ANALYSIS OF THE INSPECTION RESULTS ON THE PRIMARY COOLING PIPE OF RSG-GAS REACTOR

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ABSTRACT

ANALYSIS OF THE INSPECTION RESULTS ON THE PRIMARY COOLING PIPE OF RSG-GAS REACTOR. Multipurpose reactor of G.A. Siwabessy (RSG-GAS) is a research reactor with 30 MWt operated by BATAN since 1987. This reactor has obtained the permission from the regulatory body of BAPETEN to operate with the silicide fuels up to year 2025. In 2003, an ageing management of RSG-GAS was formed to evaluate the ageing process of the structures, systems, and components of the reactor. To support the ageing management, an inspection activity has been conducted to assess to the primary coolant pipe after 29 years operation. The main objective of this inspection was to determine whether a thinning of the primary pipe has occurred. The method used was the non-destructive test method with ultrasonic device to measure the thickness of pipe installed in place. The measurement was conducted two times in one year time span from 2014 to 2015. The results of measurement at three different places of the primary pipe show that the thinning has been occurred although it is very small. There are two forms of thinning that is occuring, which are the non-axisymmetric and axisymmetric. The non-axisymmetric shape thinning tends to occur in the area of the primary pipe upward of the primary pump, while the axisymmetric shape occurs at the pipe downward of the primary pump. In order to provide certainty to the thinning process at the primary pipe of RSG-GAS, re-testing should be performed routinely every 5 years.

Keywords: *inspection, RSG GAS, primary pipe, ultrasonic, thinning*

ABSTRAK

ANALISIS HASIL INSPEKSI PADA PIPA PENDINGIN PRIMER REAKTOR RSG-GAS. *Reaktor G. A. Siwabessy (RSG-GAS) adalah reaktor riset dengan daya termal 30 MW yang dioperasikan oleh BATAN sejak tahun 1987. Reaktor ini telah mendapatkan izin operasi menggunakan bahan bakar silisida dari BAPETEN sampai tahun 2025. Pada tahun 2003, dibentuk manajemen penuaan reaktor RSG-GAS dengan tujuan untuk melakukan evaluasi proses penuaan pada komponen, struktur, dan sistem dari reaktor. Untuk mendukung kegiatan manajemen penuaan, telah dilakukan kegiatan inspeksi untuk mengkaji kondisi pipa pendingin primer setelah 29 tahun operasi. Tujuan inspeksi terutama untuk mengetahui terjadinya penipisan pada pipa primer RSG GAS. Metode yang digunakan adalah metode uji tak rusak ultrasonik dengan peralatan ultrasonik untuk mengukur tebal pipa terpasang di tempat (insitu). Pengukuran dilakukan dua kali selang waktu satu tahun dari 2014 hingga 2015. Hasil pengukuran pada tiga bagian berbeda menunjukkan adanya penipisan tebal pipa walaupun sangat kecil. Terdapat dua bentuk penipisan yang terjadi yaitu non-axisymmetric dan symmetric. Penipisan secara non-axisymmetric terjadi pada bagian pipa primer sebelum pompa primer, sementara penipisan axisymmetric terjadi pada bagian pipa primer setelah pompa primer. Untuk mendapatkan kepastian adanya proses penipisan pada pipa primer RSG-GAS, pengujian ulang sebaiknya dilakukan secara rutin setiap 5 tahun.*

Kata kunci: *inspeksi, RSG GAS, pipa primer, ultrasonik, penipisan*

INTRODUCTION

The multipurpose reactor of G.A. Siwabessy (RSG-GAS) is a 30 MW thermal research reactor owned by the National Nuclear Energy Agency (BATAN). RSG-GAS is a pool type reactor cooled and moderated by light water [1]. When the reactor was commissioned in 1987, the core used the low-enriched uranium oxide [2] and in 1999 the use of uranium silicide fuel was introduced [3]. In 2007, RSG-GAS obtained an operating permit for the use of the urainium silicide fuel from BAPETEN until 2025. In 2003, the RSG-GAS management formed an aging management to evaluate the aging condition in the RSG-GAS after 29 years operation. In relation with that, the Regulatory Body (BAPETEN) has issued a regulation in 2015 regarding the assessment of the periodic safety every 10 years on the research reactor [4]. Therefore, the obligation to carry out testing on all system, structure and component of RSG-GAS including the testing on the primary pipe have been required.

