CONCEPTUAL DESIGN OF EXPERIMENTAL TEST RIG FOR PIPE FAILURE RATE ASSESSMENT AT PUSPATI TRIGA REACTOR

REKABENTUK KONSEP RIG UJIAN EKSPERIMEN UNTUK PENILAIAN KADAR KEGAGALAN PAIP DI REAKTOR TRIGA PUSPATI

Tonny Lanyau[1], Julia Abdul Karim[1], Norasiah Ab Kasim[2], Amirul Syamil Ahmad Rushdi[3], Batrisyia Huda[4],Mohamed Farhan Azmi[5], Mohd Fazli Zakaria[1], Mazleha Maskin[1], Zaredah Hashim[1], Atifa Nabila Abd Rahman[4]

[1]Reactor Technology Center, Technical Support Division
[2]Material Technology Group, Industrial Technology Division
Malaysian Nuclear Agency, Bangi, 43000 Kajang, Selangor, Malaysia

[3]Universiti Teknologi MARA

[4]Universiti Teknologi Malaysia

[5]Universiti Putra Malaysia

Abstract

Cooling system which consist of numerous pipelines network poses significant problems including in a nuclear reactor. Thermal and irradiation activities, corrosion, embrittlement mechanism as well as aging, provide an environment susceptible to increased pipe failure rates (PFR).The occurrence of PFR is mostly due to aging mechanism including (a) thermal embrittlement, (b) low and high cycle thermal fatigue, (c) stress corrosion cracking mechanisms, and (d) Flow Accelerated Corrosion (FAC) as well as high cycle mechanical fatigue that causing loss of material toughness. Concerning possible accidents due to unreliable pipe integrity, a study on parameters involved in evaluating PFR needs to be developed. However, in assessing PFR, an experiment on a real plant is impossible due to safety issues. Thus, this paper aims to design an experimental test rig by simplifying the primary piping system in reactor TRIGA PUSPATI (RTP). Three alternatives of conceptual design option have been proposed. Methodology in simplifying and designing the test rig is explained briefly in this paper. Finally, a combined design concept of the test rig has been produced based on pre-determined design requirements and presented in this paper. This experimental test rig will be used extensively in generating a comprehensive database which will be used to predict PFR models.

Abstrak

Sistem penyejukan terdiri daripada rangkaian paip yang banyak boleh menimbulkan masalah termasuk di dalam reaktor nuklear. Aktiviti terma dan penyinaran, kakisan, mekanisme kerapuhan serta penuaan, memberikan persekitaran yang mudah terdedah kepada peningkatan kadar kegagalan paip (PFR). Kewujudan PFR disebabkan oleh mekanisme penuaan termasuk (a) kerapuhan terma, (b) kitaran rendah dan tinggi keletihan haba, (c) mekanisme retakan hakisan kakisan, dan (d) kakisan dipercepatkan aliran (FAC) serta kitaran tinggi keletihan mekanikal yang menyebabkan kehilangan keliatan bahan. Mengambil kira kemalangan yang mungkin disebabkan oleh integriti paip, kajian terhadap parameter yang terlibat dalam menilai PFR perlu dibangunkan. Walau bagaimanapun, penilaian PFR sukar dilakukan pada loji sebenar kerana isu keselamatan. Oleh itu, tujuan kertas kerja ini ialah untuk merekabentuk rig ujian eksperimen, untul mempermudahkan sistem perpaipan utama dalam reaktor TRIGA PUSPATI (RTP). Tiga pilihan alternatif reka bentuk konsep telah dicadangkan. Metodologi dalam mempermudahkan dan mereka bentuk rig ujian dijelaskan secara ringkas di dalam kertas ini. Akhirnya, konsep reka bentuk gabungan rig ujian telah dihasilkan berdasarkan keperluan reka bentuk yang telah ditetapkan dan dibentangkan dalam kertas kerja ini. Rig uji eksperimen ini akan digunakan secara meluas dalam menghasilkan pangkalan data komprehensif yang akan digunakan untuk meramalkan model PFR.

