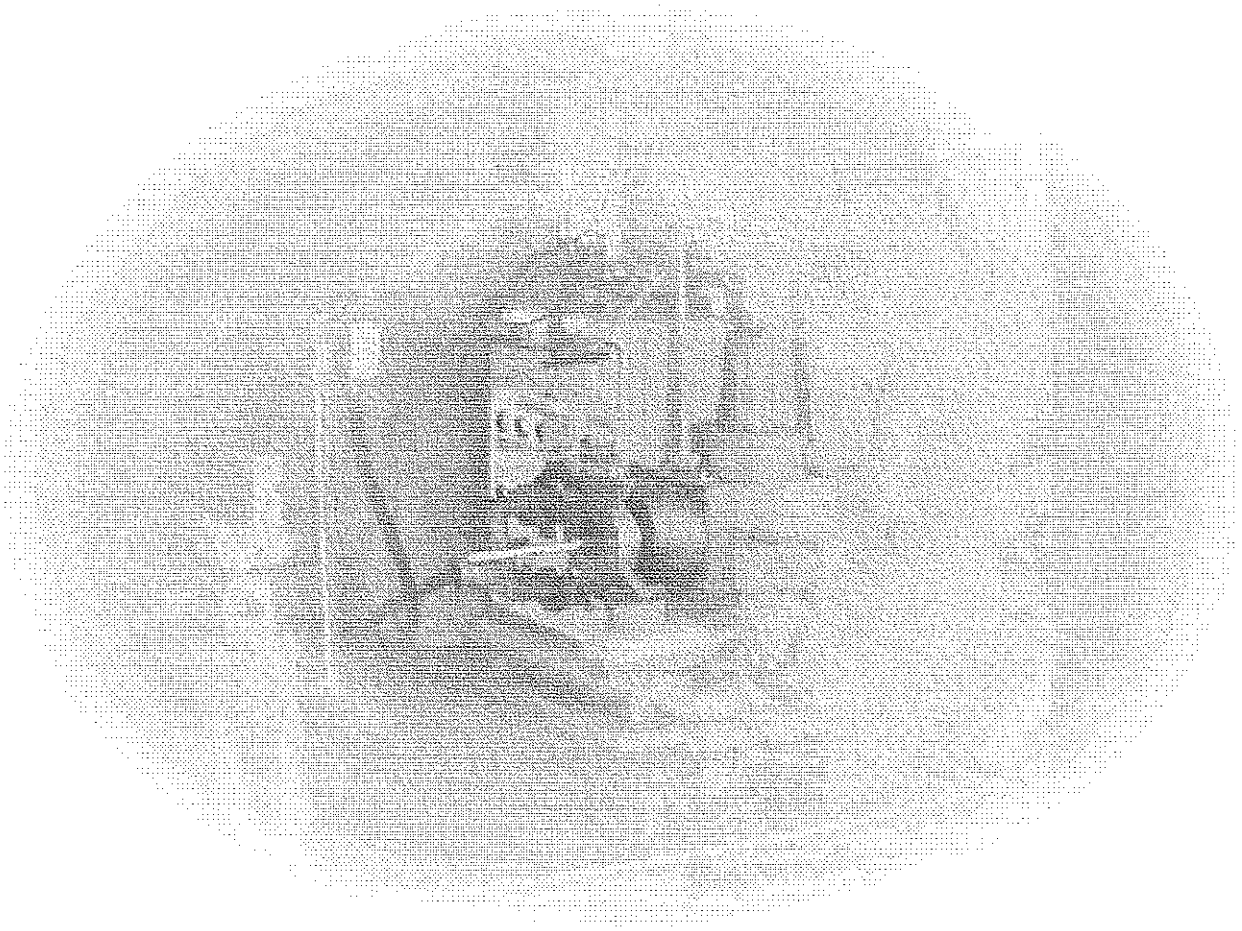
Recent experience in high burn-up fuel pin puncturing



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Introduction

Within the framework of PIE (Post - Irradiation - Examination) studies at PSI, we are performing fission gas release measurements on irradiated fuel pins from Swiss BWR and PWR reactors. Since 1997, a new puncturing and pumping station has been in use which has demonstrated stable performance and safety in operation. Since that time, over 120 gas samples have been taken and successfully analysed, and exceptionally high accuracy has been achieved.

In order to obtain reliability in high burn-up fuel rod puncturing, the gas sampling and gas flow of a fuel pin with 72 GWd/tU burn-up have been investigated. The fuel pin was punctured in the plenum and also on the opposite side of the pin. The gas flow after puncturing and the refilling of the fuel pin with helium, to determine the free gas volume, were recorded on-line and have been compared with corresponding lower burn-up fuel pin data.

