Post-Irradiation Examination Capabilities of M1 Hotcell in IMEF

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Abstract

The Irradiated Material Examinations Facility (IMEF) in Korea has been conducting post-irradiation examinations (PIE) on materials and fuels irradiated in the HANARO research reactor and commercial reactors.

IMEF has been operated regularly since 1993. The hotcell on the ground floor consists of six concrete cells (M1 ~ M6) and one lead cell (M7). One hotcell (M8) is placed in the basement for the electrolytic reduction process. In addition, a pool with a depth of 10m is located in the service area to handle the transport cask.

Various type of R&D fuels have been developed in Korea. Because R&D fuels such as a coated particle fuel, a metallic fuel, and plate fuel have various shapes and characteristics, the development of various equipment and jigs are needed in IMEF. In particular, in the M1 hotcell, non-destructive test equipment such as a gamma scanning, an X-ray CT, and a dimensional measurement were developed. In addition, a fission gas analysis and vacuum heating system were developed and have been in operation.

After briefly introducing the IMEF hotcell, this paper focuses on the post-irradiation examination capability of the M1 hotcell and introduces the equipment with research examples.

1. Introduction

PIEs on materials and fuels irradiated in the HANARO research reactor and commercial reactors have been performed in IMEF since 1993. The IMEF hotcell on the ground floor consists of eight concrete cells (M1 ~ M6) and one lead cell (M7). The main functions and equipment of each hotcell for the PIE are shown in Table 1. In addition, the hotcell layout is shown in Figure 1.

Irradiated fuels and materials transferred through the cask receiving area are moved into the M1 hotcell by the bucket elevator. After the capsule is dismantled at the M2 hotcell, PIEs are performed in each hotcell shown in Figure 2. In the M1 hotcell, various equipment such as a gamma scanning, and an X-ray CT have been developed and operated to fit the needs of researchers. This paper focuses on the post-irradiation examination capability of the M1 hotcell and introduces the equipment with research examples.

Table 1. Main function and equipment of hotcell

Hotcell	Main Function	Equipment
M1	Non-destructive test	Gamma scanning system, X-ray CT, Dimension measurement system, Fission gas analysis system, Vacuum heating system
M2	Dismantling & Cutting	CNC milling M/C, Capsule cutting M/C
M3	Specimen preparation	Micro cutting M/C, Mounting press, Polishing M/C
M4	Specimen storage	Storage rack
M5 line	Mechanical tests	Impact tester, 2-D optical coordinate tester
M7	Microscopy	OM, Hardness tester, Density equipment, SEM
Hot Lab.	Material Morphology	Shielded EPMA, TEM with EDX, Micro X-ray CT