Keywords: pipe failure rate assessment, conceptual design, experimental test rig, nuclear reactor, TRIGA cooling system

INTRODUCTION

A typical pool-type nuclear research reactor consists of three main important systems which are the reactor pool, primary cooling system, and a secondary cooling system. Reactor pool is an assembly of a water tank, reactor core where the fuel elements are located, beam ports and irradiation channels facilities. The reactor pool provides indispensable space for water inventory where neutron moderation, cooling, and shielding took place. Meanwhile, the primary and secondary cooling systems are two independent loops connected by a heat exchanger to allow heat removal from the reactor core. These systems consist of numerous pipelines network with different length, size, material, and arrangement. For example, the schematic layout of primary and secondary systems at PUSPATI TRIGA Reactor (RTP) is as shown in Fig. 1, adapted from Safety Analysis Report for RTP (Malaysian Nuclear Agency, 2017). The complexity of the pipelines network may differ upon a different type of the reactor and it is highly dependent on the specific design of the reactor itself.

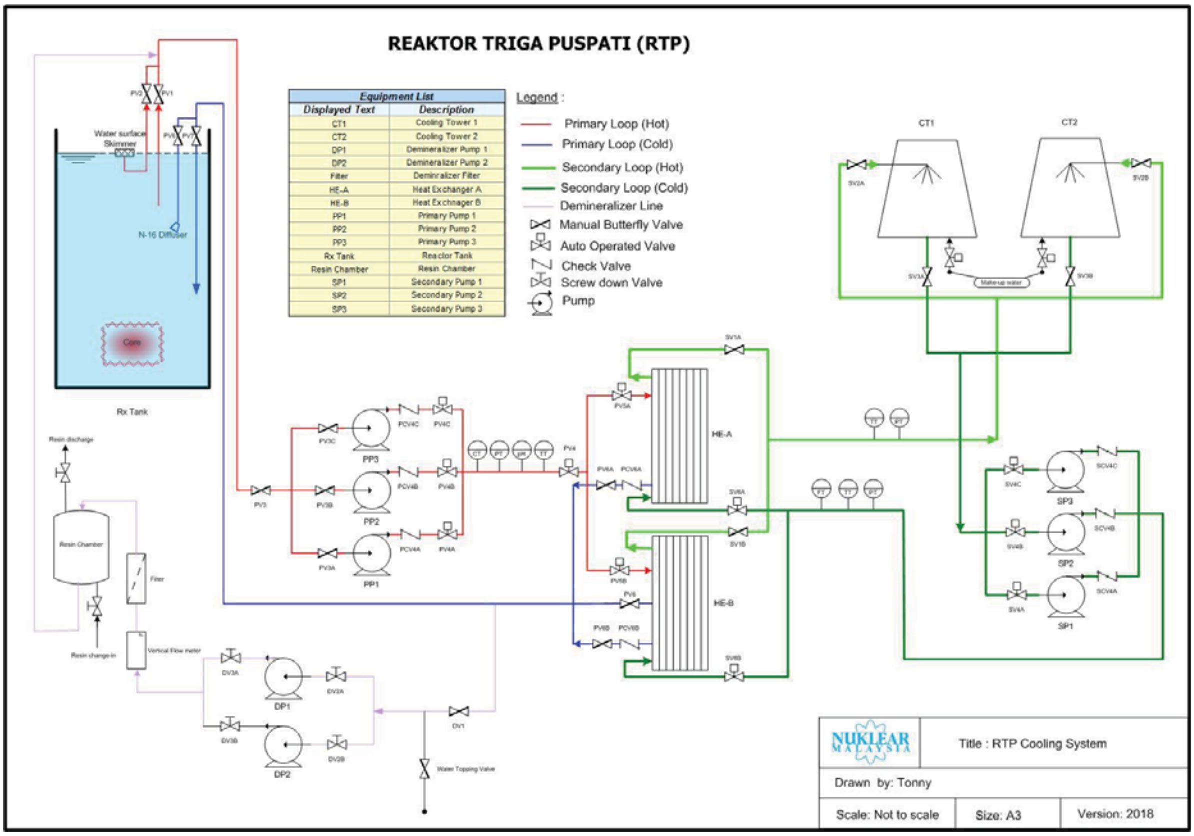

Figure 1. Schematic diagram of RTP Cooling System

In order to ensure the functionality and safety of the pipelines, monitoring and assessment shall be conducted periodically. Waiver of the proper monitoring and assessment of the pipelines may affects the integrity of the system. Damage of the pipelines could contribute to loss of coolant accident (LOCA) whether it is through small break or large break which subsequently contribute to the failure of the other integrated systems. The consequences of the failure could bring significant impact to the safety of the reactor due to loss of cooling and shielding. Therefore, piping reliability needs to be closely monitored and failure rate should be determined.

