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FAILURE RISK ASSESSMENT ON PRESSURE RELIEF DEVICE USING QUANTITATIVE RISK BASED INSPECTION METHOD BASED ON API RP 581 IN PT. Z

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Abstract
This research is about conducting a risk assessment of the pressure relief device unit by conducting a risk-based inspection analysis method. With the aim of mapping the risk categories in the PRD unit and providing recommendations for actions that must be taken to mitigate these risks with a quantitative approach. Pressure relief device (PRD) is a device that automatically discharges a certain pressure which is controlled by upstream static pressure from the valve and opens naturally with an increase in pressure above the opening pressure. The risk-based inspection method is carried out to calculate the risk value on an equipment by conducting analysis and calculations to determine the probability and consequence values on the PRD unit, the data used to calculate the risk value in the form of PRD data sheets include: general data, process condition data, data materials, data connection, and database and selection data, as well as inspection history records at the PRD unit (17 – PSV – 298) which are used to determine risk values, inspection plans, and recommendations for actions to be taken in mitigating risks. According to the calculation of the risk value on the PRD unit equipment (17 – PSV – 298) which was analyzed using the risk-based inspection method, the risk value for the PRD unit was 0.1135 m^2/year, so it can be determined that the risk category is the medium category according to plotting against the risk matrix. The PRD unit (17 – PSV – 298) will approach the risk target as determined by the company in the 24th year since the first risk assessment was carried out using the RBI method and estimated on January 11, 2042. Based on the inspection history, there has been a leak in the PRD unit (17 – PSV – 298) during the pop test. Thus, the recommended type of inspection is the type of shop inspection/overhauls and is carried out periodically at least every 4 years. This is in accordance with PERMEN ESDM No. 32 of 2021 Article 21 Paragraph 4a.

Keywords:
Pressure relief device; risk-based inspection; risk assessment; statical equipment; safety equipment.

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1. Introduction

Work safety is an aspect of an effort for people who work to get safety and health guarantees when working. In Law Number 23 of 1992 Article 23 concerning occupational health which states that K3 efforts must be applied by all workplaces, especially work areas that have a high risk.

One of the accident incidents that occurred on Saturday, March 12, 2022, was the relief valve leak incident in the existing well of PLTP Dieng Unit I, Central Java which caused one of the workers in the area to die and six other workers were treated at the hospital due to inhalation. poison gas when the incident occurred. According to the Secretary of PT Geo Dipa Energi, Endang Iswandi, the accident occurred when the contractor was carrying out repairs in the area, the relief valve was under overpressure and opened automatically at a pressure that exceeded the pressure that had been set earlier. Thus, the relief valve leaks [5].

A pressure relief device (PRD) is a device for safety that is useful for limiting and regulating pressure by making pressured fluid flow away from the main protected system towards the PRD system. Based on API RP 581 explains that the Pressure relief device (PRD) has 2 failure modes [2]:

1. Fail to Open (FAIL)
   - Failure to open
   - Device is only partially open

- Automatically open device exceeds the set pressure

2. Leakage Failure (LEAK)
   - Device unlocks automatically
   - Device stuck in unlock
   - The device has had a leak

Risk mitigation on equipment relief valves is important to ensure that the installed pressure relief device (PRD) can operate safely. Risk mitigation in the risk assessment must be based on API RP 581. In carrying out risk mitigation, periodic inspection activities are required. Periodical inspection in risk mitigation can extend the service life of the tool and minimize the potential for failure of the pressure relief device (PRD) which results in incidents of work accidents that have previously occurred so that they do not happen again [3].

2. Method

Risk assessment is done by calculating the combined value of the probability of failure with the consequences of failure. The first step in the PRD analysis using the RBI method is to calculate the value of the probability of fail to open and probability of leakage [4].

The second step after calculating the probability of failure, is to calculate the consequence of Failure. To perform calculations consequence of failure affected by detection and isolation systems, release mass or release rate, escape hole size, etc. The last step is to calculate the risk value by doing multiplication calculation between the probability of failure value and consequence of failure value. After that, the risk value is compared to the risk target and plan date is conducting the RBI assessment, the aim is to determine the appropriate inspection method and inspection schedule for the PRD. Details of steps of the RBI assessment carried out in the PRD unit are shown in Fig. 1.

