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SAFETY INTEGRITY LEVEL ASSESSMENT AT URANIUM EVAPORATOR AND DEPOSITION VESSEL IN NON NUCLEAR REACTOR INSTALLATIONS

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ABSTRACT

SAFETY INTEGRITY LEVEL ASSESSMENT AT URANIUM EVAPORATOR AND DEPOSITION VESSEL IN NON NUCLEAR REACTOR INSTALLATIONS. The operation of non-reactor nuclear installations that use nuclear material in the process must be ensured safely during the process. One of the assessments of the safety level of the protection system that has been owned by the installation is using the Safety Integrity Level (SIL) which assesses the safety level of the protection system based on the value of the risk reduction factor that the protection system can achieve. The uranium evaporator and deposition vessel at the Experimental Fuel Element Installation (EFEI) is one of the installations that uses nuclear material in the process so it is necessary to assess the SIL of these 2 vessels. The piping and instrumentation diagram (P&ID) is used to determine the SIL value and Safety Instrumented System (SIS) component are installed in evaporator and deposition vessel. Maintenance data and OREDA (Offshore Reliability Data) are used to determine the failure rate. After knowing and determining the installed SIS components, then determining the architecture vote of the Safety Instrumented Function (SIF) based on the P&ID diagram, so that it can be known that the installed SIS uses vote 1oo1, 1oo2, 1oo3, or the appropriate vote. The installed SIF architecture vote will determine the equation used to calculate the Probability Failure on Demand (PFD). The total PFD obtained is adjusted to the SIL table to find out what SIL level the installed protection system is at. The value of the safety level of the protection system with SIL assessment in the evaporator vessel obtained 2 protection systems with SIL values of level 2 all and in the deposition vessel obtained 2 protection systems with SIL values of level 1 and level 2. The SIL value in the evaporator and deposition vessel analyzed has not reached level 3 or 4, so it is necessary to add SIF to the SIS protection system to increase the SIL value until the SIL value is obtained between level 3 or 4 because safety in the operation of non-reactor nuclear installations is absolute.

Keywords: Non-Reactor Nuclear Installations, PFD, SIF, SIL, SIS

ABSTRAK

PENILAIAN SAFETY INTEGRITY LEVEL TANGKI EVAPORATOR DAN PENGENDAPAN URANIUM PADA INSTALASI NUKLIR NON REAKTOR*. Pengoperasian instalasi nuklir non reaktor (INNR) yang menggunakan bahan nuklir dalam prosesnya harus dipastikan akan keselamatannya selama proses berlangsung. Penilaian tingkat keamanan sistem proteksi yang telah dimiliki oleh instalasi tersebut salah satunya menggunakan Safety Integrity Level (SIL) yang menilai tingkat keamanan sistem proteksi berdasarkan nilai faktor pengurangan risiko yang mampu dicapai sistem proteksi yang dimiliki. Tangki evaporator dan tangki pengendapan uranium pada Instalasi Elemen Bakar Eksperimental (IEBE) merupakan salah satu instalasi yang menggunakan bahan nuklir dalam prosesnya sehingga perlu dilakukan penilaian SIL terhadap 2 tangki ini. Penentuan nilai SIL tangki evaporator dan tangki pengendapan ditentukan dengan melihat diagram perpipaan dan instumentasi (P&ID) untuk kedua tangki tersebut. Dari diagram P&ID dapat ditentukan komponen Safety Instrumented System (SIS) yang terpasang pada kedua tangki tersebut, lalu dengan menggunakan data perawatan maupaun data OREDA bisa untuk menentukan nilai failure rate nya. Setelah diketahui dan ditentukan komponen SIS yang terpasang, selanjutnya dilakukan penentuan vote arsitektur dari Safety Instrumented Function (SIF) berdasarkan diagram P&ID, sehingga dapat diketahui SIS yang terpasang menggunakan vote 1oo1, 1oo2, 1oo3, atau vote yang sesuai. Vote arsitektur SIF yang terpasang akan menentukan persamaan yang digunakan untuk menghitung Probability Failure on Demand (PFD). Setelah tiap SIF dihitung nilai PFD nya, selanjutnya dilakukan perhitungan nilai PFD total. Nilai PFD total yang didapat disesuaikan dengan tabel SIL untuk mengetahui sistem proteksi yang terpasang ada pada level SIL berapa. Nilai tingkat keamanan sistem proteksi dengan penilaian SIL pada tangki evaporator didapatkan 2 sistem proteksi dengan nilai SILnya level 2 semua dan pada tangki pengendapan didapatkan 2 sistem proteksi dengan nilai SILnya level 1 dan level 2. Nilai SIL pada tangki evaporator dan tangki pengendapan yang dianalisis belum mencapai level 3 atau 4, maka diperlukan penambahan SIF pada SIS sistem proteksi untuk meningkatkan nilai SIL sampai didapatkan nilai SIL antara level 3 ataupun 4 karena keselamatan pada pengoperasian instalasi nuklir non reaktor bersifat mutlak.*

