Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 22, 2009

An Enhancement of Visual Test Performance for Nuclear Fuel Assembly

JaiWan Cho[1], YoungSoo Choi[1], and Jung Cheol Shin[2]
[1]*Korea Atomic Energy Research Institute,* [2]*Korea Nuclear Fuel.*
E-mail: jwcho@kaeri.re.kr

1. Introduction

In the overhaul period of the nuclear power plant, integrity of the neutron-irradiated fuel assembly is evaluated. Nuclear regulations require that nuclear power plants meet the design, operation, and inspection requirements of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (B&PV). Section XI of the ASME B&PV Code provides the specific requirements for inspecting the systems, structures, and components; Section V of the ASME Code provides requirements for inspection methods, including volumetric (e.g., ultrasonic testing), surface (e.g., eddy current testing), and visual testing (VT). Visual testing of neutron-irradiated fuel assembly is conducted generally for a variety of purposes, for example (1) to detect discontinuities and imperfections on the surface of fuel rods, (2) to detect evidence of leakage from end-cap welds, and (3) to determine the general mechanical and structural condition of one. VT is performed remotely using video camera.

As the neutron-irradiated fuel assembly is a high dose-rate gamma-ray source, approximately a few kGy, radiation-hardened underwater camera is used in the VT of the fuel assembly. Utilities today follow the EPRI guidelines for VT-1 tests on nuclear components (BWR Vessel and Internals Project-3 1995). The VT-1 guidelines specify which areas around a weld should be examined, how to measure the sizes of indications found, and how to test the resolving power of the visual equipment used for the test. The EPRI guidelines use two 12μm (0.0005-in.) wires or notches as a resolution calibration standard. According to the EPRI guidelines (BWRVIP-03 1995), the camera systems employed were marginally able to detect the 0.0005-inch (12-μm) diameter wire on a steel background [1].

In the some future, it is required that the VT of nuclear fuel assembly follows the EPRI VT-1 guideline. In order to meet the VT-1 guideline, any system used in VT (ranging from the naked eye to a digital closed-circuit TV system) will have a measurable visual acuity. The visual acuity parameter describes what a system can detect and discern. Current underwater radiation-hardened video camera, which is composed of tube- type vidicon image sensor, used in the VT of fuel assembly has not sufficient resolution regardless of high cost. As the resolution of the COTS SOTA (state-of-the-art) CCD image sensor is higher than the tube-type image sensor, the VT of the fuel assembly clearly meets the EPRI VT-1 guideline, if assumed that the radiation-weakened SOTA CCD camera is properly shielded from the high dose-rate gamma-ray source. In this paper, it is described that a radiation-tolerant camera system, which are composed of COTS SOTA CCD camera, zoom lens, anti-reflection mirror, and visible window, meets the EPRI VT-1 guideline for the VT of the nuclear fuel assembly.

Generally, the VT of the four face of nuclear fuel assembly, which is a high dose-rate gamma source, is performed in the underwater canal. The width of canal, d_1, is about 1,500mm. As the distance, d_2, between the fuel assembly (d_3, 224mm) and the camera system, assumed that the width of camera system is about 200mm, is short below one-tenth shielding thickness of gamma-ray of water, about 660mm, a COTS SOTA CCD camera cannot be used directly.

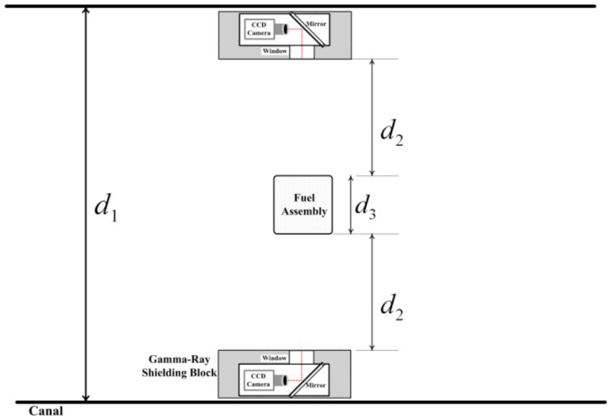


Fig. 1. A schematic diagram for the VT of fuel assembly

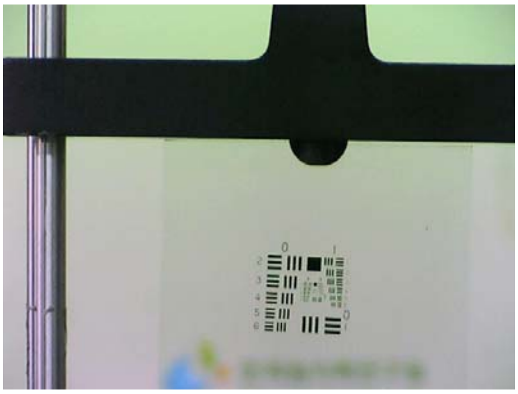
Table 1. VT environments of nuclear fuel assembly