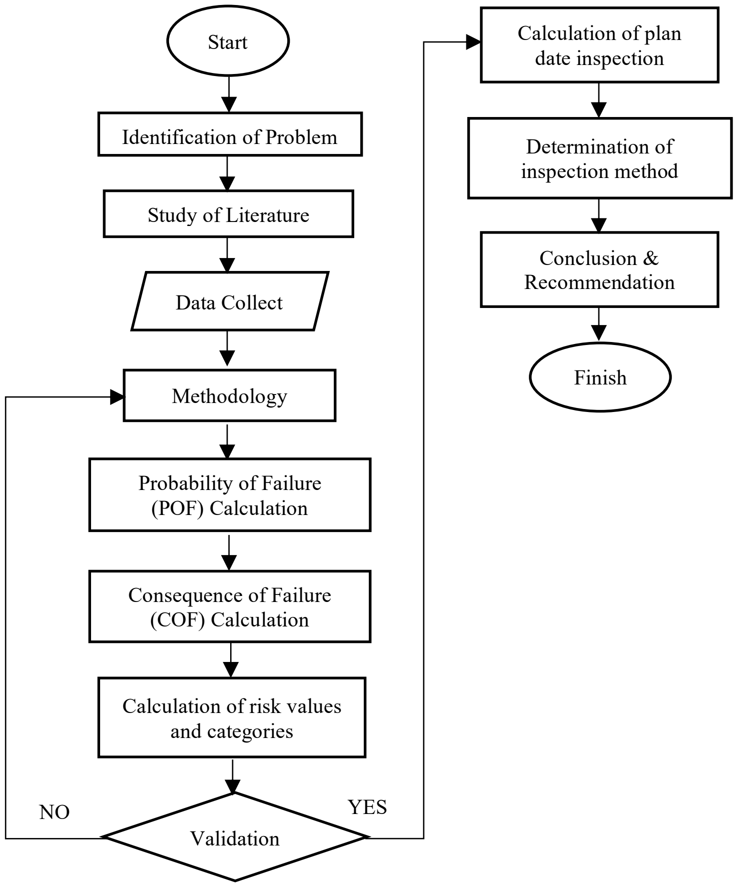

Figure 1. Flow Chart

3. Result and Discussion

A. Probability of Fail to Open (POFOD)

For the case of fail to open failure mode on the PRD, the calculation basis to be applied to the PRD is the frequency of cases of overpressure or demand rate. PRD failed to open when need and PRD, possibly other protected devices experienced loss of containment. PRD protects equipment components in several overpressure scenarios. Each overpressure scenario gets a different level of overpressure. So, equation (1) can be made [2]

$$P_{f,j}^{prd} = P_{fod,j} . DR_j . P_{f,j} \tag{1}$$

The notation in equation (2), needs to be calculated for each case of overpressure that is likely to occur which is related to the PRD. $P_{f,j}$ is a function of time and potential overpressure.

PRD demand rate is obtained by multiplying the frequency of the default initial occurrence by the demand rate reduction factor as shown in equation (2). Default initiating event frequency and demand rate reduction factors are obtained in Table 7.2 API 581.

$$DR_j = EF_j . DRRF_j \tag{2}$$

Probability of Failure on Demand (POFOD) is the probability that the PRD will fail to open when needed. The API 581 provides default failure cases at demand rate which have been developed from industry data. This default value is expressed as a Weibull parameter modified by several factors to get the equation (3).

$$P_{f,Prior}^{prd} = 1 - exp\left[-(\frac{t}{\eta_{upd}})^{\beta}\right] \tag{3}$$

where:
t : time inspection interval
β, η: Weibull parameter

If $\beta = 1$ then the failures are random and a constant failure rate can be assumed where failure rate =1/ η
If $\beta > 1$ then the failure rate is increasing
If $\beta < 1$ then the failure rate decreasing

Each protected equipment has a failure value that is adjusted by generic failure frequency on the equipment which is multiplied by the DF (damage factor) value. The DF value is obtained based on the inspection history and the condition of the equipment in which case there is a failure mechanism for maintenance. The DF value contained in the protected equipment is calculated as a function of time.

When evaluation the PRD, calculate the failure value which is adjusted by the frequency of failure and the calculation is carried out at the normal point of operating pressure (equipment adjusted). The pressure on the protected equipment will rise above the operating pressure significantly in this type of failure mode above the MAWP (maximum allowable working pressure) when the PRD fail to open when need. The calculation of the frequency failure adjustment with the calculation of the frequency failure adjustment with the same damage will experience a probability of loss of containment on the protected equipment within a certain level of overpressure as shown in equation (4)

$$P_{f,j} = \left(0.0312881 . gff_{total} . D_f . F_{ms}\right) e^{3.464837 \frac{P_o,j}{MAWP}} \tag{4}$$

From the analysis of the PRD unit (17 – PSV – 298), the results of probability of fail to open are obtained as shown in Table 1.

