THERMAL INSTABILITY OBSERVATIONS DURING RAMP TESTS IN THE STUDSVIK R2 REACTOR

G. ROENNBERG
Studsvik Energiteknik AB,
Nyköping, Sweden

N. KJAER-PEDERSEN
Exxon Nuclear Company, Inc.,
Richland, Washington,
United States of America

Abstract

A series of ramp tests on ENC-built BWR fuel from the Big Rock Point reactor was performed in September 1982 in the Studsvik R2 Reactor. The tests involved segmented rods with a burnup of 18 MWd/KgU, and constituted part of the Fuel Performance Improvement Program sponsored by the United States Department of Energy.

Rods of different designs were tested. The reference design had solid, dished pellets and was unprepressurized. The alternative designs were annular pellets and sphere-pac. Some of the rods with annular pellets were prepressurized, and some were not.

During the ramp tests the rod power is controlled by a helium depressurization loop which causes a strictly linear power ramp versus time. The thermal output of the test rig is measured calorimetrically, the data immediately being recorded on a strip chart and later processed by a computer. Furthermore, elongation detectors permit the immediate recording of the rod length variation versus time.

For some of the rods the thermal output went constant for a fraction of a minute after reaching a certain value, then continued to rise, while the helium depressurization continued to proceed linearly with time. For the duration of this plateau of the thermal output curve the slope of the elongation detector signal was significantly higher than before, but fell back to its original value after the plateau.

This observation was made only for the reference rods. None of the annular rods, with or without prepressurization, nor the sphere-pac rods, showed the effect. When observed, the effect occurred at about 40 kw/m.

The effect is attributed to fission gas release rapidly being enhanced by thermal feedback. The increase in stored energy associated with the temperature rise in the fuel causes the delay in thermal output. The larger available internal volume and/or the prepressurization of the annular rods, and the lack of a distinct fuel-clad gap for the sphere-pac rods prevented the effect from occurring in those other designs.

1. INTRODUCTION

In September 1982 a series of ramp tests were conducted in the R2 reactor at Studsvik, Sweden, under the Fuel Performance Improvement Program, sponsored by the United States Department of Energy and managed by Exxon Nuclear Company, USA.

During these ramp tests several instances of slight anomalies in the experimental recordings were noted. The anomalies consisted in a shift of the rate of change versus time of the rig thermal output and the signal from the elongation detector mounted on each rod.

By comparing these observations to previous Studsvik observations of power spikes and associated rapid changes in elongation signal, it was possible to interpret the anomalies as manifestations of thermal feedback, the process by which the fuel temperature is rapidly increased in response to the temperature dependent fission gas release to the fuel-cladding gap.

The testing program comprised rod segments supplied by Exxon Nuclear Company. These rods included a solid pellet design without prepressurization, annular pellet designs with and without prepressurization, and a sphere-pac design without prepressurization. All the rod segments had been irradiated to a burnup of 18 MWd/kgU in the Big Rock Point boiling water reactor, Illinois, USA, prior to the ramp tests. The anomalies were only observed in the solid pellet, unprepressurized design, and occurred at 40 kw/m.

2. RAMP TESTING TECHNIQUES

The ramp tests in the Studsvik R2 reactor were carried out in a rig equipped with a helium coil capable of suppressing the thermal flux by approximately a factor of two at full helium pressurization, relative to the flux level at full depressurization.

The transition between the two levels occurs linearly as a function of helium pressure. Thus, by closely controlling the depressurization rate, the system can be set to produce a well defined ramp rate.

For the present tests ramp rates in the range of 6-20 kW/m/min were used. For each test, the ramp rate was held constant throughout each power change.

During the performance of the tests, data are instantly recorded on strip charts. The data are also collected on magnetic tape for later computer processing. This procedure provides for on-line monitoring during the test as well as for automated in-depth analysis after the test.

The data recorded for rod power, or linear heat rate (LHR), is really the thermal output from the rig, measured calorimetrically at the point of coolant outlet. When properly calibrated, this measurement yields a value identical to the rod power if the rig is operating in steady state. In transient operation the thermal output may differ from the rod power on account of the various thermal capacities and associated time constants of the system.

The rod elongation detector, mounted on the end of the rod, yields a direct measurement of the change of length of the cladding tube during the test.

3. OBSERVATION OF ANOMALIES DURING THE RAMP TESTS

During the performance of the ramp tests on the solid pellet, unprepressurized rod design, a total of four tests, the observation was made that the recorded thermal output did not rise linearly throughout the period of power change, despite the fact that the helium loop was depressurizing normally corresponding to a fixed rate of power increase. The thermal output displayed a region of about 15 seconds' duration during which no change was seen. Before and after that time interval, the thermal output recording showed the expected rate of power increase.

Correspondingly, during the 15 seconds' interval of no increase in thermal output, the recorded rate of change of the elongation went up considerably. After the thermal output resumed its increase, the rate of change of the elongation signal fell back to its original value.

Figure 1 shows the computer processed data of linear heat rate and elongation vs. time for one of the four ramp tests on solid pellet, unprepressurized rods.

Figure 2 shows the pertinent part of the on-line recorder chart for the same test.

In both figures the effects described above are clearly visible.

The power level at which the anomali was observed was 38.2 kW/m for the case of Figures 1 and 2. The other three cases of anomalies were observed at power levels of 39.5, 40.5 and 40.0 kW/m, respectively.

None of the tests involving alternative fuel designs displayed a similar effect.

