PUSPATI TRIGA REACTOR UPGRADING: TOWARDS THE SAFE OPERATION & FEASIBILITY OF NEUTRONIC APPROACH

J. ABDUL KARIM, M.P. ABU, Z. MASOOD, M.H. RABIR, M.A.S. SALLEH, M.F ZAKARIA
Malaysia Nuclear Agency,
Kajang,
Malaysia

C. IORGULIS
Institute for Nuclear Research Pitesti,
Pitesti,
Romania

Abstract

The PUSPATI TRIGA Reactor (RTP) has been safely operated for the last 29 years with no incidents as listed in the unusual event reporting categories being reported. However, in order to maintain the reactor integrity and safety, several reactor components and system were refurbished or replaced over the years. The latest approach to enhance safety was the replacement of the heat exchanger from previously shell and tube heat exchanger to plate-type heat exchanger. Prior to have this reactor extensively and safely utilised, the feasibility of neutronic approach to upgrade the reactor have been carried out and reported. This paper will describe the strategies for ensuring prolonged and continuously safe operations of the reactor and also discussed on the feasible of the neutronics approach towards the safe operation.

1. INTRODUCTION

For the last 29 years, the PUSPATI TRIGA Reactor (RTP) has been safely operated with no incidents as listed in the unusual event reporting categories being reported. However, in order to maintain the reactor integrity and safety, several reactor components or system have to be refurbished or replaced over the years. The reassessment of the present reactor main system and reactor building has also been conducted to reflect the recent emphasis placed on the safety of the operations and maintenance of research reactors around the world. A pragmatic approach and strategy to enhance safety has ensured that the reactor is operated within its operating limits and controls, while regular maintenance has been carried out according to a new systematic maintenance programme developed in 2008 and implemented in mid 2009. In addition to this, ageing management programme was also developed in 2010 and will be implemented in 2011. In 2006, the quality assurance programme was developed and revised in Feb 2011 in order to be in line with the practice in the nuclear industry that require a high safety measures in all aspects of the reactor operations and maintenance.

Another important element in ensuring reactor safety is the personnel involved in the reactor operation and maintenance were trained or retrained according to the DS325 ‘Guideline on Certification and Recertification of Research Reactor Operators’ and endorsed by regulatory body. The safety analysis report was first update in 2006 and 2007 and with the replacement of the heat exchanger and refurbishment of reactor instrumentation and control a concerted effort to update the SAR was carried out and submitted to regulatory body in March 2011 as part of the requirement for the issuance of the operation license of RTP. Besides, the neutronics and thermalhydraullic analyses were carried out as part of the feasible studies for the upgrading activities towards the safe operation of the RTP.

2. OPERATIONS AND MAINTENANCE

The RTP has been operated since 1982 with accumulative operation time 24 042.03 hr and 16,044.00 MW·hr of energy release. The average operating hours and energy release for the past ten years is around 340.60 MW·hr and 506.59 hr respectively. The trend of operational history for RTP for 2001 until 2010 is shown in Table 1 and Figure 1 below.

TABLE 1: RTP OPERATING HOURS AND ENERGY RELEASE

Year	Operating Hours (Hr)	Energy Release (MW·Hr)
2001	545.63	359.87
2002	490.93	331.25
2003	640.05	430.08
2004	565.44	383.37
2005	563.73	390.64
2006	586.61	408.44
2007	404.98	265.56
2008	440.52	309.38
2009	305.98	192.35
2010	522.03	335.09
Total	**5,065.90**	**3,406.03**