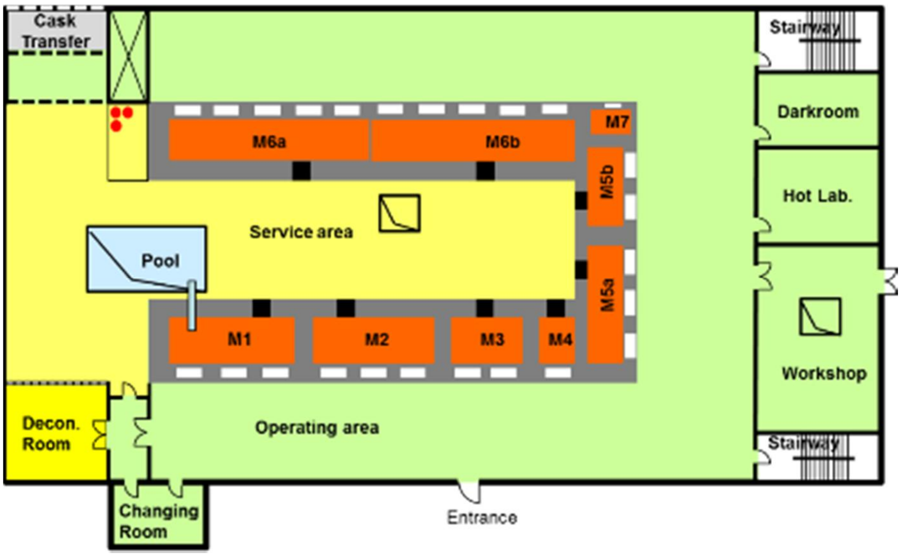

Figure 1. IMEF 1st floor layout

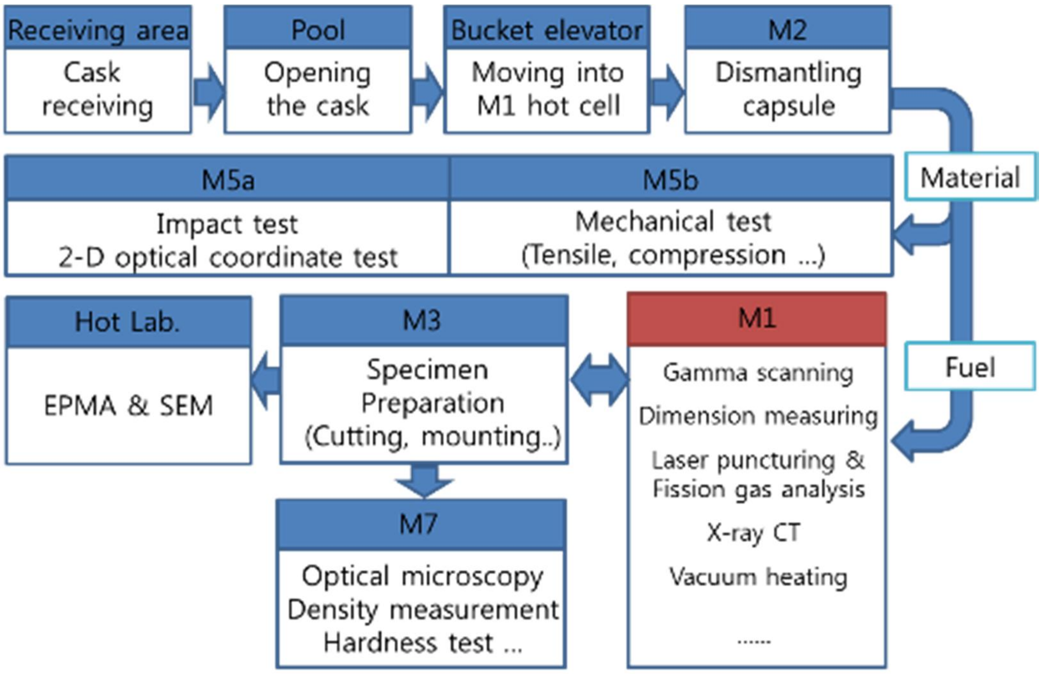

Figure 2. General PIE procedure of IMEF

2. M1 hotcell equipment

Various R&D fuel such as a metallic fuel, coated particle fuel, and plate fuel have been developed in Korea. Test equipment and jigs for handling various fuel shapes and properties are needed. To control various specimens, various equipment such as an X-ray CT, and vacuum heating system were developed and have been operating in the M1 hotcell.

2.1 X-ray CT system

An X-ray system has been used globally because a high-resolution image of internal behavior can be obtained without destruction. The 450kV shown in Figure 3 was installed and operated in the M1 hotcell [1]. The X-ray CT system is highly useful to observe internal pellet deformations and defects. In addition, the fuel dimension can be measured using 3-D software and CT technology.

