13

Power Uprate Effect on Thermal Effluent of Nuclear Power Plants in Taiwan

Jinn-Jer Peir
NSTDC, National Tsing Hua University
Hsinchu, 30013
Taiwan, R.O.C.

1. Introduction

Power uprate is presently being considered by several nuclear power plant (NPP) utilities as a promising way to increase the power generation efficiency of existent power plants with or without increasing nuclear fuel consumption since 1970s. In general there are three types of power uprate: measurement uncertainty recapture power uprate (MURPU, <2%), stretch power uprate (SPU, 2 to 7 %), and extended power uprate (EPU, 7 to 20%) (US NRC, 2011 a). Thorough evaluations of existing plant equipments and environmental impact must be assessed before a final decision and an optimal selection of power uprate are made. Upon a power uprate, the power density and thermal release of a nuclear reactor would increase instantly, followed by the impact due to the waste heat from the thermal effluent to the environment. In Taiwan, two BWR NPPs and one PWR NPP were scheduled for MURPU. These NPPs are all located at the seacoast and using marine water as the coolant due to that fact that there is no rivers can supply enough light water near the site of the NPP in Taiwan. The marine water temperature is high during summer time due to the fact that Taiwan's weather is marine tropical. According to the Effluent Standards of Taiwan's Environmental Law: for effluents discharged directly into marine waters, the temperature at the discharge point shall not exceed 42°C; and the temperature difference should not exceed 4°C for surface water at 500 meters from the discharge point. Hence, the effect from the waste heat is always a very crucial issue to the power uprate of NPPs in Taiwan.
Currently the three operating NPPs of Taiwan are all owned by the Taiwan Power Company (TPC). There are two reactor units setup at each NPP. The technology chosen for the reactors is General Electric (GE) BWR for Chinshan Nuclear Power Plant (NPP1) and Kuosheng Nuclear Power Plant (NPP2), and Westinghouse PWR for Maanshan Nuclear Power Plant (NPP3). Moreover, Lungmen Nuclear Power Plant (NPP4), which is GE ABWR and will to be the largest NPP in Taiwan, is still under construction at present. Fig. 1 shows the locations of NPPs in Taiwan. As can be seen, NPP1 and NPP2 are located in the most northern part of Taiwan in which is a subtropical zone, whereas NPP3 is located in the most southern part of Taiwan where is a tropical zone. They are all located next to the seacoast and using marine water as the coolant due to the fact that there is no any big rivers can

enough supply light water near the site of the NPPs. Table 1 lists the basic operational parameters for one unit of NPP1, NPP2, and NPP3, respectively. The total installed capacity is 5144 MWe which is around 20% of its entire electricity generation in 2007. This makes