Kata kunci*: Instalasi Nuklir Non Reaktor, PFD, SIF, SIL, SIS.*

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INTRODUCTION

In implementing the safety of a nuclear facility, it is necessary to assess the level of security of the protection system that has been owned by the facility whether it is able to support safety during the process, or whether an additional protection system is needed in the facility. The safety level of the protection system based on the value of the risk reduction factor that the protection system can achieve is analyzed using the Safety Integrity Level (SIL) method. The Pilot Conversion Plant (PCP) facility, which is a facility owned by the Experimental Fuel Element Installation (IEBE) DPFK - BRIN as a facility that processes nuclear material (yellow cake), has directly implemented safety standards as a reference for safety operations at the facility, namely using Hazard Identification Risk Assessment Determining Control (HIRADC) and Hazard and Operability Study (HAZOPS). If HIRADC and HAZOPS analyze safety based on the identification of potential hazards that can arise if an accident occurs at a nuclear facility, SIL analyzes the level of security in terms of the protection system that already exists at the facility. So SIL is used to evaluate the existing protection system so that it does not cause hazards such as accidents at the facility. HIRADC and HAZOPS are qualitative analyses for hazard identification when the equipment is in operation, while SIL analysis is a quantitative analysis to determine the safety level of a safety system [1].

SIL is a way of indicating the acceptable failure rate of a particular safety function [2,3]. SIL parameters include sensors on devices related to temperature, pressure, flow, and level in the device. The concept of measuring the value of SIS performance can function as a security system that has been introduced in the International Electrotechnical Commission (IEC) 61508 protection functional standard on electrical protection systems, and IEC 610511 on instrument protection systems [4]. IEC 61508 is a performance-based safety standard and addresses E/E/PE SRSs (electrical, electronic, and programmable electronic safety-related systems) with respect to the entire industry [5]. Based on IEC 61508, SIL is classified into four levels, namely SIL 1, SIL 2, SIL 3, SIL 4. This standard provides a framework for conducting SIL assessments in general, namely qualitatively and quantitatively. SIL assessment is established based on the standard reliability testing of the device by the manufacture, such as burn test, material quality test, mechanical shock test, electronic function test, and leakage test. SIL 1 is the lowest level of safety protection and SIL 4 is the highest, which is only used for the nuclear industry. Risk/Hazard Analysis is used to determine SIL. It identifies all hazards in a process and estimates the risks initially involved, and determines the tolerance and acceptability of those risks [6,7]. The protection system is a system that keeps the process safe when dangerous and unwanted circumstances are detected. The safety system is separate from the control system and independent of each other, but the system components have similarities. safety systems are usually referred to as Safety Instrumented System (SIS) which consists of several instruments that work in one system called a safety instrumented function (SIF). SIS is just like a basic process control system (BPCS) which consists of sensors, controllers, and actuators. Although they look similar in terms of hardware, SIS and BPCS have differences in terms of function. The main function of the control loop in general is to keep the process variables within the specified limits, while the SIS monitors the process variables and initiates safety measures if needed [8,9]. SIS also consists of three instruments namely transmitter, logic solver, and final element that perform their functions in an integrated manner to control the risk of potential high temperature and pressure hazards [10,11].

