DEVELOPMENT OF LASER PUNCTURING AND FISSION GAS ANALYSIS SYSTEM FOR FUEL ROD IN HOTCELL

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ABSTRACT

To measure a very small fission gas amount in a fuel rod, laser puncturing is available to make a hole on the surface of a cladding tube instead of using steel needle puncturing owing to a reduction of the chamber volume. After puncturing, the pressure difference was measured using a fine pressure gauge. A small chamber and a quartz tube were used to measure a small gas amount and penetrate the laser shot from outside. The pressure and vacuum ranges are 1~1,000 torr and ~10^{-6} torr, respectively. This system can be measured at least 2cc at room temperature. After measuring the gas pressure, fission gases were transferred to a QMS (Quadruple Mass Spectrometer) in a high vacuum state, which is installed in a glove box to analyze the gas content (up to 200 amu). QMS is useful for measuring xenon, krypton, and helium. It must be calibrated using several reference gases (He+Xe+Kr). Measurements of the total amounts and quantitative contents of the fission gases in a fuel rod were carried out concurrently. U-Zr metallic fuel rods were used to measure the total gas amounts and analyze the contents of helium, xenon, and krypton.

1. Introduction

The measurement of the released fission gas amount in a fuel rod is one of the important factors of the fuel performance. A released fission gas influences the fuel temperature and internal pressure owing to the low thermal conductivity. Therefore, the fission gas released into the internal void of the fuel rod must be measured based on the burnup. To measure the amount of fission gas, the fuel rod must be punctured in a chamber equipped with a pressure gauge and a thermocouple. The ideal gas law (PV=nRT) is applied to obtain the atomic concentration (mole). A steel needle type is good for a large amount of fission gas such as in a commercial spent fuel rod. However, some cases of a small fuel rig in a research reactor for the R/D program are unable to use a steel needle type because of a large chamber volume. A laser puncturing technique was thus developed to solve the measurement of a small amount of fission gas. A fiber laser was used to make a hole on the rod surface and to be operated easily. A QMS (Quadruple Mass Spectrometer) was installed in this system to analyze the quantities of helium, xenon, and krypton. It was activated in a high vacuum state and under a very low gas content. The system used in this study is useful for the measurement of the total amount of fission gas and a quantitative analysis using a QMS concurrently.

2. Experimental

The system apparatus was developed to measure a very small amount of fission gas because small rods have been used and irradiated in a research reactor for R/D. Then, all parts were prepared for fine measurements.

2.1 Apparatus

The system consists of four parts: a vacuum device a puncturing chamber, a laser device, and a QMS (Quadruple Mass Spectrometer). The system was installed in the operation area and hot cell, as shown in Figs. 1. and 2. A rotary pump and turbo pump were installed to keep the chamber at ~10^{-6} torr. The chamber was made of stainless steel, and a quartz tube was installed in the chamber for a laser shot, as shown in Fig. 3. A fine pressure gauge (1~1,000 Torr) and a thermocouple were installed in the chamber. A fiber laser system is useful for the operation, and the pulse mode of the laser is good for a puncture with 1.5 kW as one shot. Generally, the puncturing point on the rod surface was set up by the guide laser (red light), and is moved by the XYZ laser bench. Whenever a laser shot occurs, the quartz tube was not clear by the chips on the surface. Thus, the puncturing point must be changed up and down, and sometimes the quartz tube was turned around.

