Conceptual Design of Reactor TRIGA PUSPATI (RTP) Spent Fuel Pool Cooling System

Tonny Lanyau*[*], Mazleha Maskin, Mohd Fazli Zakaria , Mohammad Suhaimi Kassim, Ahmad Nabil Ab Rahim , Phongsakorn Prak Tom , Mohd Fairus Abdul Farid, Mohd Huzair Hussain

Nuclear Power Division, Malaysian Nuclear Agency,
Ministry of Science, Technology and Innovation,
Bangi, 43000 Kajang, Selangor Darul Ehsan, MALAYSIA
[*]***tonny@nuclearmalaysia.gov.my***

Abstract

After undergo about 30 years of safe operation, Reactor TRIGA PUSPATI (RTP) was planned to be upgraded to ensure continuous operation at optimum safety condition. In the meantime, upgrading is essential to get higher flux to diversify the reactor utilization. Spent fuel pool is needed for temporary storage of the irradiated fuel before sending it back to original country for reprocessing, reuse after the upgrading accomplished or final disposal. The irradiated fuel elements need to be secure physically with continuous cooling to ensure the safety of the fuels itself The decay heat probably still exist even though the fuel elements not in the reactor core. Therefore, appropriate cooling is required to remove the heat produced by decay of the fission product in the irradiated fuel element. The design of spent fuel pool cooling system (SFPCS) was come to mind in order to provide the sufficient cooling to the irradiated fuel elements and also as a shielding. The spent fuel pool cooling system generally equipped with pumps, heat exchanger, water storage tank, valve and piping. The design of the system is based on criteria of the primary cooling system. This paper provides the conceptual design of the spent fuel cooling system.

Keywords: RTP, cooling, design

Abstrak

Setelah beroperasi dengan selamat selama 30 tahun, Reaktor TRIGA PUSPATI (RTP) telah dirancang untuk dinaiktaraf untuk memastikannya beroperasi pada keadaan keselamatan yang optimum. Dalam masa yang sama, penaiktarafan ini juga penting untuk memperolehi fluk yang lebih tinggi bagi mempelbagaikan kegunaan reaktor. Kolam bahan api terpakai diperlukan untuk menyimpan sementara bahan api tersinar sebelum dihantar balik ke negara asal untuk diproses semula, digunakan semula selepas kerja menaiktaraf selesai ataupun pelupusan. Bahan api tersinar perlu disimpan dengan selamat dengan penyejukan yang berterusan bagi menjamin keselamatannya. Haba terhasil daripada proses penyepaian berkemungkinan masih wujud walaupun bahan api tersebut tidak lagi berada di dalam teras reaktor.Oleh itu, penyejukan yang secukupnya adalah diperlukan untuk membuang haba yang terhasil daripada penyepaian produk pembelahan di dalam bahan api tersinar.Rekabentuk sistem penyejukan kolam bahan api terpakai (SFPCS) telah diilhamkan bagi membekalkan penyejukan yang mencukupi kepada bahan api tersinar dan juga sebagai perisai. Secara umum, sistem penyejukan kolam bahan api terpakai dilengkapi dengan pam, penukar haba, tanki simpanan air, injap dan system perpaipan. Rekabentuk sistem in adalah berdasarkan criteria sistem penyejukan primer. Penulisan ini akan mempersembahkan rekabentuk konsep sistem penyejukan kolam bahan api terpakai.

Kata kunci : RTP, penyejukan, rekabentuk

I. Introduction

Reactor TRIGA PUSPATI (RTP) with nominal 1MWatts thermal power was safely operated since June 1982. The RTP system composed of two main system which called primary cooling system and secondary cooling system. The primary cooling system is a closed loop system consists of reactor tank, primary pumps, associated piping system and plate type heat exchangers with main function to provide the sufficient cooling for reactor core. Meanwhile, the secondary cooling system also needed to carry out heat generated to the cooling towers as a heat sink.

The source of heat in the reactor could be direct from fission where about 200MeV was released per fission during the operation. Even though after reactor shutdown the heat still exists as a result from decay of fission products, this is commonly called residual heat. To remove the residual heat after shutdown, the reactor cooling system is operated until the reactor pool water falls to either 30^{o}C or ambient temperature.