In its determination, the SIS that will calculate its SIL value is divided into two, namely low demand operation and high demand operation. Low demand operation is a device or system that operates less or equal to once a year, in general for protection systems. High demand operation is a device or system that operates more than once a year, in general, usually included in the high demand operation category is a control system. Determining the SIL value quantitatively can be done through the calculation of the Probability Failure on Demand (PFD) for each SIF constituent of the SIS and then calculating the total PFD. To get the PFD value, you can use the following simple equation [12]:

1) 1oo1

$$PFD_{avg} = \frac{\lambda \, x \, TI}{2} \quad (1)$$

1oo1 means one out of one, there is 1 output from 1 SIF.

2) 1oo2

$$PFD_{avg} = \frac{\lambda^2 \, x \, TI^2}{4} \quad (2)$$

1oo2 means one out of two, there is 1 output from 2 SIF.

3) 1oo3

$$PFD_{avg} = \frac{\lambda^3 \, x \, TI^3}{8} \quad (3)$$

1oo3 means one out of three, there is 1 output from 3 SIF.

4) 2oo2

$$PFD_{avg} = \lambda \text{ x } TI \quad (4)$$

2oo2 means two out of two, there is 2 output from 2 SIF.

5) 2oo3

$$PFDavg = \lambda^2 \text{ x } TI^2 \quad (5)$$

2oo3 means two out of three, there is 2 output from 3 SIF.

6) 2oo4

$$PFDavg = \lambda^3 \text{ x } TI^3 \quad (6)$$

2oo4 means two out of four, there is 2 output from 4 SIF.

with:

PFD_{avg} = Probability Failure on Demand Average
λ = Failure rate
TI = Interval time / test function (hour)

SIL is determined by the PFD, which indicates that the SIS can perform the required safety functions. Any SIL determination must conform to a specific standard that follows the philosophy of IEC 61508 [13]. This standard is a combination of IEC 61508 and ANSI/ISA S84.01. Representative methods for SIL determination are the layer of safety matrix, calibrated risk graph, and Layer of Protection Analysis (LOPA) [14].

In this study, SIL will be analyzed on the evaporator vessel and settling vessel which are tools found in the PCP facility. The evaporator vessel is used to carry out the evaporation process (concentration), which is a process to reduce the water content in the Uranyl Nitrate (UN) solution until its density becomes 1.27 Kg/L or the equivalent of 200 gr U/L as feed preparation for the deposition process after the UN solution has been purified until it reaches nuclear grade [15]. The evaporation process is heated using steam that flows through the evaporator jacket (E-601) until it reaches a temperature of ±120°C [16]. The UN solution from vessel V-404 is continuously flowed into the evaporator (E-601). The volume of UN solution in the evaporator (E-601) will continue to be reduced due to evaporation so that the uranium content rises. The solution density indicator (DR-0601) is used as a controller of uranium levels in the solution which is set at a value of 1.27 Kg/L equivalent to 200 gU/L. If the solution density value has reached 1.27, the P-603 pump will automatically turn ON and send the UN solution to the evaporation process storage vessel (V-602). Meanwhile, the settling vessel (C-901/C-902) is used to precipitate the concentrated UN solution from the evaporation process into Ammonium Diuranate (ADU). The process usually chosen to obtain sinterable uranium dioxide (UO2) is by deposition of uranium as ADU. In the deposition process, there are several things that can affect the quality of the precipitate, including pH, reaction temperature, and contact time [17]. The deposition process is carried out by adding ammonium hydroxide solution to the UN solution in the deposition vessel (C-901/C-902) so that ADU solids will form at the bottom of the deposition vessel. Some UN solution from the evaporation process is flowed into the settling vessel (C-901/C-902) which is heated by flowing hot water into the jacket of the settling vessel to a temperature of ±60-70°C. Furthermore, ammonia solution from vessel V-208/V-214 through pump P-208 A/B is flowed into the settling vessel (C-901 / C-902) with a flow rate of ±20 liters/hour and automatically decreases in speed if the pH of the solution approaches the setting value. Deposition is carried out at pH ± 7 and temperature 60°C. The deposition process is considered complete when the pH reaches a value of 9 [15].

With nuclear material as the main ingredient and other hazardous solutions, the safety system in the evaporator vessel and

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settling vessel needs to be analyzed so that the process can run safely and nothing happens that endangers the operator and the environment during the process.

METHODOLOGY

The determination of the SIL value of the evaporator vessel and settling vessel at the Piot Conversion Plant (PCP) facility at the Installation of Experimental Burning Elements (IEBE) can be determined by looking at the piping and instrumentation diagram (P&ID) for the evaporator vessel and settling vessel as shown as in Figure 1 and 2.