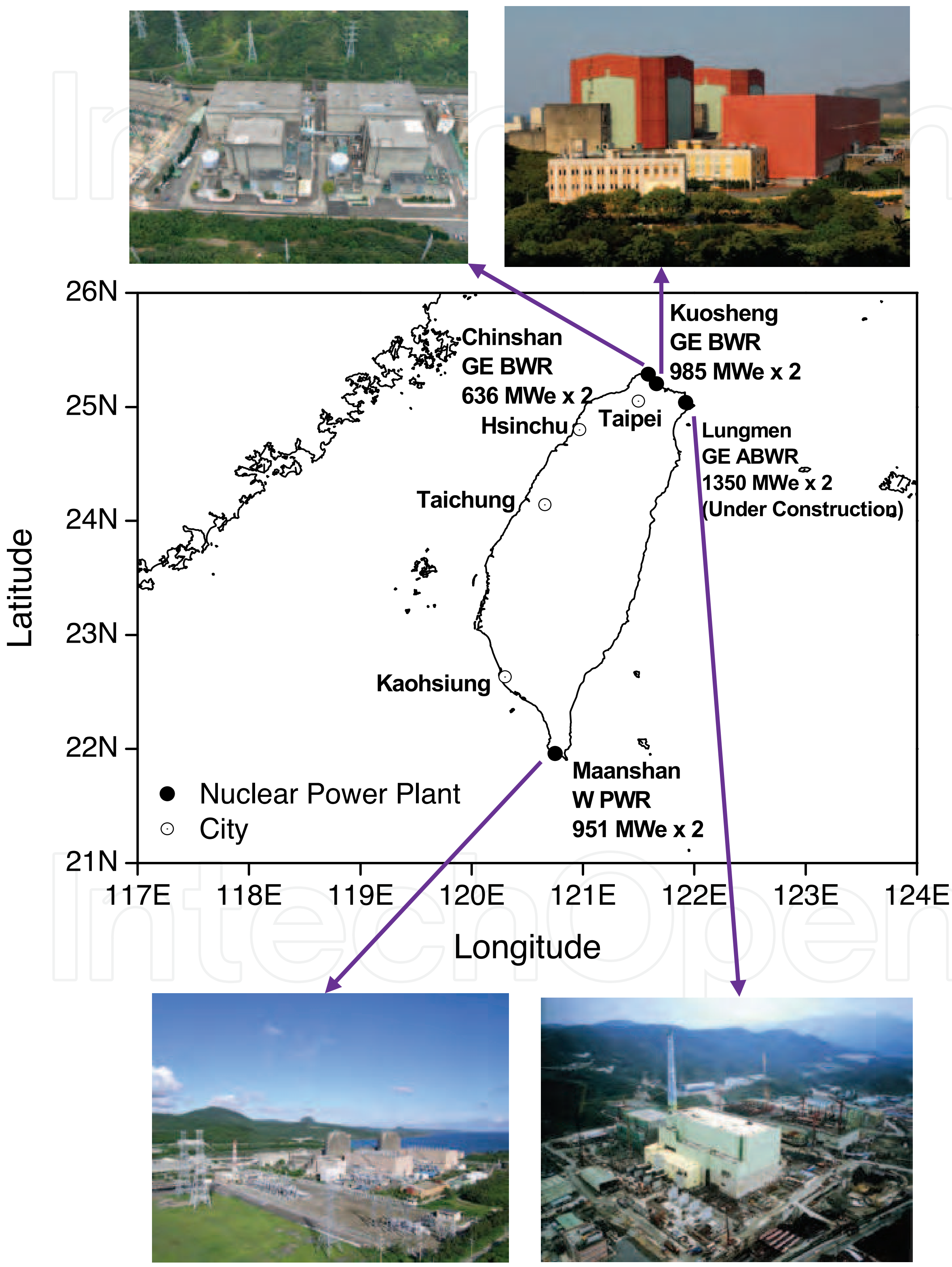


Fig. 1. The locality and outlook of nuclear power plants in Taiwan

Taiwan the 15th largest user of nuclear power in the world. TPC was planned to perform the 1.7% MURPU for all TPC's three operating nuclear power stations by schedule before the end of 2009 (Table 2). Therefore, the impact from the increasing power density and thermal release of a nuclear reactor to the environment from the heated effluent of NPP could enlarge simultaneously. Due to Taiwan's climate is marine tropical, the entire island is hot and humid from June to September. Moreover, the western side of the Pacific Ocean is warmer than the east as a result of the ocean current (WTT, 2011).
The marine water temperature around Taiwan could be more than 30°C during summer time. Therefore the impact from the waste heat of NPP could be severe and is needed to be evaluated when performing the power uprate of NPPs. Furthermore, to comply with the Effluent Standards of Taiwan's Environmental Law, especially in summer, the thermal effluent's problem will cause the reactor must be operated at a reduced power and consequently influence the electricity supply. This paper studies the power uprate effect due to waste heat release from the thermal effluent of Taiwan NPPs. The investigations were based on the thermal equilibrium of 100%, 105%, and 110% rated power, respectively. The long term monitor data of marine water temperature were also used to evaluate the impact level from waste heat during normal operation of NPPs. Moreover, the assessments of some helpful methods to mitigate thermal impact on thermal effluent from NPPs and the feasibility of these methods are also discussed correspondingly.

Parameter	NPP1	NPP2	NPP3
Thermal efficiency	35%	33%	34%
Rated thermal power	1817 MW	2985 MW	2785 MW
Net electric power	636 MW	985 MW	951 MW
Waste thermal power	1181 MW	2000 MW	1834 MW
Cooling water flow rate	34570 kg/sec	43906 kg/sec	47442 kg/sec

Table 1. The operational parameters of each NPP reactor unit in Taiwan

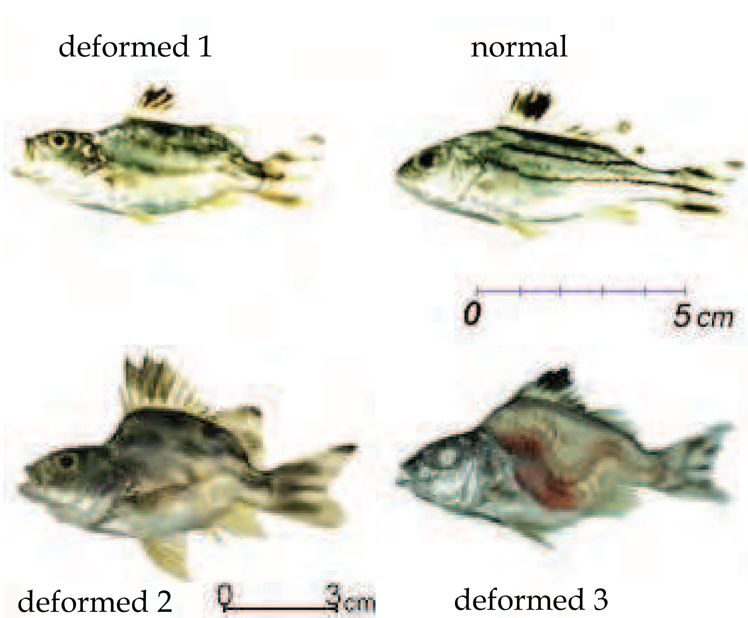
Reactor Unit	NPP1	NPP2	NPP3
Unit 1	2009.02.24	2007.11.30	2009.07.07
Unit 2	2008.07.09	2007.07.07	2008.12.02

Table 2. The MURPU completed date of NPPs in Taiwan

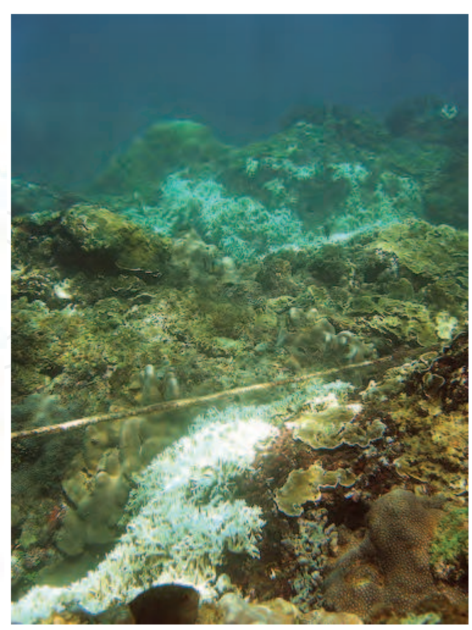
2. Impact of waste heat in Taiwan

In accordance with the second law of thermodynamics of Derive Kelvin Statement which is also called heat engine formulation, it is impossible to convert heat completely into work in a cyclic process (Hyperphysics, 2011). Hence, it is unattainable to extract energy by heat from a high-temperature energy source and then transfer all of the energy into work. At least some of the energy must be passed on to heat a low-temperature energy sink. Therefore, there is no heat engine with 100% efficiency is possible. Waste heat is always an unavoidably by-product of NPPs. Generally the electrical efficiency of NPP, defined as the ratio between the input and output energy, most of the time amounts up to 33%. So the 67% heat is waste heat and must be released to the environment. Economically the most convenient way is to exchange such heat to water and then discharge them to sea, lake or river. If no sufficient cooling water available, most of the NPPs will equip with cooling towers to reject the waste heat into the atmosphere. In Taiwan, all NPPs are using marine water as the coolant and discharge the thermal water to the nearby sea. Therefore, waste heat impact to the marine environment is very sensitive and monitor by the public rigorously. Much more attention has been paid to workplace ecology for quite a time.

In northern Taiwan, a number of deformed thornfishes (Fig. 2. (a)) were first found since 1993 near the thermal outlet of NPP2. Although there is no clear links between the deformed fishes and the NPP, people directly think that the radiation is from nuclear power plant and therefore resulted in the deformed fishes. Through research studies, high temperature of ocean water had been proved to be the main factor of deformed Terapon jarbua and Liza macrolepis (Hung et al., 1998; Fang et al., 2004). In southern Taiwan, coral bleaching (Fig. 2. (b)), the whitening of diverse invertebrate taxa, was reported in July 1987 and July 1988 in adjacent marine water of the NPP3 (Fang et al., 2004). High sea surface temperature with high irradiance is assumed to be the primary factor in summer coral bleaching (Huang et al., 1992; Fang et al., 2004; Shiah et al., 2006). The increasing use of marine water for industrial cooling and the global warming might present a potential threat to the ecological environment in the ocean.