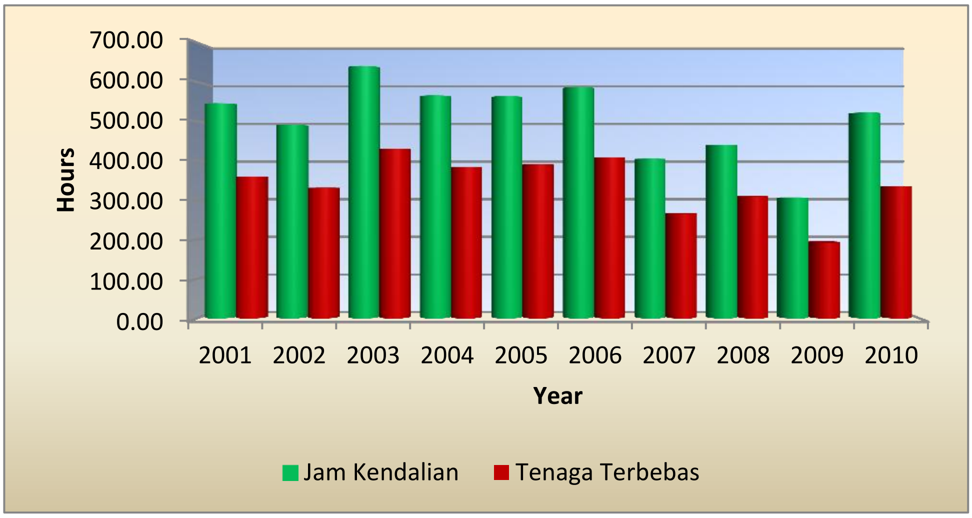


FIG 1. Operating hours and energy released trend.

3. STRATEGIES TO ENHANCE SAFETY

Five main strategic keys were drawn prior to enhance the safe operation of the RTP.

3.1. Refurbishment of RTP primary cooling system

The latest approach to enhance the safety of RTP operations is the replacement of the heat exchanger from previously shell and tube heat exchanger to plate-type heat exchanger as shown in Figure 2 and Figure 3. The refurbishment was completed in April 2010 over an eight-month outage. The project was implemented with the dual objectives of meeting current user needs as well as future power-upgraded reactor core.

The safety objectives of the project were to enhance the efficiency of RTP primary cooling. In addition, it is also done to optimize the natural circulation for sufficient heat removal during operation time as well as residual heat after reactor shutdown. The cooling system was also partly modernized to cater for a three-megawatt reactor thermal power by installing higher capacity heat exchangers and pumps, while maintaining the piping and valve sizes. With the new SCADA control system the operation of RTP can be more simplified and now the operator can automatically control the pumps and valves remotely from the control room.

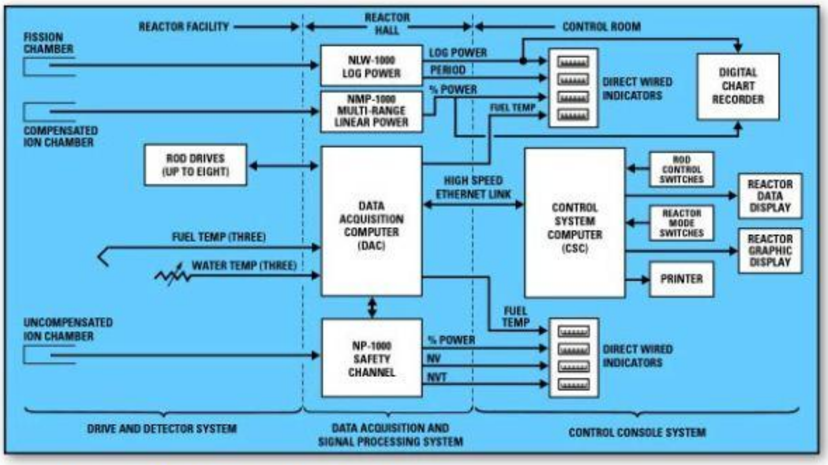
FIG. 2. New plate heat exchanger.

FIG. 3. New primary pump.

The new cooling system has successfully performed the required duty to ensure compliance with the criteria for core cooling. All activities and verification process were completed in accordance with design, safety, quality assurance and regulatory requirements.

3.2. Upgrading of the RTP instrumentation and control

The console of PUSPATI TRIGA Reactor (RTP instrumentation & control) was installed and commissioned by General Atomic, USA in 1982. It is an analog base engineering that is used to control and monitor the 1 MW thermal power, maximum neutron flux of 1×10^{13} $cm^{-2}s^{-1}$. However, since 2005 it was found that there is an increased in system instability, errors on system’s indicators, non-functional functions, intermittent signals in the system, increased of reactor down time and increased in maintenance time. Maintenance of the console faced a major difficulty due to ageing factors, spare parts procurements and lack of support by the manufacturer. The process of tender for the new console is still ongoing and expected to start early 2012.



Simplified Research Reactor Control System Block Diagram

FIG. 4. Digital block diagram for reactor instrumentation and control system.