The primary piping is part of the two cooling system of RSG-GAS, which are the core cooling system (CCS) and the secondary cooling system (SCS) to remove the heat generated in the core [5]. The significance of the pipe wall of a nuclear installation became a major concern after the accident related to the pipe break of the secondary system at Mihama nuclear power plant unit 3 in 2004 as reported by KEPCO [6,7]. Since then, measuring the thickness of the secondary reactor systems is a important measure to evaluate the aging process as also conducted in RSG-GAS secondary system. Using the ultrasonic methods, it has been found that there was a thinning of the secondary pipe walls by 0.5 mm due to pitting corrosion [8]. Pipe-wall thinning is mostly caused by the flow-accelerated corrosion (FAC) [9] and partly due to liquid droplet impingement (LDI) [10,11]. The mechanism of FAC depends on water chemistry, flowrate, and materials pipes. While the water chemistry and pipe material set an overall tendency for FAC, the local flow will determine the local distribution of wall thinning [12]. Therefore, FAC and LDI in the flow orifices, elbows and T-junctions causing a very turbulent flow condition must always be observed.

Therefore, this inspection was conducted to determine the occurrence of dilution in the primary pipe of RSG-GAS, especially in the local connection due to the aging after 29 years of operation. Since the primary pipeline construction in 1983, any inspection to measure the pipe wall thickness had not been done until 2014, when the measurement was finally performed using the ultrasonic non-destructive testing to support the ageing management program. Repeated testing was then conducted in 2015 to support the previous measurement. This paper contains a description of the inspection results of the pipe wall thickness by ultrasonic non-destructive testing methods. An analysis and discussion regarding the measurement results are also included after that activity to enhance safety of the RSG-GAS operation in the future.

THEORY

Primary piping of RSG-GAS

The primary coolant loop is used to cool the reactor and remove the heat from the reactor core. The heat from the primary system is then removed by the secondary cooling system using heat exchanger (HX) in to the cooling tower as the ultimate heat sink as shown in Figure 1. The parts of primary loop system consist of stainless steel pipes, valves, primary pumps, heat exchanger, and delay chamber [13]. The primary cooling system of RSG-GAS is coded as JH-01. The primary coolant pipe is made of a stainless steel (SS) 316 of standardized German Numbering (DIN), and consists of two diameters, which are 406.4 mm and 609.9 mm.

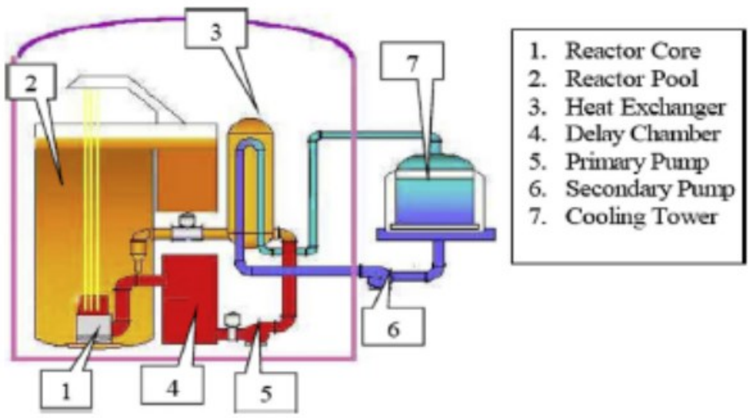


Fig.1. Schematic layout of RSG-GAS cooling system [13]

Ageing management in RSG-GAS

Ageing is defined as a general process in which the characteristics of systems, structures and components (SSCs) are gradually changed with time [14]. Ageing may cause degradation of functional and performance properties, change of material properties, and degradation of structures reliability. The implementation of aging evaluation management needs raw data information such as of designing, manufacturing, installment and debugging, real-time operation data, daily maintenance information and operation experience feedback [15]. Furthermore, a review of ageing mechanisms to understand behaviors and influence on reactor components and systems is needed [16]. Related to the a geing in the pipe component, pipe-wall thickness inspection needs to be done [17] in order to prevent accidents such as burst of pipe and water leakage. Therefore, the inspection to measure the pipe wall thickness should be carried out periodically.