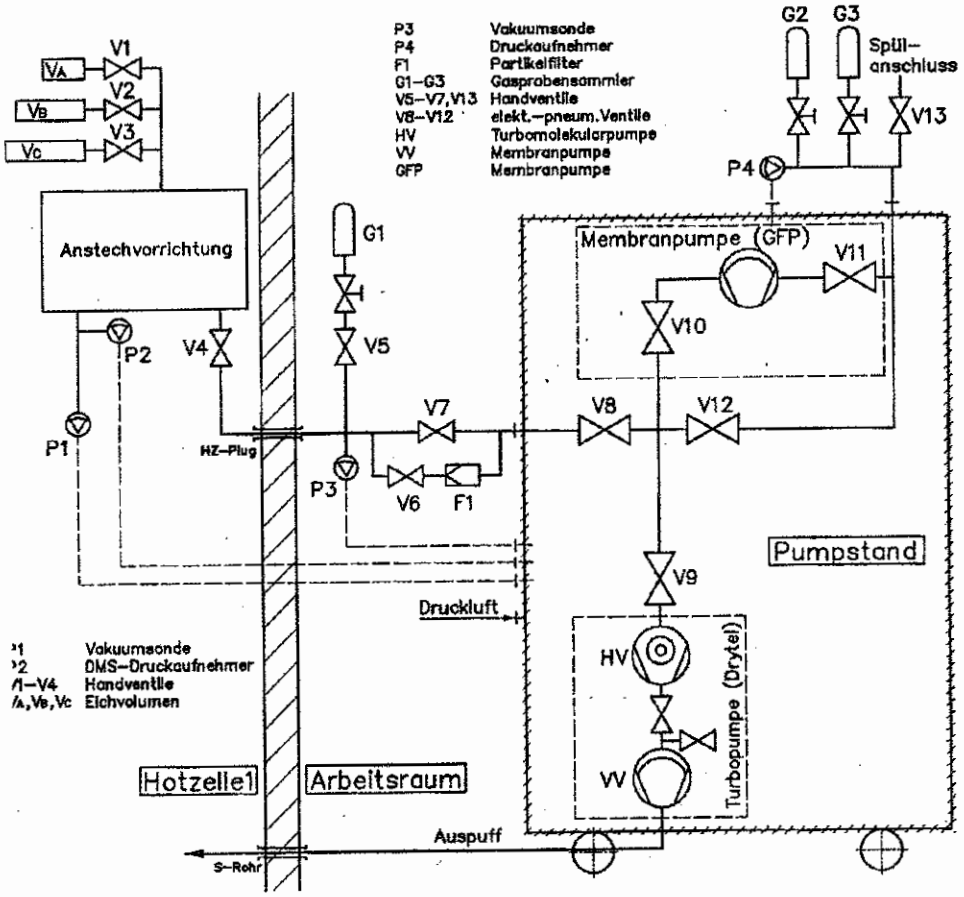
The goals of these gas release and flow studies are to:

- **Demonstrate the accuracy of determining the free gas volume of high burn-up fuel pins**

- **Evaluating the gas collected from the bottom of the fuel pin**

Pumping facility

Layout



Technical data

Components	Performance	Leakage rate
Turbo molecular pump	1x 10^{-6} mbar at 4 l/s (He)	
Membrane pump	2 mbar at 3.3 m^3/h	< 5x 10^{-4} mbar l/s
Gas phials	50 cm^3 (including valve)	< 4x 10^{-9} mbar l/s (He)
Pirani gauge	1000 - 10^{-6} mbar	
Pressure gauge	0- 1000 mbar ±0.8%	(piezoresistive)
Pneumatic valves	1x 10^{-7} mbar up to 5 bar	
Puncturing unit with pumping station	1x 10^{-5} mbar at fuel pin (total volume 3000cm^3)	4x10^{-6} mbar l/s (4x10^{-3} mbar l/s) **

