [1] and an assumed annual capacity factor of 0.90. Blowdown requirements, which may add approximately half of the evaporative consumption [1], were excluded from the present calculation. Consequently, the water-consumption values reported below should be interpreted as conservative estimates of total make-up-water demand:

$$V = r \cdot P \cdot \tau \cdot k, (4)$$

where V is the annual evaporative water consumption, r is the evaporation rate, P is the gross electrical capacity,

τ is the number of hours in a year, and k is the capacity factor.

Limitations of the method. Four methodological limitations should be noted. First, the use of monthly mean climatic values does not fully capture the short-term temperature extremes experienced by an air-cooled condenser. Because the dry-cooling penalty increases with ambient temperature and afternoon temperatures in July can exceed the monthly mean by 3 K or more, the calculated summer penalties should be interpreted as conservative estimates.

Second, a single ITD value cannot fully represent the behaviour of a real air-cooled condenser, whose performance may vary with wind conditions, hot-air recirculation, air-side fouling, and other site-specific operating factors.

Third, no economic optimisation was undertaken in the present study. The analysis is limited to thermodynamic performance, auxiliary power demand, and water consumption, without extending to capital cost, operating cost, or levelised electricity-cost optimisation.

Fourth, calibration of the steam-cycle model anchors the absolute efficiency level to a published design point rather than to measured operating data from the specific plant. For this reason, the principal conclusions of the study are based on relative differences between the cooling configurations, while the absolute efficiency values are used primarily for reference.

ANALYSIS AND RESULTS

Table 1

Design parameters of the reference unit

Parameter	VVER-1000 (V-320)	VVER-1200
Reactor thermal power, MWt	3000	3200
Gross electrical power, MWe	1000	1200
Net thermal efficiency, %	31.7	≈34.5
Gross thermal efficiency, %	33.3	≈37.0
Primary circuit pressure, MPa	15.7	16.2
Steam generator pressure, MPa	6.3	6.9
Turbine inlet pressure, MPa	6.0	7.0
Coolant temperature in / out, °C	289 / 319	298 / 329

Source: compiled by the authors from [1], [5], [6]. The VVER-1000 gross efficiency is the nameplate ratio 1000/3000, its net figure assumes a house load of 5 %, and its primary and steam generator pressures are derived from the increments reported in [5].

The comparison between the cooling options is presented in Table 2, which combines their principal physical characteristics with the cost and footprint data reported for a unit of comparable capacity [8].

Table 2

Heat rejection options for a gigawatt-class nuclear unit

Characteristic	Once-through	Evaporative tower	Air-cooled condenser
Governing temperature	Water source	Wet-bulb	Dry-bulb
Water consumed	Half a wet tower	2.0–3.0 L/kWh evap.	<0.3 L/kWh
Station service, MW	8–12 (est.)	12.2–17.4	46.1
Capital cost, wet tower = 1	<1	1.0	≈5
Annual maintenance, \$ mln	0.05–0.5	0.05–0.95	6.9
Footprint	Small	Moderate	≈90 × 820 m
Feasible at Jizzakh	No	Water-limited	Yes

Source: authors' compilation from [1], [7], [8]; station service scaled to 1000 MWe. The once-through station service is an estimate by the authors; all other figures are sourced.

The psychrometric asymmetry. The results of this analysis are largely determined by one important local climatic characteristic: Jizzakh summers are both hot and very dry, producing a substantial separation between dry-bulb and wet-bulb temperatures. In July, the monthly mean dry-bulb temperature is 31.3 °C at a relative humidity of 21.1%, corresponding to a wet-bulb temperature of approximately 17.1 °C. The resulting temperature difference is 14.2 K.

An evaporative cooling tower operates with reference to the lower wet-bulb temperature, whereas an air-cooled condenser is governed primarily by the higher dry-bulb temperature. Consequently, the two cooling technologies enter the summer operating condition with an inherent climatic temperature difference of approximately 14 K even before equipment-specific characteristics are taken into account.

In January, the corresponding dry-bulb–wet-bulb temperature difference is only about 2.8 K. The thermodynamic

penalty associated with dry cooling is therefore not constant throughout the year but varies seasonally, reaching its highest levels during the hottest months.