There are growing concern that current monitoring and inspection programs are conducted at the locations that generally have less contribution to the piping failure, while other failure occur in locations not accounted for in the current inspection programs. A related concern is derived from the insight that for a non-destructive test (NDT) to assure a high degree of reliability, the inspection must be geared to look for specific degradation mechanisms.

The most accepted approach to evaluate the safety and performance of the nuclear installation including research reactor is by system and component integrity monitoring. This involved the assessment of the integrity of pipelines. The monitoring of pipelines could be through physical inspection and material strength analysis or probabilistic assessment of pipe failure rate. The widely used method for integrity monitoring is through NDT techniques such as dye penetrant test, acoustic emission (AE), radiography test (RT) and ultrasonic test (UT). However, application of these techniques could be challenging at nuclear facility including research reactor system due to complexity of the pipelines and radiation risk. Sometimes, these techniques are avoided at place where high radiation level is recorded. In other approach, Probabilistic Safety Analysis (PSA) can be applied to estimate and predict the reliability of the pipeline.

There is no one best method to estimate failure probabilities (Swedish Nuclear Power Inspectorate, 1997). Therefore, the estimation has to rely on insight from the relatively large number of incipient and degrade failures occurred in the pipelines system. In order to have a convincing failure probabilities, the safety engineers and PSA practitioners should always consider the broadest possible database on operational events.

Pipe failures are caused by applied forces exceeding the residual strength of the pipe material. Pipe rupture occurs when the stresses (operational and environmental) act on pipes where corrosion, degradation, inadequate installation or manufacturing defects has impacted the pipes structural integrity (Rezaei, Ryan, & Stoianov, 2015).

The reliability of the pipeline can be estimated by knowing the pipe failure rate (PFR) which determine the frequency of the system failure in specific condition. The occurrence of PFR is most likely due to aging mechanism including (a) thermal embrittlement, (b) low and high cycle thermal fatigue, (c) stress corrosion cracking mechanisms, and, (d) Flow Accelerated Corrosion (FAC) as well as high cycle mechanical fatigue that causing loss of material toughness. The PFR can be obtained from generic database which is developed by experiences of the worldwide plant operators. However, to deal with specific assessment for the specific plant, dedicated test facility is essential. For example, Yoichi UTANOHARA *et al.* (Utanohara, Kamahori, & Nakamura, 2016) has developed a test loop for measurement of flow accelerated corrosion (FAC) rate measurement which is an important issue in aging management of fossil and nuclear power plants in Japan. Therefore, development of the test facility will open up the flexibility to conduct various experiment and testing for generation of engineering reliability data including PFR. The objective of this paper are:

- to determine the important criteria of the test rig for determination of PFR; and
- to illustrate the conceptual design of the experimental test rig for pipe failure rate assessment at RTP

The ultimate goal of this study is to establish the methodology of PFR of the water-cooled reactor (WCR) due to internal initiating events that capable to describe its fault detection system using artificial intelligent approaches. The examination of the aging of passive systems, structures and components (SSCs) is vital to assess safety limitations and to decide on reactor life span in WCR. As mentioned earlier in this paper, other failure mechanisms are often not accounted for in the current inspection program and not reflected in a realistic manner on ageing effects. A physics-based models explained the impact of complex aging processes and can be utilized to estimate failure rates using realistic NPP data from simulation, as well as data from surveillance and maintenance activities. However, in this paper, the physics-based models are not described because the main focus of this paper is to incorporate the prediction of PFR using a range of measurable parameters of the system such as pipe age, diameter, depth, length, pressure, the length of piping, the number of welds and joints through the conceptual design of an experimental test rig that is currently being developed.