(a)



(b)

Fig. 2. (a) Deformed thornfishes in northern Taiwan ; (b) Coral bleaching in southern Taiwan (Ching-wai Yuen, 2011)

3. Effluent temperature evaluation

Because the events mentioned above were related to thermal discharge from NPPs, which elevated the marine water temperature and caused the damage, so the Effluent Standards of Taiwan's Environmental Law: for effluents discharged directly into marine waters, the temperature at the discharge point shall not exceed 42 °C; and the temperature difference should not exceed 4 °C for surface water at 500 meters from the discharge point, are

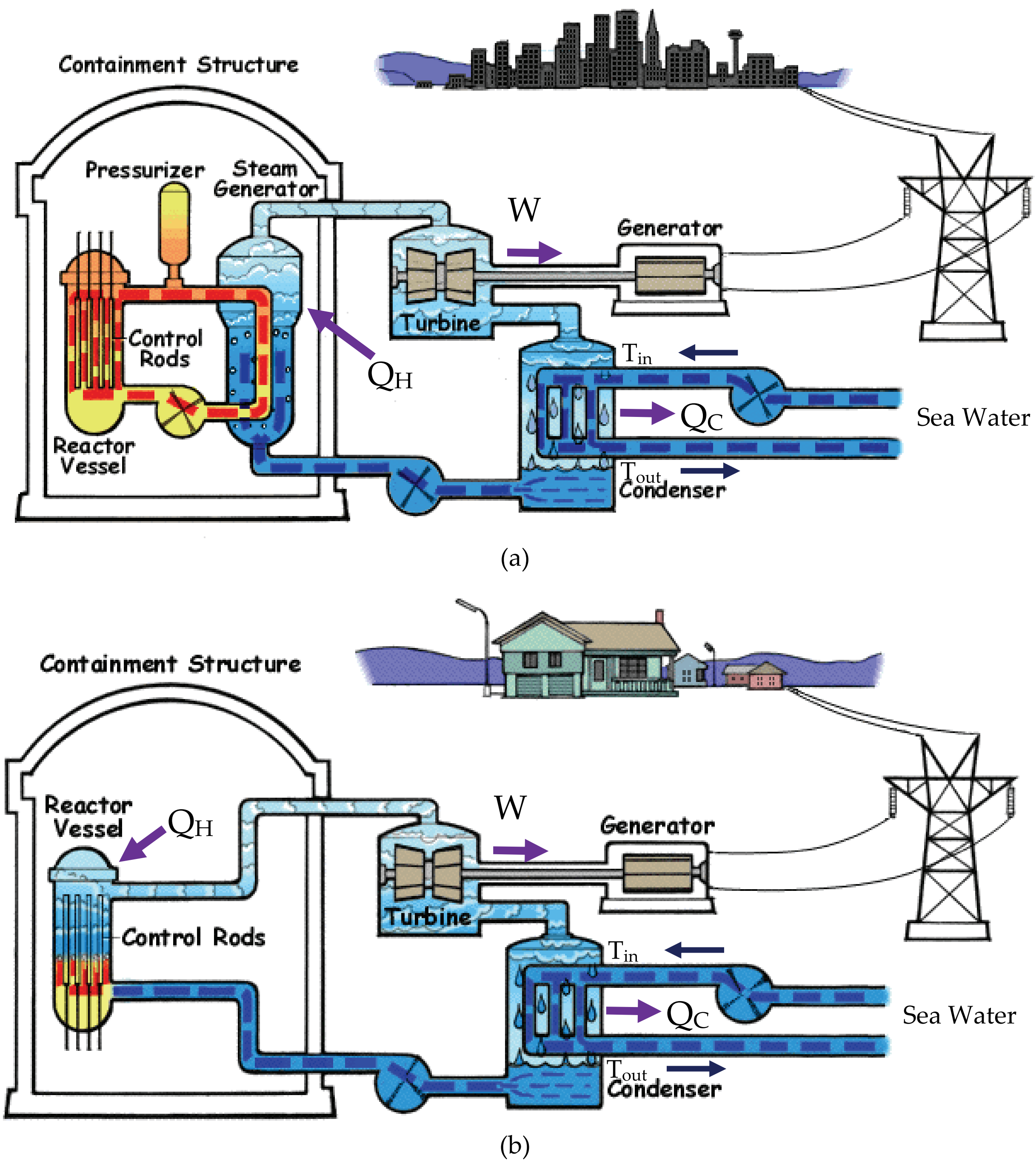


Fig. 3. The schematic diagram of (a) a PWR; (b) a BWR. The heat transfer routes are also depicted, respectively. (background images are taken from USNRC, 2011 b)

formulated to protect the ecological environment in adjacent marine water of NPPs. To assure the feasible of power uprate in Taiwan's NPPs, based on the Effluent Standards, we conservatively evaluate the temperature difference between the outlet and inlet of condenser at 100%, 105%, and 110% rated power, respectively, by simply using specific heat capacity equation and the basic data in Table 1. Moreover, inlet and outlet temperatures of condenser, the marine water temperatures of 500 from the effluent discharge points, and the background marine water temperatures of 1000~1500 meters from the effluent discharge points, which were all taken from long term temperature monitor setup by TPC's NPPS, are used to assess the impact level of thermal water from June to September, respectively.

Fig. 3 (a) shows the schematic diagram of a PWR system and Fig. 3 (b) is the schematic diagram of a BWR system. As can been seen the cooling cycle from the figure, an amount of heat QH, which can be derived from the thermal power of NPP, is transferred from the reactor, the net work W is delivered to the electric generator as it is driven by turbine, and the waste heat Q_C is rejected to the cooling water in the condenser and then discharged to the sea which could lead to the thermal pollution problem. To evaluate the elevated temperature of the effluent from NPPs, the waste heat Q_C of the is simply got by the following equation:

$$Q_C = \dot{m} \cdot C \cdot (T_{out} - T_{in}) = \dot{m} \cdot C \cdot \Delta T \tag{1}$$

where $\dot{m}$ is the mass flow rate of cooling water (kg/sec), C is the specific heat of water (4186 joule/kg/°C), T_{out} is the outlet temperature of condenser (°C), T_{in} is the inlet temperature of condenser (°C), and ΔT is the difference between the outlet temperature and of the inlet temperature condenser (°C). Moreover, the waste heat Q_C can also be expressed by

$$Q_C = Q_H(1\text{-}\eta) \tag{2}$$

where η is the thermal efficiency and is defined as:

$$\eta = \frac{W}{Q_H} = \frac{Q_H\text{-}Q_C}{Q_H} \tag{3}$$

Using (1), (2), and the data listed in Table 1, the elevated temperature can be simply calculated. Furthermore, the ΔT at 100% power is used to predict the average elevated temperature of cooling water at 105%, and 110% power, respectively.

4. Effluent temperature and the reduction of seawater temperature

Table 3 lists the results of calculated temperature difference between inlet and outlet of condenser at 100%, 105%, and 110% rated power of NPP1, NPP2, and NPP3, respectively. The differential temperature from on-line monitor, at 100% normal operation power, and the predicted temperature differences at 105% and 110% rated power, are also shown in the table, correspondingly.

