THE RISØ FISSION GAS PROJECT
An overview

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The RISØ Fission Gas Project has provided experimental data on fission gas release from high-burnup water reactor fuel. The data are well-characterized with respect to pre-irradiation measurement, irradiation and post-irradiation examination, thus enabling their use in fuel performance code validation.

The experimental data were obtained with 12 Zircaloy clad UO_2 pellet fuel pins, irradiated in a test assembly to an average of 32,000 MWD/tU. Most of the fuel pins were submitted to short-term reirradiations at increased power levels ("bump testing") in a test reactor, in order to simulate postulated power increases late in life. The bump tests covered a range of bump terminal levels of 320-462 W/cm (peak pellet), mostly with a hold time of 24 h. Extensive hot-cell examinations were performed of base-irradiated and bump-tested fuel pins.

The fission gas release resulting from the bump testing was in the range 0-16%, increasing with peak pellet levels above 400 W/cm. Local fission gas releases were determined from retained gas measurements on pellet size samples. Release of fission product cesium as a function of local bump terminal level resembled the local fission gas release. The gas release measurements were corroborated by extensive ceramographic examinations and pore size analysis.

BACKGROUND

There is a recognized need for experimental data on fission gas release from water reactor fuel exposed to burnups well in excess of 20,000 MWD/tU. Such data are needed for fuel irradiated under "steady-state" conditions and also for fuel exposed to power increases late in life, since fairly moderate power increases after the accumulation of significant burnup can result in important fission gas releases.

The RISØ Fission Gas Project was designed to expand the existing data base in these areas and at the same time provide insight into the changes in the fuel that accompany burnup accumulation and fission gas release.

The Project objective was to provide experimental data on fission gas release from high-burnup water reactor fuel; the data should be sufficiently well-characterized with respect to pre-irradiation measurement, irradiation and post-irradiation examination to enable their use in fuel performance code validation.

The Project was organized as a joint international project with sponsorship from a number of organizations in the USA and Europe. The Project was executed by RISØ. A Project Committee with representatives of the sponsors supervised the progress of the work and assisted RISØ in the execution of its tasks. The sponsoring organizations are listed in the below table.

Organizations Sponsoring the RISØ Fission Gas Project
British Nuclear Fuels Ltd. (U.K.)
Department of Energy (USA)
Elkraft (Denmark)
Elsam (Denmark)
Exxon Nuclear Company (USA)
General Electric Company (USA)
Inspectorate of Nuclear Installations (Denmark)
Institutt for Energiteknikk (Norway)
Rheinisch-Westfälisches Elektrizitätswerk (F. R. Germany)
Swedish Nuclear Power Inspectorate (Sweden)
United Kingdom Atomic Energy Authority (U.K.)
Westinghouse (USA)
RISØ National Laboratory (Denmark)

The project period was 1980-81. According to the Project Agreement, there are restrictions on the full public disclosure of project information. With the resulting limitations, the present paper will outline the experimental investigations and indicate some of the observations.

TEST FUEL AND BASE IRRADIATION

The results were obtained with 12 Zircaloy clad UO_2 pellet fuel pins. Most of the 89 cm long pins had pellet densities in the range 93-95% TD. The cladding was cold-worked and stress-relieved Zircaloy.

During the base irradiation in the OECD Halden Reactor (Norway), the fuel pins were part of a Danish test fuel assembly. The assembly average burnup was 32,000 MWD/tU, with a corresponding peak pellet value of 44,000 MWD/tU. The assembly power history is shown in Figure 1. The pin average heat load was generally decreasing from 320 to 180 W/cm, with a short period at 390 W/cm in the beginning of the irradiation period.

BUMP TESTING

Most of the 12 fuel pins were submitted to short-term reirradiations at increased power levels, so-called "bump testing", in the DR 3 test reactor at RISØ. A total of 11 tests were carried out with 9 pins; rebumping of two of the pins was feasible because the fission gas content could be assessed non-destructively by the RISØ plenum spectrometry technique[1]. Similarly, the fission gas content prior to bumping was measured for all pins.

The bump testing was performed in water-cooled facilities at a coolant pressure of 70 atm [2]. At low power, there were no restrictions on the power increase rate, above 250 W/cm (peak pellet) the approach to bump terminal level (BTL) was executed in steps of approximately 20 W/cm every 4 h, thus giving an average increase rate of 5 W/cm·h (peak pellet).