From Figure 1, it can be determined which safety instrumented system (SIS) components are installed in each of the main solid equipment for each process, then using maintenance data or OREDA data can determine the failure rate value. After knowing and determining the installed SIS components, the next step is to determine the architectural vote of the safety instrumented function (SIF) based on the piping and instrument diagram, so that it can be known that the installed SIS uses vote 1oo1, 1oo2, 1oo3, or the appropriate vote. The installed SIF architecture vote will determine the equation used to calculate the probability failure on demand (PFD). After the architecture vote is known, we can calculate the PFD value based on the vote. After each SIF PFD value is calculated, the total PFD value is calculated. After obtaining the PFD value, we adjust it to Table 1 to determine the SIL that has been obtained using the following equation [18]:

$$PFD_{total} = PFD_{censor} + PFD_{logic\ solver} + PFD_{FCE} \quad (7)$$

with:

PFD_{total} : Average PFD of safety related system safety function
PFD_{censor} : PFD of sensor subsystem
$PFD_{logic\ solver}$: PFD of logic subsystem
PFD_{FCE} : PFD of the final element subsystem

Based on the total PFD value, the risk reduction factor, RRF can also be known as follows [18];

$$RRF = \frac{1}{PFD} \quad (8)$$

Failure rate and test interval affect the PFD value of a component. If the failure rate is greater, the chance of failure will be greater and vice versa. In addition, a long test interval makes the chance of component failure even greater. To get the failure rate value, it is done by analyzing maintenance and failure record data or commercial failure rate data, namely data obtained from failure rate databases, such as one of them is OREDA (Offshore Reliability Data).

The safety layer matrix is based on qualitative knowledge regarding the frequency, consequences of accidents and the available IPL (In Protection Layer), so a matrix with the severity of hazardous events, the likelihood of hazardous events, and a number of IPLs can be used to determine SIL [19], so each IPL should be able to prevent or mitigate the potential consequences of accidents.

Table 1. SIL *and required safety system performance for low demand mode System* [8]

Safety Integrity Level (SIL)	Probability Failure on Demand (PFD)	Safety Availability (1-PFD)	Risk Reduction Factor (RRF)	Safety Integrity Level (SIL)
4	0.0001 - 0.00001	99.99 - 99.999%	10000 – 100000	4
3	0.001 - 0.0001	99.9 - 99.99%	1000 – 10000	3
2	0.01 - 0.001	99 - 99.9%	100 – 1000	2
1	0.1 - 0.01	90 - 99%	10 – 100	1

