ABSTRACT

In recent years, the digitization techniques for RT (Radiographic Testing) are making rapid advances in healthcare field. It is DR (Digital Radiography) that has much advantage compared to the conventional film method. First, application of the DR method will reduce the costs for the time of development and storing so many films because of filmless. Second, DR is able to share the photographic image with other user. Accordingly, it is possible to exchange timely information. And the DR technique has wide dynamic range on the radiation. it will be able to photography the product that has different thickness. For example, the welding of socket.

On the other hand, there is little or no report about application of these techniques for the testing of components and piping in nuclear power plants. This is because reliability and proven method are required for the testing in nuclear power plants.

In our research, CR (Computed radiography) is selected in some technique of DR. To apply the CR method for the testing of components in nuclear power plants, it is necessary to meet the requirements by the codes such as ASME or Japan Society of Mechanical Engineers, JSME. Therefore, first applying for non-code inspection and optimized conditions of CR shooting was found out, on comparing the testing results by the CR method with that by the film method under the optimized conditions, and finally the CR method was applied for the detection of welding detects for the small piping welds as generally used in nuclear power plants.

Composition of CR equipment

Composition of CR equipment is shown in Fig. 1.

(A)IP: Imaging Plate
(B)Cassette
(C)Scanner
(D)Software for analyzing (process the images of testing results)
RT BY USING THE CR METHOD

The difference between the CR method and the film method

By the film method, the images of testing results are achieved after developing films by film developer. By the CR method, the images are achieved by scanning IP. IP is able to bend flexibly and it is portable, so CR method is suitable for uses in RT of nuclear power plant.

In the past there was no report about the application of IP for the welding testing of nuclear power plants, therefore, it needs to study the probability of detection, POD, by IP and to compare the results by IP with by film.

When using the CR method, some parameters should be specified to coordinate scanning sensitivity, scanning clearance, and so on. It is necessary to research about effects of these parameters and find the optimized condition.

Shooting condition

(1) Shooting object: Small piping
Material: Stainless steel type SA 312
Size: Outside Diameter 60.5mm, Wall Thickness 8.7mm
Same with the actual piping used in reactor coolant system of nuclear power plants
(2) Radiation source
X-ray source and gamma ray source, Ir192.
(3) Radiographic arrangement
Double wall double image technique because of small diameter piping.

RESULTS AND CONSIDERATIONS

Optimized condition of the CR equipment parameters

In this section, kind of the parameters are described in the CR equipment that adopted in this research (hereafter, CR equipment parameters). These parameters have effects on the images of testing results. Optimized conditions are found out in terms of the unevenness of images and visibility of IQI (Image Quality Indicator). CR equipment parameters are shown in Fig.2 to 4.

CR equipment Parameters

(1) IP: Imaging Plate
High sharpness IP; graininess is fine and low sensitivity
Low sharpness IP; graininess is coarse and high sensitivity

(a) High sharpness IP
(b) Low sharpness IP

Figure 2 - IP
(2) Screen
   Pb0.25mm; Insert Pb0.25mm to a cassette at source side.
   No Pb; No screen.

Fig. 3 Screen

(3) Scanning clearance
   50µm scanning clearance…Scanning IP at clearance 50µm in very high resolution Cassette.
   100µm scanning clearance…Scanning IP at clearance 100µm in high resolution Cassette.

(a) 50µm scanning clearance          (b) 100µm scanning clearance

Figure 4 - cassette

(4) Scanning sensitivity
   Low sensitivity scanning…Scanning amplified image information
   High sensitivity scanning…Scanning amplified image information
   Gain is twice as much as low sensitivity scanning

Optimized condition of the CR equipment parameters

The effects and optimized condition of the CR equipment parameters were researched by used on the steel plate (material: Stainless steel type SA240) and X-ray. The evaluation based on POD of IQI and evenness of CR image. Conditions of shooting are shown in Table 1. D-0 is the basic condition. In D-1～4, each parameters was changed and compared the image of testing result to that of D-0.
Table 1 - Condition of shooting to find the optimized condition