** (pumping station with membrane gas collecting pump)

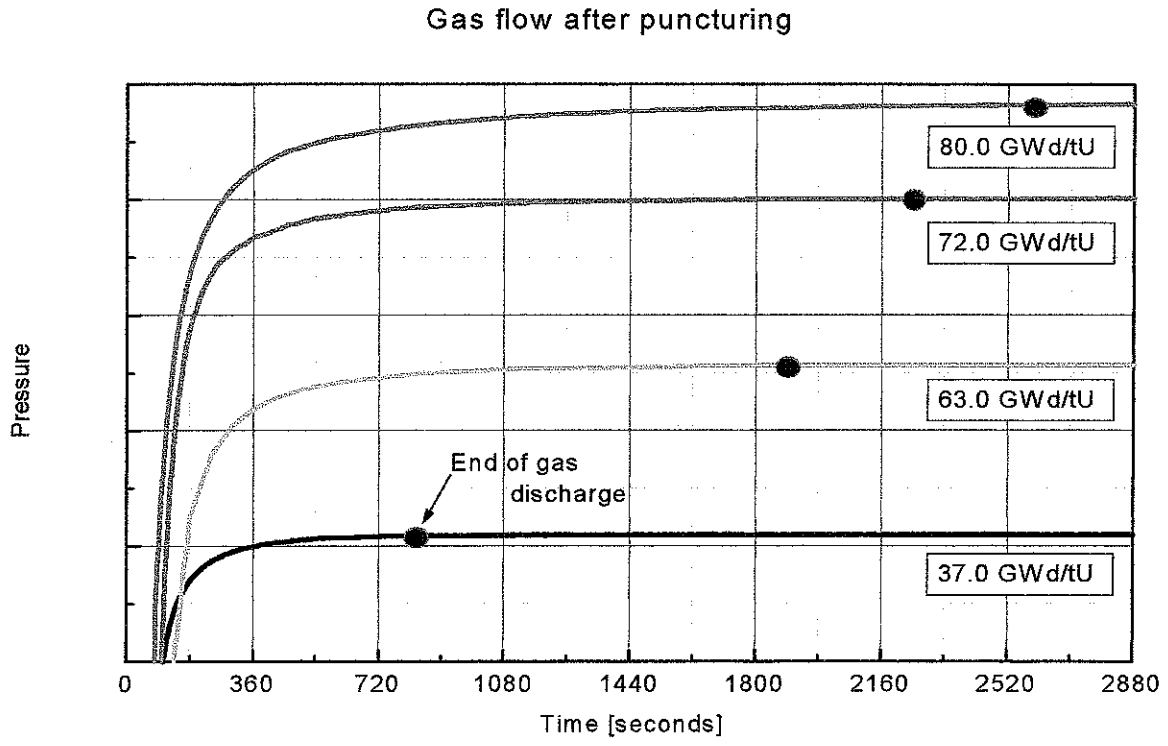
Measurement technique

The fuel pin is introduced into the chamber of the puncturing station, sealed on both sides with flat rubber seals, and finally mechanically punctured with a steel needle. The gas is released into the gas chamber, while the pressure is recorded on a plotter up to a constant gas pressure, at a rate < 2 mbar/h, and gas samples are collected for mass spectrometry. Afterwards, the free volume in the fuel pin is determined, and the internal pin pressure and amount of released fission gas are subsequently calculated.

Fuel pin puncturing

The fuel pins are normally punctured at the plenum end of the pin. The gas flow diagrams below were taken on-line after puncturing of the fuel pin.

Gas flow diagram after puncturing



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Determination of the free gas volume in the fuel pin

Three calibrated gas volumes are used to determine the free gas volume. The three different gas volumes are filled with helium and the gas pressure and temperature are noted. Afterwards, the gas puncturing unit with the punctured fuel pin has to be evacuated down to < 1 x 10^{-3} mbar. The times of evacuation of the fuel pin and of the transfer of the helium from the calibration volumes into the fuel pin depend on the burn-up of the pin. The time needed for refilling the pin free volume can be obtained from the gas effusion curve, which is recorded during degassing after puncturing.

Gas analysis of residual gas from the bottom of the pin

To study the remainder of the gas still left in the fuel pin, the pin also had to be punctured at the side, near the bottom, to obtain the necessary information. For these tests, the fuel puncturing hole in the top plenum had to be sealed, and after puncturing at the side, near the bottom, gas was collected into two ampoules and analysed by gas mass spectrometry.