Fig. 4 displays the average water temperature of each NPP at the condenser inlet and outlet from June to September in 2006. Apart from, the corresponding data of 2007 are shown in Fig. 5. The elevated temperatures of cooling water after passing through condenser can also be seen in the figures. As can be seen, the average inlet temperatures are 27.0, 27.9, and 28.9 °C for NPP1, NPP2, and NPP3; whereas the corresponding outlet temperatures are 36.2, 39.9, and 36.8 °C for NPP1, NPP2, and NPP3 by averaging the values of 2006 and 2007, respectively. Also shown in the figures of the elevated temperatures are calculated to be 8.2, 10.9, and 9.2 °C for NPP1, NPP2, and NPP3; whereas the corresponding monitoring data are 9.2, 12.0, and 7.9 °C for NPP1, NPP2, and NPP3 by averaging the values of 2006 and 2007, respectively. Therefore, the temperature difference between calculated and monitor data are 1.0, 1.1, and -1.3 °C. The different trend between them might be caused by more heat loss into atmosphere during heat exchanging at steam generator of PWR. Notably, the highest elevated temperature of NPP2 is 12 °C. According to the ocean observation of Taiwan, the marine water temperature could be near 30 °C in summer (CWBS 2011), thus the outlet temperature of condenser could be possible over 42 °C. From Fig. 4 and Fig. 5, we can also observe the outlet temperature of condenser is just around 42 °C especially in July. To avoid the effluent temperature exceeding 42 °C which is the limitation temperature of the Environmental Law, TPC cautiously operates NPP in the condition that the outlet temperature of condenser could be under 42 °C. Otherwise the operators of NPPs will operate the reactor from full power to a lower power. This will make TPC in a dilemma especially when the electricity demands are often urgent in summer. Thus for NPP2's power uprate it is better to take feasible engineering actions to lower 0.6~1.1 °C of the elevated temperature.

% Power	Calculated elevated temperature (°C)	Average elevated temperature of cooling water (°C)
NPP1		
100	8.2	9.2
105	8.6	9.6*
110	9.0	10.0*
NPP2		
100	10.9	12.0
105	11.5	12.6*
110	12.0	13.1*
NPP3		
100	9.2	7.9
105	9.6	8.3*
110	10.1	8.8*

*Predicted value

Table 3. Average water temperature differences between condenser inlet and outlet of NPP1, NPP2, and NPP3, respectively

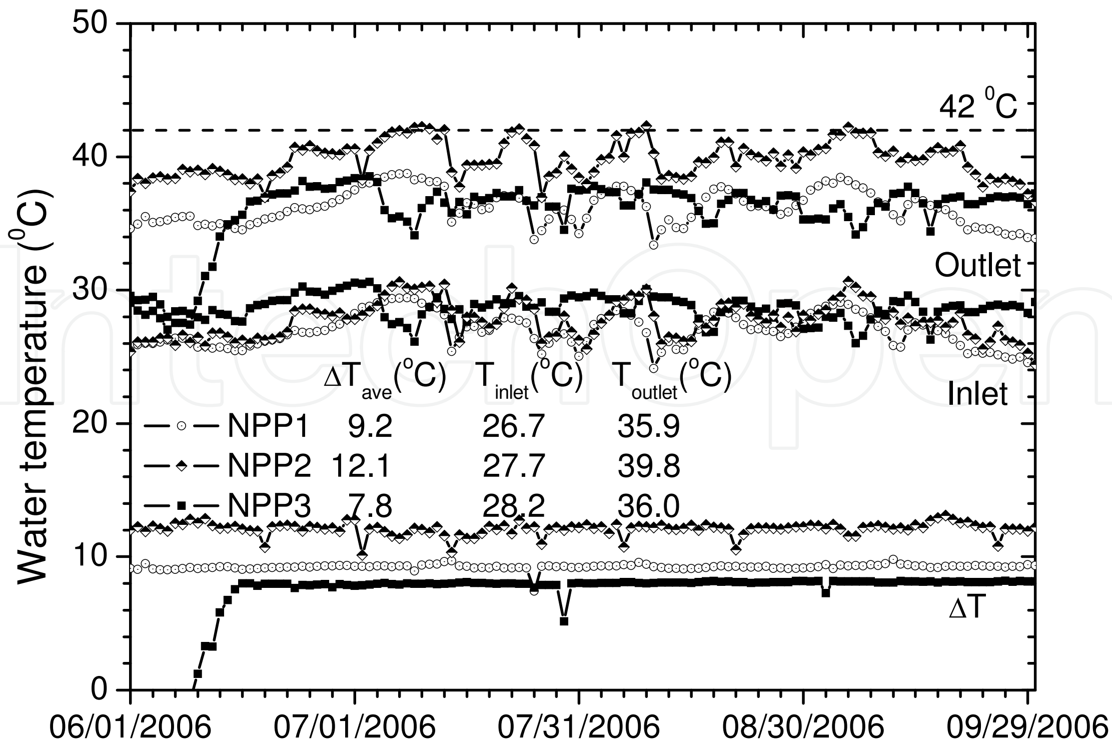


Fig. 4. The average temperature of NPP1, NPP2, and NPP3 at the condenser inlet and outlet from June to September in 2006. ΔT is the elevated temperature of cooling water between the condenser inlet and outlet. NPP3 was not operated in full power before June 15