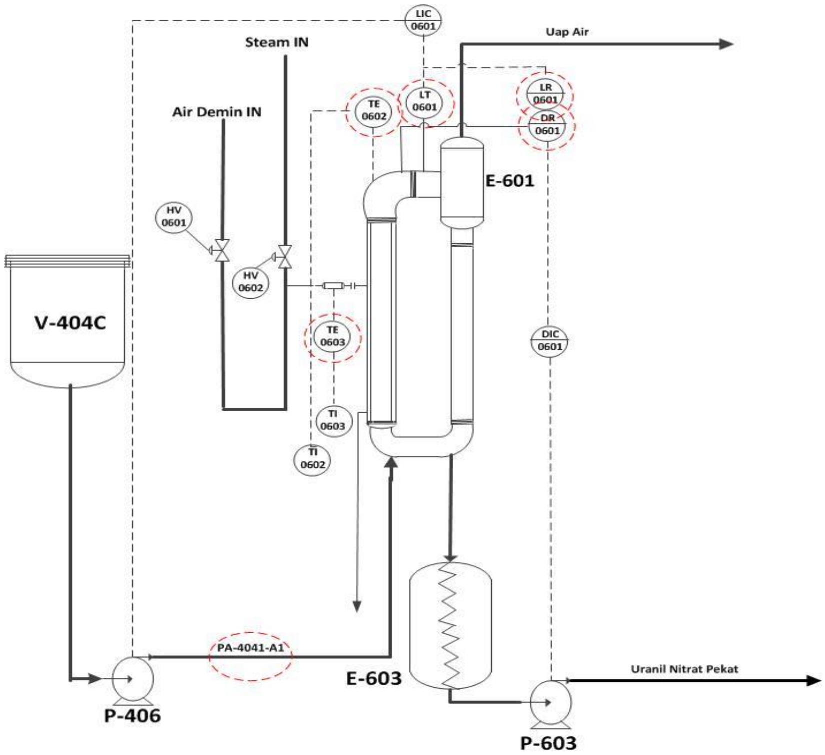

Figure 1. P&ID Diagram of Evaporator Vessel

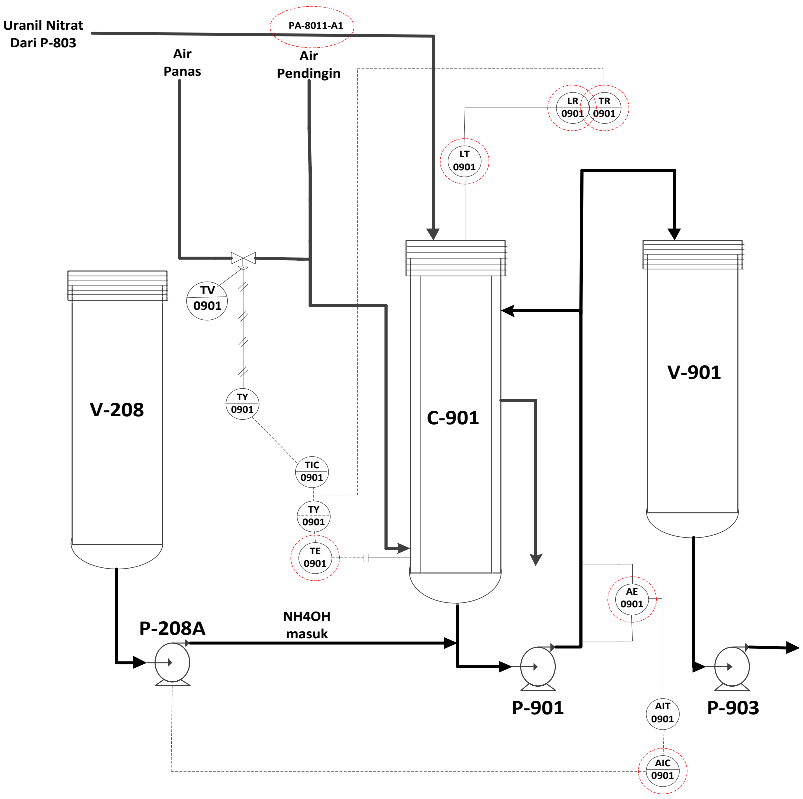

Figure 2. P&ID Diagram of Deposition Vessel

RESULTS AND DISCUSSION

Based on the P&ID as shown in Figure 1 and 2, we obtained several SIS that have been installed in the evaporator vessel and settling vessel. To get the failure rate value of each component of the tool using failure rate data from the 2002 OREDA book, while for the test interval (TI) 1 year is used. For calculations, equations (1), (7), and (8) are used, then we adjust the results to Table 1 to determine the SIL value.

a) SIL Assessment of Evaporator Vessel

In the evaporator, we obtained two SIS, namely SIS as a protection system for the UN feed system and SIS as a protection system for the process result transfer system. The UN feed system is used to feed the UN solution from vessel V-404C to evaporator E-601. The level in the E-601 evaporator is maintained so that the level does not exceed 80% so that overflow can occur. If the level of evaporator E-601 has reached 80%, the level indicator control (LIC-0601) will signal the P-404C pump to stop sending UN feed to evaporator E-601. The process result transfer system is used to send the UN from the pressing process to the result storage vessel (V-602), which has reached a density of 1.27 kg/l or equal to 200 g U/L. Therefore, if the UN density has reached 1.27 kg/L, the density indicator control (DIC-0601) will give a signal to pump P-603 to send the UN solution to the V-602 vessel.

Based on the P&ID in Figure 2, the SIF of the UN feed system SIS consists of a level indicator control (LIC-0601) as a sensor, using a logic solver in the form of a relay, and pump P-404C as the final element. The SIF of the process transfer system SIS consists of density indicator control (DIC-0601) as a sensor, using a logic solver in the form of a relay, and pumps P-603 as the final element. We present the results of determining the SIL value of the UN feed system in the evaporator in Table 2.