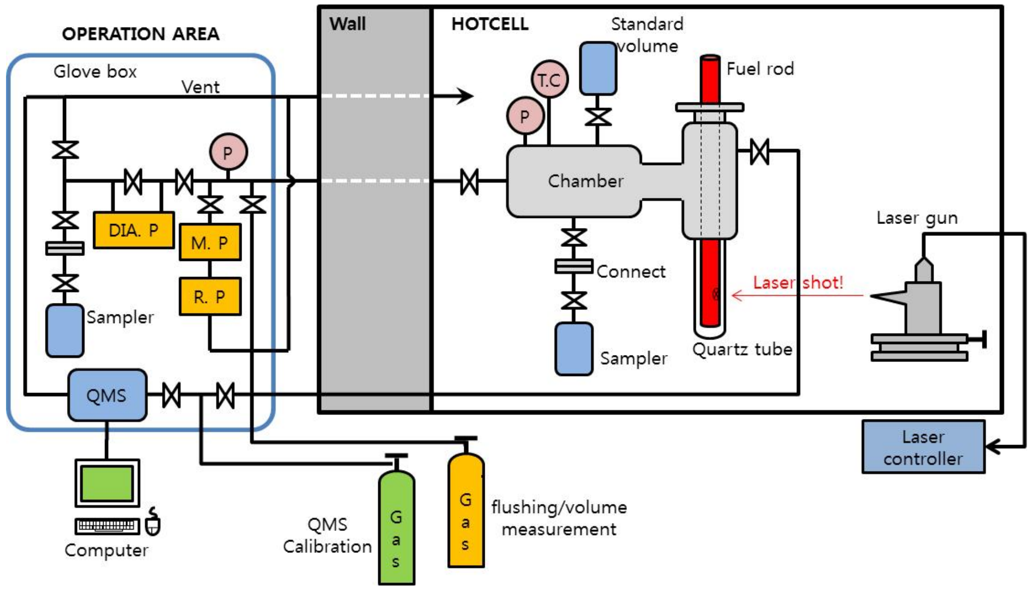

Fig. 1 System layout

Fig. 2 Glove-box (vacuum pump, control panel and QMS), chamber, and laser gun in a hot cell

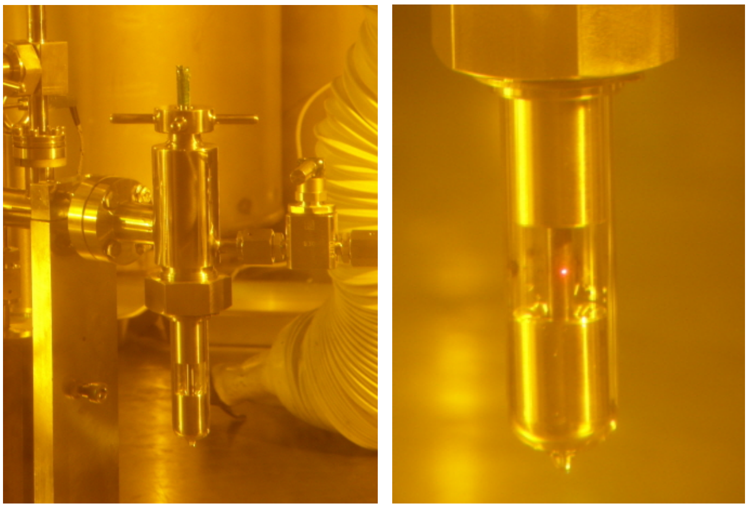

Fig. 3 Quartz tube installed in a chamber for a laser puncture

After the system setup, a stainless steel tube with 2 mm of thickness can be punctured using one laser shot. After reducing the chamber volume, at least 2cc of gas volume can be measured. Tests for the laser and pressure were performed and introduced for material in a HOTLAB 2013. QMS, called an RGA (Residual Gas Analyzer), was installed in a glove box, as shown in Figs. 2 and 4, and its specifications are shown in table 1.