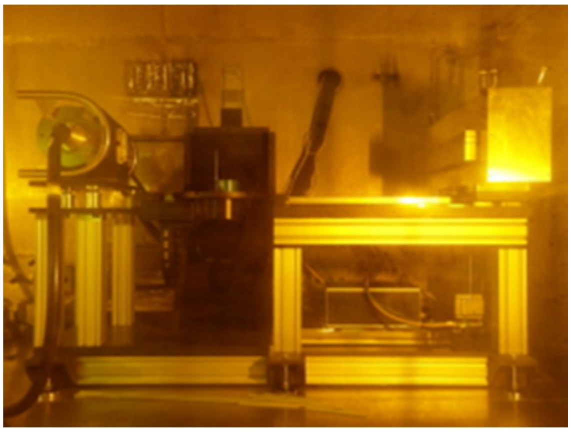

Figure 3. 450kV X-ray installed in M1 hotcell

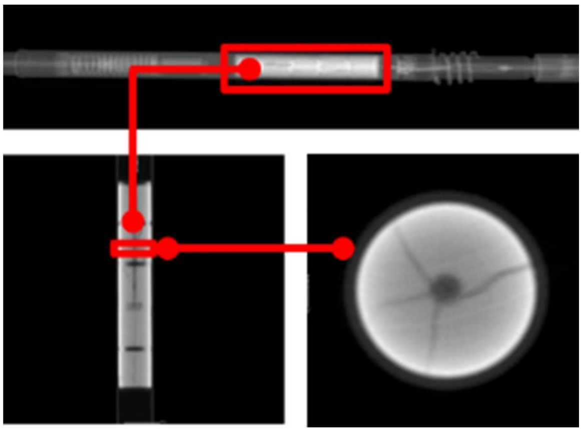

Figure 4. CT images of research reactor fuel

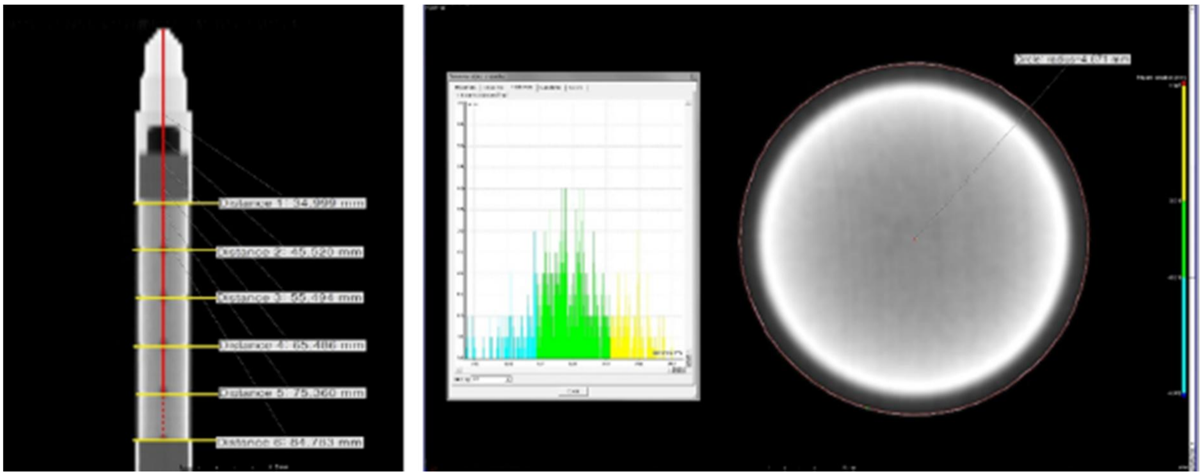

Figure 5. Dimensional measurement of R&D fuel

Information of the fuel shape and position is very useful when performing other NDTs, and allows researchers to prepare specimens of destructive test effectively. In particular, it is great advantage that various tests can be performed without specimen waste by making an effective cutting plan. In addition, the information of the dimensional changes and shape of the fuel as shown in Figures 4 and 5, are used to understand the in-pile behavior of the irradiated fuel.

2.2 Dimensional measurement system

Measurements confirming the dimensional changes from irradiation are basic PIE items. Diameter measurements of the R&D fuel rod have been conducted using an LVDT installed on the inside wall of the hotcell as shown in Figure 6. The fuel is moved up and down using a bench system installed on the inside wall when measuring the diameter of the fuel rod. The bench system can move horizontally and vertically, and can rotate 360 degrees through PLC control. The measurement rage and minimum axial displacement of LVDT is 5 to 20 mm and 0.1 mm respectively.

Special equipment for measuring the thickness and oxide layer of the plate fuel was developed as shown in Figure 7. The equipment is composed of an LVDT and ECT. The maximum measurable size is 700 mm (length) and 100 mm (width). The minimum measurable gap is 1.0 mm. The thickness and oxide layer of the fuel plate were measured as shown in Figures 7 (b) and 7 (c) respectively.