Table 3 presents the monthly results, while Figure 1 illustrates their seasonal variation.

Table 3

Computed condenser conditions and gross efficiency by month, Jizzakh

Month	T _{db} , °C	RH, %	T _v , °C	p wet, kPa	p dry, kPa	η wet, %	η dry, %	Δη, p.p.	ΔN, MW
I	2.5	65.3	-0.3	3.50	3.50	34.55	34.55	0.00	0.0
II	3.1	68.7	0.4	3.50	3.50	34.55	34.55	0.00	0.0
III	11.3	58.6	7.1	4.03	5.18	34.23	33.64	-0.59	-17.7
IV	17.6	51.1	11.7	5.25	7.29	33.61	32.82	-0.79	-23.7
V	24.3	36.8	15.3	6.39	10.37	33.14	31.92	-1.22	-36.6
VI	29.5	24.9	16.8	6.94	13.46	32.94	31.24	-1.70	-51.0
VII	31.3	21.1	17.1	7.03	14.65	32.90	31.01	-1.89	-56.7
VIII	29.6	21.2	15.9	6.61	13.48	33.06	31.23	-1.83	-54.9
IX	23.9	24.5	12.7	5.53	10.13	33.49	31.98	-1.51	-45.3
X	15.9	39.0	8.8	4.45	6.66	34.00	33.04	-0.96	-28.8
XI	7.2	55.4	3.1	3.50	4.10	34.55	34.19	-0.36	-10.8
XII	2.7	61.4	-0.5	3.50	3.50	34.55	34.55	0.00	0.0
Year	16.6	44.0	—	—	—	33.79	32.88	-0.91	-27.3

Source: authors' own calculation using [13], [14] and climate normals from [15]. Δη and ΔN are computed from the rounded efficiency columns, so the table reproduces exactly as printed.

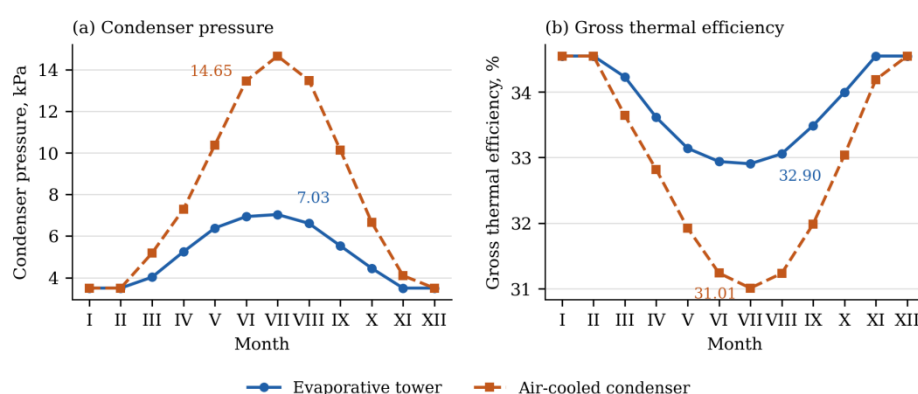


Figure 1. Monthly condenser pressure (a) and gross thermal efficiency (b) for the two heat rejection options. Source: authors' own calculation.

The seasonal pattern of the results is as important as the magnitude of the annual average. From November through February, the two cooling options produce essentially identical results because both reach the imposed condenser-pressure floor of 3.5 kPa, below which no additional turbine-output benefit is assumed in the model. The difference begins to emerge in March, increases through spring, and reaches its maximum in July. Under the July mean climatic condition, the air-cooled condenser operates at 14.65 kPa compared with 7.03 kPa for the evaporative tower. Gross efficiency consequently decreases from 32.90% to 31.01%, corresponding to a reduction of 1.89 percentage points. Expressed in electrical output, this represents approximately 56.7 MW per unit under the July mean condition, with potentially larger losses during periods when ambient temperatures exceed the monthly average. Overall, eight months of the year exhibit a measurable dry-cooling penalty, while four months show no difference under the adopted 3.5 kPa pressure constraint.

