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Reactor Operational Experience Review and Analysis Based on Un-intended Reactor Trip Data

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A B S T R A C T

To enhance the safety and reliability of a new reactor, human factors should be integrated into its design process. The experimental power reactor (RDE) currently being developed in Indonesia needs to include human factors in the design process. One approach to incorporate human factors into design is by considering reactor operational experience data. This paper reviews and analyses the operational experience data of RSG-GAS reactor. The operational experience data of RSG-GAS reactor with 40,435 hours of total operation time spanning from 2003 to 2013 was used as a base in the study. In depth analysis on human factors was applied to the primary cooling system using Human Factors Analysis and Classification System-HFACS method. An amount of 289 un-intended trips were found in the observation data period. Most of un-intended trip were caused by external factors (38%). A review on the primary and secondary cooling system operational data showed that 3.11% of un-intended reactor trip occurrence causes were associated with human failure. Most suspected human failure/human error corresponds to the pump maintenance task which is classified as A action category. Analysis on the cooling system based on HFACS showed that the challenges to the human factors are related to unsafe acts, preconditions of unsafe acts, and unsafe supervision. The result reaffirm that human factors should be treated appropriately in the design of reactor equipment and operation procedure as well.

INTRODUCTION

Comprehensive approaches were applied to the design process of a new reactor in order to enhance the operation safety and performance. One of this approach is carried out by integrating human factors into design, which can be realized through consideration of the reactor operational experience review and analysis [1, 2]. The need to incorporate human factors in the reactor design process has been stated in several documents and design standards, since the safety performance does not depend only on technical matters but also on human performance [2–4].

Many researches engaged in reactor safety have made the effort to provide lesson learned from reactor operational experience, particularly during accidents [1, 5, 6]. It is widely accepted that poor human performance is a major cause of incidents and accidents [7, 8]. Therefore, methods for assessing human performance and contributing factors to the error in conducting reactor operation were extensively developed. The approaches were exceptionally broad and covered many aspects such as personal cognitive, communication,

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organization, human interface, and team personel [9–12].

The 10 MWth experimental power reactor (RDE) is currenty being developed in Indonesia. To enhance the safety and reliability of the RDE, a comprehensive aspects should be considered including human factors. The analysis of the operational experience were conducted on several reactors in order to implement the human factor programs in the design process [4, 13]. However, relevant informations and research results correspond to human factors required in the RDE design process were very limited. Most operational evaluation and analysis conducted were related to the neutronics and thermalhydraulics aspects [14, 15]. Other analyses on the operational experience data were emphasized on the challenge due to components reliability and ageing phenomena [16, 17]. In many aspects, human factors tend to be specific and influenced by local population characteristics [18, 19]. Therefore, an analysis and research based on operation experience data of local existing reactors is essential.

This research was aimed to analyse and review human factors in the operation of RSG-GAS reactor. In this study, human contribution to the un-intended reactor trip (reactor scram) was analysed based on the operational experience data of RSG-GAS. The RSG-GAS was selected as the object of the study since its operation is considered to be more complex compared to other two research reactors managed and operated by BATAN. In accordance to the purposes of this study, it is necessary that the investigations of human factors should consider a methodology to find out not only human tangible behavior but also intangible behavior such as organizational behaviors [10, 12, 20]. Therefore, in-depth analysis was carried out to the cooling system as a sample case by using Human Factors Analysis and Classification System (HFACS) approach to identify the causes of errors and corresponding performance influencing factors. In the analysis we employ RSG-GAS reactor operational experience data from 2003 to 2013.

The result presented in this paper would be essential to develop a detailed design of human-machine interface of the control room of RDE as well as in conducting reactor operation. Moreover it can also be considered for improving the operational management to enhance the safety operation of RSG-GAS. Further analysis on human factors performance in reactor operation needs more specific additional information data that should be prepared and included to the reactor operational experience database.