Table 2. SIL Assessment Results of Uranyl Nitrate Feed System of Evaporation Process in Evaporator Vessel

Component	Failure Rate (λ)	TI (Jam)	PFD_{avg}	PFD_{total}	RRF	SIL
Sensor (LIC-0601)	$1.72x10^{-6}$	2880	0.00248			
Logic Solver (Relay)	$0.6x10^{-6}$	2880	0.000864	0.00352	284.09	2
Final Element (P-404C)	$0.12x10^{-6}$	2880	0.000173			

Based on Table 2, it is known that the UN feed system SIS on evaporator E-601 only reaches SIL level 2, with a PFD value of 0.00352 and an RRF value of 284.09. RRF value of 284.09. Based on the level of risk contained in each node, the SIL level achieved can be considered sufficient. However, if you want to increase the SIL value higher than the existing one, it is necessary to add SIF to the SIS protection system on the evaporator and then recalculate the SIL value. The SIL calculation of the process transfer system is presented in Table 3.

Table 3. SIL Assessment Results of the Process Yield Transfer System in the Evaporation Process in the Evaporator Vessel.

Component	Failure Rate (λ)	TI (Jam)	PFD_{avg}	PFD_{total}	RRF	SIL
Sensor (DIC-0301)	$1.00x10^{-6}$	2880	0.00288			
Logic Solver (Relay)	$0.6x10^{-6}$	2880	0.00864	0.00392	255.10	2
Final Element (P-603)	$0.12x10^{-6}$	2880	0.000173			

Based on Table 3, we known that the SIS of the process result transfer system in evaporator E-601 only reaches SIL level 2, with a PFD value of 0.00392 and an RRF value of 255.10. Based on the level of risk contained in each node, the SIL level achieved can be considered sufficient. However, if you want to increase the SIL value higher than the existing one, it is necessary to add SIF to the SIS protection system on the evaporator and then recalculate the SIL value.

The same SIL assessment regarding level sensors has been carried out on the ammonia stripper level control system at Factory I PT Petrokimia Gresik which uses 3 control sensors, namely level transmitter (LT 1027), level control valve (LCV 1027) and level indicator controller (LIC 1027). The SIL value obtained is level 1, so the safety level of this system is still very low [20]. When compared to the SIL value of the UN feed system of the evaporation process at the uranium refining and conversion facility, which is at level 2, we can consider the safety system in the UN feed system of the evaporation process sufficient. Then the same SIL assessment regarding the density sensor has been carried out by Schneider Electric on its product, namely the intelligent transmitter 244LD levelstar which uses a control sensor, namely a density transmitter with a SIL value of level 2, so the safety level of this system is sufficient [21]. When compared to the SIL value of the evaporation process transfer system at the uranium refining and conversion facility, which is at level 2, we can also consider the security system in the evaporation process transfer system sufficient.

b) SIL Assessment of Deposition Vessel

In the settling vessel device, we obtain two SIS , namely SIS as a protection system for the heating system with hot water and SIS as a protection system for the ammonium hydroxide solution transfer system. We use the heating system with hot water at the start-up of the yellow cake dissolving process to raise its temperature to the operating temperature of the yellow cake dissolving process, which is between 60-70^{o}C. After the temperature reaches the optimum condition of the process, the heating system is switched off and replaced with cooling water to maintain the temperature during the process. The ammonium hydroxide solution transfer system serves to send ammonium hydroxide solution to the C-901 settling vessel to raise the pH of the UN solution. Therefore, if the pH of UN has reached pH 6-9, the acidity indicator control (AIC-0901) will give a signal to pump P-208A to reduce the flow rate of ammonium solution transferred to the C-901 deposition vessel. Based on the P&ID Figure 2, the SIF of the SIS heating system with hot water consists of temperature indicator control (TIC-0901) as a sensor, using a logic solver in the form of a relay, and valve TV-0901 as the final element. Then for the SIF of the process result transfer system SIS consists of acidity indicator control (AIC-0901) as a sensor, using a logic solver in the form of a relay, and pump P-208A as the final element. We present the results of determining the SIL value of the heating system with hot water in Table 4

Based on Table 4, we known that the SIS heating system with hot water in the C-901 deposition vessel equipment only reaches SIL level 1, with a PFD of 0.013147 and an RRF value of 76.06. Based on the level of risk contained in each node, the SIL level achieved can be considered sufficient. However, if you want to increase the SIL value higher than the existing one, it is necessary to add SIF to the SIS protection system in the settling vessel equipment and then recalculate the SIL value. We can see the results of determining the SIL value of the ammonium hydroxide solution transfer system in Table 5.