After 30 years operation, some of the reactor SSCs[1] were facing ageing problem. The maintenance activities become more challenging when there are requirement to replace certain component that usually difficult to be founded in the market. This constraint brings concern to upgrade the reactor system to sustain the functionality and availability. Upgrading program also stimulated by the demand of users to increase the neutron flux.

The upgrading activity is sound simple, but in reality there a lot of thing that need to be considered. To ensure the upgrading activity run safely, the reactor core must be in subcritical enough to avoid reactivity accident. Therefore, the fuels in B-ring[2] usually transferred and stored temporarily at storage rack inside the pool. These tasks can be done for the activity that not related directly to the core itself, but for the task directly related to core, for example core upgrading, then all fuel elements should be transferred and stored safely at the designated location which is free from unauthorized access. Instead of storing the fuel elements inside the dry storage pits at the reactor hall, there is an idea to construct the spent fuel pool with means to stored and cooled the irradiated fuel safely. The conceptual design of the spent fuel pool [1] has been proposed and presented together with conceptual design of spent fuel storage rack [2] and conceptual design of fuel transfer cask [3].

Ideally, the irradiated or spent fuel can be simply store in the dry storage pit, but for the sake of safety, the spent fuel pool is the best option to ensure storage, cooling and shielding are appropriate. Furthermore, if the reactor is upgraded to higher power then the spent fuel pool as well as spent fuel pool cooling system is become compulsory. As stated previously, the heats are produced not only during the operation of the reactor, but even after shutdown. Decay heat from fission product account as much as 7.5% of full power after a long run. For the RTP, if assumed this percentage, the amount of decay heat that needs to be removed is about 75kW.This value is only heat from the decay of the fission product. But, the

---

[1] System, Structure and Components

[2] B-ring is a name of circular ring in the reactor core where the fuels are located. There are 6 rings (B, C, D, E, F, and G) available to occupy the Standard TRIGA Fuel elements, control rods and dummy elements.

external heat sources that have the potential to heat up the water in the spent fuel pool also need to be considered. Therefore, the Spent Fuel Pool Cooling System (SFPCS) is required to remove the decay heats and to provide radiation shielding. The conceptual design of the SFPCS will be discuss in the next sections.

II. Safety Requirements

The IAEA Specific Safety Guide (SSG-15) [4] states;

6.38. In the design of heat removal systems for a spent fuel storage facility, appropriate provision should be made for maintaining fuel temperatures within acceptable limits during handling and transfer of spent fuel.

6.39. The heat removal system should be designed for adequate removal of the heat likely to be generated by the maximum inventory of spent fuel anticipated during operation. In determining the necessary heat removal capability of the facility, the post-irradiation cooling interval and the burn up of the fuel to be stored should be taken into consideration. Heat removal systems should be designed to include an additional margin of heat removal capability to take account of any processes foreseen to degrade or impair the system over time. In the design of the heat removal system, consideration should also be given to the maximum heat capacity of the facility.

According to IAEA Safety Standard NS-R-4, the SSCs shall be first specified and then classified to their safety function and significance to safety. This classification reflects the significance for nuclear safety of the SSCs. Its purpose is to establish a gradation in the application of the requirements for design and the requirements for quality assurance. The selected safety functions for the research reactor as in following table:

Table 1 : Selected Safety Function for Research Reactor [5]

Items important to safety	Safety Functions
Building and structure	(a) To form barrier to the uncontrolled release of radioactive material to the environment. (b) To provide protection against external and internal events for the enclosed safety systems.
Emergency Core Cooling	To transfer heat from the reactor core following the loss of coolant accident at an adequate rate to prevent significant damage to the fuel.
Fuel Handling and storage system	(a) To minimize radiation exposure (b) To prevent inadvertent criticality (c) To limit any rise in fuel temperature (d) To store fresh and irradiated fuel (e) To prevent mechanical or corrosive damage of fuel

In order to achieve safety requirement, all related safety functions was implemented in the design.

III. Design Requirements

The SFPCS has been designed to meet the following requirements:

i. To provide sufficient cooling to the fuel element due to heat generated by decay of the fission product.
ii. To remove heat produced during any activity in the spent fuel pool.
iii. To provide appropriate radiation shielding from irradiated fuel elements.
iv. To circulate water from the spent fuel pool in order to maintain the purity of the demineralized water within the specified limit.
v. To provide sufficient coolant inventory for SFP[3] and RTP during LOCA[4] (similar to ECCS[5])

IV. General assumptions

The design is based on the following general assumptions:

i. The reactor thermal power used for design is 1MWth.So, the maximum values of decay heats are assumed.
ii. The entire core is assumed to be unloaded. All fuel elements are stored in the spent fuel pool.
iii. All cells of the spent fuels pools are assumed occupied.
iv. The water temperature of the pool is kept at least at ambient temperature.