<table>
<thead>
<tr>
<th>ID No.</th>
<th>Source</th>
<th>Exposed time (Sec.)</th>
<th>Scanning sensitivity</th>
<th>IP</th>
<th>Scanning clearance</th>
<th>Screen (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D-0</td>
<td>X-ray</td>
<td>60</td>
<td>Low sensitivity scanning</td>
<td>High sharpness IP</td>
<td>50μm scanning clearance</td>
<td>Pb0.25</td>
</tr>
<tr>
<td>D-1</td>
<td>X-ray</td>
<td>30</td>
<td>High sensitivity scanning</td>
<td>High sharpness IP</td>
<td>50μm scanning clearance</td>
<td>Pb0.25</td>
</tr>
<tr>
<td>D-2</td>
<td>X-ray</td>
<td>30</td>
<td>Low sensitivity scanning</td>
<td>Low sharpness IP</td>
<td>50μm scanning clearance</td>
<td>Pb0.25</td>
</tr>
<tr>
<td>D-3</td>
<td>X-ray</td>
<td>60</td>
<td>Low sensitivity scanning</td>
<td>High sharpness IP</td>
<td>100μm scanning clearance</td>
<td>Pb0.25</td>
</tr>
<tr>
<td>D-4</td>
<td>X-ray</td>
<td>60</td>
<td>Low sensitivity scanning</td>
<td>High sharpness IP</td>
<td>50μm scanning clearance</td>
<td>No Pb</td>
</tr>
</tbody>
</table>

**Result of optimized condition of CR equipment parameters**

The results of radiographies in each condition are shown below.

1)D-0
• This is the basic condition to compare other.
  Parameters:
  • high sharpness IP, 50μm scanning clearance, low sensitivity scanning, Pb0.25

2)D-1
• Scanning sensitivity was changed from low sensitivity scanning into high sensitivity scanning.
  • Much unevenness could be seen compared to the result of low sensitivity scanning.
  • Exposed time became half compared to that of low sensitivity scanning.

3)D-2
• The IP was changed from high sharpness IP into low sharpness IP.
  • Much unevenness could be seen compared to the result of high sharpness IP. 1T hole couldn’t be seen.
  • Exposed time became half compared to that of high sharpness IP.

4)D-3
• Scanning clearance was changed from 50μm scanning clearance into 100μm scanning clearance.
  • Much unevenness could be seen compared to the result of 50μm scanning clearance.
(5)D-4
- No insert screen.
- Much unevenness could be seen compared to the result of Pb0.25mm.

**Considerations of optimized condition of CR equipment parameters**

Optimized condition of CR equipment parameters was made in terms of presence of unevenness of images and visibility of IQI.

- IP: high sharpness IP
- Screen: Pb0.25mm
- Scanning clearance: 50μm scanning clearance
- Scanning sensitivity: low sensitivity scanning

**Comparison of images between CR and film**

The images of testing results are compared between CR and film in terms of visibility of IQI and notch under the optimized condition in section 4.1.

Small diameter piping (O.D.60.5mm, W.T.8.7mm) was used which is used generally for reactor coolant system in nuclear power plants. X-ray and gamma ray were used as sources.

Piping test piece is shown in Fig.5, and condition of shooting is shown in Table.2. No.15 IQI was used in accordance with requirement of ASME.

![Figure 5 - Piping test piece](image-url)

- Depth of notches 0.2mm ~ 1.6mm
- Clearance 0.2mm
- Width of notches 0.3mm, 0.4mm ~ 1.0mm
- Clearance 0.2mm
### Table 2 - Condition of shooting (comparison of image between film and CR)

<table>
<thead>
<tr>
<th>ID No.</th>
<th>Source</th>
<th>Exposed time (min.)</th>
<th>Scanning sensitivity</th>
<th>IP</th>
<th>Scanning clearance</th>
<th>Screen (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Film Xray-1</td>
<td>X-ray</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td>Pb0.027</td>
</tr>
<tr>
<td>CR Xray-1</td>
<td>X-ray</td>
<td>4</td>
<td>Low sensitivity</td>
<td>High sharpness IP</td>
<td>50μm scanning clearance</td>
<td>Pb0.25</td>
</tr>
<tr>
<td>Film γray-2</td>
<td>Gamma ray</td>
<td>50</td>
<td>Low sensitivity</td>
<td>High sharpness IP</td>
<td></td>
<td>Pb0.027</td>
</tr>
<tr>
<td>CR γray-2</td>
<td>Gamma ray</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
<td>Pb0.25</td>
</tr>
</tbody>
</table>

### Result of comparison of images quality between film and CR

The results of radiographies were shown in each condition below.