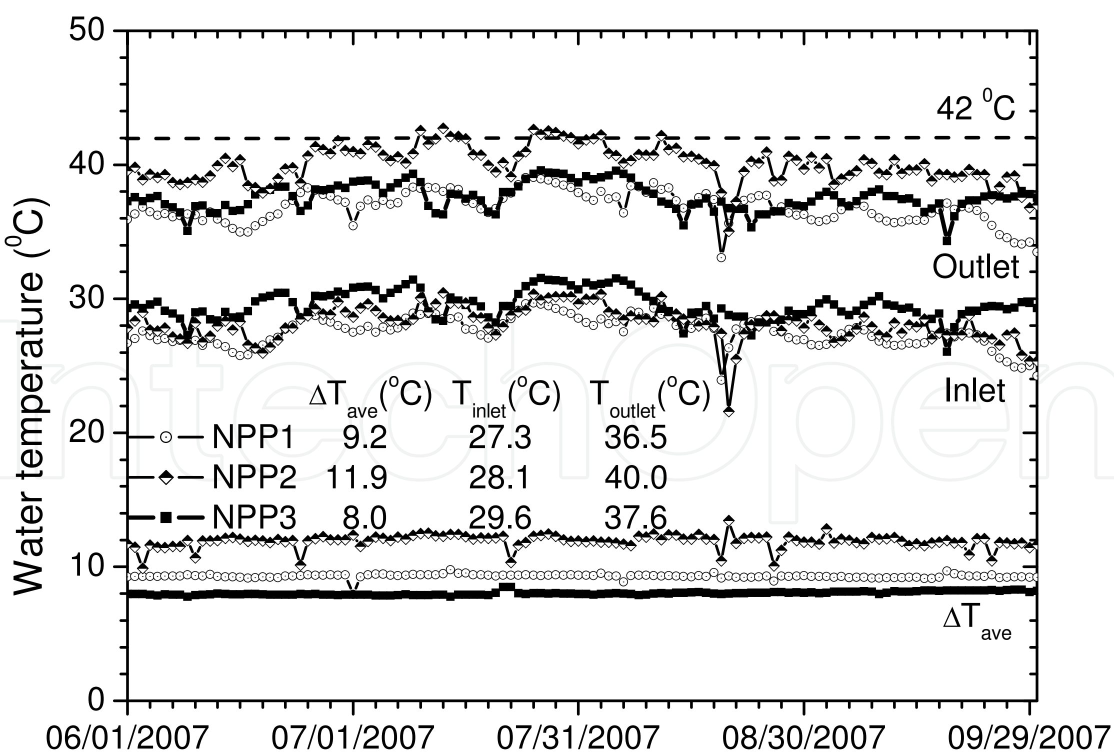


Fig. 5. The average temperature of NPP1, NPP2, and NPP3 at the condenser inlet and outlet from June to September in 2007. ΔT is the elevated temperature of cooling water between the condenser inlet and outlet

To reduce the effect of thermal effluent to the marine water ecology adjacent NPP, some effective methods: for example, prolong the discharge point by extending the path distance of effluent, lower the influent temperature by pumping deep level (deeper than 300 m) marine water, enlarge the transfer area of condenser, increase the flow rate of coolant by using higher power pumps, and improve the heat transfer efficiency by cleaning the pipes or replacing high efficiency pipes, can be used. However, these methods could be difficult to perform because of the huge engineering cost or the induction of side effects, such as water hammer, to the reactor system. Therefore, they are economically impractical or infeasible in solving the thermal effluent problem of NPPs.

Recently, a possible technical solution for increasing the thermoelectrical plant efficiency has been proposed by reducing the cold source temperature (Şerban et al., 2010). The method is originated from the concept of lowering the cooling water temperature by pumping deep level marine water. Approximate 10~20 °C reduction of influent temperature can be achieved by pumping from the 150~500 m ocean depth where the temperature is independent on the season and ranges between 5 ~15 °C. It can effectively reduce the cold source's temperature for open circuit and may increase the rated power of a thermal power plant with 2~4 % without increasing fuel consumption. The method can obviously overcome the problem of large variations of temperature function of the weather conditions and season. Moreover, the surface sea water often contains a lot of microorganisms that can nourish and deposit on the heat transfer pipes. Thus can more or less affect the heat exchange ability and lower the power efficiency. This innovative installation can provide a cold influent to NPPs and circumvent the pumping of polluted sea water. It will be very helpful to the power uprate of NPPs.

In Taiwan, dilution pump, which is currently being used at NPP3 (Fig. 6), of the same level as circulation pump can be employed to pump the background marine water (~30 °C) to mix with thermal effluent (~38 °C) before it is discharged into the ocean. Moreover, there are at least two obvious advantages to install the dilution pump at NPP although additional electricity consumption needed to operate the pump: firstly, it can regulate the thermal effluent temperature of NPP especially in summer time; secondly, it can be also a redundancy of circulation pump.

The idea of dilution pump is originated with the thermal equilibrium concept:

Heat rate lost by thermal water = Heat rate gained by cool water

$$-\dot{Q}_{tw} = \dot{Q}_{cw} \tag{4}$$

and then the following equation can be utilized to calculate the reduced temperature diluted by the marine water,

$$-C\dot{m}_{tw}\Delta T_{tw} = C\dot{m}_{cw}\Delta T_{cw} \tag{5}$$

where $\dot{Q}_{tw}$ is the thermal water heat loss rate (W/sec), $\dot{Q}_{cw}$ the cool water heat gain rate (W/sec), $\dot{m}_{tw}$ the thermal water flow mass (kg/sec), $\dot{m}_{cw}$ the cool water flow mass (kg/sec), C the specific heat of water (4186 joule/kg/°C), ΔT_{tw} the temperature difference of thermal water (°C), ΔT_{cw} the temperature difference of cool water (°C), respectively.

In NPP3, there are four circulation pumps for each unit; the power of dilution pump is 1.07 larger than the circulation pump. Thus 2.1 °C reduction of the outlet coolant for one unit can be got from equation (5). Similarly, the reduced temperature of the outlet coolant can be 2.4 °C if one dilution pump installed on one unit at NPP2. It is sufficient to compensate the thermal impact causing by the power uprate and make sure that the effluent temperature can be less than 42 °C.