V. System and Components Descriptions

The descriptions of the different components of the system are given below:

A. Pumps

The system comprises of two centrifugal pumps with the capacity that enough to remove 75kW heat for normal condition and 1MWth during accident condition whenever this system is needed to take over the function of primary cooling system. The exact size of the pumps will be determined later in the detail design.

B. Demineralized Water Storage Tank

The demineralized water storage tank is purpose to store about 87.75 m^3 (SFP) and 20.42 m^3 (Reactor Tank) of demineralized water which is enough to fill the SFP as well as reactor tank in situation that total loss of coolant during LOCA.

C. Purification System

Purification system is being used to maintain water quality by removing any mineral in the coolant. The water is taken directly from tap water through filter and

[3] Spent fuel pool
[4] Loss of Coolant Accident
[5] Emergency Core Cooling System is a series of systems that are designed to safely shut down a nuclear reactor during accident conditions.

demineralizer. The conductivity of the water daily monitored so that the value not exceeded 2μS.

D. Piping and Fitting

All piping and fittings in the system are of aluminum alloy or stainless steel.

E. Instrumentation and Control

Appropriate instrumentation and control devices such as flow meter, conductivity meter, pressure meter and temperature meter were attached on the piping system.

F. Heat Exchanger

Plate type heat exchanger can be used. As the spent fuel pool cooling system is used to reject residual heat which is not having significant amount as heat directly from fission during reactor operation, single heat exchanger is adequate to be used.

VI. General Technical Specification

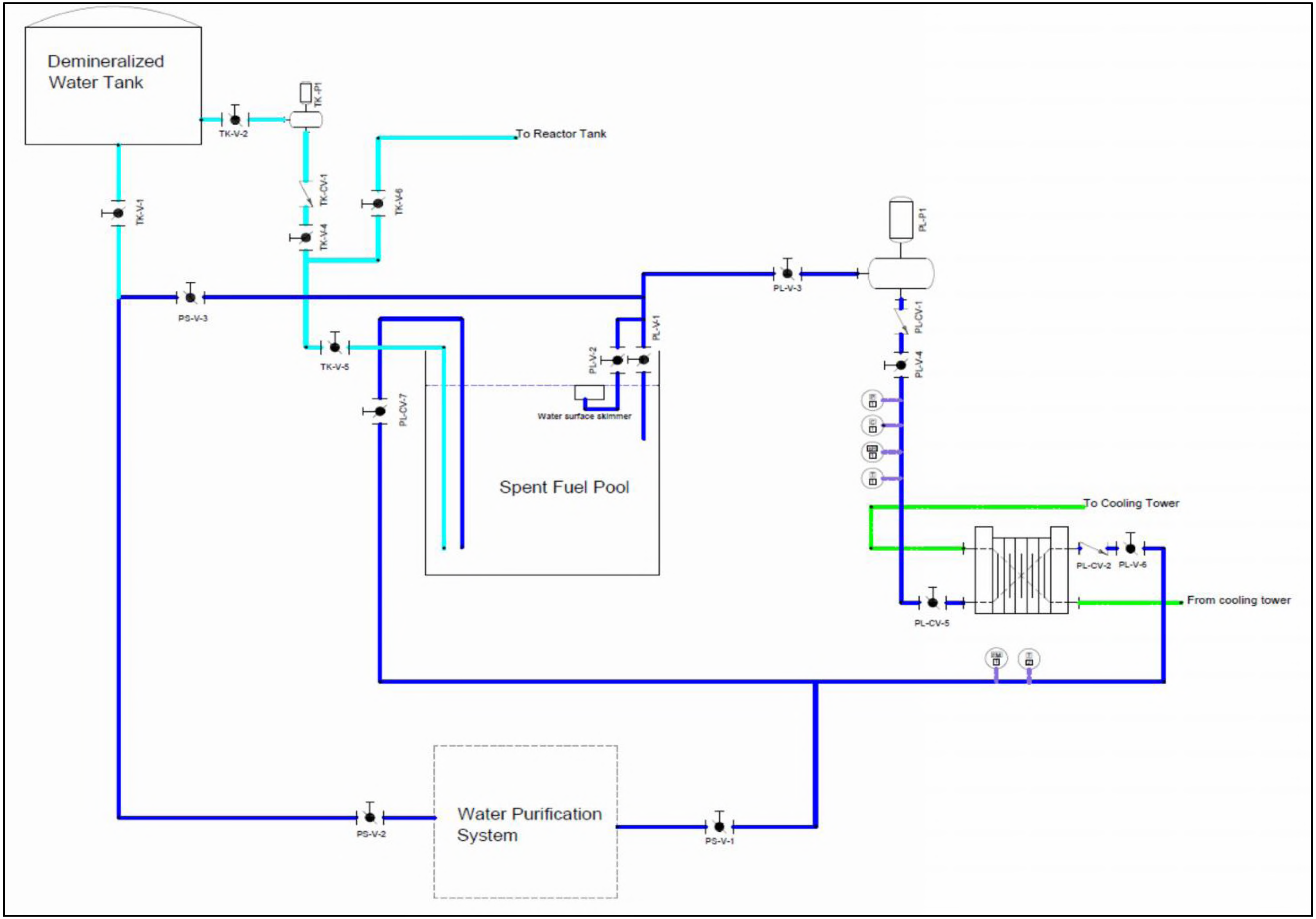
The SFPCS is design as the following general specifications:

Table 2 : General Specification of Proposed Spent Fuel Pool Cooling System

System / component	Unit	Specification
Centrifugal pump	Two(2)	Able to provide ~ 6 m^3/h
Demineralized water storage tank	One(1)	Able to provide half volume of SFP and full volume of reactor tank
Purification system	One(1)	To be included in separate design document
Pipework	Depend on system layout	Aluminum 6061
Fitting (Elbows, valves, connectors, etc.)	Depend on system layout	Made of aluminum alloy or stainless steel
Instrumentation and Control		
• Temperature meter	Two(2)	Range : 0.0°C ~ 60.0°C
• Pressure meter	One(1)	Range : 0.0 ~ 60.0 psi[6]
		Range : 0 .0 ~ 50μΩ
• Conductivity meter	One(1)	Range : 1 ~ 14
• pH meter	One(1)	Range : 0 ~ 2400 gpm[7]
• Flow rate meter	One(1)	
Heat Exchanger	One(1)	• Plate type with capacity rejection of heat of at least 75kWth • Counter current flow

[6] 1psi = 6.8947572932 kPa
[7] 1gpm = 0.22712470704 m^3/h

VII. Figure 1 : Proposed Layout



VIII. Operation of Spent Fuel Pool Cooling System

The operation of SFPCS is divided to two conditions;

i. Normal operation

During normal operation, only water purification system is operated. Meanwhile, the pump and heat exchanger are in standby mode. The normal operation illustration is as in Figure 2.

ii. Emergency Situation

Emergency Situation concerned in this design is divided into two scenarios:

a) Emergency Operation Scenario #1: Emergency at SFP (including LOCA).

Generally, all equipments will be activated to provide sufficient cooling to the pool and in case of LOCA; water should be supplied from the demineralized water storage tank. The illustration of the operation is as in Figure 3.

b) Emergency Operation Scenario #2 :LOCA at reactor tank

Supply water system will provided sufficient coolant inventory to the reactor tank by pumping the demineralized water from demineralized water storage tank. Figure 4 shows the illustration of this scenario.