Based on Table 5, we known that the SIS of the ammonium hydroxide solution system in the C-901 deposition vessel only reaches SIL level 2, with a PFD of 0.00392 and an RRF of 255.10. Based on the level of risk contained in each node, the SIL level achieved can be considered sufficient. However, if you want to increase the SIL value higher than the existing one, it is necessary to add SIF to the SIS protection system in the settling vessel equipment and then recalculate the SIL value.

We have performed the same SIL assessment regarding the temperature sensor on the safety system in the furnace 05 (F05) system at the Pusdiklat Migas Cepu refinery, the control sensor is the temperature transmitter (TT X01). The SIL value obtained is level 1, so the safety level of this system is still very low. [22]. When compared to the SIL value of the heating system with hot water in the deposition process at the uranium refining and conversion facility which is at level 1, the security system is equally insufficient and must be increased by adding SIF to the SIS. Then the same SIL assessment regarding the pH sensor has been carried out by Konradin Industrie on its product, namely the TÜV-certified SIL2 analysis measuring point which uses a control sensor, namely a glass pH sensor with a SIL value of level 2, so the safety level of this system is sufficient. [23]. When compared with the SIL value of the ammonium hydroxide solution transfer system in the deposition process at the uranium refining and conversion facility which is at level 2, we can also consider the safety system in the ammonium hydroxide solution transfer system in the deposition process sufficient.

Table 4. SIL Assessment Results of Heating System with Hot Water in the Deposition Process in the Deposition Vessel

Component	Failure Rate (λ)	TI (Jam)	PFD_{avg}	PFD_{total}	RRF	SIL
Sensor (TIC-0901)	$8x10^{-6}$	2880	0.01152			
Logic Solver (Relay)	$0.6x10^{-6}$	2880	0.000864	0.013147	76.06	1
Final Element (TV-0901)	$0.53x10^{-6}$	2880	0.000763			

Table 5. SIL Assessment Results of Ammonium Hydroxide Solution Transfer System in the Deposition Process in the Deposition Vessel

Component	Failure Rate (λ)	TI (Jam)	PFD_{avg}	PFD_{total}	RRF	SIL
Sensor (AIC-0901)	$1.00x10^{-6}$	2880	0.00288			
Logic Solver (Relay)	$0.6x10^{-6}$	2880	0.000864	0.00392	255.10	2
Final Element (P-208A)	$0.12x10^{-6}$	2880	0.000173			

CONCLUSIONS

The value of the safety level of the protection system with SIL assessment in the evaporator vessel obtained 2 protection systems with SIL values of level 2 all and in the deposition vessel obtained 2 protection systems with SIL values of level 1 and level 2. The SIL value of all analysed devices has not reached level 3 or 4, so it is necessary to add SIF to the protection system SIS to increase the SIL value until the SIL value is obtained between level 3 or 4.

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REFERENCES

[1]. N. Hyatt, "*Guidelines for process hazards analysis, hazards identification & risk analysis",* CRC Prcss LLC, 2003.

[2]. N. S. Pamungkas, “Penilaian safety integrity level iradiator gamma kategori-IV pada kegagalan sistem crane pengontrol sumber zat radioaktif,” *J. Forum Nukl.*, vol. 12, no. 1, p. 1, 2018, doi: 10.17146/jfn.2018.12.1.4147.

[3]. F. Wang, O. Yang, R. Zhang, and L. Shi, “Method for assigning safety integrity level (SIL) during design of safety instrumented systems (SIS) from database,” *J. Loss Prev. Process Ind.*, vol. 44, pp. 212–222, 2016, doi: 10.1016/j.jlp.2016.09.020.

[4]. M. Catelani, L. Ciani, and V. Luongo, “Microelectronics reliability a simplified procedure for the analysis of safety

instrumented systems in the process industry application," *Microelectron. Reliab.*, vol. 51, no. 9–11, pp. 1503–1507, 2011, doi: 10.1016/j.microrel.2011.07.044.

