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Cooling Water for Nuclear Power Plants

The main cooling water requirement for nuclear power plants and coal-fired power plants is condenser cooling water for plants that use a steam turbine to generate electricity. The exhaust steam from the turbine is condensed back into water to be recirculated to the nuclear reactor or boiler. As in any electrical generation plant that uses a steam turbine, including all coal-fired power stations, this requires separate condenser cooling water supplies.
Typical thermal efficiency of a PWR/BWR is ~ 33%. Coal-fired power stations operate at higher steam temperatures and pressures than PWR/BWRs, and therefore typically have a higher thermal efficiency. Average thermal efficiency of coal fired power stations in the UK is ~ 36% (Statistica). This means that a nuclear power plant will require slightly more, but not significantly more, condenser cooling water than a coal fired power plant of the same MW electrical capacity.
Unlike the water supplied to a boiler in a coal-fired power station or to the steam generator in a nuclear power plant, condenser cooling water does not have to be high quality and seawater/lake/river/recycled water is commonly used.

There are three condenser cooling arrangements

Direct once through cooling

Water is taken from a lake, river or the sea, passes through the condenser and is discharged back into the original water source, but at a point where it will not immediately recirculate. There are usually environment limits on the temperature of the water being returned.
Direct cooling **withdraws** more water than other condenser cooling methods to ensure that the temperature rise is within environmental limits, but the water **consumption** is smaller. If the water source is a lake, they will be some small evaporation losses.

Examples of withdrawal rates:
UK Environmental Agency report[1]:
Westinghouse PWR, AP-1000, 1117 MWe, 57,000 l/s = 4,925 Ml/day, 1,798 GL/year, ~184,000 l/MWh
Framatome PWR, EPR, 1,600 MWe, 72,000l/s= 6,221 Ml/day,2,271 GL/year, ~162,000 l/MWh
Typical **consumption** rates are <1% of the withdrawal.
NREL report[2] : Nuclear range 95,000 – 227,000 l/MWh

[1] https://assets.publishing.service.gov.uk/media/5a7c7688ed915d6969f450b2/scho0610bsot-e-e.pdf

[2] https://wwwnrel.gov/docs/fy11osti/50900.pdf

An Australian example of a coal-fired power station using direct cooling is the 1,680 MWe Gladstone power station in Queensland. This requires 5,880 Ml/day = 2,146 Gl/year, 40.5 l/sec/MWe of seawater[3] pumped from Aukland inlet. (compare to 6,221 Ml/day, 2,271 Gl/year, 45 l/sec/MWe for 1600 MWe EPR).

A 300 MWe SMR with direct cooling would withdraw ~ 15,000 litres/sec = 1,300 Ml/day (based on UK figures for AP1000 proportioned to 300 MWe).

Indirect cooling with cooling towers

The condenser cooling water is circulated through cooling towers which discharge the heat to the air, both directly and through evaporation. This is the plume of condensed water vapour that is seen rising from a cooling tower. Tower cooling **withdraws** less water but **consumes** more. The consumption makes up the water loss from evaporation and drift.

Examples of consumption
UK 1,600 MWe, 2,000 l/s = 63,072 Ml/year

NREL supercritical coal 1730 – 2250 l/s
Nuclear range 380 – 1,500 l/s

Towers can be natural draft (chimney effect) or mechanical draft using large fans.

The new Vogtle nuclear power plant in the USA has 2 x 1,250 MWe Westinghouse AP-1000 PWRs with natural draft cooling towers. The US NRC Construction and Operating Licence (COL) application Chapter 2, Site Characteristics, table 2.4-217 states the normal circulating water/turbine plant cooling water system consumption from the Savannah River is 1,837 l/sec = 159 Ml/day = 58 Gl/year replacing the water loss from evaporation and drift from the natural draft cooling towers for 2,500 MWe, 0.73 l/sec/MW. Drift is 0.002% of the tower circulating water flow.

Mt Piper (1,390 MW) coal-fired power station in NSW uses natural draft tower cooling. They have a water licence for 25 GL/year, equivalent to 0.57 l/sec/MW at full load.

AGL's Loy Yang B coal-fired power station (1,160 MW) with natural draft cooling towers consumed 18.86 GL in 2023[4].

The 20 MW (thermal) OPAL research reactor at Lucas Heights, Sydney uses tower cooling. This reactor does not generate electricity and the 20 MW of heat produced in the reactor is dissipated in the tower cooling system. The system has five counter flow forced draft cooling towers with a wet basin and 3 x 50% cooling pumps. Flow rate is 4,400 l/s per pump. Heat transfer to the atmosphere is by variable speed cooling fans.

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[3] https://www.nrggos.com.au/the-process#:~:text=The%20station%20requires%20245%20million,repeated%20use%20in%20the%20boilers.

[4] https://www.loyyangb.com.au/environment-and-sustainability

Dry cooling

The condenser cooling water flows through a large radiator in a closed circuit. Fans blow air through the radiator removing the heat. Water **consumption** is very low as there is no water loss through evaporation. Dry cooling increases the house load (electricity required to operate the plant) because of the fans and hence decreases the electrical output slightly. Dry cooling also increases the cost of the cooling system.

The largest coal-fired unit in Australia uses dry cooling. Kogan Creek[5], QLD, 750 MWe supercritical located on the Western Downs consumes only 80 l/MWh, about 5% of a typical Australian coal-fired power station. The giant radiator has 48 fans, each 9m diameter.

Milmerran, QLD, 2 x 426 MWe supercritical coal also uses dry cooling with a consumption of ~150 l/MWh.

The proposed NuScale SMR 6 x 77 MWe plant to be sited at Idaho National Laboratories was designed to have dry cooling, reducing water usage by 90%[6] and decreasing power output by 5-7%.

Summary

- It is not true that a nuclear power plant requires substantially more cooling water than a coal-fired power station of the same capacity.
- When there are abundant cooling water supplies or adequate supplies without too restrictive environmental limitations, direct cooling is the most efficient and least cost option.
- Indirect cooling using wet cooling towers is a widely used option when water supplies are restricted.
- Dry cooling is a more expensive and less efficient option, but enables power plants to be situated practically anywhere

Many of the advanced Small Modular Reactors and microreactors under development now do not use a steam turbine and therefore will not require significant cooling water supplies.

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[5] https://www.csenergy.com.au/news/blog/the-giant-radiator-keeping-kogan-creek-cool

[6] https://world-nuclear.org/information-library/current-and-future-generation/cooling-power-plants