Figure 2 : Normal Operation

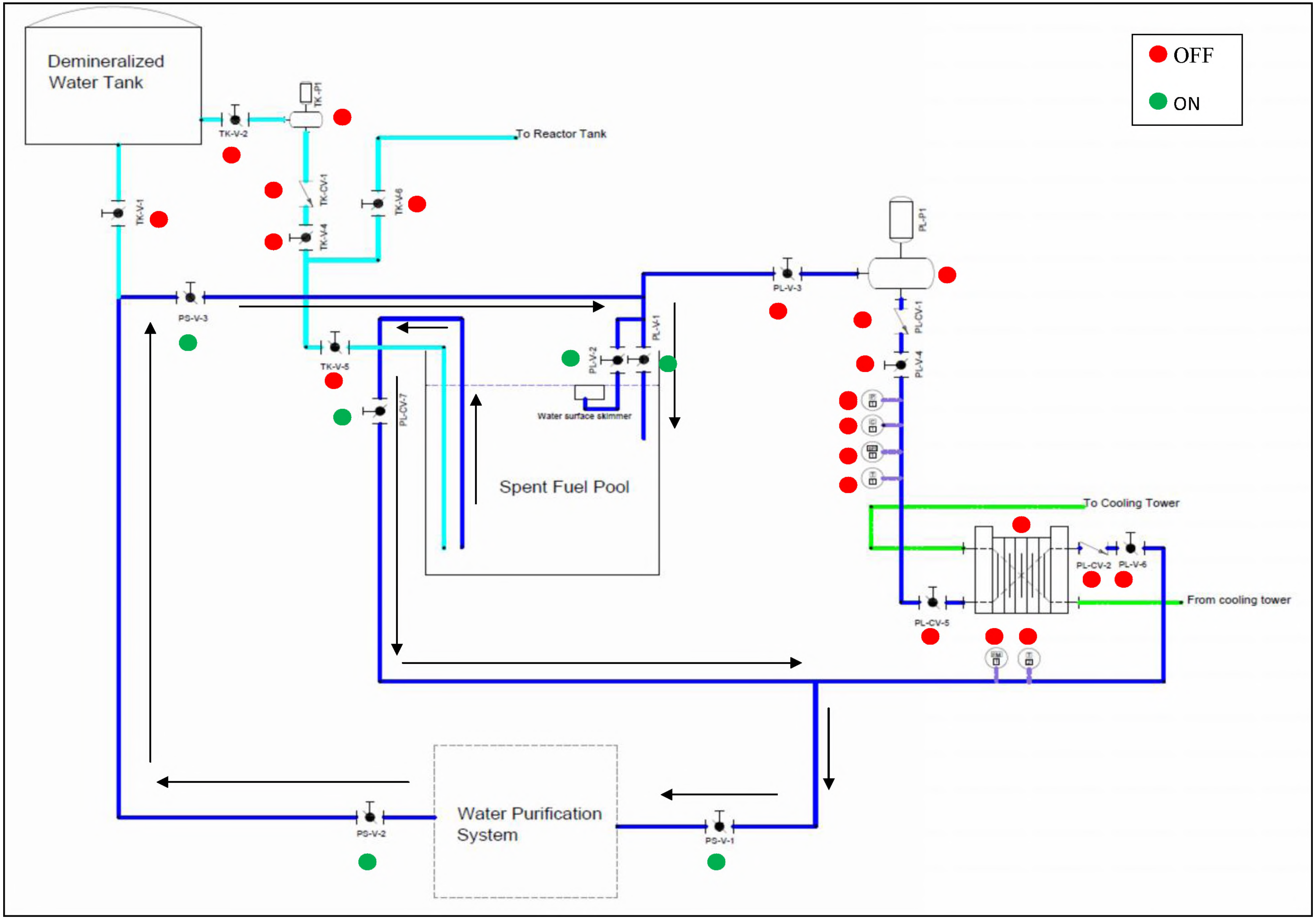


Figure 3 : Emergency Operation