Ultrasonic testing

Ultrasonic testing (UT) is one of the important techniques of nondestructive testing (NDT). It uses ultra-high-frequency sonic energy to locate and identify discontinuities in materials that are both on and below the surface of the material [18]. The technique needs access only to the outer edge of the pipe and does not require emptying the pipe [19]. Because the sensing mode of ultrasonic evaluation is a mechanical process, the frequency ra-

range is limited to avoid permanent damage to the targeted objects. The most often used frequencies are in the range from 0.1 MHz to 25 MHz. UT is also useful for other types of inspection, including welds, wall thinning, and surface defects [18]. Non-destructive testing to identify discontinuities in the pipeline with UT during manufacturing is the most effective method. Ultrasonic, angle beam probe is an example for examination of the pipe body as illustrated in Fig. 2, where θ_R is the angle of wave reflection, T is the thickness of the pipe, 1st leg, 2nd leg, and 3rd leg show the configuration of the sound paths. Note that flaws in the pipe body are usually laminations or inclusions [20].

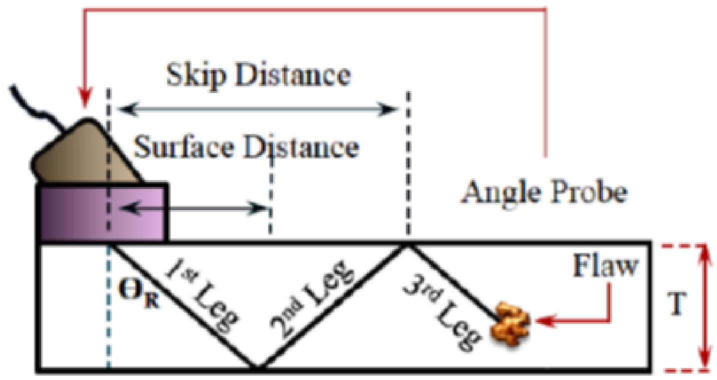


Fig. 2. Schematic layout of the ultrasonic angle beam probe used for pipeline [20]

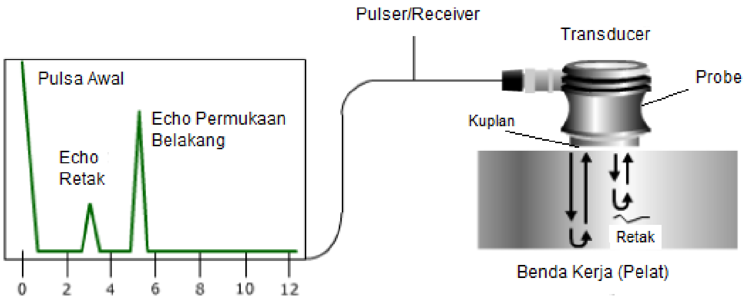
To generate ultrasonic energy, transducers are used. The transducer is a device that transforms sound energy into other form of energy. In case of Ultrasonic Inspection, it plays the role of interfacing between the mechanical & the electrical energy (pulse) [21]. There are five general categories of ultrasonic transducers used in NDE: straight beam, angle beam, dual elements, delay line and immersion transducers [18]. The UT measures the thickness of a material by transmitting an ultrasonic wave into the material using an ultrasonic transducer and calculating the time for the wave to pass through the material and reflect back to the transducer. The time multiplied by the previously determined velocity in the material and the thickness then is displayed in inches or millimeters. A short voltage pulse of less than 1/1000000 seconds and a voltage of 300-1000 volt excite the crystal into oscillations at its natural frequency (resonance), which depends on the thickness and the material of small plate. The thinner is the crystal, the higher its resonance frequency. Therefore, it is possible to generate an ultrasonic signal with a definite primary frequency. The thickness of the crystal calculated from the acquired resonance frequency according to the following formula (1) [21].

$$T = \frac{v}{2f} \quad \ldots\ldots\ldots.. (1)$$

Where V = velocity of the crystal material; f = resonance frequency of the crystal; and T = thickness of the crystal. When there is a discontinuity (such as cracks) in the wave path, part of the energy reflected back from the flaw surface. The reflected wave signal is transformed into an electrical signal by the transducer and displayed on a screen. Knowing the velocity of the waves, travel time directly related to the distance that the signal has traveled.

Shape and working principles of UT tool are as shown in Figure 3.