Table 1. Result of Probability of Fail to Open PRD Calculation

PRD	$P_{fod,j}$ (failure/demand)	DRj (demand/year)	Pf,j (failure/year)	$P_{f,j}^{prd}$ (failure/year)
17- PSV – 298	0.11368	1.21	5.32E-05	7.33E-06

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B. Probability of Leakage (POL)

In the case of failure, the leak mode is different from the case of fail to open, because the POF is not a function value at demand level but based on failure during continuous operation. From data industry related to leakage probability data in units per year (failure/year). Because there is not related between any required demand, the equation to calculate probability of leakage is shown in equation (5).

$$P_{l,j}^{prd} = P_{l}^{prd} . F_{set} \tag{5}$$

The probability of leakage on the PRD is the probability of failure of the PRD due to a leak in the previous equipment. API 581 provides defaults for leak rates hat have been developed from data industry. The default value is expressed as a Weibull curve modified by several factors such as the type of soft seats PRD and environmental factors. So that equation (6) obtained is

$$P_{l,prior}^{prd} = 1 - exp\left[-(\frac{t}{\eta_{\text{upd}}})^{\beta}\right] \tag{6}$$

The probability of leakage on PRD needs to be adjusted and matched between adjacent operating systems with the set pressure as shown in equation (5). Set pressure factor, F_{set} is adjusted to the type of PRD provided by API RP 581. The result of probability of leakage are shown in Table 2.

Table 2. Result of Probability of Leak PRD Calculation

PRD	P_{l}^{prd}	$\boldsymbol{Fset}$	$P_{l,j}^{prd}$
17 – PSV – 298	0.09	0.361	0.0325

C. Consequence of Failure (COF)

Consequence analysis is carried out to determine the impact of a risk if it occurs on an equipment. The consequence of analysis of the PRD installation that protects the vessel uses a well-impacted area approach with by taking into account the size of the flammable/explosive area, the area of heat radiation that affects humans, and the area that has a toxic impact.

In performing the analysis of the calculation of the consequence of failure on the PRD using the API RP 581 standard code procedure, it begins by determining the scenario and the overpressure value when a failure occurs in place of the operating pressure, $P_{o,j}$. Then the consequence of failure is calculated using the following equation (7).

$$CA = \max\left[CA_{cmd}, CA_{inj}\right] \tag{7}$$

where:

CA_{cmd} **:** Consequence of area component damage (m^2)
CA_{inj} **:** Consequence of area personel injury (m^2)

The value consequence area of component damage area is calculated by using equation (8) below:

$$CA_{cmd} = \max\left[CA_{cmd}^{flam}, CA_{cmd}^{tox}, CA_{cmd}^{nfnt}\right] \tag{8}$$

where;

CA_{cmd}^{flam} **:** Consequence of area flammable/explosion area (m^2)
CA_{cmd}^{tox} **:** Consequence of toxic area (m^2)
CA_{cmd}^{nfnt} **:** Consequence area non-toxic and non-flammable (m^2)

The value consequence area of personel injury is calculated by using equation (9) bellow:

$$CA_{inj} = \max\left[CA_{inj}^{flam}, CA_{inj}^{tox}, CA_{inj}^{nfnt}\right] \tag{9}$$

where:

CA_{inj}^{flam} : Consequence of area flammable/explosion (m^2)
CA_{inj}^{tox} **:** Consequence of area toxic (m^2)
CA_{inj}^{nfnt} : Consequence of non-toxic and non-flammable area

In general, API RP 581 provides 2 categories for consequences, namely the consequence area of component damage and consequence area due personnel injury. Consequence area is affected by operating pressure and fluid mass present in the protected equipment

The results of the calculation of consequence area for PRD are shown in Table 3, Table 4, and Table 5.

