Prediction of Remaining Useful Life for Components in SSC of RSG-GAS Based on Reliability Analysis
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ARTICLE INFO

Received: 06 July 2021
Received in revised form: 12 September 2021
Accepted: 25 September 2021

Keywords:
Remaining Component Life
SSC RSG-GAS
Safety category A
Reliability Analysis

ABSTRACT

In the maintenance system, efforts are needed to improve the effectiveness of the maintenance system and organization. For effective maintenance planning, it is necessary to have a good understanding of component availability and the reliability of the system. For this reason, it is crucial to determine the remaining component life using Remaining Useful Life (RUL), so that maintenance tasks can be planned effectively. The purpose of this study is to determine the remaining life of the safety category A component from SSC RSG-GAS based on reliability analysis. The method used in this paper is a statistical approach to estimate the RUL. The Weibull hazard model was selected for modeling the hazard function to be integrated into reliability analysis. The model was verified using data from components with safety category A on SSC from RSG-GAS. The results obtained from the analysis are beneficial for estimating the remaining useful lives of these components which can then be used to plan for effective maintenance and help control unplanned outages. The results obtained can be used for maintenance development and preventive repair planning.

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1. INTRODUCTION

The process of operating a nuclear reactor is determined by the SSC conditions to carry out its functions. In this case, the maintenance process plays a vital role in ensuring the availability of SSC. Therefore, an operation management system requires good SSC reliability. Its management is expected to be able to plan appropriate treatment for all SSCs, to support the operation and aging management system of RSG-GAS[1]. It is necessary to develop a Computerized Maintenance Management System (CMMS) or a computer-based maintenance management system used to store and retrieve maintenance data. CMMS can handle data related to the frequency and duration of maintenance breakdowns and component costs[2]. Reliability management is an activity to ensure that there are no SSC failures while the reactor is operating. Furthermore, it can optimize costs and minimize or eliminate failures and their causes[3].

Maintenance components are needed to improve the maintenance support system along with replacing traditional strategies with new ones such as RUL (Remaining Useful Life), which can estimate failure times for one or more existing components and failure modes in the future. Prediction of component/system life is aimed to predict RUL before failure, by looking at the current system conditions. Therefore, estimation of
component reliability and RUL are needed and crucial in maintenance optimization[4].

In recent years, the prediction of RUL has received more attention. It is vital to assess the RUL of an asset when it is used as it impacts the operational performance and profitability of an asset. Once an indication of failure has been detected, it is necessary to estimate the accuracy of the RUL to make timely maintenance decisions to avoid failure. Likewise, its reliability and estimation accuracy tends to result in accurate determination of the optimal inspection interval, thereby minimizing the overall cost of the system[5, 6].

RUL, which is the service life (remaining life) of a component or system at a certain time in the life cycle, is incredibly important for management integrity at a particular time[7–9]. Therefore, the ability to estimate the RUL of components and systems is beneficial for being able to employ different maintenance management strategies to optimize the life cycle phases of a component or system. In absolute terms, proactive management of the system that can be improved depends on the optimal estimation of the RUL and the reliability at various stages of degradation in the life cycle phases of components and systems[10, 11]. For this reason, many reliability estimation techniques, ranging from empirical to stochastic methodologies, have been proposed by researchers in the literature. To date, risk-based and reliability-centered maintenance techniques that incorporate predictive and condition-based maintenance strategies have been incorporated into the integrity of industrial asset management frameworks to maintain operating efficiency and enhance integrity [12].

Currently, Mean Residual Life (MRL) or RUL is recognized as a key feature in maintenance strategy, while true prognostic systems are rarely found in the industry. However, in estimating useful life, variations are found depending on the actual operating conditions and environmental characteristics, such as temperature and pressure, humidity conditions, and corrosion rates. Therefore, it is obvious that there exist many uncertainties that may lead to inaccuracy of the RUL estimation with its ability to predict and predict equipment degradation[13].

Evaluating an efficient component/system depends on classical limitations that limit, for example, the knowledge of available data, dynamics, and implementation requirements (precision, computation time, etc.). Therefore, implementing the RUL estimation method needs to be done on the safety component data A for RSG-GAS SSC to predict its remaining component life. These results can be used to optimize the maintenance system.

This research aims to estimate the expected value of the remaining life (RUL) of a component or system before failure from any time t based on the analysis of the reliability and the level of risk to optimize the life cycle phase of the component or system.