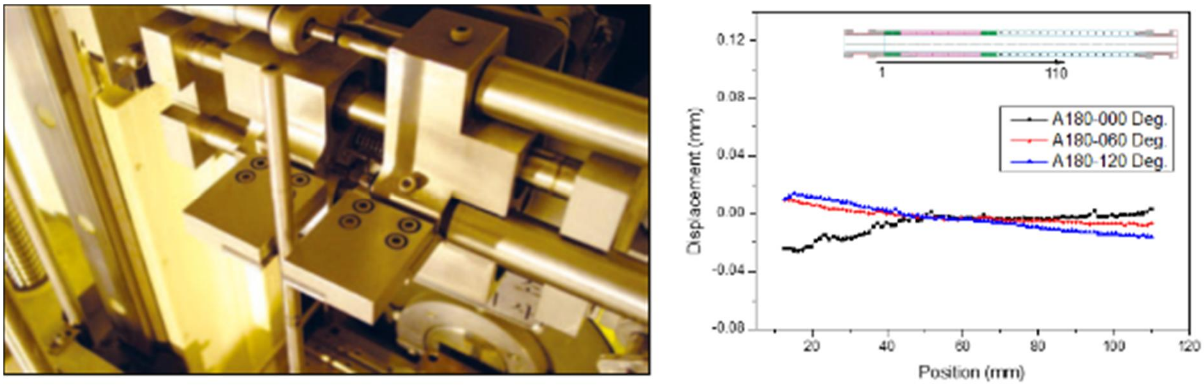

Figure 6. LVDT installed in hotcell and example of diameter measurement

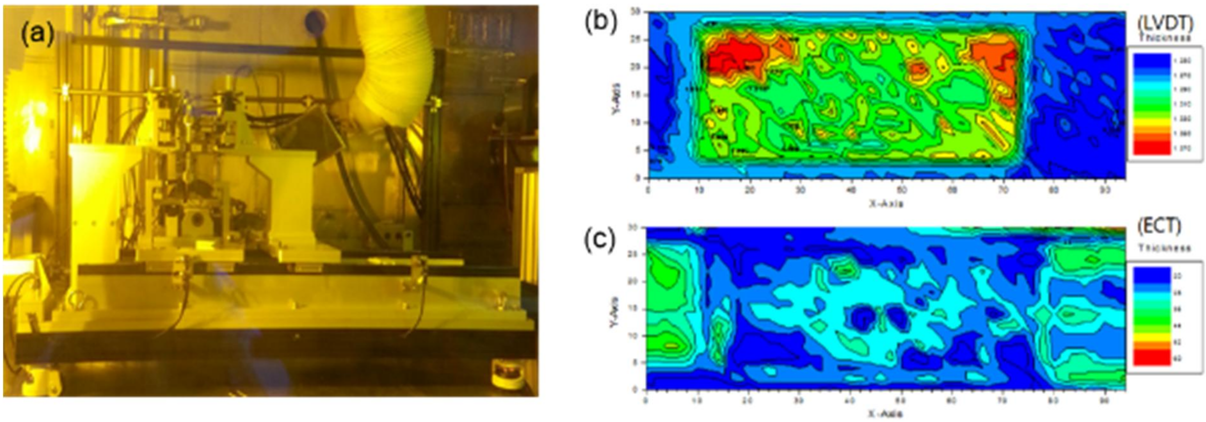

Figure 7. (a) 2-D dimensional measurement for plate fuel, (b) example of thickness measurement, and (c) example of oxide thickness measurement