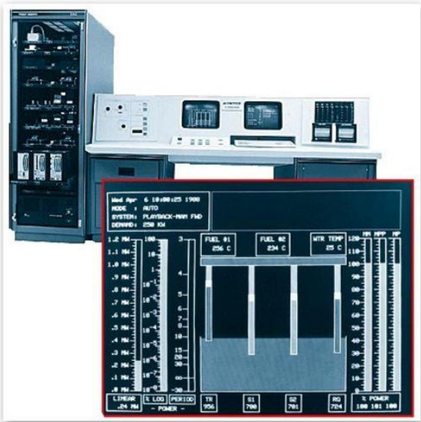
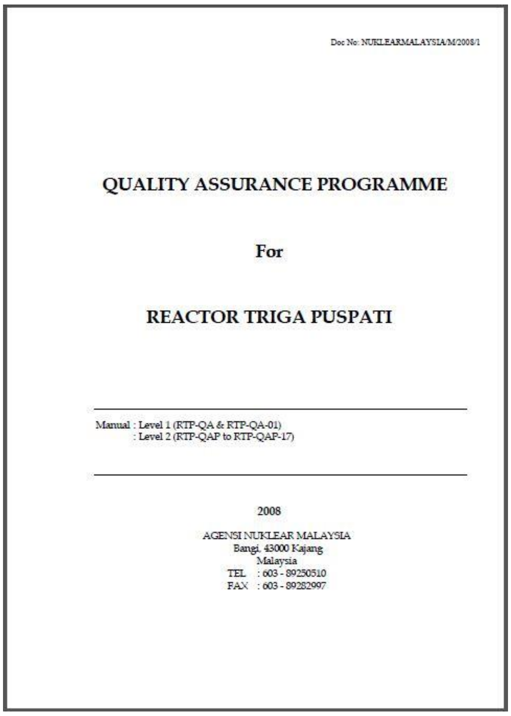


FIG. 5. Reactor instrumentation and control system.

3.3. Quality Assurance Programme

Quality Assurance Programme (QAP) for RTP was adopted from the SS50C/SG-Q code of quality and safety assurance requirement as the principle for designing this quality management system. The extent of this QAP established is based on the nature of Nuclear Malaysia organization, complexity and interaction of the processes and competence of personnel. The programme covers the entire operations and maintenance of the reactor, the management review, the control of modifications of installations, control of experimental and testing programmes and treatment, storage and transport of fissile and radioactive material.


Doc No: NUKLEARMALAYSIA/M/2008/1

QUALITY ASSURANCE PROGRAMME

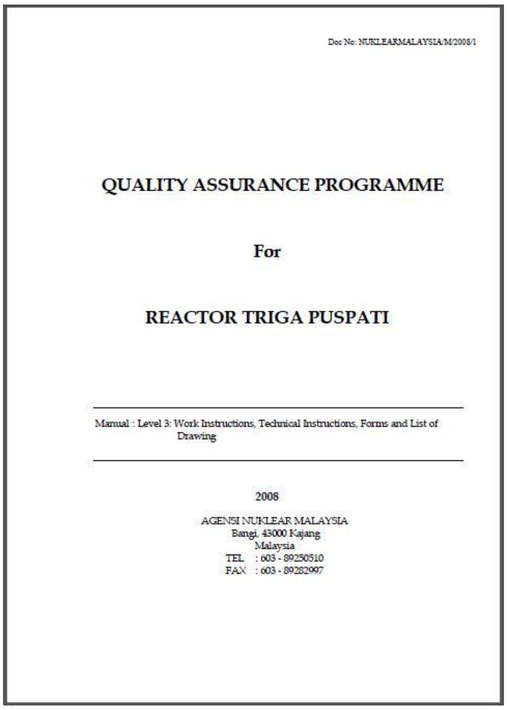
For

REACTOR TRIGA PUSPATI

Manual : Level 1 (RTP-QA & RTP-QA-01)
: Level 2 (RTP-QAP to RTP-QAP-17)

2008

AGENSI NUKLEAR MALAYSIA
Bangi, 43000 Kajang
Malaysia
TEL : 603 - 89250510
FAX : 603 - 89282997


Doc No: NUKLEARMALAYSIA/M/2008/1

QUALITY ASSURANCE PROGRAMME

For

REACTOR TRIGA PUSPATI

Manual : Level 3: Work Instructions, Technical Instructions, Forms and List of Drawing

2008

AGENSI NUKLEAR MALAYSIA
Bangi, 43000 Kajang
Malaysia
TEL : 603 - 89250510
FAX : 603 - 89282997

FIG. 6. QAP Programme – Manual Level 1, 2 and 3.

3.4. Ageing Management Programme

The system, structure and components (SSCs) in RTP have experienced an ageing problem since it was firstly operated in 1982. Several reactor components was out dated since the technology that been used is from the 70s. Periodic inspection and maintenance itself is not enough to ensure the integrity of SSCs in the reactor at all time. Therefore, a proper Ageing Management Programme should be in place which is expected to provide guidance to more easily and effectively implement the programme to SSCs that is important to safety.