Item	d_1 (canal)	d_2 (observation distance)	d_3 (fuel assembly dimension)
Distance	1,500~1,800mm	438~588mm	224mm
Estimated Dose rate	≤ 400Gy/h	≤ 600Gy/h	Source (≤ 4kGy/h)
	(From the Fuel Assembly)		
Shield (1000 x)	≤ 0.4Gy/h	≤ 0.6Gy/h	
Shields thickness	84mm at 1MeV gamma source		

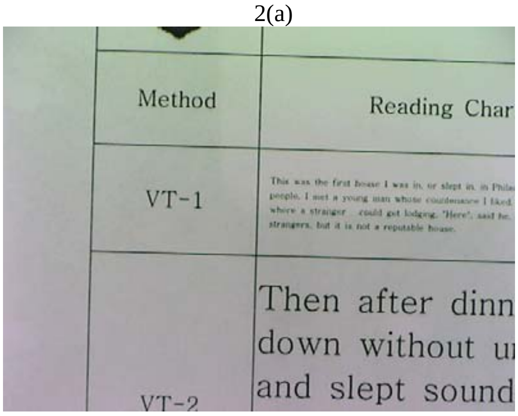
As shown in Fig. 1 and Table 1, the observation distance between the fuel assembly and the CCD camera, is 438~588mm. These observation distances are shorter than the MOD (minimum object distance) of the SOTA CCD cameras (Sony FCB-PV480 and FCB-H10). The MOD of these SOTA color CCD camera are 800mm and 1,000mm. In this paper, in order to enhance the optimum observation performance, the close-up lens (No. 2) was used. An observation distance of 400mm from the test samples was acquired.

2. Experiment

The standard used to calibrate a camera system during visual tests is a very important check of the ability of the system to detect cracks. A good standard can demonstrate that the system has resolution capability to detect the features in question and that examined areas are lighted from the most advantageous angles. An example of a camera system using a 1.06mm VT-1 NDATC (near distance acuity test chart) reading test is shown in Figure 2. It should be noted that the resolution target also contained a series of letters for use as a reading chart.

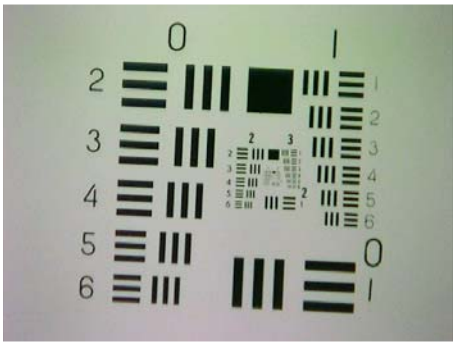


2(a)

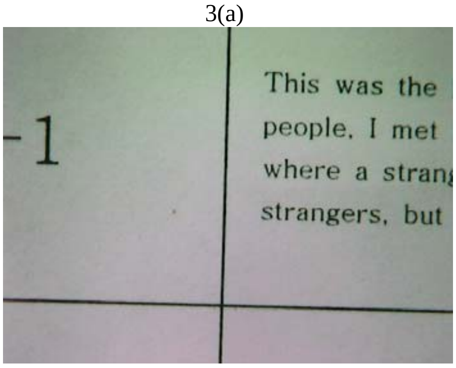


2(b)

Fig. 2. Examples of performance demonstrations at the 400mm distance from the test standard. (a) shows USAF1951 resolution test target, and (b) shows near distance acuity test chart. VT-1 characters are 0.042-inch height.



3(a)



3(b)

Fig. 3. Examples of performance demonstrations at the maximum zoom conditions from the same distance as Fig. 2. (a) shows USAF1951 resolution test target, and (b) shows near distance acuity test chart. In order to acquire 400mm object distance, close-up lens(No.2) was attached.

In the case of Fig. 2, The VT-1 characters are readable if attentively viewed. At the maximum zoom condition, the VT-1 characters are easily readable as shown in Fig. 3(b). The SOTA CCD camera (FCB-PV480) used in this example has a pixel size of 206 pixels/mm or 4.85μm.

Fig. 4. Experimental setup for performance demonstration

3. Conclusions

A radiation-tolerant camera, which is composed of COTS SOTA CCD camera, zoom lens, anti-reflection mirror, and visible window, meets the EPRI VT-1 guideline for the VT of the nuclear fuel assembly if assumed that the radiation-weakened SOTA CCD camera is properly shielded from the high dose-rate gamma-ray source (neutron-irradiated fuel assembly).

REFERENCES

[1] D.A. Jackson and W.E. Norris, "An Assessment of Visual Testing", NUREG/CR-6860, Pacific Northwest National Laboratory, 2004