[5]. J. Ahn, Y. Noh, T. Joung, and Y. Lim, "Safety integrity level (SIL) determination for a maritime fuel cell system as electric propulsion in accordance with IEC 61511," *Int. J. Hydrogen Energy*, vol. 44, no. 5, pp. 3185–3194, 2018, doi: 10.1016/j.ijhydene.2018.12.065.

[6]. A. Salaheldine, M. Salem, and H. Farag, "Applying LOPA and fuzzy logic to identify SIL requirement for safety critical functions in a direct reduction iron industry International Society of Automation," *Alexandria Eng. J.*, vol. 59, no. 5, pp. 3575–3585, 2020, doi: 10.1016/j.aej.2020.06.003.

[7]. W. G. Gulland, "Methods of determining safety integrity level (SIL) requirements - pros and cons 1 introduction 2 definitions of SILs," *Pract. Elem. Saf. J.*, pp. 105–122, 2004.

[8]. H. C. William M. Goble, "Safety instrumented systems verification: practical probabilistic calculation," ISA-The Instrumentation, Systems, and Automation Society, 2005.

[9]. W. Rozaaq, "Analisis Hazard and Operability Study (HAZOPS) dan penentuan nilai safety integrity level (SIL) pada sulfur furnace unit asam sulfat pabrik III PT Petrokimia Gresik," *ITS Resipitory*, 2015.

[10]. K. Ahmad, Badrun; Oginawati, "Analisis risiko dengan metode Hazard and Operability Study (HAZOPS) dalam penentuan Safety Integrity Level (SIL) berbasis risk graph dan quantitative method pada unit boiler PT X," *J. Tek. Lingkung.*, vol. 25, pp. 53–66, 2019.

[11]. A. Gabriel, C. Ozansoy, and J. Shi, "Developments in SIL determination and calculation," *Reliab. Eng. Syst. Saf. J.*, vol. 177, no. September 2017, pp. 148–161, 2018, doi: 10.1016/j.ress.2018.04.028.

[12]. A. E. B. Z. Summers, "Partial-stroke testing of Block Valves," *Control Eng. J.*, vol. 1996, no. November 2000, pp. 1–8, 2001.

[13]. IEC, "Functional safety of electrical/electronic/programmable electronic safety-related systems – Part 1: General requirements", 2010.

[14]. IEC, "Functional safety – Safety instrumented systems for the process industry sector – Part 1: Framework, definitions, system, hardware and software requirements", 2003.

[15]. A. Muchsin, "Pelatihan penyegaran operator dan supervisor 2018." PUSDIKLAT BATAN, Serpong, 2018.

[16]. I. Setiawan and N. Yudhi, "Optimalisasi proses pemekatan larutan UNH pada seksi 600 Pilot Conversion Plant," *Pengelolaan Instal. Nukl.*, vol. 15, no. 8, pp. 9–16, 2015.

[17]. J. Setiawan *et al.*, "Karakterisasi morfologi dan struktur kristal serbuk UO_2 dari yellow cake dengan variasi temperatur pengendapan ADU," *Urania*, pp. 9–17, 2011.

[18]. H. G. Lawley, "Operability studies and hazard analysis," *Chem. Eng. Prog.*, 1974.

[19]. K. Jeong, K. Lee, and H. Lim, "Energy risk assessment on hazards for decommissioning safety of a nuclear facility," *Ann. Nucl. Energy*, vol. 37, no. 12, pp. 1751–1762, 2010, doi: 10.1016/j.anucene.2010.07.002.

[20]. E. Maiyana, Ya'umar, and M. Ilyas "Evaluasi safety integrity level pada element – element sistem pengendalian level ammonia," *J. Tek. Pomits*, vol. 1, no. 1, pp. 1–6, 2013.

[21]. Schneider Electric, "Functional safety according to IEC 61508 / IEC 61511," 2018.

[22]. S. Sikumbang, "Desain engineering Safety Instumented System (SIS) pada furnace 5 (F05) kilang Pusdiklat Migas," *Forum Teknol.*, vol. 03, no. 1, 2013.

[23]. Konradin Industrie, "Safety in a double pack," 2011. https://process-technology-online.com/instrumentation-automation/safety-in-a-double-pack/