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Towards efficient water management in nuclear power plants

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ABSTRACT

Nuclear power plant projects require securing a sustainable source of water for the different stages of the projects, including construction and flushing, cold and hot testing, the condenser cooling operation, including the primary coolant make-up system, as well as the safety inventory and discharge from the radioactive liquid waste treatment system. Hence, efficient water management is crucial during all phases of construction, operation, and maintenance of any nuclear power plant. In some cases, the use of water resources has developed into an environmental issue resulting in stringent regulations which limit the possibility of water withdrawal as well as water discharge. Recent experience has shown that nuclear power plants are susceptible to prolonged drought conditions, forcing shut down of the reactors or reduction of power to a minimal level. Due to water scarcity and concerns associated with climate change affecting available water resources, nations of the world are operating or considering nuclear power plants should assess the different strategies of efficient use of existing water supplies for the needs of nuclear power plants. Also, the consideration of alternative water sources; including desalination, water reclamation, or other water recycling strategies should be considered in securing sustainable water supply for the nuclear power project. Due to the importance of efficient management of water at nuclear power plants during the entire phases of construction, operation, and maintenance; the IAEA Water Management Programme (WAMP) was developed to enable member states to assess various types of cooling systems and the need for cooling water and other essential systems in water-cooled nuclear power plants. The program estimates the water needs for cooling and other essential systems. Moreover, it helps in the selection process of cooling systems by assessing three different criteria: water resources, environment, and economics. WAMP enables users to perform comparisons of different cooling systems, reactor technologies, and at different site conditions. The reported results include water withdrawal and consumption estimation; and estimation of economics (capital and operating costs) for cooling systems. This paper highlights the aspects of and strategies towards efficient water management in nuclear power plants, focusing on two crucial strategies: the use of nuclear desalination and water reclamation for achieving efficient water management in nuclear power plants. Also, the main features of the IAEA tools in support of nuclear desalination and water management are discussed.

Keywords: Nuclear; Desalination; Water management

1. Introduction

To approach sustainable development, while there are ongoing increasing risks of global water scarcity, and concerns over environmental impact along with population growth in arid and semi-arid regions of the world, it is necessary to adopt proper and efficient water management strategies and techniques in conjunction with the implementation of the sustainable and reliable energy plan. Water management is a crucial strategy during the entire phase of the construction, operation, and maintenance of any nuclear power plant. This emphasizes the importance of considering innovative solutions and alternatives for securing sustainable water resources when considering nuclear power projects. Using nuclear energy for producing fresh water from seawater has been drawing broad interest among Member States of IAEA due to acute water issues in many arid and semi-arid areas

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worldwide. Several demonstration programs on nuclear desalination have been taken up to confirm its technical and economic viability under country-specific conditions with the technical coordination and support of the IAEA, which continue to support its Member States with achieving sustainability of water through nuclear desalination and efficient water management.

This paper discusses the water-energy nexus in the light of nuclear power plants and highlights the IAEA current and future activities in support of nuclear desalination and efficient water management, and the related IAEA tools and toolkits which are developed to provide support to Member States with more understanding of the economic viability as well as thermal performance of nuclear desalination technologies and efficient nuclear water management.

2. Water for nuclear power plants

Water demands for nuclear power plants vary depending on different factors: cooling system utilized, the thermal efficiency of the plant, the need for service water, safety and non-safety system designs, as well as the waste disposal techniques. It is important to select a site where suitable cooling water is available, and/or atmospheric conditions are suitable, all allowing higher plant efficiencies at lower water withdrawal rates. Different cooling technologies can reduce the water use and consumption. However, it depends on the tradeoff with cost when choosing nuclear power implementation and benefit analysis.

Current nuclear power plants demand more cooling water compared to those of fossil fuel power stations by about 25% on average. This is due to their lower thermal efficiency, as they operate at lower pressures and temperatures of generated steam. These parameters can be increased, but only to a limited extent, because of the limits imposed by the frequent use of zircaloy as a material for fuel cladding and coupled neutronic and thermal-hydraulic considerations in conventional light water reactors. Also, manufacturing capabilities of the main reactor, heavy components are another limitation. Table 1 shows the water use for different cooling technologies in nuclear power plants and other power plant types for comparison.

In addition to the water withdrawn and consumed during the major phases in the lifetime of nuclear power plants, that is, during construction, commissioning, operation, shutdown, and decommissioning, providing water for potable and industrial use during all the pre-mentioned stages is of great importance importance (Khamis and Kavvadias 2012). Two innovative approaches to efficient water management in NPPs are hybrid nuclear desalination and water reclamation.