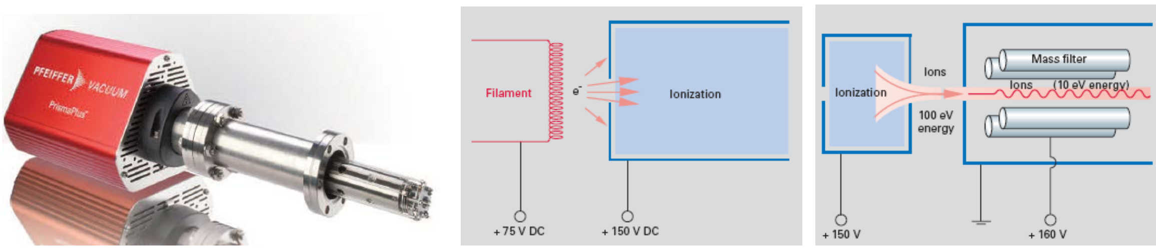

Fig. 4 QMS (or RGA) and principle

Table 1 Specifications of QMS

Content	Value	Content	Value
Mass range	1-200 amu	Operating temp.(electronics)	0 – 40°C
detection limit	2E-12 ~ 1E-4 mbar	Resolution at 10% peak height	0.5 – 2.5 amu
Operating temp.(analyzer)	150°C	Measurement speed	20 – 60 s/amu

It was calibrated using xenon and krypton with a helium base before testing the fission gas in a fuel rod. To check the reliability of a QMS, three standard mixed gases were made: 3%, 5%, and 10% of xenon in a helium base. They were connected to a vacuum line to the QMS chamber. A computer program was used to check the xenon portions in helium, as shown in Fig. 5.

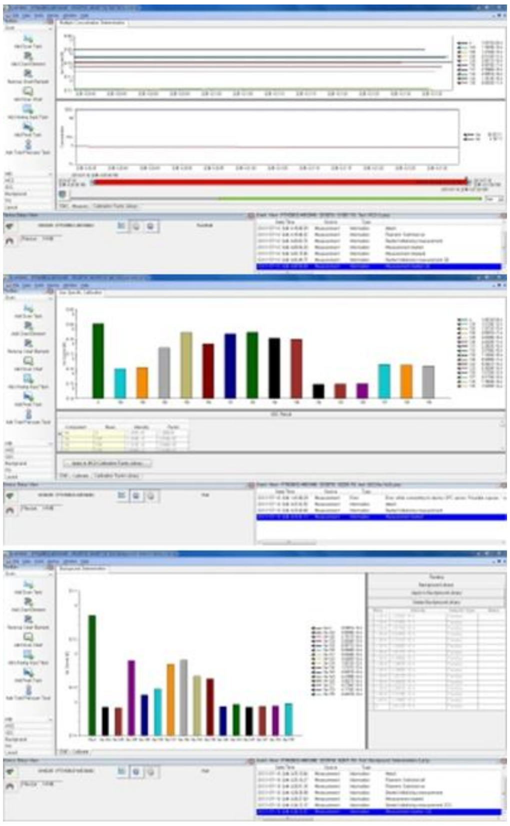

Fig. 5 QMS Software for quantitative analysis

Two standard gases were prepared: Xe(5%)+Kr(5%) and Xe(45%)+Kr(5%) in helium. Two gases were used to measure the portions of Xe and Kr.

First, an ~10^{-7} torr vacuum existed in the QMS chamber, and residual elements (impurities) were checked. One of standard gases flowed into the chamber at $2x10^{-5}$ torr for calibration. Then, other gases were measured, and the results are shown in tables 2 and 3.

Table 2. The results of STD gases of Xe (helium base)

Gases	Meas. of (3% of Xe)	Meas. of (5% of Xe)	Meas. of (10% of Xe)
3% of Xe	2.96 %	3.46 %	8.33 %
5% of Xe	3.57 %	5.05 %	11.21 %
10% of Xe	4.55 %	6.09 %	9.9 %

Table 3. The results of STD gases of Xe & Kr (helium base)

Gases	Meas. of (Xe-5% & Kr-5%)	Meas. of (Xe-45% & Kr-5%)
Xe-5% & Kr-5%	5.12%(Xe) 4.9%(Kr)	40 %(Xe) 5.5 %(Kr)
Xe-45% & Kr-5%	7.7 %(Xe) 5.99 %(Kr)	44.5 %(Xe) 4.9 %(Kr)

2.2 Test of U-Zr metallic Fuel Rods

Metallic fuel rods were irradiated as shown in Fig. 6. Fuel meat was U+10%Zr and Ce as additives. Three rods were punctured and the fission gas amount was measured as shown in Fig. 7. After measurement of the total gas amount, QMS was activated to measure the helium, xenon, and krypton. The results are shown in table 4. Good agreement was shown, and the Xe/Kr ratios were reasonable.