The tests covered a range of peak pellet BTLs of 320-462 W/cm. The hold time was 24 h, except for one test at 72 h.

HOT-CELL EXAMINATIONS

Non-destructive examination (NDE) after base-irradiation and after bump testing was carried out as follows:

NDE Technique	Observation
Axial gamma scanning	Local, relative power and bunrup
Profilometry	Diameter changes
Eddy-current testing and visual examination	Cladding integrity
Neutron radiography	Fuel structure, fuel column integrity
Plenum spectrometry	Fission gas content

Destructive examinations (DE) of base-irradiated and bump tested fuel pins included the following examinations:

DE Technique	Observation
Puncturing	Fission gas analysis of whole pin
Retained gas measurement	Fission gas content of pellet size samples
Electron microprobe analysis	Diametral Xe and Cs distribution
Micro gamma scanning	Diametral Zr-95 and Cs-137 distribution
Ceramography with quantitative image analysis	Fuel structure, especially pore size distribution and grain size
Burnup and heavy isotope analysis	Burnup; basis for calc. of fission gas generated

The above hot-cell examinations were performed at RISØ, except for electron microprobe analysis which was carried out at the European Institute for Transuranium Elements at Karlsruhe (F.R. Germany).

The hot-cell examinations were very extensive as illustrated by Figure 2 which shows the locations of the destructively examined samples.

OBSERVATIONS

Well-characterized experimental data on fission gas release at high burnup were generated according to the Project objective. Some of the experimental observations are listed below:

1. The integral pin fission gas release resulting from the bump testing was in the range 0-16%. These bump releases were close to zero at BTL less than 400 W/cm (peak pellet) and they increased with BTL above 400 W/cm.

2. The axial power shape during the bump testing differed from the base irradiation shape because the DR 3 reactor has a smaller core height than the Halden Reactor. As a result, each bump test was in fact a whole series of experiments with a range of BTLs. This was exploited by means of retained gas measurements on pellet size samples. The results are illustrated in Figure 3.

3. The diametral micro gamma scanning gave information on the local distribution of Zr-95. This showed that the radial power profile late in the base irradiation was flat except for an outer rim significantly less than 4% of the pellet radius. The power profile during bump testing is expected to be similar.

4. The diametral Cs-137 scans showed various degrees of depletion in the hotter, central pellet part, depending on the local BTL. Local Cs releases could be calculated from these scans. The local fission gas and Cs releases seemed to correlate with local BTL in a similar manner.

5. Extensive ceramographic examinations of base irradiated and bump tested fuel samples as well as unirradiated archive pellets were carried out, and pore structures were evaluated by quantitative image analysis. The results of these examinations further characterized and supported the fission gas release observations and gave information regarding swelling at high burnup.

FURTHER DEVELOPMENTS

The most important test parameter in the RISØ Fission Gas Project was the terminal power level in the bump tests, with a constant hold time of 24 hours in almost all of the tests. There is, however, interest in data on the fission gas release of high-burnup fuel as a function of hold time and there are very few data available.

On this background, preparations are being made for a new RISØ project to study the transient fission gas release at high burnup. This project will be internationally sponsored similar to the previous project. The well-characterized high-burnup test fuel will come partly from another Danish Halden assembly and partly from a BWR or PWR power reactor. The fuel will be refabricated in the RISØ hot-cells into shorter test pins, most of which will be provided with pressure transducers. These test pins will then be subjected to typical power transients in the DR 3 reactor and the changes in the internal pin pressure will be monitored continuously. There will also be the possibility of testing short, unopened, high-burnup fuel segments. After the transient testing, the fuel will be examined in detail in the hot-cells.

ACKNOWLEDGEMENT

The members of the Project Committee of the RISØ Fission Gas Project are thanked for permitting early publication of selected project results. Similarly, thanks are extended to staff members at RISØ, Halden and the European Institute for Transuranium Elements at Karlsruhe for their efforts and collaboration in the execution of the Project.

REFERENCES

C. Bagger, "Non-Destructive Assessment of Fission Gases Released in Water Reactor Fuel Rods", paper presented at the IAEA Specialists' Meeting on "Examination of Fuel Assembly of Water Cooled Power Reactors", Tokyo, 9-13 November 1981.