3. Nuclear desalination

Among several other promising alternatives and techniques for efficient water management in nuclear power plants is seawater desalination using nuclear energy for industrial and potable water production for securing water needed for the plant (IAEA). The main currently available and mature technologies of seawater desalination are multi-stage flash (MSF), multi-effect distillation (MED), and seawater reverse osmosis (RO). In addition, a hybrid desalination concept, which is the combination of two or more processes to provide better performance at lower cost is eyed as the most optimized for consideration in nuclear power projects involving desalination (Khamis and El-Emam 2016). Hybrid desalination plants combine the advantages of the main desalination processes, both membrane-based (i.e., RO which required electric power for pumping the feedwater to the osmotic pressure) and distillation (i.e., MSF and MED). The quality of water produced from MSF or MED is proper for industrial uses including the water needs for a nuclear power plant operation and through its lifetime. The water product of RO is of potable quality and proper for domestic use. The water produced from the hybrid desalination plant can be blended for improving the quality of water produced from RO.

In a nuclear desalination project employing a hybrid desalination plant, the electricity-driven RO technology can cover the water demands for construction purposes as well as covering the demands of the community serving the construction plant. In operation phase, the waste heat rejected at the condenser of the secondary cycle of the NPP can drive a thermal-based desalination plant to provide water for covering the makeup water demands, while the RO plant covers the potable water demands or other needs. In case of an accident, the RO would serve as an efficient route to ensure sustainable reactor cooling if required, considering the electric power to be provided from the grid electricity or standby generators. In addition, RO can be used during wet decontamination (e.g., full flush of the primary system).

4. Water reclamation

Another proven approach for efficient water management is the recycling of wastewater after being chemically treated against any contained solid impurities or other contaminations. The usage of recycled water depends on the degree of treatment it passes through. In general, recycled water is used for irrigation, fire suppression, or dust control. However, In Singapore and California, reclaimed water can be used indirectly for potable use after being processed

Table 1
Water use for different cooling systems (m^3/MWh)

	Once-through (withdrawal)	Cooling pond (consumption)	Cooling towers (consumption)
Nuclear	95–230	2–4	3–4
Fossil-fuelled	76–190	1–2	2
Natural gas/oil cc	29–76	–	1

through advanced treatment. This approach is very promising to be applied in the NPPs, especially in water-stressed and arid regions and desert locations, mainly for the cooling of the power plant. This technique has been successfully implemented in Palo Verde NPP in California, where 100% reclaimed water is used for cooling.

5. IAEA tools and toolkits on nuclear desalination and water management in NPPs

The IAEA has developed different tools in support of analyzing and understanding the feasibility of different options involving water desalination and water uses and consumption in nuclear power plants. These tools are available on the IAEA website.

5.1. Desalination economic evaluation program (DEEP)

The IAEA DEEP software can be used for performance and cost evaluation of various power and seawater desalination co-generation configurations. DEEP provides detailed cash flow analysis of dual-purpose desalination plant, showing a detailed overview of the project financing; and is capable of conducting sensitivity analysis (Kavvadias et al. 2010). Also, DEEP is suitable for conducting a comparative assessment, among different plants, fuels and desalination technologies including MSD, MSF, RO, and hybrid options. It includes the formulation of different alternatives such as different turbine configurations, backup heat, intermediate loop, water transport cost, and carbon tax (Fig. 1).

5.2. Desalination thermodynamic optimization program (DE-TOP)

DE-TOP developed by the IAEA for performing thermodynamic and optimization analyses of nuclear cogeneration systems. It simulates steam power cycle of different water-cooled reactors or fossil plants, and the coupling with other applications (currently with options for nuclear desalination and district heating applications) (Sánchez-Cervera et al. 2013). With an intuitive graphical user interface and flexible system configuration, The user can select different arrangements between power plant and the coupled plant (single steam extraction, multiple steam extraction, backpressure operation, etc.; Fig. 2).

5.3. Water management program

Due to the importance of efficient management of water at nuclear power plants during the entire phases of construction, operation, and maintenance; the IAEA Water Management Programme (WAMP) was developed to enable Member States to assess various types of cooling systems and the need for cooling water and other essential systems in water-cooled nuclear power plants. The program estimates the water needs for cooling and other essential systems. Futhermore, it supports the choice of cooling systems by assessing three different criteria: water resources, the environment, and economics. WAMP enables users of performing comparisons of different cooling systems, reactor technologies, and at different site conditions. The reported results include water withdrawal and consumption estimation; and estimation of economics (capital and operating costs) for cooling systems (Fig. 3).