Sources of the annual loss. On an annual-average basis, the thermodynamic penalty associated with increased condenser back-pressure is 0.91 percentage points, equivalent to approximately 27.3 MW of gross output per unit. This loss should be considered together with the auxiliary-power requirement of the cooling system. When the AP1000 station-service data are scaled to a 1000 MWe unit, the air-cooled condenser requires approximately 46.1 MW of station-service power, compared with approximately 12.2 MW for a natural-draught wet cooling tower. The resulting difference is 33.9 MW during plant operation.

The auxiliary-power difference is therefore larger than the annual-average thermodynamic loss caused by increased condenser back-pressure. Under the assumptions of the present model, the annual-average back-pressure effect accounts for 27.3 MW, whereas the additional fan and associated auxiliary demand accounts for 33.9 MW. This result indicates that optimisation of fan efficiency, plenum and duct aerodynamics, variable-speed drives, and air-side pressure drop may be at least as important as efforts to reduce the ACC initial temperature difference.

Combining the thermodynamic and auxiliary-power components gives a total annual-average penalty of 61.2 MW per unit, equivalent to approximately 6.1% of gross capacity. For the two VVER-1000 units together, this corresponds to approximately 0.97 TWh of electricity per year at the assumed capacity factor, or about 6.4% of the more than 15 billion kWh of annual generation expected from the integrated plant by 2035 [2]. In capacity terms, the combined effect is equivalent to approximately 122 MW of continuously unavailable gross output. Under the July mean climatic condition, the corresponding penalty increases to 56.7 MW from back-pressure effects plus 33.9 MW from additional auxiliary demand, giving a combined value of 90.6 MW, or approximately 9.1% of unit gross capacity.

Water savings associated with dry cooling. The principal benefit of the dry-cooling option is the substantial reduction in water consumption. Two VVER-1000 units operating with evaporative cooling towers at a capacity factor of 0.90 would evaporate approximately 31.5–47.3 million m³ of water annually at published evaporation rates of 2.0–3.0 L/kWh [1]. Blowdown requirements, which may increase total make-up-water demand by approximately one-half of the evaporative component, are not included in these values.

For comparison of scale, an annual volume of 31.5–47.3 million m³ corresponds to the annual domestic water requirement of approximately 430,000–650,000 people at an assumed consumption of 200 litres per person per day. The dry-cooling option therefore represents a substantial water-saving measure under conditions of constrained water availability.

Relating the annual electricity penalty to the corresponding water savings provides an additional indicator for evaluating the trade-off. Based on the present calculations, each MWh of electricity forgone through the combined dry-cooling penalty corresponds to approximately 33–49 m³ of avoided evaporative water consumption. This indicator does not determine whether the trade-off is economically or socially optimal, but it provides a quantitative basis for comparing electricity and water outcomes in subsequent policy and economic assessments.

The hybrid case. A third cooling configuration was also evaluated because the monthly results indicate that most of the thermodynamic penalty is concentrated in the summer period. Under the modelled hybrid configuration, wet assistance is applied only during June, July, and August, while dry cooling is used during the remaining nine months. The resulting annual gross efficiency is 33.34%. This configuration recovers approximately 13.7 MW of the 27.3 MW annual-average thermodynamic gap, or about one-half of the thermodynamic loss, while using approximately one-quarter of the water required by a fully evaporative cooling system.

Using the upper evaporation rate consistently for both configurations, the hybrid option requires approximately 55 m³ of water for each MWh of thermodynamic output recovered, compared with approximately 110 m³/MWh for the fully evaporative option on the same per-unit basis. Thus, under the assumptions adopted in this study, seasonal wet assistance approximately doubles the marginal water efficiency of the recovered electrical output.

The hybrid configuration therefore offers a potential compromise between water conservation and thermal performance. However, its principal operational limitation is that wet assistance would be required during the same summer months in which agricultural and other water demands are typically elevated. Consequently, the optimal capacity, operating schedule, water source, and economic performance of a hybrid system require a separate site-specific assessment.