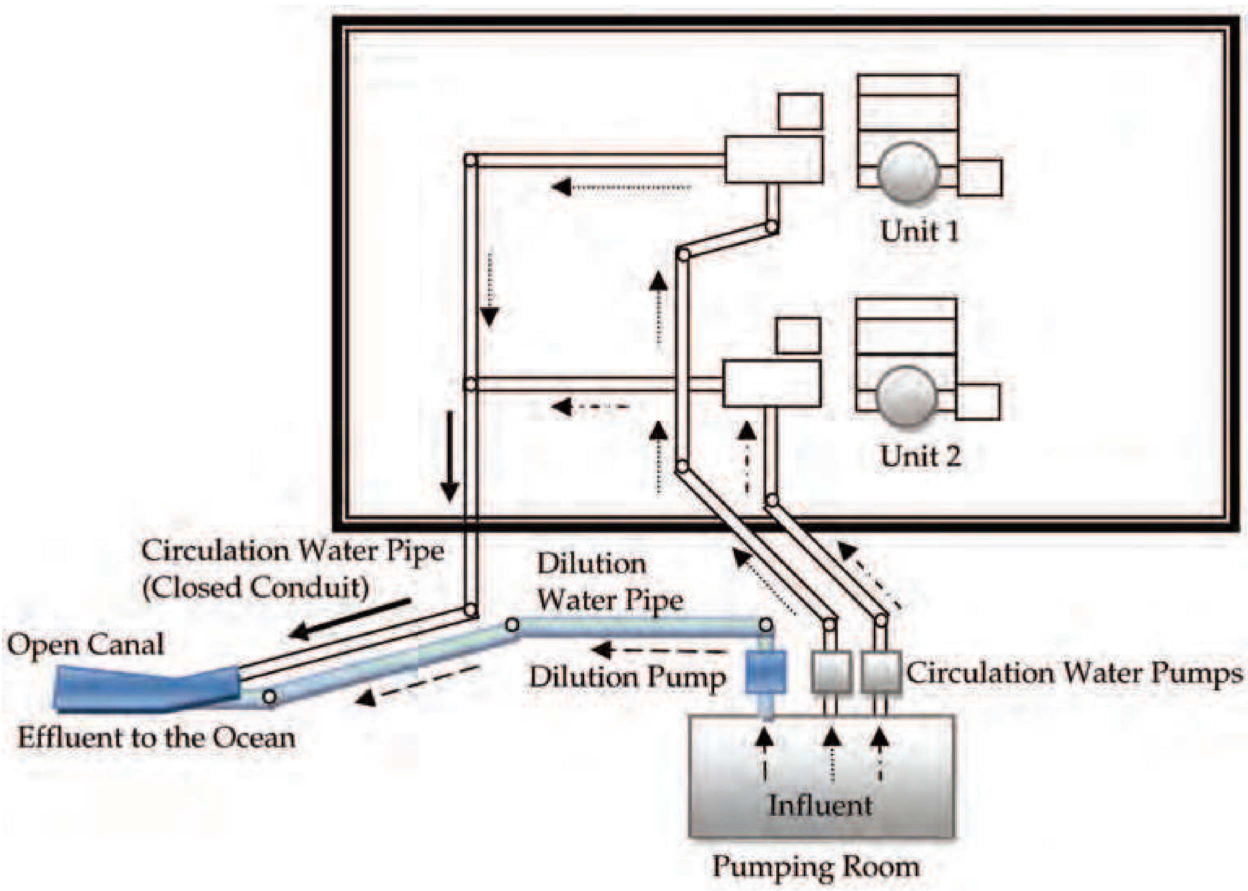


Fig. 6. The schematic flow diagram of dilution pump at NPP3

On the other hand, the Effluent Standards also require that the temperature difference (ΔT) should not exceed 4°C for surface water at 500 meters from the discharge point. Therefore, TPC arranges temperature monitors around the outfall point at each NPP to biweekly inspect the water temperature (Peir et al., 2009). Fig. 7, Fig. 8, and Fig. 9 show the monitor locations of NPP1, NPP2, and NPP3, respectively. As can be seen, there are two monitor groups, group A which is 500 m away from the discharge point, and corresponding group B, which is 1000~1500 m away from the discharge point and is set as the background temperature of marine water. The monitor results showed that the average temperature differences between group A and corresponding group B should less than 4 °C. The most probable zone for ΔT exceeding 4°C is an area in the range of thermal effluent outfall and group A monitors. Intuitively, the ΔT greater than 4°C should be more frequently observed at the points N1A1, N2A2, N2A3, N3A2, and N3A3 than other points. But the discharged effluent travels in a canal and then mixes with sea water at a distance of 50-500 meters from the discharge point. The travelled distance of the effluent is dependent on the coastal current and littoral drift. Therefore, we observe some of the prompt values of ΔT could not be as expected under the limitation of 4°C (RRTC, 2006, 2007).

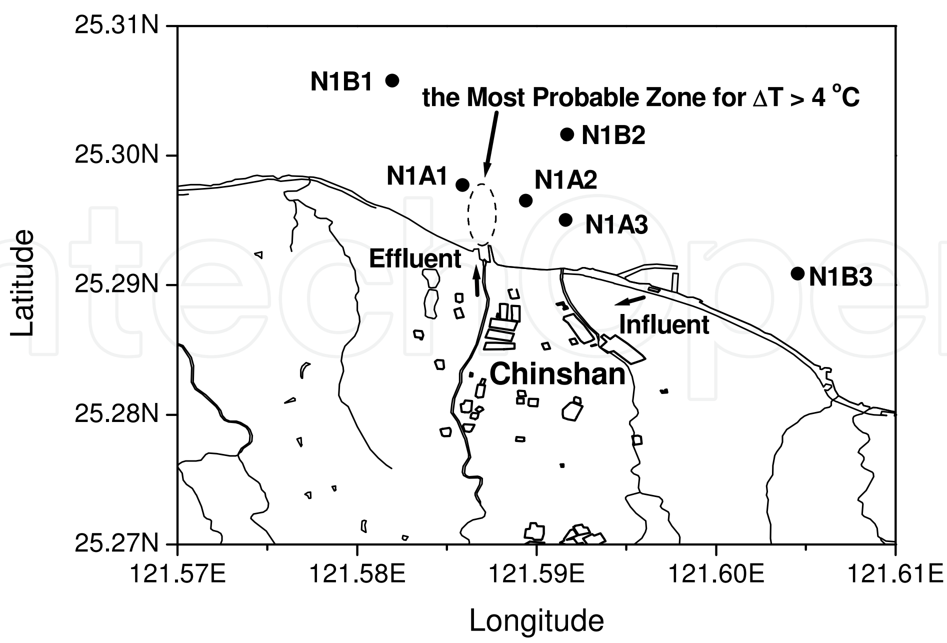


Fig. 7. The locations of water temperature monitors group A, N1A1, N1A2, and N1A3 and corresponding group B, N1B1, N1B2, and N1B3 at NPP1. Group A is 500 m away from the effluent discharge point. Group B is set as the background temperature of marine water

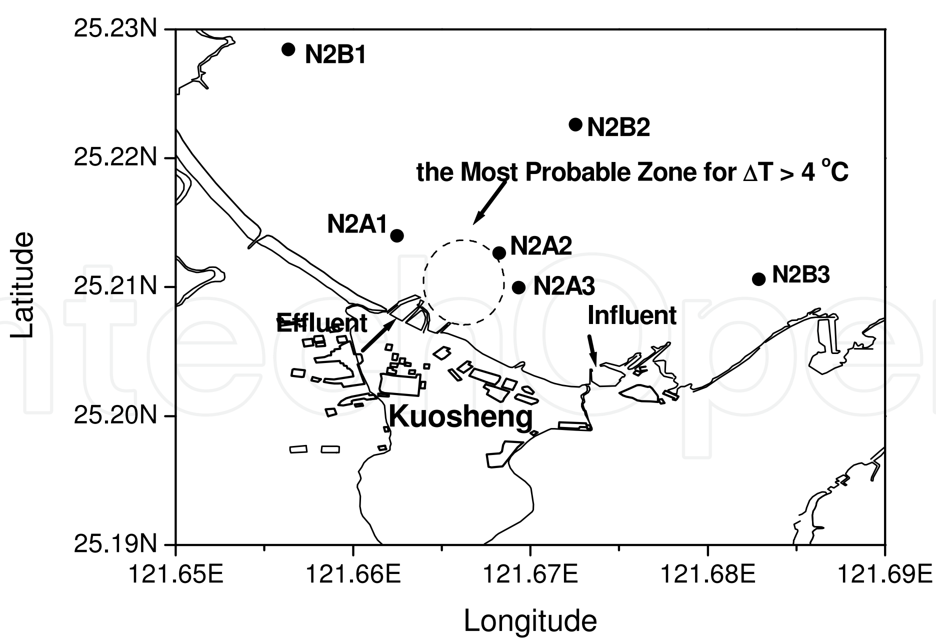


Fig. 8. The locations of water temperature monitors group A, N2A1, N2A2, and N2A3 and corresponding group B, N2B1, N2B2, and N2B3 at NPP2. Group A is 500 m away from the effluent discharge point. Group B is set as the background temperature of marine water