THEORY

RSG-GAS Research Reactor Operation

The design document and safety analysis report showed that RSG GAS design which was developed more than 30 years ago has also considered human factors in the design [21]. During normal condition, the operation of RSG-GAS is categorized as the following types: start-up, low power reactor operation, high power operation, power change/maneuvering, shutdown, and reactor scram.

To maintain the operator performance in conducting operation task, a shift work system is applied on RSG-GAS operation. Daily operation is divided into 3 operation shifts, each shift covers eight operation hours. One shift consists of at least one supervisor, two operators, one radiation protection officer, and one technical service/maintenance worker. To carry-out the reactor operation, there are 11 supervisors, 21 operators, 20 staffs as maintenance technicians, and 9 maintenance supervisors belong to the operation organization. Qualifications and required training for personnel working in the reactor facility are established and described in BAPETEN Chairman Regulation No.6 of 2013 [22].

The RSG-GAS reactor power control system is carried out by maneuvering 8 control rods inside the core, manually or automatically. The control activities are performed by using the provided reactor control desk, which also presented control rod status information consisting of control rod group (7 bank control rods) and a regulating control rod (1 rod). Control line from the operator will be stopped if the reactor protection system generates a scram signal, then control rod will be rapidly dropped and cause the reactor to shut-down/scram. The immediate emergency shut down or reactor scram is controlled by the reactor protection system unit [21].

The main components of the RSG-GAS reactor protection system (RPS) consist of data acquisition systems, analog systems, logic systems, and six contact systems (Figure 1). From the logic diagram, it is understood that reactor scram can be activated based on established reactor parameter measurements considered as safety critical. These parameters include a gamma dose rate in the reactor pool ventilation system, surface elevation of reactor pool water, primary isolation valve position, reactor core neutron flux density, and gamma dose rate in the primary system. Otherwise the scram can also be performed manually by the operator in the control room.

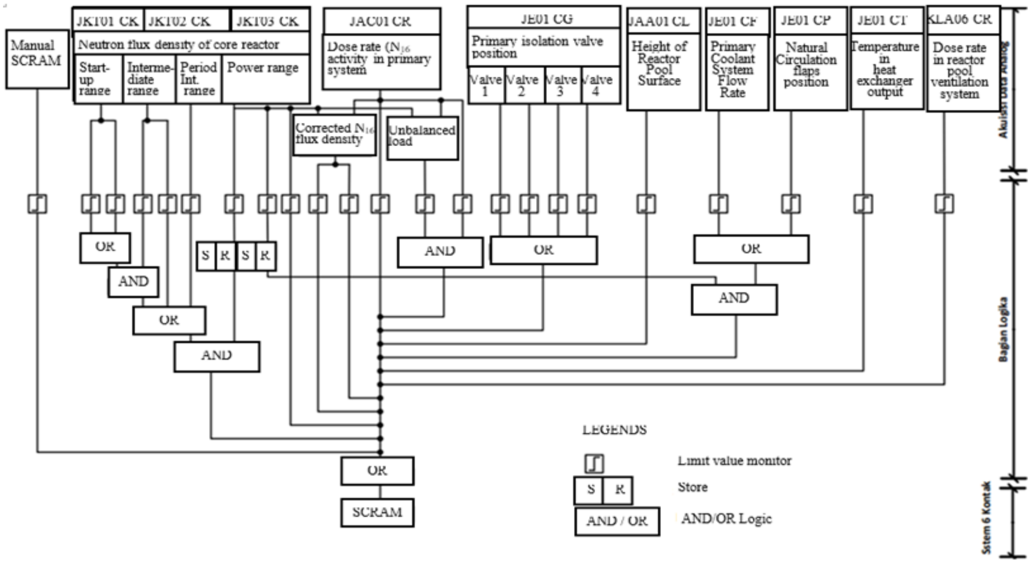

Fig. 1. Scram logic diagram for the RSG-GAS reactor protection system [21]

Human Factors Analysis and Classification System

IAEA Safety Series No. 50-P-10 differentiated human actions in three categories that are Category A, B and C. Category A of human actions or called pre-initiator associated to the actions that cause equipment or systems failure or unavailable when required. This pre-initiator is mainly related to the activities for preparation of equipment before operated including calibration, maintenance, replacement, etc. The category A can be explicitly modeled and are usually included in the system fault trees. Category B related to the actions that either by themselves or in combination with equipment failures lead to initiating events, or actions that contribute to initiating events. Category C human actions, which can be divided into three subtypes C1, C2, and C3 are associated with the human actions occurring post-fault [1, 23].