In this paper, the reliability method is used to estimate the RUL at a certain time t. First, several theoretical points are explained, then followed by a case study and the use of the reliability method in determining the RUL. It is necessary to consider the following assumptions: (a) The most suitable distribution for the failure time of a mechanical component is the Weibull distribution. The Assumptions of Independence and Identical Distribution (iid) of the data must be ensured so that a process model such as Weibull can be used; (b) in reliability analysis, hazard level function is needed to estimate RUL of components with safety category A on SSC from RSG-GAS.

2. THEORY

Analysis of Reliability, Risk Level and Estimation of The Remaining Useful Life Of Components using Statistics

The Weibull distribution is the most widely used empirical distribution and appears in almost all products of failure characteristics because it includes all three phases of damage that may occur in the damage distribution. The Weibull distribution is used in special cases, assuming the baseline hazard has a two-parameter Weibull form. The parameters used in this Weibull distribution are \( \theta \) which is called the scale parameter and \( \beta \) which is called the shape parameter. The parameter \( \beta \) is useful for determining the level of damage from the formed data pattern and the scale parameter \( \theta \) affects the mean value of the data pattern. The probability density function of the Weibull distribution model is provided in Eq. 1[14].

\[
f(t) = \frac{\beta}{\theta} \left( \frac{t}{\theta} \right)^{\beta-1} e^{-\left( \frac{t}{\theta} \right)^\beta}, \quad t > 0
\]

In the parameter estimation stage, the distribution parameter values will be determined, which is by the time data between component damage (TTF) with the least square method and Maximum Likelihood Estimation (MLE). Furthermore, the parameter values were substituted
into the formula for the level of risk, component reliability, and RUL.

Different types of failures were considered in the reliability analysis. Failure is defined as the inability of a component to timely perform the expected activities. In the reliability analysis, this data is collected in the form of time between failures (TTF), the time between maintenance (TBM), and for the topic of reparability in the form of repair time (TTR), time for corrective maintenance (TCM), time to perform preventive maintenance (TPM) and procurement and management downtime (TTD).

Four different functions are statistically defined to describe failures as follows: (1) the failure distribution is known as the probability density function (PDF) with the symbol f(t), (2) the cumulative distribution function (CDF) with the symbol F(t), (3) the joint function of F(t) is called the reliability function with the symbol R(t), and (4) the failure rate function or the hazard function with the h(t) symbol. The hazard level is considered as the rate at which failure occurs over a certain time (t₁, t₂). This level is defined as the probability of occurrence of failure per unit time interval (t₁, t₂) so that failure has not occurred before t₁ (initial interval)[6].

The risk level is calculated to determine the intensity of the probability that the product will fail at a certain time with the hazard function model. The level of risk for the Weibull distribution is provided in Eq. 2[7],

$$h(t) = \frac{\gamma}{\alpha} \left(\frac{t}{\alpha}\right)^{\gamma-1}$$

(2)

System reliability is defined as the ability of a component or system to perform and maintain the required functions under certain conditions without failure for a specified time[9]. Equation (1) is applied to determine mathematically the reliability of the system (R(x)), where R(x) shows the reliability of the system (%) at time t. Weibull reliability is expressed as

$$R(t) = e^{-\left(\frac{t}{\alpha}\right)^{\gamma}}$$

(3)

Remaining Useful Life (RUL)

Remaining Useful Life (RUL) or Mean Residual Life (MRL) is the time left for components to carry out their functional abilities before failure occurs. RUL can also be defined as the duration from the current time to the end of its useful life for a component (Figure 1)

![Component Health Index](Fig 1. Component Health Index)

Classification of RUL Prediction Techniques

There are several prognostic prediction methods used to determine the RUL of a subsystem or component. For Model-Based Prediction Methodology, RUL prediction can be applied to the Statistics and Computational Intelligence (CI) approach. This model is derived from configuration, usage, and historical failure data and applies to maintenance decision-making. Model-based methodologies are often used to estimate RUL thereby informing maintenance decisions based on failure thresholds, where the time-frequency feature allows more precise results than using only the time feature. Similarly, failure-derived methods and historical data can be used to predict the RUL of a component's assets[8].

Estimated RUL

RUL is widely used in reliability-based research [3]. The RUL is a component/system that is considered as the correct operating time remaining before the failure. RUL estimation is recognized as an important factor for condition-based maintenance (CBM) [3]. The remaining component life is the length of time that the component remains functional after a certain time. The mean residual life (L) is the meantime expected for failure to occur. RUL = MRL = m (t) expressed as

$$m(t) = \frac{\int_{0}^{t} f(\tau) \, d\tau}{R(t) - t}$$

(4)
3. METHODOLOGY

After entering the data, the relevant software is selected in the first step of the appropriate statistical approach, followed by the selection of an appropriate function or model of one of the main functions, for example, f(t) with the Weibull function. Furthermore, the cumulative distribution function F(t), reliability function R(t), the level of risk h(t), and then the remaining life of the component m(t) can be calculated using the available functions[6].