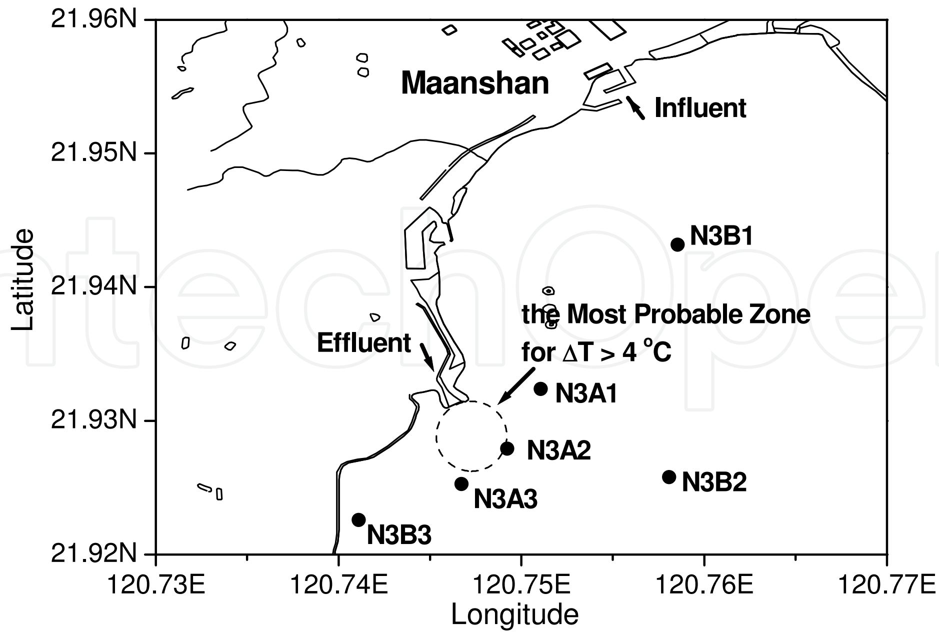


Fig. 9. The locations of water temperature monitors group A, N3A1, N3A2, and N3A3 and corresponding group B, N3B1, N3B2, and N3B3 at NPP3. Group A is 500 m away from the effluent discharge point. Group B is set as the background temperature of marine water

ID No.	2006	2007
NPP1		
N1A1	0	0.49
N1A2	0	0
N1A3	0	0
NPP2		
N2A1	0	1.61
N2A2	0.18	0.62
N2A3	0.85	0.13
NPP3		
N3A1	0.03	0
N3A2	0	0
N3A3	0	0

Table 4. The prompt probability that the temperature difference greater than 4°C between monitor group A and corresponding group B in 2006 and 2007

Table 4 lists the prompt probability of exceeding temperature, which is the data number ratio between exceeding temperature and all measured data, that the temperature difference is greater than 4 °C between group A and corresponding group B in 2006 and 2007, respectively. As shown, the probability is highest at NPP2; while NPP1 is the second and then is the NPP3. The temperature differences were all less than 4.8 °C and all events were happening in summer (RRTC, 2006, 2007). The probability is apparently dependent on the elevated temperature of effluent and probably on its flow rate, its discharge type, the wind's direction, and coastal current. Current stagnation near the coast, where forming the most probable zone for the temperature difference greater than 4 °C, could also be another possible reason. As shown in Table 5 (the seawater temperatures measured at Longdong buoy which is also set up by Central Weather Bureau located at 120.82280E, 21.90220N near NPP1 and NPP2) and Table 6 (the seawater temperatures measured at Erluanbi buoy which is set up by Central Weather Bureau located at 121.93073E, 25.09348N near NPP3), the average seawater temperatures in adjacent to NPP3 can be 1.0~2.1 °C higher than those of NPP1 and NPP2 during summer, while the prompt probability of exceeding temperature is not correspondingly high. Obviously, by using the dilution pump the heated effluent can be effectively diluted with the background marine water and the discharge flow rate can be increased. The former will directly reduce elevated temperature of effluent; while the latter makes the thermal water be pushed longer away from the seashore. Thus makes the power uprate of NPPs not violating the Environmental Law. Besides, according to the observation data of the seawater temperatures in Table 5 and Table 6, the average seawater temperatures were in the range of 26.1 ~ 27.9 °Cnear NPP1 and NPP2, and of 28.2 ~ 29.1 °Cnear NPP3 from

Month	Maximum Seawater Temperature(°C)	Observation Year	Average Seawater Temperature(°C)	Minimum Seawater Temperature(°C)	Observation Year
1	22.8	2001	19.1	15.6	2003
2	23.2	2007	18.7	15.1	2005
3	25.0	2007	19.4	13.8	2000
4	27.9	2002	21.6	14.5	2000
5	28.9	2007	23.9	18.2	2009
6	29.7	2001	26.1	20.0	1999
7	31.5	2001	27.6	16.6	2008
8	31.7	2001	27.9	16.1	2009
9	31.1	2001	26.7	18.6	2008
10	27.4	2000	24.0	19.2	2005
11	26.3	2001	22.2	17.5	2009
12	24.2	2006	20.2	16.8	2004

Table 5. The seawater temperatures measured at Longdong buoy which is set up by the Central Weather Bureau located in the northern Taiwan near NPP1 and NPP2 (CWBS, 2011)

June to September, respectively. In the northern Taiwan near NPP1 and NPP2, the maximum seawater temperature 31.7 ℃ was observed in August, 2001, and in the southern Taiwan near NPP3, the maximum seawater temperature 36 ℃ was observed in July, 2005. Notably TPC has performed the 1.7% MURPU for all TPC's operating NPPs during 2007 and 2009. The increasing release of waste heat should directly causing the maximum seawater temperature is observed immediately after 2007. However, based on the observation data of CWBS, the elevation of seawater temperature does not increase correspondingly after the MURPU of NPPs in Taiwan. Although the additional influence of the ecology due to the thermal effluent of MURPU is insignificant at present, TPC has better monitor the seawater temperatures near NPPs continually for further power uprate (SPU or EPU) in the future. Moreover, the installation of dilution pump or innovation of pumping deep level water to effectively reduce the influent temperature could be two feasible options for prevailing over the difficulty of waste heat problem in power uprate.