One of the most common human factors analysis framework is HFACS, which based on Reason's Accident Causation Model and addressed to aviation accidents investigations and safety system development as well [24, 25]. Typically, HFACS is used as a retrospective tool for analyzing accident and incident reports. There are four levels of HFACS hierarchy, consist of unsafe acts, preconditions for unsafe acts, unsafe supervisions, and organizational influences. To apply the framework to the nuclear domain, the HFACS terminology used in aviation is necessary to be modified owing to the slightly different generic nature of the terminology.

In contrast to the engine or components of high hazard system such as nuclear reactor, human factors tend to be complex, and their performances are also influenced by various factors. Analysis on human performances and influencing factors in HFACS are realized by implementing its four layers. The corresponding factors contributes to the performing task and subtask which broken down from the human role/function affecting the un-intended reactor trip are investigated based on the those layers.

METHODOLOGY

A total of 39 reactor operation cycles data spanning from 2003 to 2013 compiled and documented in RSG-GAS data system were used as object for investigation. The reactor operational experience data period were selected and screened out based on the completeness of scram information. From the selected data, un-intended reactor trip event was identified and its cause was analyzed. The particular cause of reactor trip are differentiated into five categories, namely availability of power supply, reactor flux and power detector, control rod drop, availability of pump at cooling system, and other factors. Then, HFACS was applied for in-depth analysis on the cooling system availability, as one of the internal cause of reactor scram occurence. The cooling system was selected since it was identified that human actions is very much prevalent in the system. Observation to the related documents such as maintenance and operation procedure, as well as discussion with operators was conducted in this step. During the analysis phase in order to conformize the detail human task and activities, and to identify the performance-influencing factors, further discussion with supervisors and related experts were performed. Discussion and analysis were based on the influence of corresponding factors to the suspected human failure based on the four layers of HFACS, that are unsafe acts, pre-conditions for unsafe acts, unsafe supervision, and organizational influence.

RESULTS AND DISCUSSION

The operation experience data of RSG-GAS between year 2003 to 2013 were selected from the provided experience data. The screening was based on the completeness of information, such as scram event and its causes. In the selected period, a total of 40,435 operation hours were performed and 39 core cycles were applied at RSG-GAS.

The result from observation and document survey showed that human actions in the operation of RSG-GAS could be differentiated as actions related with direct operation in main control room (MCR), on site activities associated to the dose and components monitoring task, preparation of operation which includes core management, and activities related to the maintenance of reactor component/equipment. All of these activities possess the possibility to cause reactor trip if performed incorrectly. Investigation on the extracted operation data showed, in total, 289 un-intended reactor trip occurred during the observed operation range. The highest number of un-intended scram, 48 times, occurred in year 2005, while the lowest scram occurrence is six times in year 2006. The data showed a specific trend pattern, that a significant decrement of scram frequency would take place in the next year after the year when the reactor experienced a large number of un-intended scram. This observation revealed that reactor organization management tend to apply reactive strategy to cope with the evidence of un-planned shutdown occurred in reactor facility. However, this approach showed its effectiveness to remove problems that initiated the un-intended reactor trip. The trend of un-intended trip number of RSG-GAS and the factors affected to the reactor scram in the period from 2003 to 2013 are presented in Fig. 2.