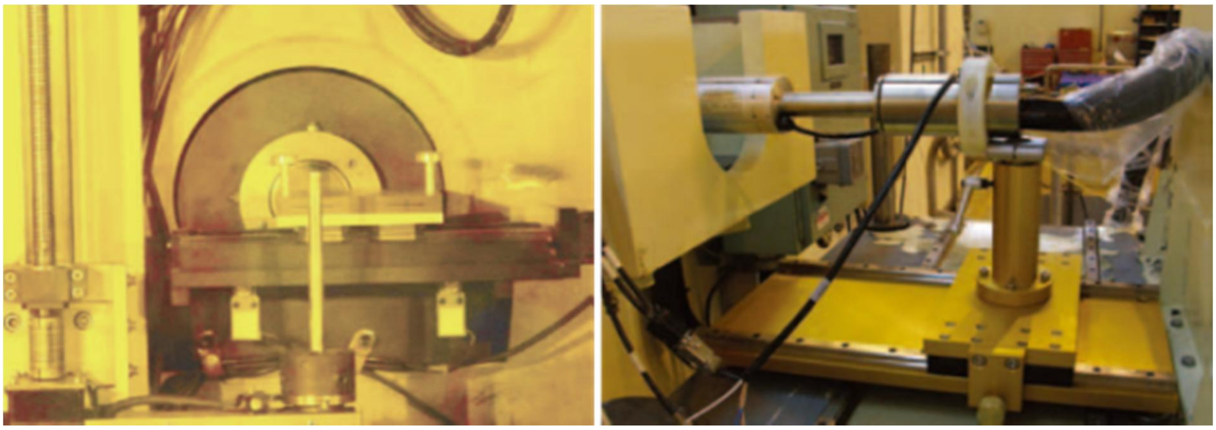

Figure 8. Gamma scanning system and HPGe detector

2.3 Gamma scanning system

Gamma scanning is also one of the basic PIE items. As shown in Figure 8, a HPGe detector was installed on the outside the hotcell wall, and gamma scanning was performed using the bench system same with the dimensional measurement system. A tungsten collimator was used to minimize the detector dead time caused by a high radioactivity of the fuel. Through gamma scanning, radionuclides emitting gamma-rays can be analyzed and can obtain the relative burn-up profile with the fuel length by measuring the ratio of Cs-134/Cs-137.

2.4 Laser puncturing and fission gas analysis system

The measurement of the released fission gas amount and internal void in a fuel rod is one of the important factors of the fuel performance. A laser puncturing and fission gas analysis system, as shown in Figure 9 was developed to measure a very small amount of fission gas because small fuel rods have been used and irradiated in a research reactor for R&D [2].

The pressure and vacuum ranges are 1-1,000 torr and ~10^{-6} torr, respectively. This system can be measured in at least 2cc at room temperature. After measuring the gas pressure, fission gases can be analyzed at up to 200 amu using a QMS (Quadruple Mass Spectrometer) in a high vacuum state.

2.5 Vacuum heating system

Some R&D fuels are need to confirm various reactions according to the temperature. A furnace was developed for the fuel plate and coated particle fuel. As shown in Figure 10, it was currently renovated as a vacuum heating furnace for metallic fuel [3]. The temperature is controlled by one heating zone furnace, which measures the temperature of the furnace and inside of the vacuum tube using two thermocouples. In addition, there are thermocouple connectors at the furnace for easily connecting with the furnace controller installed in the operating area. Specimens can be installed and removed using a tray. A rotary and diffusion pump were connected with a vacuum furnace and vacuum storage to achieve a high vacuum environment. Using the vacuum system, the oxidation of the specimen can be prevented during and before the heating test. After high-temperature heating tests, the reactions between the fuel and material are analyzed using an optical microscope and an EPMA (Electron Probe Micro Analyzer).