Data Processing Diagram on reliability analysis is shown in Figure 2[6]. Calculation of reliability and RUL were performed using Matlab code.

4. RESULTS AND DISCUSSION

The evaluated data is component damage with Safety A category on SSC of RSG-GAS reactor for core configuration number (CCN) from 72 to 94 between the years 2010 to 2018. Damage data for the SSC component is presented in Appendix A.

Determination of the distribution of component damage data and estimated data distribution parameters (Weibull distribution). Furthermore, the Goodness of Fit Test for the TTF distribution for the selected distribution, namely Normal, Exponential, Log-Normal, and Weibull, The Anderson Darling test was used. From the parameter value estimation, the shape and scale parameter values are obtained.

The plot of the probability function to determine the goodness of fit test of the exponential, normal, lognormal, and Weibull distribution functions for the BRV10 component is shown in Figure 3.

Table 1. Level of Risk and Reliability for Components of Safety Category A on SSC from RSG-GAS

<table>
<thead>
<tr>
<th>Component</th>
<th>Scale (θ)</th>
<th>Shape (β)</th>
<th>T (day)</th>
<th>h(t)</th>
<th>R(t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical power supply, Reactor pool (Al-Lining) JAA01</td>
<td>390.42</td>
<td>0.979</td>
<td>100</td>
<td>0.0026</td>
<td>0.7781</td>
</tr>
<tr>
<td>Measuring point of the process systems:</td>
<td>139.08</td>
<td>0.694</td>
<td>50</td>
<td>0.0068</td>
<td>0.7790</td>
</tr>
<tr>
<td>Reactor pool purification KBE01</td>
<td>309.36</td>
<td>1.250</td>
<td>50</td>
<td>0.0026</td>
<td>0.0019</td>
</tr>
<tr>
<td>First and second experiment on system</td>
<td>150</td>
<td>0.0034</td>
<td>300</td>
<td>0.0040</td>
<td>0.0297</td>
</tr>
<tr>
<td>Reactor pool, Rabbit systems</td>
<td>450</td>
<td>0.0044</td>
<td>600</td>
<td>0.0048</td>
<td>0.0884</td>
</tr>
<tr>
<td>(inside the reactor pool) JBB</td>
<td>750</td>
<td>0.0051</td>
<td>70</td>
<td>0.0019</td>
<td>0.0019</td>
</tr>
</tbody>
</table>

Fig. 3. Results of Component Distribution Conformity Test Electrical power supply (BRV10)

The value of the scale, shape, level of failure risk/damage rate h(t), and the reliability value of the component R(t) are presented in Table 1.
The remaining component life (RUL) was calculated from the year 2010 \( (t_1) \), namely the time of the last year’s component failure data, until the year 2018. The remaining component life for the electrical power supply component, B (BRV10) Component emergency diesel aggregates, electrical power supply, B (BRV20) Component emergency diesel aggregates, reactor system, JA reactor pool (Al-Lining) JAA01, measuring point of the following process systems: reactor pool purification KBE01, experiment system reactor pool reactor, rabbit systems inside the reactor pool (JBB), experimentation system reactor pool, JB control rods drive and suspension (JDA), cranes and hoist, SM crane, reactor building, measuring point of the process systems: pool cooling system JNA 20, out-of-core temperature and neutron flux measurement JKT 02 and JKT 03, are consecutive: 422.029, 389.165, 393.941, 177.336, 288.091, 71.124, 472.436, 429.052, 77.951, and 77.951 days.

RUL estimation can provide information and data input for maintenance management to determine the appropriate and efficient treatment strategy. Strategy determination is the process of selecting components from the system with the lowest RUL value, so that replacement can be carried out before more serious damage occurs.

As seen in calculation results in Table 2, the estimation of RUL of RSG-GAS components is derived by projecting out the failure prediction during operation. This prediction assists to improve the operating conditions and protective measures, and hence avoid serious failures. Consequently, data in Table 2 should be compared with adequate litera for course certnessure of the methodology used in the present study. As in the cases studies inspected herein, the failure model of RUL was simulated using Fortran code-based on the estimation method of Ref.[14] and by applying Weibull distribution predicated on Ref.[6]. The results of the comparison for the RUL simulations are plotted in Fig. 5. It can be noticed in Figure 5 that the present study has the RUL estimation.
similar to the Fortran code and the Weibull distribution.