2 C. Bagger, H. Carlsen and K. Hansen, "Calculation of Heat Rating and Burnup for Test Fuel Pins Irradiated in DR 3", RISØ-M-2185, 1980.

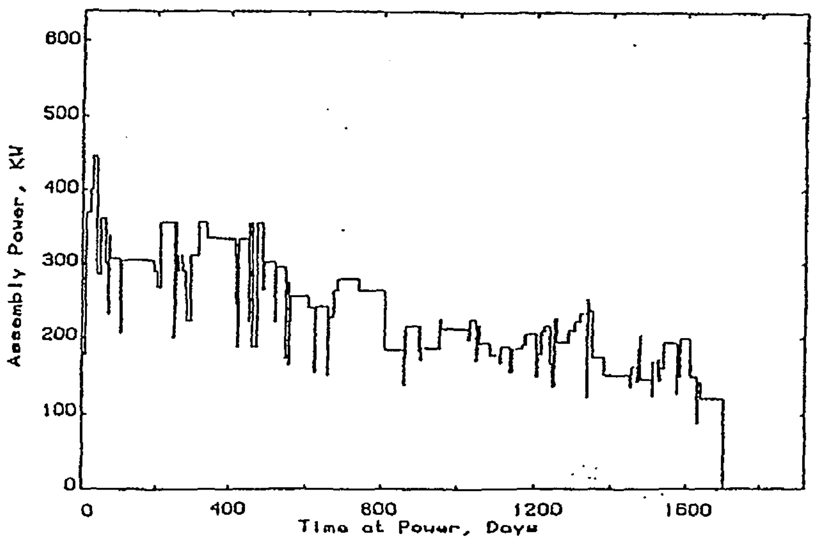

Figure 1. Assembly power for IFA 148

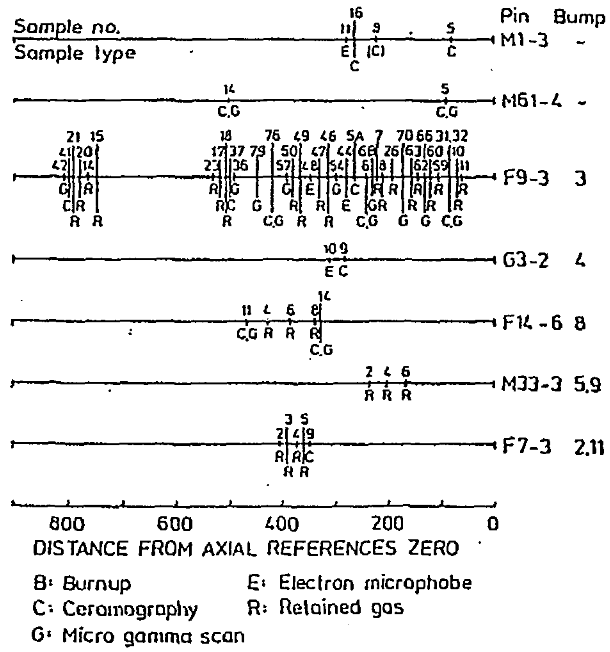

Figure 2. Location of samples for destructive exams

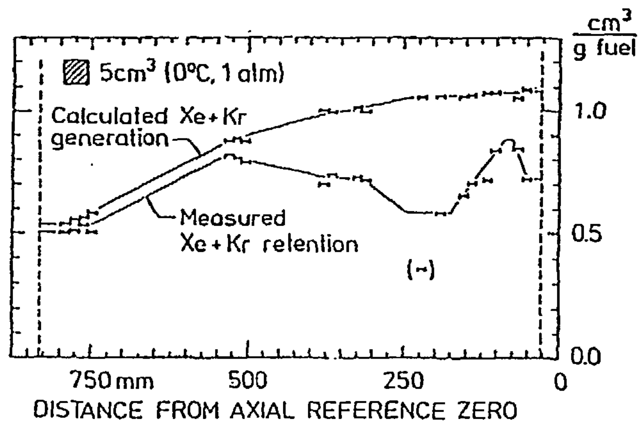

Figure 3. Xe+Kr retention in bump tested fuel pin