Table 3. Calculation of Result the Consequence of Component Damage Area

PRD	CA_{cmd}^{flam} **(m²)**	CA_{cmd}^{tox} **(m²)**	CA_{cmd}^{nfnt} **(m²)**	CA_{cmd} **(m²)**
17 – PSV – 298	1.32	-	-	1.32

Table 4. Calculation of Result the Consequence Injury Personel Area

PRD	CA_{inj}^{flam} **(m²)**	CA_{inj}^{tox} **(m²)**	CA_{inj}^{nfnt} **(m²)**	CA_{inj} **(m²)**
17 – PSV – 298	3.492	-	-	3.492

Table 5. Final Calculation Result of Consequence Area of PRD

PRD	CA_{cmd} **(m²)**	CA_{inj} **(m²)**	**CA**
17 – PSV – 298	1.32	3.492	3.492

D. Risk Assessment

Risk is calculated by multiplying the probability of failure with the consequence of area. The risk value is calculated based on the RBI plan date condition. API RP 581 provides a formula for calculating risk using the following equation (10) [3]

$$Risk = POF \times COF \tag{10}$$

where:
POF: Probability of failure
COF: Consequence of failure

The risk level on the PRD is done by comparing the results of the risk calculation on the RBI date and plan date with the risk target given by the company [2].

The risk value on the RBI date and plan date is shown in Table 6 below:

Table 6. PRD Risk Calculation Result

PRD	**RBI date (m²/year)**	**Plan date (m²/year)**
17 – PSV – 298	0,11355	0,705

To determine the risk category that occurs in the PRD unit by plotting the probability category and the consequence category against the risk matrix. Mapping the probability category and consequence category onto a risk matrix is an effective method for presenting risk graphically. API RP 581 provides related the probability of failure and area-based consequence of failure as shown in Table 7.

Table 7. Numerical Values Associated with POF and Area-based COF Categories

Probability Category		**Consequence Category**	
Category	**Probability Range**	**Category**	**Consequence Range**
1	$Pf(t, I_E) \leq 3.06E-05$	A	$CA_f^{flam} \leq 9.29$
2	$3.06E-05 < Pf(t, I_E) \leq 3.06E-04$	B	$9.29 < CA_f^{flam} \leq 92.9$
3	$3.06E-04 < Pf(t, I_E) \leq 3.06E-03$	C	$92.9 < CA_f^{flam} \leq 929$
4	$3.06E-03 < Pf(t, I_E) \leq 3.06E-02$	D	$929 < CA_f^{flam} \leq 9290$
5	$Pf(t, I_E) > 3.06E-02$	E	$CA_f^{flam} > 9290$

E. Determining Risk Level

API RP 581 provides risk level categories into low, medium, medium, high, and high-risk categories. The level of risk obtained is determined by combining the category of probability of failure with category of consequence in the risk matrix [1].

The probability of failure of the PRD unit (17 – PSV – 298) ranges from 0,00140 failures/year – 0,00143 failures/year so based on Table 7 it can be seen that the probability category of the PRD unit (17 – PSV – 298) is category 4.

Meanwhile, the result of the PRD analyzed is less than 9,29 m^2, so that the failure consequence category is A. Fig. 2 shows the current level of risk experienced by the PRD unit (17 – PSV – 298). From the PRD unit failure risk plotted with the risk matrix, the PRD risk level is medium risk.

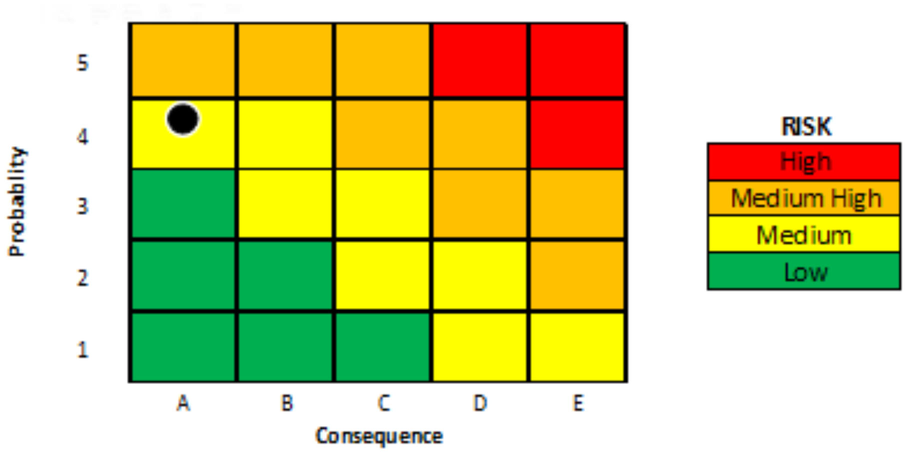

Figure 2. Current risk level

F. Risk-baed Inspection (RBI)

RBI assessment is carried out by comparing the total risk on the RBI date and Plan date with the risk target given by the company. The curve in Fig. 3 shows the comparison between the RBI date and target date. So, it can be estimated on January 11, 2042 for a plan date inspection before the PRD unit (17 – PSV – 298) reaches the risk target.