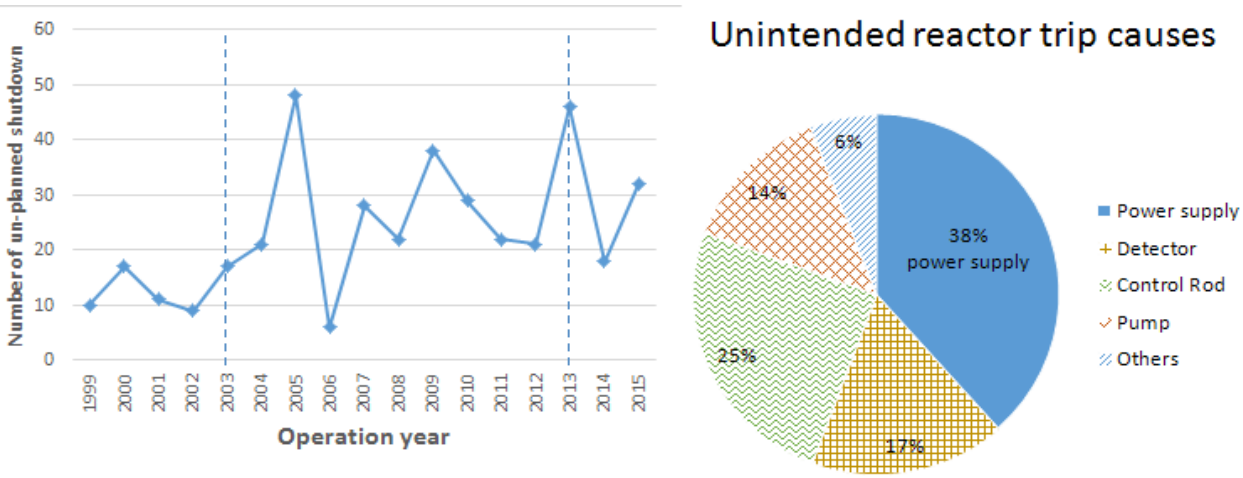

Fig. 2. Un-intended reactor trip frequency and the causes of trip during the observation period

The cause and initiator of un-intended trip of RSG-GAS was categorized in five factors that are out of power supply, reactor flux and power detector, control rod drop, primary and secondary pump at cooling system, and other causes. Most of reactor scram was caused by external factor, which was unavailability of power supply (38%). Other causes which contributes 6% of reactor scram comprise of manual scram, purification system failure, radiation monitor trouble, improper object fell into the core, etc. Figure 2 shows the contribution of each category to the reactor scram. In conformity to the research purpose, the pump availability as one of cause of reactor scram was selected for in-depth analysis, since it was assumed that availability of pump strongly depend on the applied maintenance program where the sequence of human actions should be carried out. Identification results showed that 14% of reactor scram occurrence were caused by pump unavailability, contributed both by primary pump (6 scrams) and secondary pump (33 scrams). Detailed investigation result corresponds to the pump unavailability is presented in Table 1.

Table 1. Reactor scram number caused by pump unavailibility.

No	Causes of pump failure	Primary pump (identified HE)	Secondary pump (identified HE)
1	Pump suddenly off	-	10(4)
2	Mechanic filter	-	6 (2)
3	Low limit flow/no flow	-	4 (1)
4	Valve closed/break	-	3
5	Above Limit temperature	2 (1)	1
6	Motor timer/trouble/burn	1	1
7	Radiation control	-	2 (1)
8	Oil lubricant/seal leakage	1	1
9	Fuse break	-	1
10	Motor coupling break	1	-
11	Pressure drop	1	-
12	Instrumentation module	-	1
13	Others	-	3

There is a number of scram initiation parameters designed for RSG-GAS safety protection system, where the associated components to those parameters should be maintained and or be inspected periodically. Among them including scram caused by primary pump failure, loss of power source, and manual scram. Therefore, the preventive maintenance was applied for the specific components such as valve and rotated component equipment. According to this function, human activities applied for a valve includes visual inspection, grease, cleaning/maintenance, and changing of spare parts. For the rotating equipment, maintenance activities consists of visual inspection, rotation assembly balancing, grease couplings, electric current measurement, checking the reactor protection circuit, and spare part replacement.