Table 4
Summary of the Three Heat-Rejection Strategies, per Unit Unless Otherwise Stated

Quantity	Evaporative	Air-cooled	Hybrid (VI–VIII wet)
Annual gross efficiency, %	33.79	32.88	33.34
Thermodynamic penalty, MW	—	27.3	13.6
Station service, MW	12.2	46.1	≈46
Total penalty, MW	—	61.2	≈47.5
Penalty, % of gross	—	6.1	≈4.8
Water evaporated, mln m ³ /yr (2 units)	31.5–47.3	≈0	7.9–11.8
July efficiency, %	32.90	31.01	32.90

Source: authors' own calculation. Hybrid station service assumed unchanged from the dry case.

Two further observations belong here. The first concerns heat-exchange surfaces. An air-cooled condenser has no waterside fouling, which is often presented as an advantage, but it acquires an air-side equivalent in the form of dust, insects, and windblown soil on the finned tubes, and the Jizzakh steppe supplies all three in quantity. The mechanism is the same as that documented for water-cooled condensers, where deposits reduce the overall heat-transfer coefficient and raise back-pressure [10], and the remedy is also the same: scheduled cleaning informed by performance monitoring rather than by the calendar.

The second concerns the small modular units on the same site. Their combined capacity of 110 MW is approximately one-tenth of that of a single large unit, so the cooling penalty they carry is correspondingly smaller in absolute terms. Their lower steam parameters also make them a reasonable candidate for cogeneration or desalination applications that could put the rejected heat to use instead of releasing it into the air.

CONCLUSION AND SUGGESTIONS

The analysis supports five conclusions.

First, dry cooling at Jizzakh costs 0.91 percentage points of gross efficiency on an annual-average basis, rising to 1.89 percentage points in July and falling to zero between November and February. The penalty is seasonal and concentrated rather than uniform.

Second, fan power matters more than back-pressure over the course of a year. The 33.9 MW of additional station-service demand exceeds the 27.3 MW annual-average thermodynamic loss. The authors consider this an important practical conclusion of the study: at a site of this kind, auxiliary power represents the larger of the two components and should receive corresponding attention in system design.

Third, the combined penalty of 61.2 MW per unit, equivalent to 6.1% of gross capacity, amounts to approximately 0.97 TWh per year across the two large units. This is roughly 6.4% of the plant's projected annual output and is equivalent to approximately 122 MW of continuously unavailable gross capacity.

Fourth, the water savings are substantial, amounting to between 31.5 and 47.3 million cubic metres of avoided evaporation per year for the two units. This confirms the importance of the water-saving rationale for dry cooling, while also indicating that its associated energy cost deserves explicit quantitative consideration. The calculated exchange rate is approximately 33–49 m³ of water saved per MWh of electricity forgone.

Fifth, a hybrid arrangement with wet assistance limited to June, July, and August recovers approximately half of the thermodynamic penalty while using about one-quarter of the water required by full evaporative cooling, making it approximately twice as water-efficient at the margin.

Four recommendations follow from these findings. The capability for seasonal wet assistance should be considered during the initial design stage, since retrofitting a deluge or hybrid section to a completed air-cooled condenser may be technically difficult and costly. Fan and plenum aerodynamics, air-side pressure drop, and variable-speed drives deserve particular attention because auxiliary power represents the larger annual loss component. Procurement specifications should include guaranteed ITD performance at ambient temperatures of 40 °C and above, rather than relying solely on rating-point conditions that may not fully represent summer operating conditions at the Jizzakh site. Performance monitoring of air-side heat-transfer surfaces should also begin at commissioning so that cleaning intervals can be determined from operating data rather than fixed assumptions.

The limitations stated in Section 3 apply to all numerical results presented above. Monthly mean values smooth the afternoon temperature extremes that determine the most demanding operating hours, a single ITD value represents a real machine subject to wind and recirculation effects, and no economic optimisation was performed. The figures should therefore be interpreted as conservative model-based estimates rather than direct measurements. They nevertheless establish the approximate magnitude of the cooling penalty for the Jizzakh site and indicate that the hybrid option merits a detailed hourly assessment before the final cooling-system design is established.