(a)



(b)

Fig. 3. The basic principles of how the UT detector works

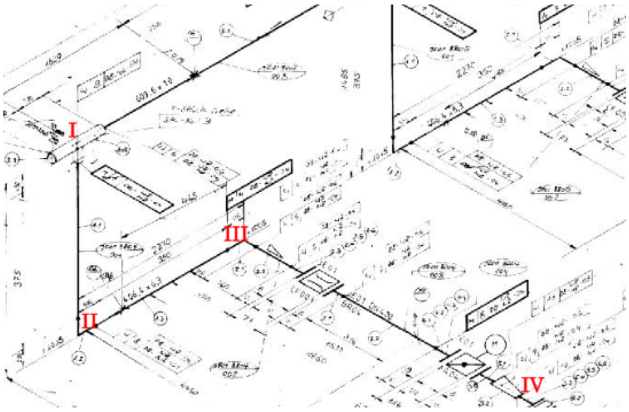
Basically, the working principle of UT is the application of the nature of the wave propagating in an isotropic solid object with three main parameters, namely wave length (λ) in meter, frequency (f) in hertz and speed (v) in meter per second. The relationship of these three parameters is mathematically stated in equation (2) [22].

$$\lambda = \frac{v}{f} \quad \ldots\ldots\ldots\ldots\ldots (2)$$

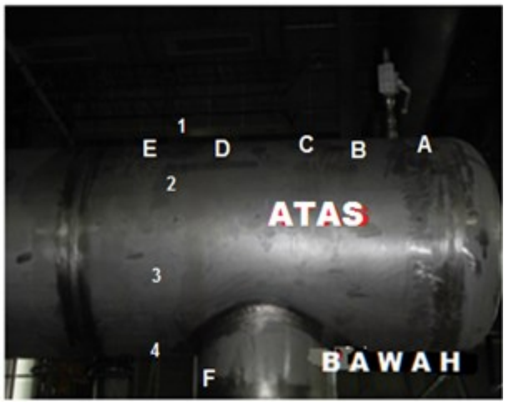
METHODOLOGY

The thickness of the pipe was measured by using a type StressTel Ultrasonic Thickness Gauge: the "T-MIKE ELM" type. Step Gauge instrument calibrators are used. Figure 4 shows the procedure to prepare the ultrasonic testing on the pipe based on the layout of the primary pipe. Places to be tested are marked using a permanent marker such as the branching area (Tee joint), bending area and local reducer pipe. In these places, collision between the water flow and the pipe wall occurs continuously and creates a vortex that causes accelerated corrosion of axisymmetric flow [9].

Next, the direction of the marking to the circumferential clock-wise direction is specified and numbered from 1 to 8, meaning that a loop of pipe is divided into eight measurement points then the axial direction is marked with a capital letter (A, B, C) as shown in Figure 4b.



a. Lay-out of primary pipe after marking



b. Marking on the T joint

Fig. 4. The procedure for numbering the primary pipe lay out and flagging in-situ

RESULTS AND DISCUSSIONS

The results of measurement conducted in 2014 at the T junction with the marking I in Figure 4a are shown in Table 1. Table 2 contains the the results of measurement conducted in 2015 at the sama place.

Table 1. The measurement results at the T-junction in 2014

Pipe Thickness Measurement Results (mm)								
SIGN	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
A	9.92	9.91	10.04	8.62	8.58	8.60	8.54	8.51
B	8.56	8.58	8.64	8.64	10.01	10.04	9.94	9.87
C	9.97	10.03	10.06	-	-	10.05	10.05	9.93
D	10.00	10.02	10.07	10.09	10.11	10.02	9.98	9.90
E	10.07	10.04	9.99	10.06	10.06	10.05	10.07	9.95
F	6.10	6.15	6.23	6.14	6.15	6.19	6.09	6.11

Table 2**.** The measurement results at the T-junction in 2015

Pipe Thickness Measurement Results (mm)								
SIGN	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
A	10	9.81	9.96	10.07	9.96	9.91	9.82	10.09
B	9.78	9.83	9.84	9.96	9.93	9.92	9.92	9.89
C	9.78	9.25	9.87	9.87	-	9.96	9.88	9.84
D	9.8	9.77	9.83	9.9	9.91	9.96	9.89	9.94
E	9.82	9.75	9.82	9.88	9.93	9.95	9.95	9.84
F	6.21	6.1	5.99	6.01	6.22	6.22	6.23	6.21

Table 3 indicates that there is a difference in thickness at the pipe wall. Section A to F has differences in value of 1.53 mm, 1.48 mm, 0.13 mm, 0.21 mm, 0.12 mm, and 0.14 mm. In 2015, starting from A to F, the differences are 0.26 mm, 0.13 mm, 0.71 mm, 0.19 mm and 0.2 mm, respectively. The results in Table 1 are compared with those in Table 2 by calculating the average value as shown in Table 3.

