Conceptual Design of Hybrid Safety Features for NPP by Utilizing Solar Updraft Tower

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1. Introduction

These days, nations in Middle East are very interested in nuclear power plant (NPP). Republic of Korea exported 4 units of APR1400 [1] to United Arab Emirates (UAE) in 2009. Jordan and Turkey also imported commercial NPPs from the consortium of Japan and France. Recently, Republic of Korea contracted a memorandum of understanding (MOU) with Saudi Arabia for exporting Small System-integrated Modular Advanced Reactor, SMART [2]. Egypt has a plan to import commercial NPP from foreign vendors.

Usually NPPs are constructed near seashore to utilize sea water as an ultimate heat sink. Residual heat or decay heat of nuclear reactor will diffuse into the ocean through the condenser. NPPs in Middle East are expected to be placed in seashore of Arabian Gulf. The NPP site of Barakah is an actual example.

For NPPs in seashore of Arabian Gulf, an additional safety concern should be considered. Arabian Gulf is the largest oil transporting route in the world. The oil spill risk in Arabian Gulf will be the largest simultaneously [3]. Unfortunately, not like other oceans, Arabian Gulf is a kind of closed ocean which does not have strong ocean currents connected to out of the gulf. If once oil spill is occurred, its influence can be propagated more than our expectation. The spilled oil also can affect to NPPs in seashore by covering surfaces of condenser. It will directly cause loss of ultimate heat sink.

In this study, hybrid safety features for NPP with solar updraft tower (SUT) is conceptually suggested to cope with loss of ultimate heat sink accident. The hybrid safety features utilizing SUT target NPPs in seashore of Arabian Gulf.

2. Concept of Solar Updraft Tower and its Potential Applications

2.1 Concept and Structure of SUT

The basic concept of SUT is an electricity generation system with glass covered large circular area, turbine generator and sufficiently tall tower [4]. The schematic figure of SUT is presented in Fig. 1. in vertical cross-sectional view. The glass covered large area is simply named as 'collector' because the air under the glass would collect solar energy with green house effect. The heated air beneath the collector would flow toward the center of the collector.

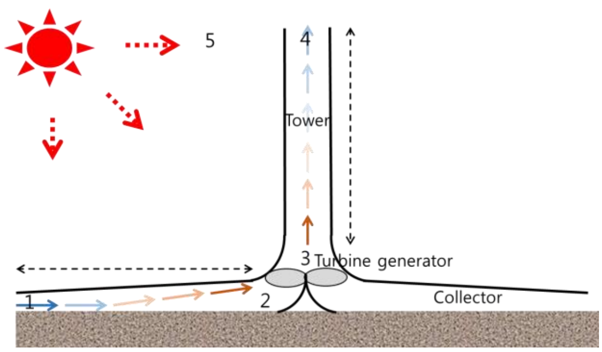

Fig. 1. Schematic diagram of SUT

The outer circumference of collector is open and it takes a role as air-intake. The only possible escape of heated air is the top of tall tower placed at the center of collector. The temperature and density of air at high altitude are lower than that of the air at ground. If the height of tower is tall enough, stable and sustainable pressure difference can be maintained through side of the collector and top of the tower during daytime. Stable air flow would be provided so the air flow can drive the turbine generator while rising up the tower.

2.2 Potential of Desalination in SUT System

SUT system produces electricity, and utilizes solar thermal energy so various desalination processes can be applied onto the system. Among them, solar humidification method is regarded as the most feasible way for SUT system [5]. Simplicity is one of the biggest advantage of SUT system so complex or combined system with many other components is not recommended.

The recommended and possible sites of SUT system are mostly placed near the equator where lack of water is serious. If SUT system is placed near seashore and combined properly with the appropriate desalination system, electricity and water production can be achieved simultaneously.

2.3 Potential of SUT System as Hybrid Safety Features for NPP

The primary and ultimate objective of NPP safety features is stable and sustainable decay heat removal [6]. Functions of NPP safety system and features are mainly focused on it. Usually, multiple heat transfer loops are provided from reactor core to ultimate heat sink. For typical pressurized water reactor (PWR) and other NPP types of which have electric power output in commercial size, water is mostly utilized as coolant and ultimate heat sink.

The safety systems of them have plenty amount of water in their in-house storage to comply with safety regulation. The injection and circulation of coolant are usually driven by electricity except for several passive systems. Many backup systems are also prepared for the electricity to drive safety systems in the guidance of safety regulation and concept of defense in depth. Anyhow, the amount of water and the capacity of electricity backup system are limited.

If consequences of accident propagate severely more than anticipated design basis accident (DBA), the operation of safety system won't be more effective at all. For example, duration of accident can be extended significantly longer than designated coping time. Furthermore, physical damage on NPP can be more severe than normal expectation. It can influence on integrities of safety systems and their components. Those kinds of situation are designated as beyond DBA (BDBA). Fukushima accident gave an important momentum for emphasizing BDBA [7]. Conclusively, researches on passive (electricity-free) safety system and dry (water-free) cooling system are being highlighted these days to cope with BDBA of NPP.