Scenario #1

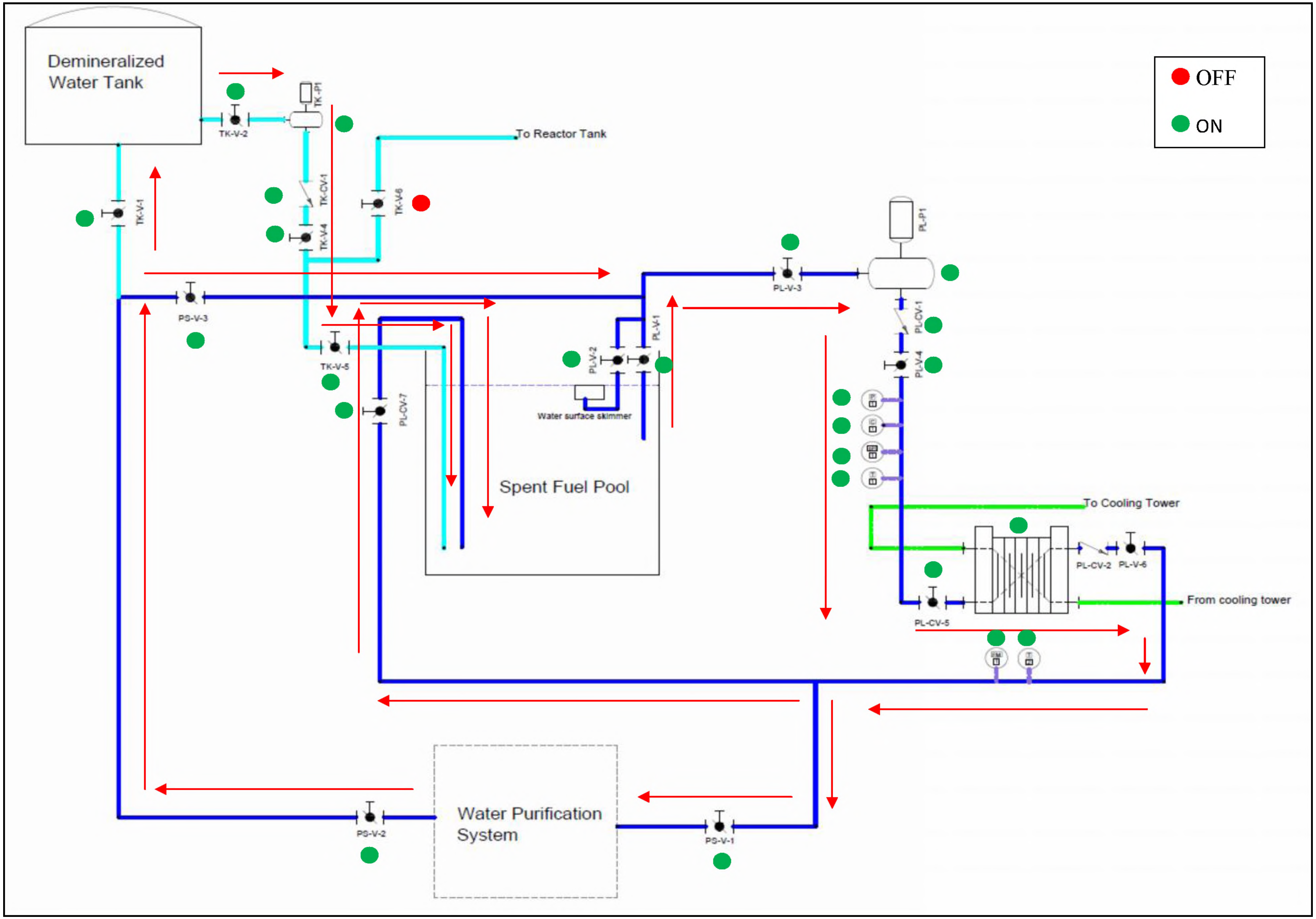
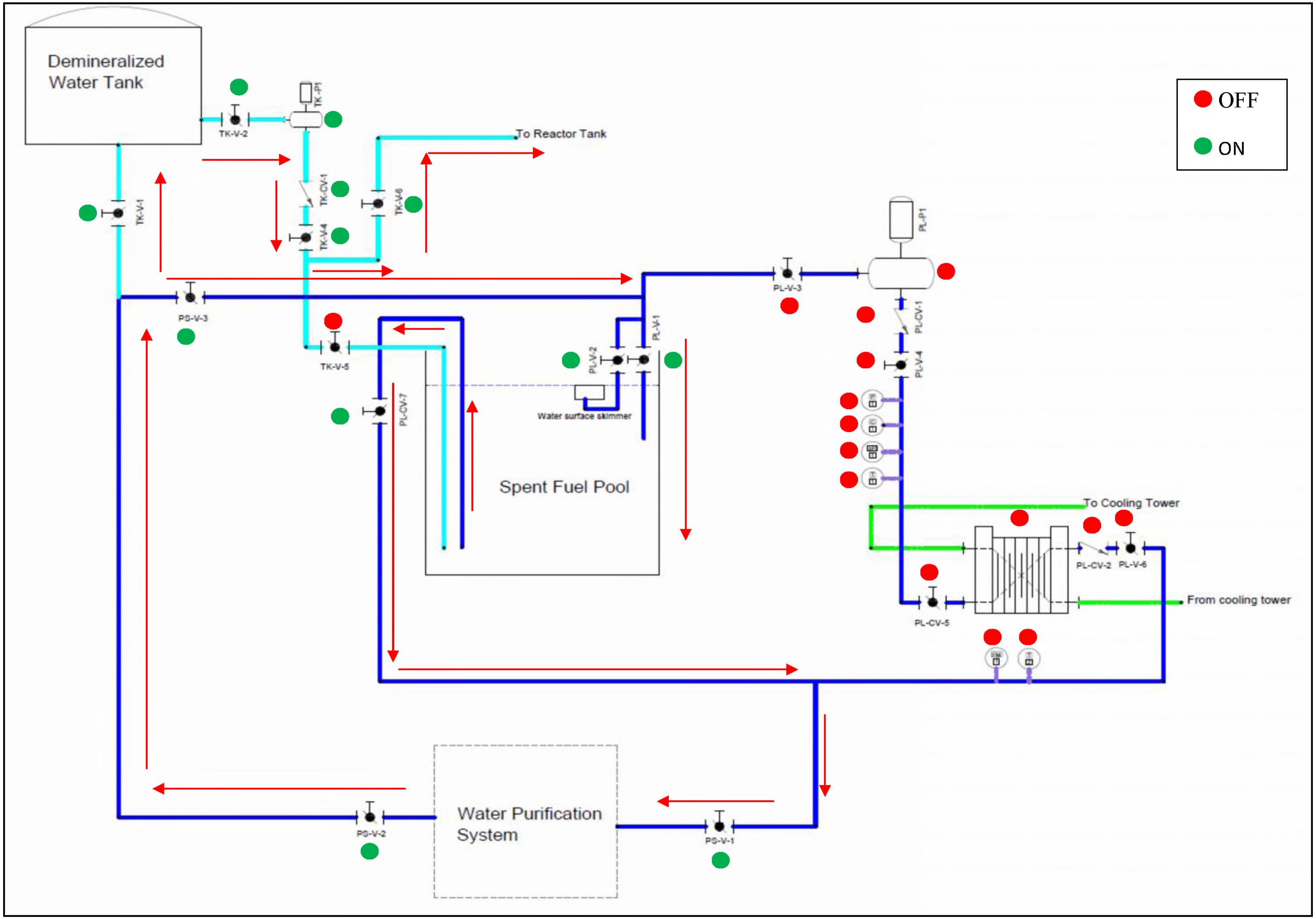