Considering the maintenance procedure applied to the RSG-GAS reactor, as well as specification and characteristics of the pump components, in this study we agree to justify several assumptions. A type human failure will probably exists (human error suspected-HES) in the maintenance task when a failure occurs at the same pump components and affects to the occurring of a reactor scram during a single reactor core operation, or during a consecutive reactor core operation configuration. Each of un-intended scram needs at least a single response task from operator to remove the existing failure causes and to prepare a successful operation.

Investigation on the scram/trip reactor caused by unavailability of primary pump showed that one of HES in maintenance (repair/remove or replace components) tend to exists in the total of 6 conducted maintenance activities. On the other hand, an amount of 8 human error suspected also tend to exist during the maintenance of secondary pump. The result as listed in Table 1 showed that un-intended reactor trip caused by unavailibility of secondary pump occurred for 33 times (84%), where 24% of them tend to be contributed by human failure. Within the observation period, it was also found that 23% of A-type HES occurred in the maintenance activities of RSG-GAS cooling system. Large portion of identified human failure was caused by pump suddenly turned off, and failure in conducting the pump filter maintenance. Figure 3 presented the distribution of suspected human error in pump maintenance, and un-intended scram caused by unavailability of pump at reactor cooling system per operation year.

Observation on existing procedure of RSG-GAS showed the distribution of task, role, and responsibility in conducting maintenance has been defined clearly. Maintenance and periodic testing are the responsibility of reactor manager, but can be delegated to the maintenance supervisor nevertheless. In accordance to the human failure in maintenance, the study identified that dominant factors influenced to A-category of human failure includes completeness of procedure, lack of supervisory, and fidelity in applying the procedure. Inconsistency in filling out the maintenance report form tends to initiate a failure in performing the next order of task activities.

The HFACS analysis of RSG-GAS is qualitatively summarized in Table 2. The causes of un-intended trip which identified as human failure were based on the four tiers of the HFACS framework: unsafe acts, pre-conditions for unsafe acts, unsafe supervision, and organizational influence. In accordance with the organizational factors, the availability of personal resources and financial resources are sufficiently provided in the organization of RSG-GAS in order to perform a required maintenance task. Safety culture in organization of RSG-GAS has been promoted intensively during the last decade. Self-assessment and re-inforcing program in safety culture were conducted annually by organization management. Therefore, unsafe acts, such as action violations which may affect to the performance in conducting operation and maintenance, can be minimized, even though it remains exist during observation period. Moreover, operators have adequate training relevant to their task, and therefore the occurence of knowledge based errors and failure in conducting diagnosis can be prevented.

Other two layers of HFACS, which are pre-condition of unsafe acts and unsafe supervision are identified to be having contribution to the occurring of human failure in maintenance activities of cooling system. The issues of pre-condition of unsafe acts was found in practicing the task, such as too much reliance on the human operator and design performance (complacency). It can be recognized that in certain conditions, the formal existing task procedure was not fully applied in the maintenance or repairing process, which then resulted the similar failure occurs in the next short time operation period. The availability of appropriate tools or equipment at a workplace when required may also contributes to the error in conducting a task. Unsafe supervision tend to exist in some of maintenance task, which affects the identified problem so that it was not entirely removed. However, in general, the supervisory role and task was clearly showed in performing the maintenance task of RSG-GAS.