Coordination of existing maintenance programme, in-service inspection and surveillance as well as operation and technical supports is still in practice to accomplish the effective RTP Ageing Management Programme. An ageing management programme manual was developed using the IAEA TECDOC 792 as a reference. The implementations of the programme in 2011 are in phases as follows.

Phase 1

- Identify the ageing factor that occurs in SSCs;
- Identify the party responsible for each SSCs;
- Further explanation and study on problems related to ageing of safety related SSCs.

Phase 2

- Reviewing the ageing mechanisms to understand their behaviour and influence to the reactor system;
- Provides guidelines to assists the operator in the detection and assessment of ageing effects;
- Implementation of transformation plans to overcome the ageing effects.

Phase 3

- To provide information that can be used to assess the safety on operation of reactor;
- To propose preventive and corrective measures to mitigate the effects of ageing;
- To provide guidance for the manager in decision making on replacement or upgrading the SSCs.

Phase 4

- Training, courses or information sharing to capture new ideas or method to handle ageing of SSCs in reactor facility;
- Providing guidance and consultancy for the ageing management of other facility in the organization.

3.5. Neutronics and thermalhydraulics analyses

The neutronics analyses were carried out using MCNP to calculate keff, power distribution, peaking factor and shutdown margin for reactor upgrading exercises. Whilst in the thermalhydraulics analyses, PARET was used to calculate coolant and fuel temperature. In order to calculate those parameters in PARET, a simplified modeled using RELAP was developed to calculate the flow rate value in the natural circulation for RTP as shown in Figure 7. Prior to calculate the total flow rate of RTP core with RELAP, three main parameters in Safety Analysis Report (SAR) were considered and compared, i.e., (i) total flow rate of the core at 6.7 kg/s, (ii) maximum fuel temperature at 415^{o}C and (iii) the water temperature evolution for the average channel in the range of 32^{o}C to 67^{o}C as per stated in the SAR. The RELAP calculation results were shown as in Table 2.

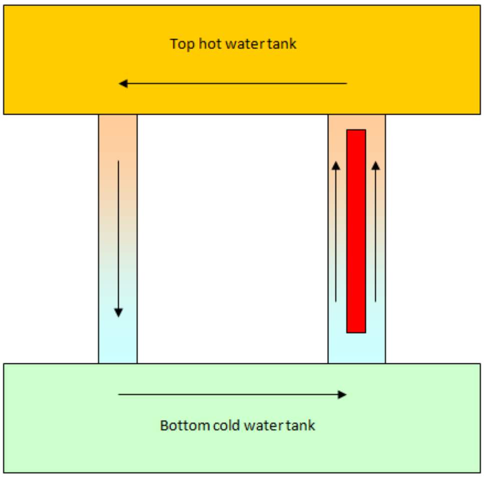


FIG. 8. Simplified RELAP model of natural circulation for RTP.

TABLE 2: RELAP CALCULATION OF TOTAL FLOW RATE OF RTP CORE IN COMPARISON WITH SAFETY ANALYSIS REPORT (SAR) VALUE

	SAR	**RELAP**
Maximum Fuel Temperature	415^{o}C	415^{o}C
Total Flow Rate of the Core	6.7kg/s	7.1kg/s

The flow rate for the average channel (P=12500W, flow area 450 cm^2) was determined in above calculations using RELAP5 which obtained the value of **7.1kg/s**, which is in good agreement with original SAR. From these parameters, two PARET inputs have been made to calculate the average maximum channel.

The neutronics and thermalhydraulics were carried out for the exercises on RTP calculation. MCNP and PARET calculation were analyses for 1 MW and 2 MW with natural circulation, 3 MW with natural circulation and forced cooling condition. The calculation results were shown in Table 3. For these calculations, some restrictions have been taken into accounts as stated in the SAR which including:

— Maximum fuel temperature shall not exceed 900^{o}C;
— Maximum DNB heat flux shall not exceed 127 W/cm^2;
— Maximum clad temperature shall not exceed 400^{o}C. However, due to the temperature of the clad is situated under DNB Heat flux, therefore, to avoid corrosion problems the clad temperature should be <150^{o}C);
— Exit coolant temperature should be < 90C to avoid boiling and flow instabilities.