6. Conclusion

The high consumption of water for power generation is a major concern that faces nuclear power plants. Desalination and wastewater reclamation and treatment are currently utilized and of strong potential to increase as sources of freshwater, and these are considered as effective techniques to be implemented in the nuclear power sector. It is imperative to improve the efficient treatment and the use of water. The

Fig. 1. Interface of the IAEA desalination economic evaluation program (DEEP).

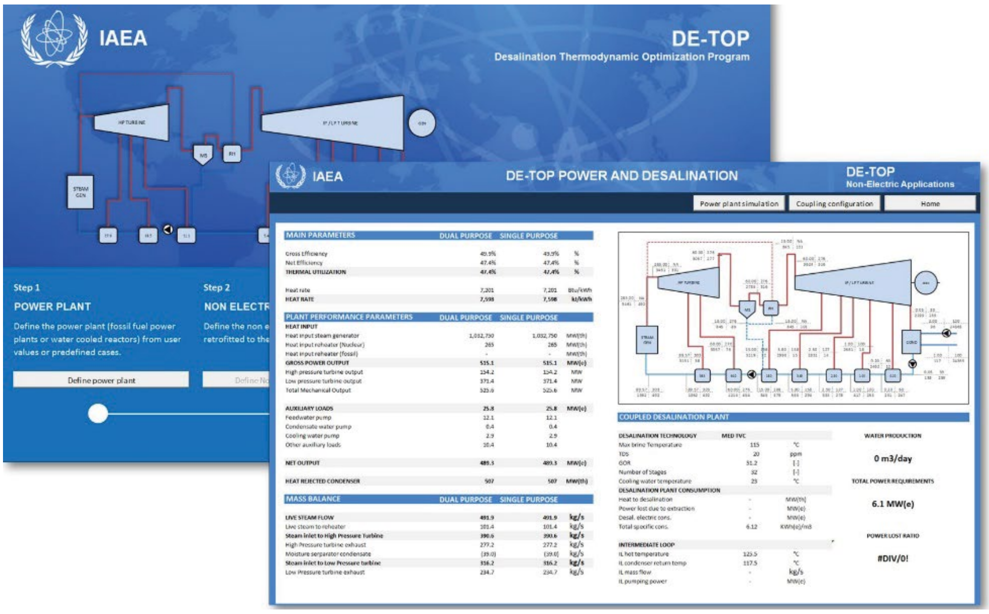

Fig. 2. Interface of the IAEA desalination thermodynamic optimization program (DE-TOP).

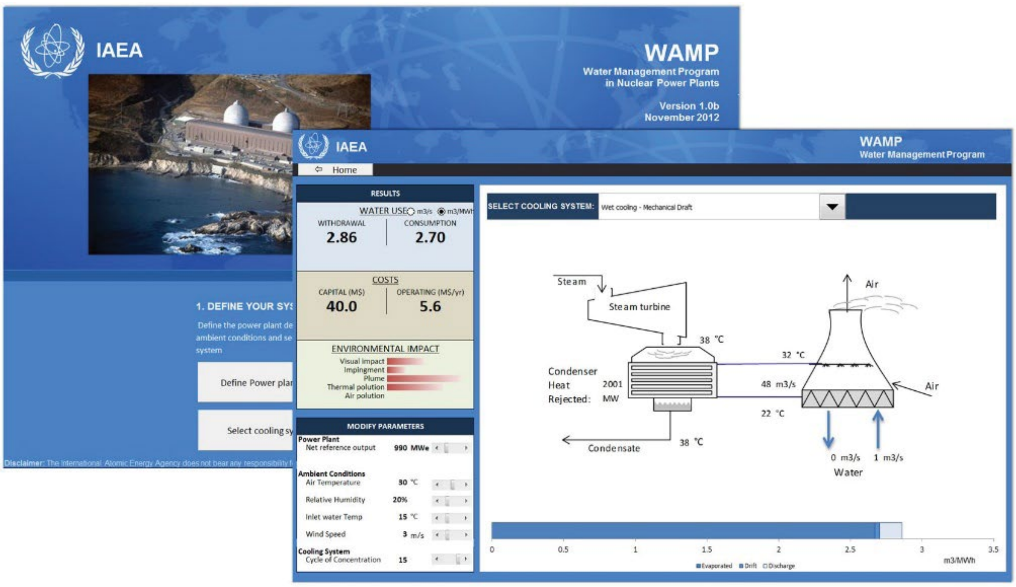

Fig. 3. Interface of the IAEA water management program (WAMP).

IAEA conducts several activities on the nuclear cogeneration of desalination applications as well as for efficient water management in nuclear power plants. The IAEA developed several tools to enable interested Member States to investigate the economics of such projects and determine their thermodynamic performance.

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