METHODOLOGY

The general design process model as in Figure 2 has been adapted to produce the conceptual design of the test rig. The initiation of the design process has been done from the identification of the need to develop experimental test rig for pipe failure rate assessment at RTP. The discussions among multi-disciplined team members have been conducted to identify the need of this project. The goal of the project has been determined through the further discussion amongst the team members. Extension to that, related documents have been gathered.

Second main process is to define the problem. This includes problem statement, information gathering and determination of design objective. Clear problem statement supported by essential information will contribute to clear design objective.

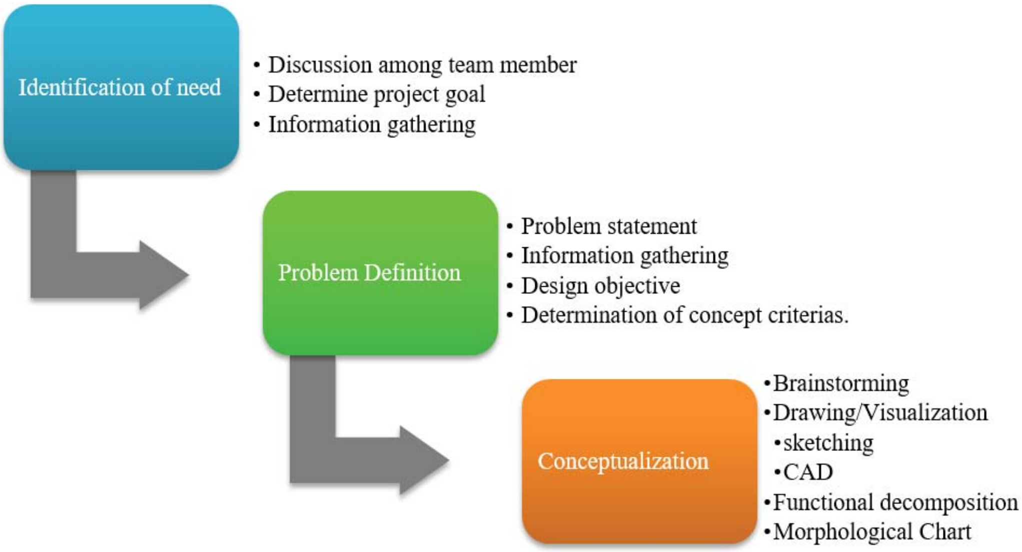

Figure 2. General Design Process Model

Guidance from clear design objectives drive the team members to proceed on conceptualization of the design. There are several strategies used in the concept generation as shown in Figure 3. The concept ideas are illustrated using sketching and Computer Aided Design (CAD) software. The 2-D and 3-D drawing is better to express the whole concept ideas.