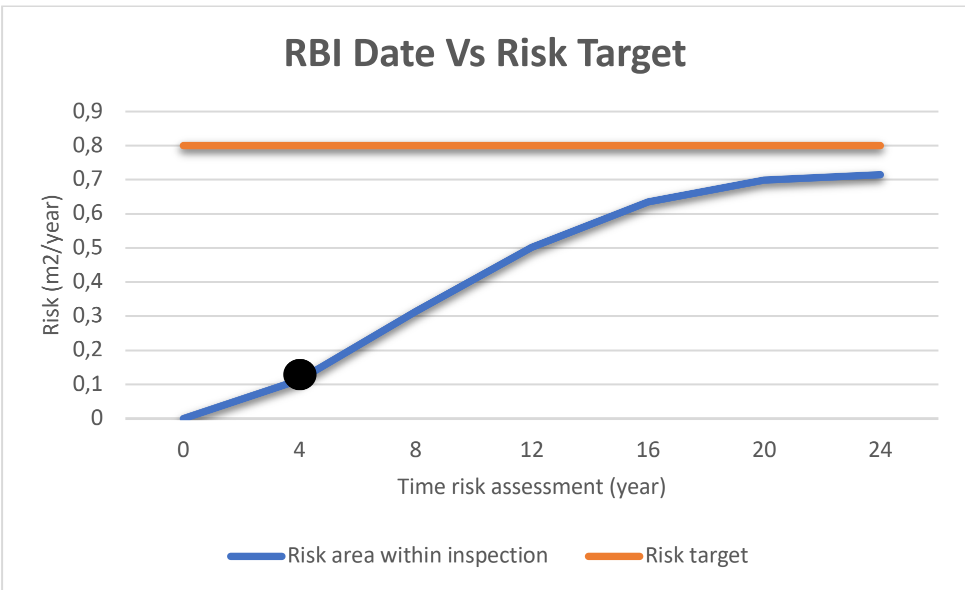

Figure 3. RBI date and plan date risk value comparison

G. Inspection Plan

Inspection effectiveness category A is shop inspection/overhauls. Based on API 576 a full, shop inspection/overhauls should ensure the following [13]:

1. Safety

2. Valve identification
3. Operating conditions noted
4. Removal of device form system in operation
5. Initial inspection
6. Inspection of adjecent inlet andoutlet piping
7. Transportation of Pressure-relieving devices to shop

Shop inspection, testing, maintenance, and setting of direct-acting Spring-loaded Pressure-relief valves used for unfired pressure vessels

4. Conclusion

Based on the analysis conducted on the PRD 17 – PSV – 298 unit using the RBI method in accordance with API RP 581, it is as follows:

1. Based on the calculation of the probability of failure (POF), the most dominant probability of failure is the probability of leakage. This means that the possibility of a leak in the PRD unit (17 – PSV – 298) is greater than the possibility of failure to open. So based on the calculation of risk, the risk value in the PRD unit (17 – PSV – 298) is 0.11355 m^2/year so that the risk category when plotting the risk matrix is included in the medium risk category. Medium risk is an acceptable level of risk.
2. PRD Unit 17 – PSV – 298 will approach the risk target that has been set by the company in the 24th year if periodic inspections are carried out in accordance with PERMEN ESDM No. 32 of 2021 Article 21 Paragraph 4a. It is estimated on January 11, 2042. Therefore, a method is needed to extend the remaining service life for installations and equipment that have passed the residual life assessment as regulated in PERMEN ESDM No. 32 Year 2021.
3. The results of the analysis and calculations using the inspection-based method show the possibility of leakage in the PRD unit (17 – PSV – 298) due to a history of leakage, and the calculation of the probability of failure has validated this. Thus, the recommended inspection method to be applied is shop inspection/overhaul and periodic inspections using that inspection method are required at least every 4 years. This is in accordance with PERMEN ESDM No. 32 of 2021 Article 21 Paragraph 4a.

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