TABLE 3: NEUTRONICS AND THERMALHYDRAULIC CALCULATION RESULTS FOR RTP UPGRADING EXCERCISES

Location	Axial Node	Liquid (vapor) temperature (°C)	Clad surface temperature (°C)	Fuel surface temperature (°C)	Fuel center temperature (°C)	Mass flow rate (kg/s^{1}m^2)	Moderator regime
condition	PARET for SAR using 80FE-average; Average channel; Natural convection (SAR water exit 67°C); P=1 MW; Subchannel power=12500 W; PPF=1; APF=1.; CPF=1; Qmax.=27.01 W/cm^2						
inlet	1	32	118.0678	160.6136	269.5145	155	LIQUID
exit coolant	21	65.9024	118.9735	160.5193	269.4202	155	NUCLEATE BOIL
condition	PARET for SAR using 80FE-maximum; Maximum channel; Natural Convection(SAR max fuel temperature 415C); P=1 MW; Subchannel power 26500W; PPF=1.7; APF=1.25; CPF=2.12; Qmax.=56.7W/cm2						
inlet	1	32	119.2542	173.9933	316.5068	185	LIQUID
exit coolant	21	81.2667	119.0392	161.6237	273.2471	185	NUCLEATE BOIL.
condition	PARET for 2MW using 119FE-maximum; Maximum channel; Natural convection; P=2MW; Subchannel power=35294 W; PPF=1.7; APF=1.25; CPF=2.12; Qmax.=75.3 W/cm^2						
inlet	1	32	119.6941	193.5664	386.3688	220	LIQUID
exit coolant	21	87.6916	119.8912	177.1749	327.3282	220	NUCLEATE BOIL.
condition	PARET for 3MW using 119FE-maximum, natural convection Maximum channel; Natural Convection; P=3MW; Subchannel power=53941 W; PPF=1.7; APF=1.25; CPF=2.12; Qmax.=113.42 W/cm^2						
inlet	1	32	121.3068	231.6154	520.819	260	NUCLEATE BOIL.
exit coolant	21	102.5691	121.2651	207.1906	432.4206	260	NUCLEATE BOIL.
condition	PARET for 3MW using 119FE-maximum, forced flow Maximum channel; Forced Flow; Power =3MW; Flow rate= 200 l/s; Subchannel power=53941 W; PPF=1.7; APF=1.25; CPF=2.12; Qmax.=113.42 W/cm^2						
exit coolant	1	36.6163	76.5765	170.8851	418.0887	-4000	LIQUID
inlet	21	32	70.0893	156.0149	381.2449	-4000	LIQUID

From the table above, configuration for 3 MW using 119 fuel elements with natural convection cooling will resulted in nucleate boiling state with the maximum exit and clad temperature at 102.6^{o}C and 124.4^{o}C respectively. The exit coolant was at 103^{o}C, would have exceeded the allowable limit at <90^{o}C. Therefore, this core configuration would not be able worked at 3MW that will cause boiling and instability occurred due to high exit coolant temperature. Whilst, configuration at 3 MW would be worked well when the forced cooling system introduced to the reactor core with extended flow rate at 200 l/s will resulted in liquid state at the entrance and exit coolant temperature. Though it is liquid phase, nevertheless a lot more modification work should be carried out prior to have force cooling system introduced at the RTP core.

4. CONCLUSION

The safety approaches that were implemented for RTP has ensured the prolong operations and safety of the reactor. The introduction of Ageing Management Programme has contributed very significantly towards to enhance the safe operation of the reactor and increase the efficiency of every system in RTP. The reactor instrumentation and control upgrading project that is expected to begin in 2012 will become the stepping stone for RTP to provide a better performance in term of reactivity controlled to support continuous utilization of the neutron sources in various field. Furthermore, with these capability and capacity increased, it will also support the agency to become a Technical Support Organization (TSO) for Malaysia Nuclear Power Programme in future. Whilst, the objective of increasing the human capability and capacity building in the sense of to develop expertises in reactor physics, thermal hydraulics, and instrumentation and control was achieved through the upgrading exercises.

REFERENCES

[1] ATOMIC ENERGY LICENSING BOARD, “Standards for Certification and Recertification of Research Reactor Operator,” 2007.

[2] NUCLEAR MALAYSIA, “Program Pengurusan Penuaan,” NUKLEARMALSYSIA/L/2011/16.

[3] NUCLEAR MALAYSIA, “Commissioning Report of RTP Primary Cooling System,” NUKLEARMALAYSIA/L/2010/34.

[4] NUCLEAR MALAYSIA, “Safety Analysis Report for PUSPATI TRIGA Reactor”, 2008.

[5] REACTOR OPERATION & MAINTENANCE SECTION (O&M), “RTP Annual Report 2010.”