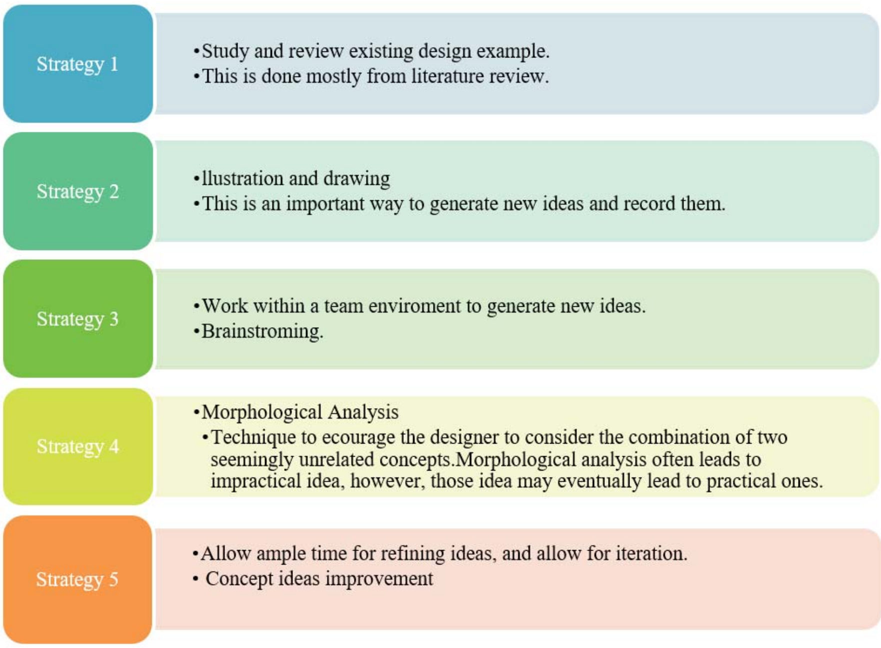

Figure 3. Concept Generation Strategies

RESULT AND DISCUSSION

From the brainstorming and discussions among the team members, the important criteria of the test rig have been determined as the following requirements:

- The test rig shall as much as practicable, follows the arrangement and simplification of the RTP.
- The test rig arrangement shall as much as practicable to cover all pipeline conditions at RTP.
- The material used shall be similar or equivalent to the material used in RTP.
- Scaling shall be applied at reasonable condition.
- Equipment, tools and material shall be from the existing inventory and additional need shall be proposed prior to consideration.

These requirements are set to acquire the best design concept that practically represent the actual piping conditions in the reactor. It is very important to ensure that the design of the test rig able to generate reliable and necessary data in the PFR study. Taking into account of the requirements, a general concept layout plan of the test rig has been developed as shown in Figure 4.