**Fig 5.** Comparison of RUL estimation (in days)

**CONCLUSION**

The effective prediction of RUL encourages fast maintenance, repair, and overhaul (MRO) decision making and increases the availability of reliable SSC RSG-GAS components for use. The results presented can be used for preventive maintenance planning based on failure probability or RUL. This can reduce regular maintenance costs and increase operational efficiency, as well as a guide for care management to make fast maintenance and better decisions. In the future, there will be more focus on estimating RUL based on the context of which parameters are more influential to be considered to achieve a more realistic approach and outcome. Prediction techniques by mapping techniques against data types can enable the selection of relevant modeling methodologies.

**ACKNOWLEDGEMENT**

The authors are firstly very appreciative to the Head of Center for Nuclear Technology and safety, as well as the staff of the Division of Reactor Safety Technology, for supporting the development of this paper. Second, the authors would also thank you for the support of DIPA PTKRN 2020. Finally, the authors hope that this paper will be useful, especially for the aging management of the RSG-GAS research reactor.

**AUTHOR CONTRIBUTION**

All authors contribute together as the main contributors to this paper. All authors read and approved the final version of the paper.

**REFERENCES**

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APPENDIX

Damage Data for Components with safety category A on SSC from RSG-GAS

<table>
<thead>
<tr>
<th>Component</th>
<th>CCN</th>
<th>Date of Damage</th>
<th>TTF</th>
<th>Type of Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical power supply, B (BRV 10) Component: Emergency diesel aggregates</td>
<td>73</td>
<td>24/11/2010</td>
<td>0</td>
<td>Diesel</td>
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<td>Day tank</td>
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<td></td>
<td>Fusible link, 120°C</td>
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<td></td>
<td>Fuse BRV10 break</td>
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<td></td>
<td>BRV10 cannot be operated</td>
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<td>Day tank fuel level too low &quot;fuel&quot; cannot be reset</td>
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<td>The accuracy is broken</td>
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<td>The flexible radiator hose for diesel generator no. 2 (BRV20) is leaking</td>
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<td>Charger</td>
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<td>BRV20 water pump water line is leaking</td>
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<td>The flexible radiator hose for diesel generator no. 2 (BRV20) is leaking</td>
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</tbody>
</table>
is operating, but there is no flow
Fault system, in the CXB02 Marshalling Kiosk the system is dead, there is no power supply

<table>
<thead>
<tr>
<th>Date</th>
<th>Event Description</th>
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<tbody>
<tr>
<td>13/05/2014</td>
<td>The KBE01 AP001 pump sounds rough</td>
</tr>
<tr>
<td>03/02/2015</td>
<td>KBE01 AP001 sounds harsh</td>
</tr>
<tr>
<td>01/04/2016</td>
<td>KBE01 AP001 Pump On Blink indicator cannot be reset</td>
</tr>
<tr>
<td>22/03/2017</td>
<td>The indicator is below the limit/drop plate</td>
</tr>
<tr>
<td>22/10/2017</td>
<td>0 valve cannot be opened/closed from RKU</td>
</tr>
<tr>
<td>30/03/2010</td>
<td>The water level is too low</td>
</tr>
<tr>
<td>22/07/2010</td>
<td>JBB 01 rabbit system facility is not operating optimally</td>
</tr>
<tr>
<td>14/05/2011</td>
<td>The radiation timer counter is abnormal (sometimes runs doesn’t)</td>
</tr>
<tr>
<td>07/05/2013</td>
<td>MCB 4A on bit system</td>
</tr>
<tr>
<td>25/06/2013</td>
<td>The solenoid valve cannot be turned on when the capsule returns to the drum.</td>
</tr>
<tr>
<td>04/03/2014</td>
<td>Armatur Drop JDA02 Blink, cannot be reset JDA06 when rod drop test, not responding to indicator</td>
</tr>
</tbody>
</table>
15/07/2014 26 JDA07 + 14 (Regard) cannot be downgraded manually Cranes and hoist, SM Crane, Reactor Building

12/08/2014 28 JDA03 - 05 if compensated rise/fall a fault occurs
During the rod-drop time test, the counter does not stop JDA03 + 10/12 oscillation analog indicator Measuring point of the process systems: Pool cooling system JNA 20