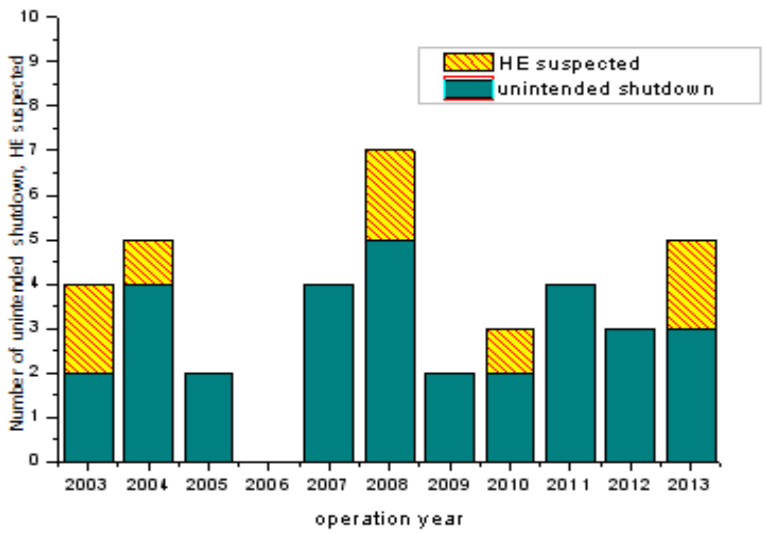

Fig 3. Un-intended reactor trip caused by pump unavailability, and HE suspected per operation year

Table 2. The HFACS analysis of RSG GAS

No	Components HFACS	Advantages	Challenge/disadvantages
1	Unsafe acts	High safety culture, well trained and experienced operator.	Skill based error due to attentional and memory failure. Violations
2	Preconditions for unsafe acts	Human factor has been considered in the design of reactor equipment. High safety design standard. Appropriate operator's workload and competency (adequate training)	Availibility of proper tools and method. Quality of procedure. Modifications of human machine interface tend to be conducted partially.
3	Unsafe supervision	The supervisory's role and task were acommodated in the operation and maintenance procedure. High safety awareness.	Complacency(over confidence) to the design capability and individual operator performance. Self satisfied, Inadequate supervision.
4	Organizational influence	Management of resource and financial, Safety policy, Maintaining safety culture and safety awareness.	Preservation of knowledge and operators personell.

CONCLUSION

Review and analysis of the RSG-GAS reactor operation experience was conducted, where a total of 39 reactor operation cycles data from 2003 to 2013 were selected and used as an object for investigation. The result showed that 289 unintended reactor trip occurs during the operation period. Most of un-intended trip was caused by external factor, that is unavailability of power supply (38%). In-depth analysis on the primary cooling system showed that 3.11% of A-type categorized human failure tend to contributes to the un-intended reactor trip of RSG-GAS. The qualitative analysis with HFACS showed the dominant factors influenced to the suspected human failure include completeness of procedure, lacking in supervisory, and fidelity in applying the procedure. The result study is essential for considering human factors in the design and operation management of a new reactor such as RDE. Further analysis is still needed to formulate a proper approach and required plan in reducing human error. Hence particular information intended to such purpose should be prepared and provided in the reactor operation experience database from the beginning.