Month	Maximum Seawater Temperature(℃)	Observation Year	Average Seawater Temperature(℃)	Minimum Seawater Temperature(℃)	Observation Year
1	28.9	2001	24.8	18.7	2006
2	28.4	2001	24.9	20.1	2005
3	30.6	2001	25.5	20.7	2005
4	31.2	2001	27.1	22.4	2005
5	32.5	2001	27.8	19.8	2002
6	32.1	2007	28.2	21.2	2002
7	36.0	2005	29.1	20.8	2002
8	33.7	2007	29.0	23.0	2004
9	32.7	2007	28.9	22.5	2005
10	30.4	2009	28.1	21.0	2001
11	29.4	2002	26.4	21.1	2003
12	29.2	2002	25.1	16.1	2003

Table 6. The seawater temperatures measured at Erluanbi buoy which is set up by the Central Weather Bureau located in the southern Taiwan near NPP3 (CWBS, 2011)

5. Conclusion

In conclusion, the 100%, 105%, and 110% rated power of Taiwan's NPPs are performed to assess the power uprate effect on thermal effluent under normal operation. Based on the long term monitor data of marine water temperature from June to September in 2006 and 2007, the results show that the effluent temperatures of NPP2 could have the opportunity to exceed the limitation 42 °C at the discharge point and the prompt probability of temperature difference exceeding 4 °C for surface seawater at 500 meters from the discharge point could be higher for each NPP in summer. Feasible engineering actions, such as prolonging the discharge point by extending the path distance of effluent, increasing the flow rate of effluent, or using dilution pump to mix the thermal effluent with the background marine water, could be considered to mitigate the NPP's power uprate effect to the environment. Among others, adding the dilution pump at reactor unit is a very useful method to reduce the elevated temperature of effluent in summer. It can economically and efficiently compensate the power uprate influence of thermal waste heat discharging from NPPs. TPC has accomplished the 1.7% MURPU for its three operating NPPs during 2007 and 2009. The elevation of seawater temperature is currently not significant after the MURPU of NPPs. Long term observation of the additional influence on the ecology due to the thermal effluent of MURPU is needed in the future.

6. Acknowledgment

The author is grateful to Taiwan Power Company for the financial supports. Also the author would like to express his sincere thanks to Prof. Shih C.K. for his encouragement and valuable discussions in this work.

7. References

Ching-wai Yuen (2011), available on the Internet at http://vm.nthu.edu.tw/science/shows/nuclear/t-fish/index.html

CWBS (Central Weather Bureau Statistics), Taiwan (2011). >Home>Statistics>Marine Statistics>Water Surface Temperature Statistics, available on the Internet at http://www.cwb.gov.tw/eng/index.htm

Fang, T.H., Chen, J.F., Tu, Y.Y., Hwang, J.S., and Lo, W.T. (2004). Hydrographical Studies of Waters Adjacent to Nuclear Power Plant I and II in Northern Taiwan, *J. Mar. Sci. Technol.*, Vol. 12, No. 5, pp. 364-371

Hung, T.C., Huang, C.C., and Shao, K.T. (1998). Ecological Survey of Coastal Water Adjacent to Nuclear Power Plants in Taiwan, *Chem. Ecol.*, Vol. 15, pp. 129-142

Huang, C.C., Hung, T.C., and Fan, K.L. (1992). Nonbiological Factors Associated with Coral bleaching in Shallow Water near the Outlet of the Third Nuclear Power Plant, Southern Taiwan, *UNEP Reg. Seas Rep. Stud.*, Vol. 147, pp. 205-224, Taipei, Taiwan

Hyperphysics (2011), available on the Internet at http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html

Peir, J.J., Shih, C.K., Pei, B.S., Ferng, Y.M., and Hsu, W.S. (2009). Power Uprate Impact Evaluations on Waste Heat of Nuclear Power Plants in Taiwan, Brussels, Belgium ICONE17: Proceedings of the 17th International Conference on Nuclear Engineering, Vol. 1, pp. 201-207

RRTC (Research Report of Taipower Company), Taipower Company (2006, 2007). The Survey of Thermal Effluent of the Nuclear Power Plants

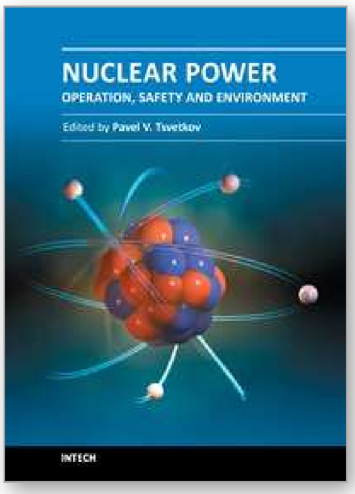
Şerban V., Panait A., Ţenescu M., Mingiuc C., Niţă I., Androne M., Ciocan G.A., and Zamfir A.M. (2010). Possible Solutions for Increasing the Thermoelectrical Plant Efficiency and for Pollution Decreasing, Neptun, Romanian, Proceedings of the WEC Regional Energy Forum – FOREN 2010

Shiah, F.K., Wu, T.H., Li, K.Y., Kao, S.J., Tseng, Y.F., Chung, J.L., and Jan, S. (2006). Thermal effects on heterotrophic processes in a coastal ecosystem adjacent to a nuclear power plant, *Mar. Ecol. Prog. Ser.*, Vol. 309, pp. 55–65

USNRC (2011 a). >Home>Nuclear Reactors>Operating Reactors>Licensing>Power Uprates> Types of Power Uprates, available on the Internet at http://www.nrc.gov/reactors/operating/licensing/power-uprates/type-power.html

USNRC (2011 b). >Home>Nuclear Reactors>Operating Reactors>Licensing>Power Uprates> Types of Power Uprates, available on the Internet at http://www.nrc.gov/reading-rm/basic-ref/students/reactors.html

WTT (Windows to Universe), (2011). Available on the Internet at http://www.windows2universe.org/earth/Water/images/ocean_temp.html



Nuclear Power - Operation, Safety and Environment

Edited by Dr. Pavel Tsvetkov

ISBN 978-953-307-507-5
Hard cover, 368 pages
Publisher InTech
Published online 06, September, 2011
Published in print edition September, 2011

Todayâ€™s nuclear reactors are safe and highly efficient energy systems that offer electricity and a multitude of co-generation energy products ranging from potable water to heat for industrial applications. At the same time, catastrophic earthquake and tsunami events in Japan resulted in the nuclear accident that forced us to rethink our approach to nuclear safety, design requirements and facilitated growing interests in advanced nuclear energy systems, next generation nuclear reactors, which are inherently capable to withstand natural disasters and avoid catastrophic consequences without any environmental impact. This book is one in a series of books on nuclear power published by InTech. Under the single-volume cover, we put together such topics as operation, safety, environment and radiation effects. The book is not offering a comprehensive coverage of the material in each area. Instead, selected themes are highlighted by authors of individual chapters representing contemporary interests worldwide. With all diversity of topics in 16 chapters, the integrated system analysis approach of nuclear power operation, safety and environment is the common thread. The goal of the book is to bring nuclear power to our readers as one of the promising energy sources that has a unique potential to meet energy demands with minimized environmental impact, near-zero carbon footprint, and competitive economics via robust potential applications. The book targets everyone as its potential readership groups - students, researchers and practitioners - who are interested to learn about nuclear power.