Table 3. Comparison of the average of thickness on T-joint in 2014 and 2015

YEAR	Pipe Thickness Measurement Results Comparison (mm)					
	A	B	C	D	E	F
2014	9.95	9.88	9.78	9.88	9.87	6.15
2015	9.09	9.29	10.02	10.02	10.04	6.15
Differences	0.86	0.59	-0.24	-0.14	-0.17	0.0

Lessons learned from the accidents that occurred at Mihama nuclear power plant (NPP) in Japan found that thinning of the pipe wall leading to accident should be partial as shown in Figure 5. It is known as the non axi-symmetric pipe wall thinning that occurs in the pipe orifice A [9]. Thus, it means that the test with average calculations can't always be used to indicate the wall thinning.

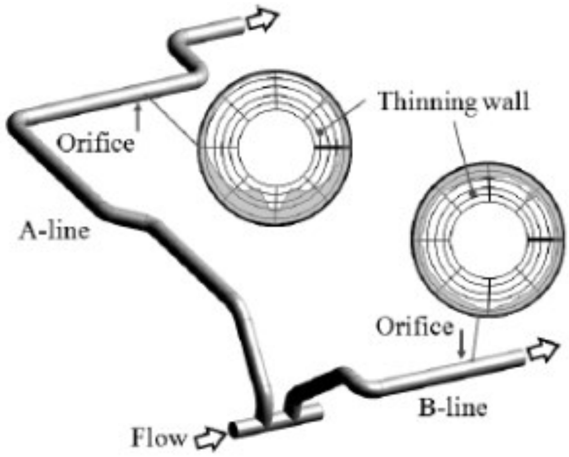


Fig. 5. Prototype pipeline of Mihama power plant [9]

Table 3 shows that the apparent differences in the rotational direction of the thickness of the pipe at number 1 position between A and B was 0.05 mm, then between A and C was 0.06 mm and the biggest difference is between E and B, around 1.51 mm. If the marking is more detailed at any point of testing as shown in Figure 6, the area numbered 1 to 3 are marked A at the T joint.

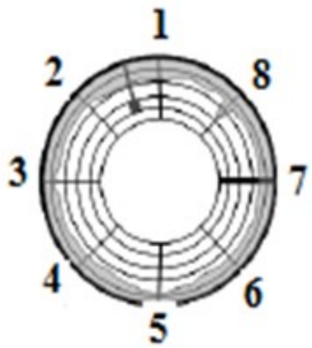


Fig. 6. Eight area measurements on primary pipe

In this section, the thinning of the pipe wall thickness are ranged from 0 to 0.13 mm. For the number 4 to 8, the depletion reached a value of 1.42 mm to 1.53 mm. Similar depletion was also found on the sign B, C, D and E with different values. This result can be considered as a depletion of non-axisymmetric way. Therefore, in the span of one year the thinning pipe corrosion due to erosion can't be ensured. At the T-junction, some values still indicated that the formed thinning is non-axisymmetric.

In addition to the T joint, the testing was also performed on the elbow section as indicated in the marking II of Figure 4a. The elbow section was chosen as the test location because the vortex water flow occurs in the elbow area. This incident causes the pipe wall thinning is faster than elsewhere. This events is also known as the flow accelerated corrosion. The data in Table 4 shows the test results in 2014, while Table 5 in 2015.