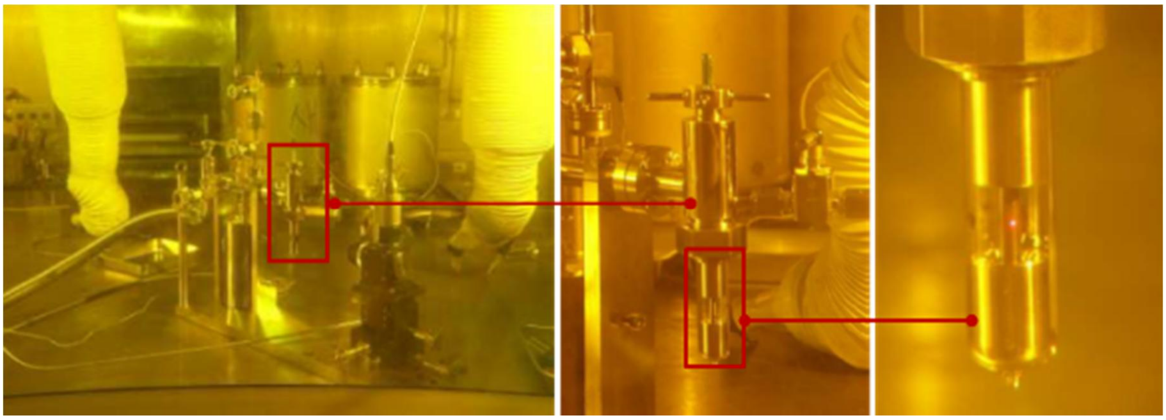

Figure 9. Laser puncturing system installed in hotcell

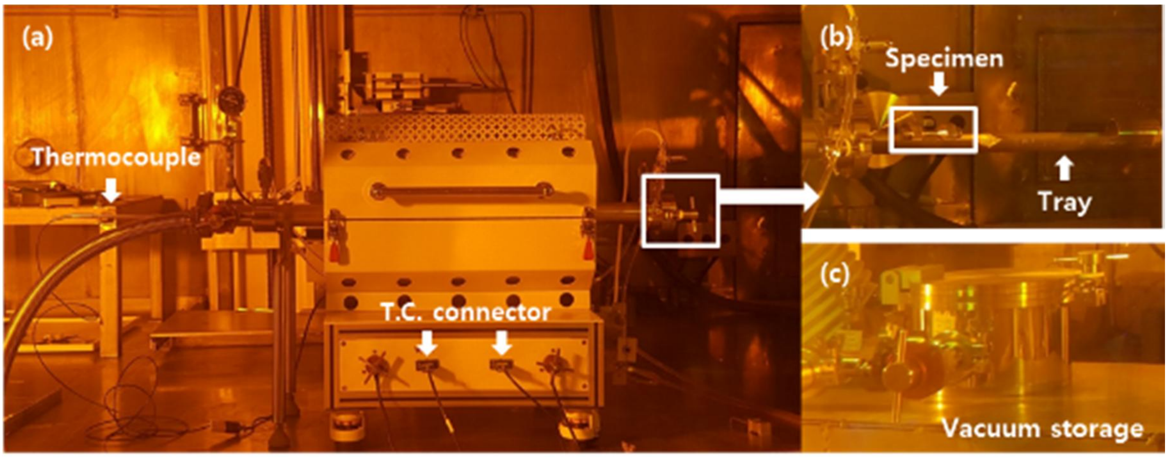

Figure 10. Vacuum heating system installed in hotcell

3. Conclusion

Test equipment and jigs for various examinations have been developed in IMEF. Various NDT were successfully performed using an X-ray CT, dimensional measurement system and so on installed in the M1 hotcell. In addition, PIEs of R&D and commercial fuels as well as surveillance tests of the pressure tube will be performed. Through this, IMEF has been devoted to supplying high-quality PIE data to R&D projects on nuclear fuel and materials.

References

[1] Young-jun Kim, Boung-ok Yoo, Hee-moon Kim, Sang-bok Ahn, "Development of X-ray system for irradiated fuel in hotcell", HOTLAB 2016, Karlsruhe, Germany, October 2-6, 2016.

[2] H.Kim, S.B.Ahn, B.O.Lee, Y.S.Yang, B.O.Yoo, S.Y.Baek, K.S.Heo, "Development of laser puncturing and fission gas analysis system for fuel rod in hotcell", HOTLAB 2014, Baden, Switzerland, September 21-25, 2014.

[3] Young-Jun Kim, Yong-Sun Choo, Boung-Ok Yoo, Ki-Soo Heo, Gil-Soo Kim, Ju-Seong Kim, Junehyung Kim, "Development of Vacuum System for High-Temperature Heating Test in Hotcell", Transactions of the Korean Nuclear Society Spring Meeting, Jeju, Korea, May 18-19, 2017.