In this point of view, SUT system has highly possible potential to be linked with NPP safety system. From its original concept, SUT system can generate electricity in isolation if only sufficient insolation is provided. Desalination system can be also operated in SUT system. Without any control or supplement, SUT system can produce electricity and pure water so it is truly suitable for coping with BDBA of NPP, especially for the BDBA type of unlimited elongation of accident duration without any recovery.

3. Conceptual Design of Hybrid Safety Features for NPP by SUT utilization

Based on inherent functions of SUT system, four possible hybrid applications between SUT system and NPP are suggested. Those are emergency AC power backup, emergency cooling water source, emergency dry cooling, and emergency dispersive containment venting. The hybrid safety features of SUT system can aid normal operation of safety system and can mitigate consequence of severe accident also.

3.1 Emergency AC Power Backup

The generated electricity from SUT system can utilized as a power source of many important components in NPP such as electricity driven pumps. Representatively, reactor coolant pumps and main feed water pumps are good examples. Furthermore, the power line from the SUT system also can be linked with auxiliary feed water pump. If loss of coolant accident (LOCA) is occurred, reactor coolant will be poured onto reactor cavity and recirculation mode will be started. The recirculation pump will start to operate and the decay heat delivered from reactor core to poured water is expected to be dissipated to component cooling water through the leaked coolant.

Due to the decay heat, leaked coolant will be boiled at reactor cavity, out of the pressure vessel. If inner pressure of containment increases due to coolant evaporation, in-containment spray system should start to operate for depressurization. For that, operation of containment spray pump is needed.

Like this, electricity from SUT system can be utilized as an important power source for feed, circulation, and spray of the coolant.

3.2 Emergency Cooling Water Source

SUT system can produce distilled (DI) water from seawater by direct distillation or utilization of generated electricity. The produced DI water can be supplied to the safety system of NPP.

The representative accident of NPP is LOCA. If LOCA occurs, emergency core cooling system (ECCS) starts to operate. The water in the reactor water storage tank (RWST) will be injected into reactor vessel. After LOCA, in-containment spray will be operated to depressurization of internal pressure. The sprayed water is also from the RWST.

The water supply from SUT system can be provided to RWST. Furthermore, it can be also provided to component cooling water (CCW) for long term cooling during recirculation mode.

Other accidents, main steam line break (MSLB), loss of feed water (LOFW), steam generator tube rupture (SGTR) are requiring decay heat removal by auxiliary or emergency feed water system. The produced water by SUT system can make up those feed water also. It can provide longer coping time than the original design. If dimension of the linked SUT system is large enough, the production rate of DI water can overcome the consumption rate during the accident.

3.3 Emergency Dry Cooling

The forced air convection is always provided when SUT is in normal operation. If feed water in auxiliary feed water system (AFWS) is totally dried out, the exchanged heat is exposed into atmosphere directly.

The heat transfer efficiency of air natural convection is extremely low and it is not enough to remove decay heat effectively. If forced air convection driven by SUT is provided on the cold side of indirect heat exchanger, the heat transfer efficiency will be increased in the order of several scores to hundreds times. Similarly, it can be also served as dry containment cooling method.

Particularly, this dry cooling concept can be applied to liquid metal reactor (LMR). Due to its specialty of liquid metal coolant, LMRs are usually designed to utilize atmospheric air as ultimate heat sink. KALIMER(Korea Advanced Liquid MEtal Reactor) [8] and iSFR(Innovative Sodium-cooled Fast Reactor) [9] are good instances. In those LMR, decay heat is delivered from decay heat exchanger(DHX) to air heat exchanger(AHX). Their decay heat removal performance is dominantly influenced by heat transfer rate of AHX. The air natural circulation at cold side of AHX is the performance barrier. If forced air convection is provided by SUT, the performance of decay heat removal will be enhanced much.

3.4 Emergency Dispersive Containment Venting

The SUT system has a long and slim tower at the center of it. The height of tower is usually in the order of several hundreds meter. It can reach about 1 km at most. In the normal operation of SUT, the forced air flow is escaping to the top of tower.

In case of nuclear accident, if in-containment pressure is uncontrollably increased despite all efforts to depressurize, containment venting is carried out. Several NPPs have containment filtered venting system (CFVS) for filtering radioactive nuclides. It is helpful to minimize radioactive nuclides release. However, due to lack of technology development, specific radionuclides are not filtered sufficiently. Organic Iodine is one of them.

The tall tower of SUT can be utilized as release exit of containment venting. The released air at several hundred meters high will spread over the atmosphere. The magnitude and density of radioactivity will get lower than normal venting process at ground level. Of course, the specific study for radioactive nuclides dispersion through the tower and its environmental effect should be analyzed precisely. The technical evaluation coupled with political view should be delivered in advance because it is a problem of contamination dispersion, higher density contamination in restricted area vs. lower density contamination in larger area.

4. Conclusion

SUT system can be applied on NPPs as hybrid safety features. Four possible hybrid applications between SUT system and NPP are suggested and discussed. Those are emergency AC power backup, emergency cooling water source, emergency dry cooling, and dispersive containment venting. The hybrid safety features of SUT system are expected to aid normal operation of safety system and mitigate consequence of severe accident. Detail analysis and technology development is ongoing now [10].

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