Results of the analysis of the two gas samples and comparison with fission gas

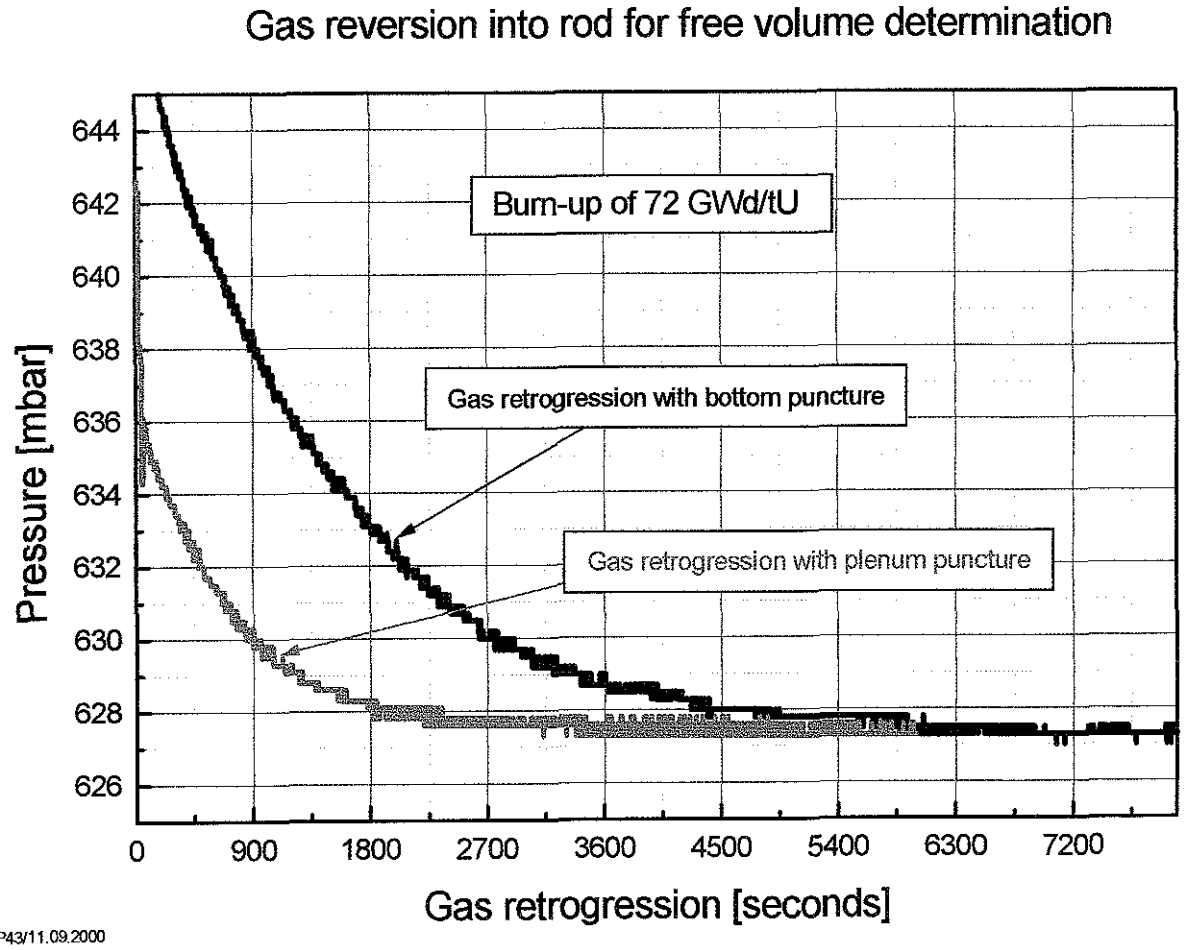
Gas component	Calibration gas 702 [Vol. %]	Gas collected from plenum [Vol. %]	Gas collection, bottom sample 1 [Vol. %]	Gas collection, bottom sample 2 [Vol. %]
Krypton	0.98 ±0.03	4.14 ±0.07	0.14	0.03
Argon	1.18 ±0.03	0.25 ±0.01	0.52	0.74
Xenon	14.31 ±0.51	58.80 ±1.5	2.34	0.98
Helium	72.77±0.73	36.8 ±1.4	53.52	37.24
Nitrogen	8.47±0.18	0.01	42.89	61.0
Oxygen	1.73±0.09		0.59	0.01
CO_2	0.565±0.016			
Sum	100	100	100	100

de rest die eventueel blijft zitten is
vrij < tov 1e extractie.
Hoedanook → lange pomptijden nemen.

Gas flow into the fuel pin

To determine the free gas volume in the fuel pin, the gas from the calibrated volumes has to be released back into the puncturing chamber and the fuel pin. The time of refilling the fuel pin is dependent on the burn-up. Insight into the gas flow kinetics within a high burn-up fuel pin can be gained from the pressure-decrease time curve shown below

Gas flow into the fuel pin



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Conclusions

Recording of the gas pressure:

There is a great advantage in recording the gas release into the puncturing unit as it gives information on the completeness of the pumping and refilling procedures for determining the free gas volume (compared with normal plenum puncturing)

Gas flow in a high burn-up fuel pin

There is still complete interconnectivity of gas reservoirs through the entire fuel pin up to high burn-up (e.g. 72 GWd/tU)

Determination of the free volume in the fuel pin

The free volume in the fuel pin can be determined from both sides of the pin

Amount of residual fission gas in the fuel pin

After gas collection and long pumping time to determine the free gas volume, there was still fission gas left at the bottom of the fuel pin

Gas sampling and determination of the free gas volume

This investigation and earlier experience have shown that FGR determination from high burn-up fuel pins is time consuming in order to obtain the correct data

Future prospects

We are planning future investigations into:

- **The behaviour of the gas mixture during the sampling process (e.g. possible changes in gas composition)**
- **Gas collection from both sides of a fuel pin and comparison of the gas composition**
- **The elimination of any risk of leakage at the pumping station**