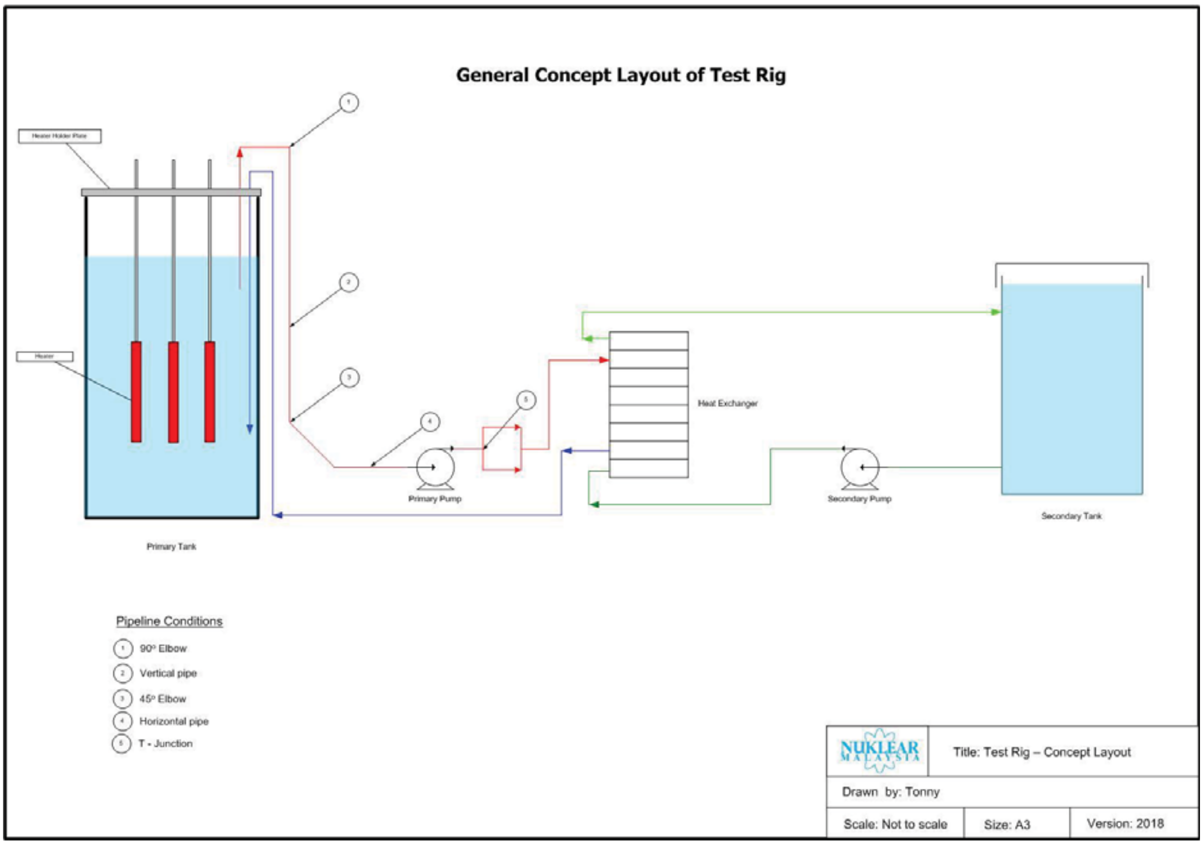

Figure 4. General Concept layout of the Test Rig

This general concept includes number of important equipment need to be available such as presented in Table 1. The general concept idea then expanded and multiple idea of concept design have been generated. In this paper, three ideas of concept design have been proposed for evaluation. These ideas are generated from sketches to CAD visualization as shown in Figure 5, Figure 6 and Figure 7. Basically, these three concepts design are proposed based on the requirements criteria and general concept layout. The difference of these concepts is on layout plan, where there are different arrangement of the equipment have been proposed. It is important to determine the suitable location to accommodate the test rig. In the meantime, the arrangement of the equipment will affect the generation of data for PFR study such as water flowrate, temperature and pressure of the system.

Table 1. Equipment List

Equipment	No. of unit (minimum)
Primary tank	1
Secondary tank	1
Heat exchanger	1
Heater	1
Water pump	2