Table 4.The measurement results at the elbow section in 2014

ElbowPipe Thickness Measurement Results (mm)								
SIGN	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
A	7.08	7.17	7.15	7.21	6.69	6.67	6.7	6.72
B	7.09	6.98	7.16	7.26	6.62	6.86	6.73	6.65
C	7.11	7.01	7.27	7.27	6.59	6.93	6.88	6.75
D	7.11	7.01	7.04	7.2	6.59	6.96	6.77	6.67
E	7.07	7.15	7.13	7.17	6.71	6.67	6.82	6.78
F	7.08	7.17	7.15	7.21	6.69	6.67	6.7	6.72

Table 5. The measurement results at the elbow section in 2015

ElbowPipe Thickness Measurement Results (mm)								
SIGN	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
A	7.07	6.7	6.77	6.7	7.42	7.19	7.13	7.57
B	7.17	6.65	6.69	7	6.82	6.55	7.25	7.2
C	7.17	6.69	6.94	6.69	6.55	7.34	7.19	6.93
D	6.81	6.74	6.88	7.02	6.52	7.2	7.2	6.99
E	6.76	6.74	6.68	6.85	6.57	7.13	7.1	7.09

Based on the test results in Table 4, the thinning occurs also non-axisymetrically in the region of 1 to 5. The tendency of thinning occurs on the one side of the pipe wall. Great value is measured with decimation range of 0.2 mm to 0.8 mm. The results of retesting in 2015 also showed the depletion of non-axisymetric with wider spreads. Based on two test results, the calculation of average values shown in Table 6 indicate that the thinning process is generally very slow because the range of values only changes from 0 to 0.15 mm.

Table 6 . Comparison of the average of the thickness at the elbow in 2014 and 2015

YEAR	Elbow Pipe tthicknesss Measurement Results Comparison (mm)				
	A	B	C	D	E
2014	6.92	6.92	6.98	6.92	6.94
2015	7.07	6.92	6.94	6.92	6.87
Difference	0.15	0	-0.04	0	-0.07

The test results in Table 1 through 6 are obtained from the primary pipe in the suction side of the primary pump. Therefore, the testing also performed on several pipe connections on discharge side of the pump. One of the segment tested is the reducer connection as indicated in the marking IV of Figure 4a. The measurement results are shown in Table 7 and Table 8 for the year 2014 and 2015 respectively.

Table 7. The measurement results at the reducer section in 2014

Reducer pipe thickness measurement result (mm)								
SIGN	1	2	3	4	5	6	7	8
A	7.97	7.97	7.93	7.89	8.01	7.93	8.01	8.01
B	8.01	7.93	7.97	7.84	7.93	7.89	7.93	7.93
C	7.97	7.97	7.89	7.72	7.85	7.80	8.03	7.97

Table 8. The measurement results at the reducer section in 2015

Reducer pipe thickness measurement result (mm)								
SIGN	1	2	3	4	5	6	7	8
A	7.99	7.79	7.72	7.63	7.79	7.75	7.73	7.76
B	7.8	7.76	7.84	7.6	7.7	7.68	7.77	7.61
C	7.82	7.79	7.72	7.62	7.64	7.68	7.63	7.62

Table 7 shows that the thickness distribution of the pipe at each point is the same. The same thing can also be seen in Table 8, which has the same pipe thickness distribution. By comparing the both results, the differences of the thinning have average value of 0.21 mm Therefore, the wall thickness distribution has the same nominal value or a symmetric depletion has been occured. All the test results shows that the differences between the measured and nominal values are still very small. Therefore it is assumed that the differences in the value of the results are simply due to the measurement uncertainty. In terms of a general trend of depletion, there are two forms of thinning occuring, which are the non-axisymmetric and axisymmetric depletion. Non-axisymmetric shape tends to occur in the area of the primary pipe upward (before) of the primary pump, while the axisymmetric shape occurs at the pipe downward (after) of the primary pump. In order to provide certainty to the thinning process at the primary pipe of RSG-GAS, re-testing should be performed routinely every 5 years.

CONCLUSION

Inspection on the primary pipe of RSG-GAS reactor has been carried out by means of nondestructive test using ultrasonic device to measure the wall thickness. Based on the test results, the differences in the test results are apparent in the period of one-year operation as shown in the small values of the thickness in the range of 0.1 to 0.86 mm. The small value indicates that any changes in the joint pipe wall thinning are due to the limitations of the initial data. However, in terms of a general trend of the thinning, there are two forms of thinning occuring, which are the non-axisymmetric and axisymmetric. Non-axisymmetric shape tends to occur in the area of the primary pipe before the primary pump, while the axisymmetric shape occurs at the pipe after the primary pump. In order to provide certainty to the thinning process at the primary pipe of RSG-GAS, re-testing should be performed routinely every 5 years.

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