Figure 4 : Emergency Operation Scenario #2 (LOCA in reactor tank)



IX. Maintenance

The maintenance of the SFPCS is proposed to be in semi-annual and annual basis, parallel with schedule maintenance of the reactor leaded by Reactor Operation and Maintenance group. Besides, corrective maintenance should be performed if needed to ensure the SFPCS is available at all time.

X. Conclusion

SFPCS is needed to ensure the safety of the spent fuels stored in the spent fuel pool. Demineralized Water Tank is used to stored water which is required during emergency situation. The proposed design presented in this paper is used as a reference for designing the details system in future work.

References

[1] Mohd Fazli Bin Zakaria, Tonny Anak Lanyau and Ahmad Nabil Ab Rahim, *Reactor TRIGA PUSPATI (RTP) Spent Fuel Pool Conceptual Design*, proceeding Seminar RND, Nuclear Malaysia, 2010.

[2] Tonny Lanyau, Mohd Fazli Zakaria, Zaredah Hashim, Ahmad Nabil Ab Rahim, Mohammad Suhaimi Kassim, *Conceptual design of RTP Spent Fuel Storage Rack,* proceeding Seminar RND, Nuclear Malaysia,2010.

[3] Ahmad Nabil Ab Rahim, Nurhayati Binti Ramli, Tonny Lanyau, Phongsakorn Prak, Mohd Fazli Zakaria, *Fuel Transfer Cask Conceptual Design for Reactor TRIGA PUSPATI (RTP)*, proceeding Seminar RND, Nuclear Malaysia, 2010.

[4] IAEA Safety Standard Series No.SSG-15 Storage of Spent Nuclear Fuel, 2012.

[5] IAEA Safety Standard Series No. NS-R-4 Safety of Research Reactor, 2005.

[6] INVAP, *Replacement Research Reactor Project: SAR Chapter 6 Reactor Cooling System and Connected Systems for Australian Nuclear Science and Technology Organization (ANSTO),* 2004.

[7] Malaysian Nuclear Agency, *Safety Analysis Report for PUSPATI TRIGA Reactor (RTP),* 2008.

[8] Ronal Allen Knief, *Nuclear Engineering: Theory and Technology of Commercial Nuclear Power,* Mechanicsburg, Pennsylvania, 1992.