09/09/2014 28 JDA03 - 05 if compensated rise/fall a fault occurs
During the rod-drop time test, the counter does not stop JDA03 + 10/12 oscillation analog indicator Measuring point of the process systems: Pool cooling system JNA 20

87 05/01/2015 118 JDA03 + 10/12 oscillation analog indicator Measuring point of the process systems: Pool cooling system JNA 20

89 27/08/2015 234 JDA03 - 05 if compensated rise/fall a fault occurs
During the rod-drop time test, the counter does not stop JDA03 + 10/12 oscillation analog indicator Measuring point of the process systems: Pool cooling system JNA 20

28/09/2015 32 JDA03 - 05 if compensated rise/fall a fault occurs
During the rod-drop time test, the counter does not stop JDA03 + 10/12 oscillation analog indicator Measuring point of the process systems: Pool cooling system JNA 20

05/10/2015 7 JDA03 - 05 if compensated rise/fall a fault occurs
During the rod-drop time test, the counter does not stop JDA03 + 10/12 oscillation analog indicator Measuring point of the process systems: Pool cooling system JNA 20

08/10/2015 3 JDA03 - 05 if compensated rise/fall a fault occurs
During the rod-drop time test, the counter does not stop JDA03 + 10/12 oscillation analog indicator Measuring point of the process systems: Pool cooling system JNA 20

27/10/2015 19 JDA03 - 05 if compensated rise/fall a fault occurs
During the rod-drop time test, the counter does not stop JDA03 + 10/12 oscillation analog indicator Measuring point of the process systems: Pool cooling system JNA 20

30/10/2015 3 JDA03 - 05 if compensated rise/fall a fault occurs
During the rod-drop time test, the counter does not stop JDA03 + 10/12 oscillation analog indicator Measuring point of the process systems: Pool cooling system JNA 20

02/11/2015 3 JDA03 - 05 if compensated rise/fall a fault occurs
During the rod-drop time test, the counter does not stop JDA03 + 10/12 oscillation analog indicator Measuring point of the process systems: Pool cooling system JNA 20

05/11/2015 3 JDA03 - 05 if compensated rise/fall a fault occurs
During the rod-drop time test, the counter does not stop JDA03 + 10/12 oscillation analog indicator Measuring point of the process systems: Pool cooling system JNA 20

90 07/01/2016 94 JDA07 + 14 (Regard) cannot be downgraded manually
At the time of the scram reactor at a power of 1.84 MW, the JKT 02 max Out of core temperature and neutron flux measurement JKT 03

05/02/2016 29 JDA04 at start-up crashed
The designation JDA05 + 11 is defective, does not turn on
At the time of the scram reactor at a power of 1.84 MW, the JKT 02 max Out of core temperature and neutron flux measurement JKT 03

91 25/07/2016 171 JDA07 + 12 down position stuck when pressed manually
At the time of the scram reactor at a power of 1.84 MW, the JKT 02 max Out of core temperature and neutron flux measurement JKT 03

92 08/03/2017 226 JDA03 cannot go up / down
At the time of the scram reactor at a power of 1.84 MW, the JKT 02 max Out of core temperature and neutron flux measurement JKT 03

93 21/05/2017 74 JDA07 is not a couple
At the time of the scram reactor at a power of 1.84 MW, the JKT 02 max Out of core temperature and neutron flux measurement JKT 03

94 01/12/2017 194 Control rod
At the time of the scram reactor at a power of 1.84 MW, the JKT 02 max Out of core temperature and neutron flux measurement JKT 03

95 07/03/2018 96 Control rod
At the time of the scram reactor at a power of 1.84 MW, the JKT 02 max Out of core temperature and neutron flux measurement JKT 03
detector did not respond when the reactor started up.

The JKT02 CX821 neutron detector showed no response.

The JKT03 CX841 HV fault

The JKT03 CX831 response is unstable. The meter does not show the true value, even though the detector position is upper.

The JKT03 CX841 oscillation occurs.

The JKT03 CX821 cannot measure.

Unbalanced load alarm JKT03 CX811 up.

Unbalanced load alarm JKT03 CX811 with JKT03 CX821 is different.

Oscillation system (JKT03 CX811) JKT03 CX811 oscillation meter designation JKT03 CX821 oscillating neutron detector designation. The JKT03 CX821 neutron detector designation oscillates momentarily causing an unbalanced load alarm JKT03 CX821 slow response neutron detector indicates that it raises an unbalanced load alarm.

The response of the JKT03 CX821 Detector was