REFERENCES

1. · Asmolov V.G., Gusev I.N., Kazanskiy V.R., Povarov V.P., Statsura D.B. New Generation First-of-the-Kind Unit – VVER-1200 Design Features // *Nuclear Energy and Technology*. – 2017. – Vol. 3, No. 4. – P. 260–269. – DOI: 10.1016/j.nucet.2017.10.003. – URL: [DOI / article page](https://doi.org/10.1016/j.nucet.2017.10.003).
2. · Chen D., Zhang W., Du X., Xu L., Wei H. Dynamic Optimization Method for Cleaning Cycle of Condenser of Nuclear Power Plant // *Energy*. – 2024. – Vol. 294. – Art. 130814. – DOI: 10.1016/j.energy.2024.130814. – URL: [ScienceDirect](https://www.sciencedirect.com/science/article/abs/pii/S03605442240130814).
3. · Generation IV International Forum (GIF). Super Critical Water Reactors (SCWR) [Electronic resource]. – URL: [GIF – Super Critical Water Reactors](https://www.gif.energy.gov/scwr)
4. · International Association for the Properties of Water and Steam (IAPWS). Revised Release on the IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam: IAPWS R7-97(2012) [Electronic resource]. – URL: [IAPWS-IF97 official release](https://www.iapws.org/property/)
5. · Jizzakh, Uzbekistan: Climate Zone, Monthly Weather Averages and Historical Data [Electronic resource] // Weather

- and Climate. – URL: [Jizzakh climate data](#)
6. · Rosatom May Build an NPP with a “Dry Cooling Tower” in Uzbekistan [Electronic resource] // *Kun.uz*. – 11.12.2023. – URL: [Kun.uz article](#)
 7. · Uzbekistan and Rosatom Sign Agreement on Construction of Large Nuclear Power Plant in Jizzakh [Electronic resource] // *Kun.uz*. – 26.09.2025. – URL: [Kun.uz article](#)
 8. · Nuclear-power.com. Cooling Towers – Dry, Wet, Natural Draught [Electronic resource]. – URL: [Cooling Towers – Dry, Wet, Natural Draught](#)
 9. · Oyedepo S.O., Kilanko O., Waheed M.A. et al. Dataset on Thermodynamics Performance Analysis and Optimization of a Reheat–Regenerative Steam Turbine Power Plant with Feed Water Heaters // *Data in Brief*. – 2020. – Vol. 32. – Art. **106086**. – DOI: **10.1016/j.dib.2020.106086**. – URL: [ScienceDirect](#).
 10. · Rosatom. *The VVER Today: Evolution, Design, Safety*. – Moscow: Rosatom Overseas, 2013. – 50 p. – URL: [Rosatom official PDF](#)
 11. · Stull R. Wet-Bulb Temperature from Relative Humidity and Air Temperature // *Journal of Applied Meteorology and Climatology*. – 2011. – Vol. 50, No. 11. – P. 2267–2269. – DOI: 10.1175/JAMC-D-11-0143.1. – URL: [Journal article / DOI](#).
 12. · U.S. Nuclear Regulatory Commission. *Feasibility of Air-Cooled Condenser Cooling System for the AP1000* [Electronic resource]. – Accession No. ML090090838. – URL: [U.S. NRC document](#)
 13. · World Nuclear Association. Bilibino Nuclear Power Plant: Bilibino 1–4, EGP-6 Reactor Data [Electronic resource]. – URL: [Bilibino 1](#); [Bilibino 2](#); [Bilibino 3](#); [Bilibino 4](#)
 14. · World Nuclear Association. Cooling Power Plants [Electronic resource]. – Updated 08.09.2026. – URL: [World Nuclear Association – Cooling Power Plants](#)
 15. · World Nuclear News. Uzbekistan Discusses Hungarian Dry Cooling System for Nuclear Project [Electronic resource]. – 15.07.2025. – URL: [World Nuclear News article](#)

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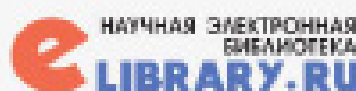
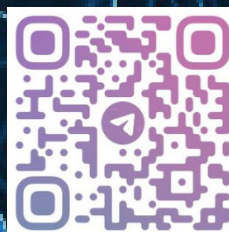
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