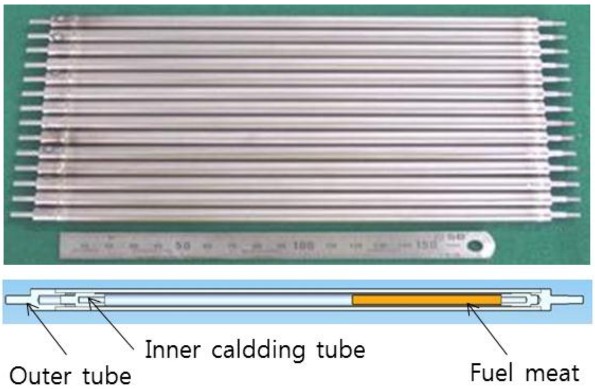

Fig. 6 U-Zr metallic fuel rods

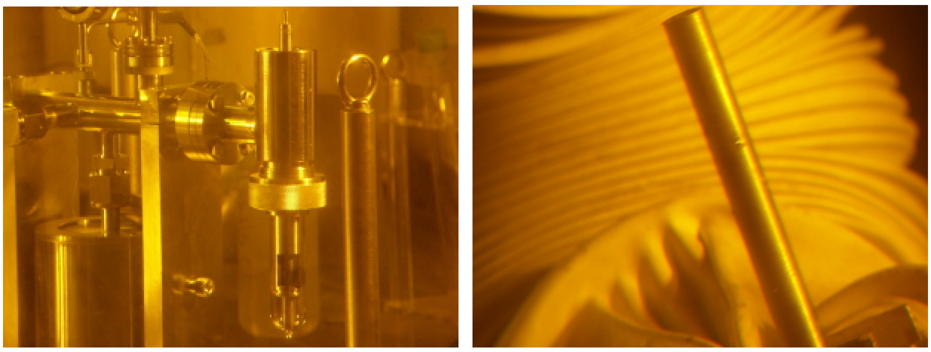

Fig. 7 Rod loading in chamber and punctured hole in a tube

Table 4 Results of U-Zr metallic fuel rods

Fuel Rod Index	*Rod internal volume(cm^3)*	*Total gas content(mol.)*	*Helium(%)*	*Xenon(%)*	*Krypton(%)*	*Xe/Kr*
U-Zr-1	1.29	3.686E-4	80.2	16.9	2.9	5.68
U-Zr-2	1.73	5.855E-4	56.5	37.3	6.2	5.99
U-Zr-3	1.43	4.489E-4	55.4	38.2	6.4	5.94

3. Results

A laser and a puncturing system without a QMS were introduced in HOTLAB 2013. In this paper, its specifications were not referred to, and only a QMS was introduced. A QMS is good for a residual gas analysis, and therefore, it is activated in a high vacuum state. Before measurement of the fission gases from chamber, a test of the reference gases must be performed for calibration. However, this is difficult, as shown in tables 2 and 3. When reference gases were prepared for calibration, the gas contents were considered to be the same as the content of the sample gases. Thus, when U-Zr metallic fuel rod tests were performed, the reference gas (Xe(45%)+Kr(5%)) was better than Xe(5%)+Kr(5%), as shown in table 3 based on the calculation data of the fuel performance. The ratios (Xe/Kr) showed good agreement with the calculations, as shown in table 4.

4. Conclusions

To measure the small fission gas inventory in a fuel rod, a new puncturing method was introduced using a laser. After installation of the QMS, a laser puncturing system was developed to analyze the gas contents concurrently. This is very beneficial for a series of PIE procedures. This system is useful for measuring not only small amounts of gas for a test rod but also large gas amounts for a commercial PWR rod when changing the chamber volume.

References

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[2] Advice of Laser welding company(IPG Photonics).

[3] Heemoon Kim, “Measurement of small fission gas volume in fuel rod using laser puncturing system”, material in HOTLAB 2013