1. **Film Xray-1**
   - 2T hole of IQI was visible.
   - 0.2mm depth and 0.3mm width of notches were detectable.

2. **CR Xray-1**
   - 2T hole of IQI was visible.
   - 0.2mm depth and 0.3mm width of notches were detectable.

3. **Film γray-2**
   - 2T hole of IQI was visible.
   - 0.2mm depth and 0.4mm width of notches were detectable.

4. **CR γray-2**
   - 2T hole of IQI was visible.
   - 0.2mm depth and 0.4mm width of notches were detectable.
Considerations of comparison of images between film and CR

In the case of the using X-ray and gamma-ray the CR method had the same POD as the film method in terms of IQI and notches. Therefore, the image quality of CR method is equal to the film method. And the 2T hole of IQI that is required ASME codes had been detected. Therefore, these results have met the requirement of ASME codes.

Radiography of welding defects

POD of welding defects by the CR method was checked.

- Piping :Outside Diameter 60.5mm, Wall Thickness 8.7mm
- Source :gamma-ray

Kinds of welding defects are shown in Table.3, and condition of radiography in Table4.

<table>
<thead>
<tr>
<th>Number of TP</th>
<th>Welding defects</th>
</tr>
</thead>
<tbody>
<tr>
<td>TP-1</td>
<td>Porosity</td>
</tr>
<tr>
<td>TP-2</td>
<td>Slag inclusion, overlap</td>
</tr>
<tr>
<td>TP-3</td>
<td>Over penetration</td>
</tr>
<tr>
<td>TP-4</td>
<td>Penetration oxidation, tungsten inclusion</td>
</tr>
<tr>
<td>TP-5</td>
<td>Undercut</td>
</tr>
</tbody>
</table>

Table 3 - Kinds of welding defects

<table>
<thead>
<tr>
<th>ID No.</th>
<th>Source</th>
<th>Exposed time (min.)</th>
<th>Scanning sensitivity</th>
<th>IP</th>
<th>Scanning clearance</th>
<th>Screen (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FilmTP-1 5(Film)</td>
<td>Gamma ray</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
<td>Pb0.027</td>
</tr>
<tr>
<td>CRTP-1 5(CR)</td>
<td>Gamma ray</td>
<td>50</td>
<td>Low sensitivity scanning</td>
<td>High sharpness IP</td>
<td>50μm scanning clearance</td>
<td>Pb0.25</td>
</tr>
</tbody>
</table>

Table 4 - Condition of radiography

Results of radiography of welding defects

The results of radiography in each condition are shown below.

Porosities were detectable in both the results by the film method and that by the CR method.
Slag inclusions and overlaps were detectable in both the results by the film method and that by the CR method.

Over penetrations were detectable in both the results by the film method and that by the CR method.

Penetration oxidations and tungsten inclusions were detectable in both the results by the film method and that by the CR method.

Undercuts were visible in both the results by the film method and that by the CR method.
Considerations of Radiography of welding defects

Porosity, slag inclusion, over penetration, penetration oxidation, tungsten inclusion and undercut were detectable in the images of testing results by both the CR method and the film method. Therefore, the CR method has the same POD as the film method in terms of welding defects with the film method.

CONCLUSION

The effects of the CR equipment parameters for the testing results were researched, and the optimized condition was found in terms of the presence of unevenness of images and POD of IQI. Optimized condition is:
- Scanning sensitivity : low sensitivity scanning
- IP : high sharpness IP
- Scanning clearance : 50µm scanning clearance
- Screen : Pb0.25mm

The images of testing results were compared by the CR method and that by the film method, and confirmed that the images of testing results by the CR method was equal to that by the film method in terms of visibility of IQI and notches.
Welding defects by the CR methods were shot, and confirmed that the images of testing results by the CR method is equal to that by the film method in terms of POD of welding detects.
In conclusion, the CR methods is applicable for the welding testing of small diameter piping in reactor coolant system in nuclear power plants.