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REFERENCES

1. Mohamed F., Hassan A., Yahaya R., Rahman I., Maskin M., Praktom P., et al. Operator reliability study for Probabilistic Safety Analysis of an operating research reactor. Ann. Nucl. Energy. 2015. **80**:409–15.
2. Joe J.C., Thomas K.D., Boring R.L. Establishing a Value Chain for Human Factors in Nuclear Power Plant Control Room Modernization. Procedia Manuf. 2015. **3**(Ahfe):1312–8.
3. Shokr A.M. Considerations of Human Factors in the Design and Operation of Research Reactors. 2015. **48**(4):170–7.
4. Hugo J. V., Kovesdi C.R., Joe J.C. The strategic value of human factors engineering in control room modernization. Prog. Nucl. Energy. 2018. **108**(June):381–90.
5. Kim A.R., Park J., Kim J.T., Kim J., Seong P.H. Study on the identification of main drivers affecting the performance of human operators during low power and shutdown operation. Ann. Nucl. Energy. 2016. **92**:447–55.
6. Park J., Kim Y., Jung W. Calculating nominal human error probabilities from the operation experience of domestic nuclear power plants. Reliab. Eng. Syst. Saf. 2018. **170**(October 2016):215–25.
7. Li C., Tang T., Chatzimichailidou M.M., Jun G.T., Waterson P. A hybrid human and organisational analysis method for railway accidents based on STAMP-HFACS and human information processing. Appl. Ergon. 2019. **79**(February):122–42.
8. Ribeiro A.C., Sousa A.L., Duarte J.P., Frutuoso e Melo P.F. Human reliability analysis of the Tokai-Mura accident through a THERP-CREAM and expert opinion auditing approach. Saf. Sci. 2016. **87**:269–79.
9. Simonsen E., Osvalder A.L. Categories of measures to guide choice of human factors methods for nuclear power plant control room evaluation. Saf. Sci. 2018. **102**(October 2016):101–9.
10. Alvarenga M.A.B., Frutuoso E Melo P.F., Fonseca R.A. A critical review of methods and models for evaluating organizational factors in Human Reliability Analysis. Prog. Nucl. Energy. 2014. **75**:25–41.
11. Santoso S. Factors Influencing Human Reliability of High Temperature Gas Cooled Reactor Operation. J. Teknol. Reakt. Nukl. Tri Dasa Mega. 2016. **18**(3):135.
12. Li P. cheng, Zhang L., Dai L. cao, Li X. fang, Jiang Y. A new organization-oriented technique of human error analysis in digital NPPs: Model and classification framework. Ann. Nucl. Energy. 2018. **120**:48–61.
13. Jang I., Kim A.R., Jung W., Seong P.H. Study on a new framework of Human Reliability Analysis to evaluate soft control execution error in advanced MCRs of NPPs. Ann. Nucl. Energy. 2016. **91**:92–104.
14. Knol S., de Groot S., Salama R. V., Best J., Bakker K., Bobeldijk I., et al. HTR-PM fuel pebble irradiation qualification in the high flux reactor in Petten. Nucl. Eng. Des. 2018. **329**(September 2017):82–8.
15. Gou F., Chen F., Dong Y. Dynamic response of the HTR-10 under the control rod withdrawal test without scram. Energy Procedia. 2017. **127**:247–54.
16. Santoso S., Bakhri S., Situmorang J. A Bayesian Network Approach to Estimating Software Reliability of RSG-GAS Reactor Protection System. Atom Indones. 2019. **45**(1):43.
17. J. Sukmana, R.Triharto Lesson Learn from Scram at JKT03 channel Using Fault Tree Analysis in RSG-GAS Reactor. 2018.
18. Park J., Jung W. Comparing cultural profiles of MCR operators with those of non-MCR operators working in domestic Nuclear Power Plants. Reliab. Eng. Syst. Saf. 2015. **133**:146–56.
19. Musharraf M., Smith J., Khan F., Veitch B., MacKinnon S. Incorporating individual differences in human reliability analysis: An extension to the virtual experimental technique. Saf. Sci. 2018. **107**(November 2016):216–23.
20. Kim Y., Park J., Jung W. A quantitative

measure of fitness for duty and work processes for human reliability analysis. Reliab. Eng. Syst. Saf. 2017. **167**(November 2015):595–601.

21. Anonymous, Safety Analysis Report of RSG-GAS, Rev 10, 2 (2008).
22. Anonymous Licensing for Working with Nuclear Installation and Material, BAPETEN Chairman Regulation No.6 of 2013. 2014.
23. Hassan A., Maskin M., Tom P.P., Brayon F., Hlavac P., Mohamed F. Operator response modeling and human error probability in TRIGA Mark II research reactor probabilistic safety assessment. Ann. Nucl. Energy. 2017. **102**:179–89.
24. Wiegmann, D.A., Shappell S.A. Human Factors Analysis and Classification System(HFACS). Ashgate, Burlington,VT. 2003.:83–103.
25. Ergai A., Cohen T., Sharp J., Wiegmann D., Gramopadhye A., Shappell S. Assessment of the Human Factors Analysis and Classification System (HFACS): Intra-rater and inter-rater reliability. Saf. Sci. 2016. **82**:393–8.