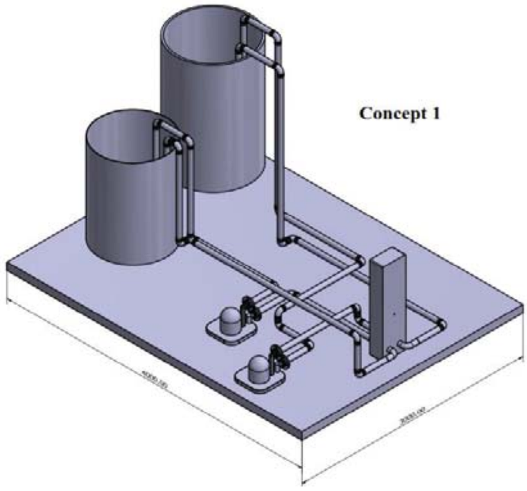

Figure 5. Concept Design No.1

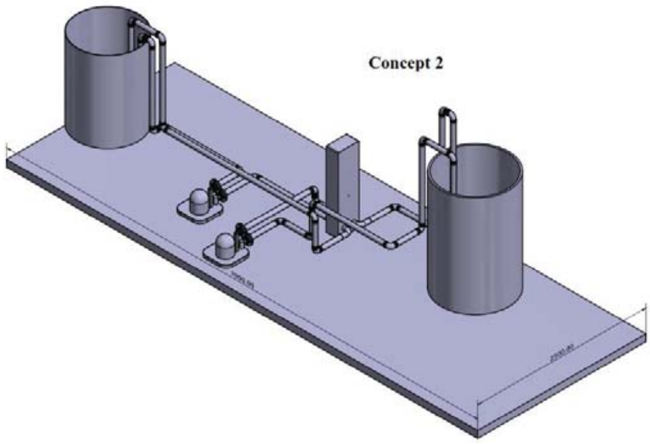

Figure 6. Concept Design No.2

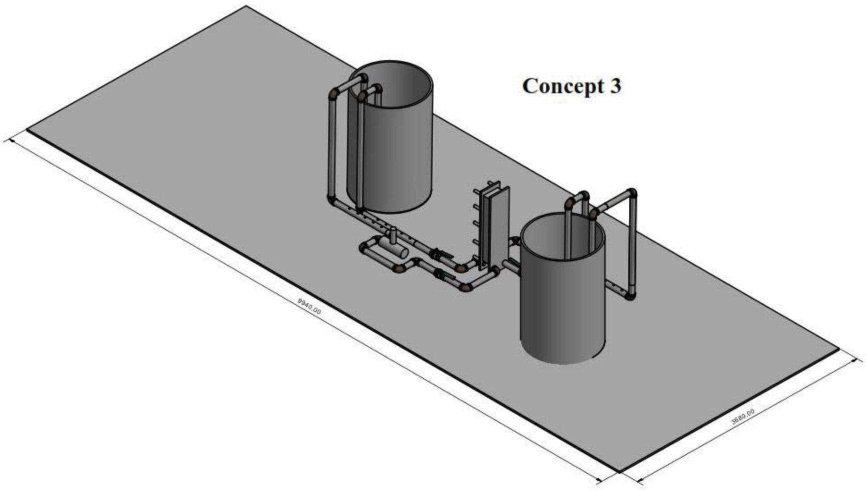

Figure 7. Concept Design No.3

Evaluation has been made on each concept design to determine the strengths and weaknesses as well as to extract the possibility of combination in order to meet the design requirements. Morphological analysis has been applied to grab the novel ideas from all design. The general summarization of the evaluation is presented in Table 2.

Table 2. Evaluation of the design concept

Requirement	Concept No.1	Concept No.2	Concept No.3
Arrangement	High	High	High
Simplification	High	High	High
Coverage of pipelines condition	High	Medium	Low
Material (stainless steel, aluminum, mild steel, etc.)	Medium	Medium	Medium
Practicability of scaling	High	Medium	Medium
Space requirement	High	Low	Medium
Usage of available material, tool and equipment	High	High	High

Note:
High - high fulfillness
Medium – Moderate fulfillness
Low – Low fullfillness

Combined idea of the design concept has been produced after evaluation of each concept based on the pre-determined requirement. The mutual idea for the design concept is strongly derived from Concept No. 1 with some improvement in coverage of pipeline condition. This combined concept idea as shown in Figure 8 are seen to be able to cover all identified pipeline conditions which are needed in PFR study.

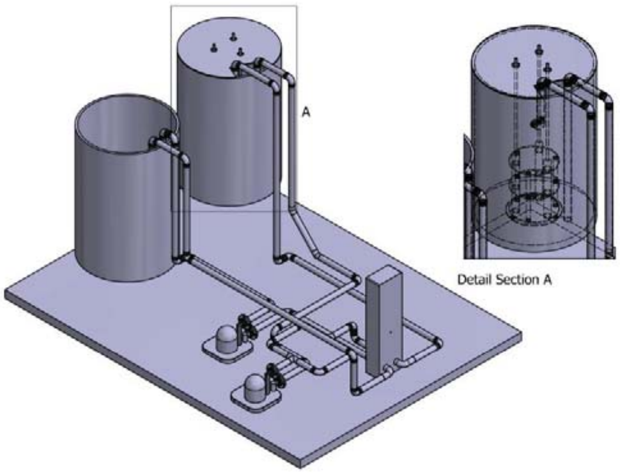

Figure 8. Combined design concept

CONCLUSION

This paper has determined the important criteria of the test rig for determination of the PFR. Combined idea of the design concept has been produced and presented.

ACKNOWLEDGEMENT

The authors express their sincere thanks to those involved directly or indirectly especially to the staffs of Reactor technology Center and Material Technology Division, Malaysian Nuclear Agency for their kind help, cooperation, comment and recommendation all the way to complete this paper. Our thanks also extended to intern students from Universiti Teknologi Malaysia (UTM), Universiti Putra Malaysia (UPM) Universiti Teknologi MARA (UiTM) for their keen to participate and contribute in this paper. All your hard work and contributions are highly appreciated.

REFERENCES

Malaysian Nuclear Agency. (2017). *Safety Analysis Report for PUSPATI TRIGA Reactor 2017*.

Rezaei, H., Ryan, B., & Stoianov, I. (2015), Pipe failure analysis and impact of dynamic hydraulic conditions in water supply networks. *Procedia Engineering*, *119*(1), 253–262. https://doi.org/10.1016/j.proeng.2015.08.883

Swedish Nuclear Power Inspectorate. (1997), *Reliability of piping system components framework for estimating failure parameters from service data* (Vol. 26).

Utanohara, Y., Kamahori, K., & Nakamura, A. (2016), Measurement of Flow Accelerated Corrosion Rate at an Elbow Pipe and Combination Effect of an Upstream Orifice. *E-Journal of Advance Maintenace*, *8–1*(2016), 1–12.