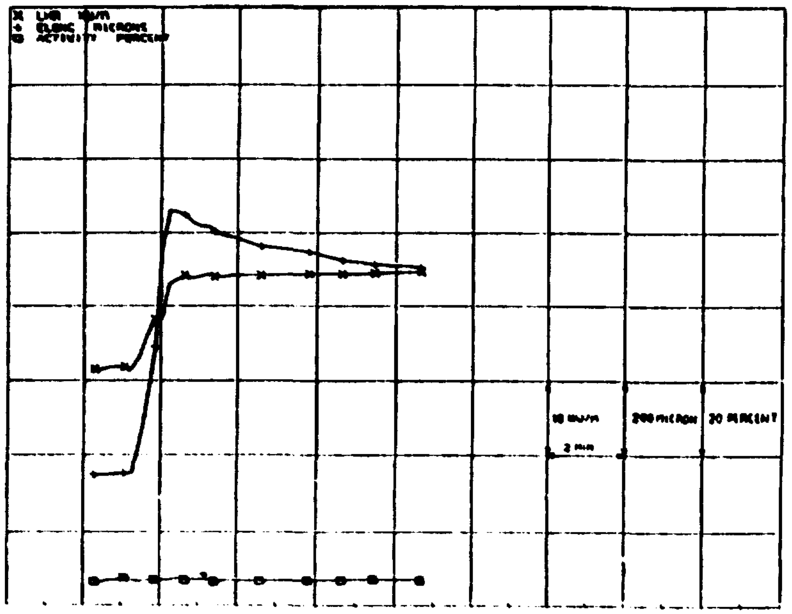

FIGURE 1 - PROCESSED DATA FROM UNFAILED RAMP TEST

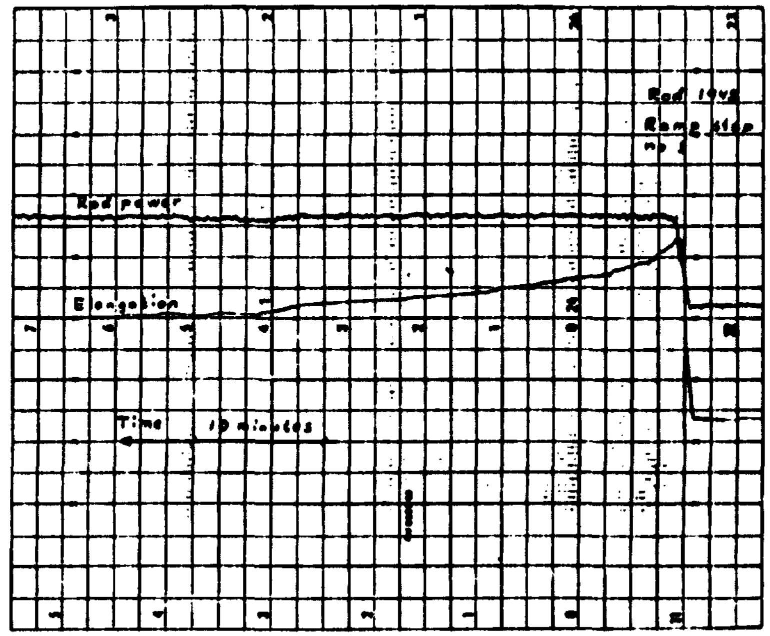

FIGURE 2 - RECORDER CHARTS FROM UNFAILED RAMP TEST

4. PREVIOUS STUDSVIK OBSERVATIONS OF ANOMALIES

Studsvik has previously on several occasions observed spikes in the recorded thermal output of the rig, associated with a sudden drop in elongation detector signal. These observations in all cases related to rods that were later shown to have failed in the ramp test.

The data base of these dual power spike/elongation drop observations in failed rods is extensive and consistent enough to permit the use of new occurrences of such observations as a failure indicator. This permits the termination of ramp tests involving a failed rod prior to onset of activity release.

Figures 3 and 4 show an example of the data recordings from an experiment in which subsequently detected failure was preindicated by the power spike/elongation drop observation.

The physical explanation of the above phenomenon is the following:

At or shortly after the time of rod failure, water from the coolant channel leaks into the rod. The H_2O steam greatly improves the thermal conductivity of the fuel-cladding gap, which leads to a decrease in fuel temperature.

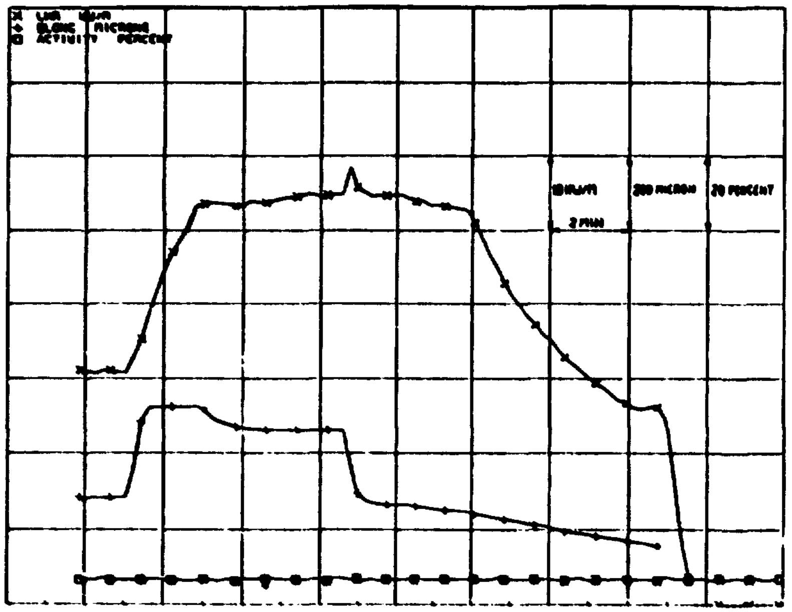

FIGURE 3 - PROCESSED DATA FROM CASE OF ROD FAILURE

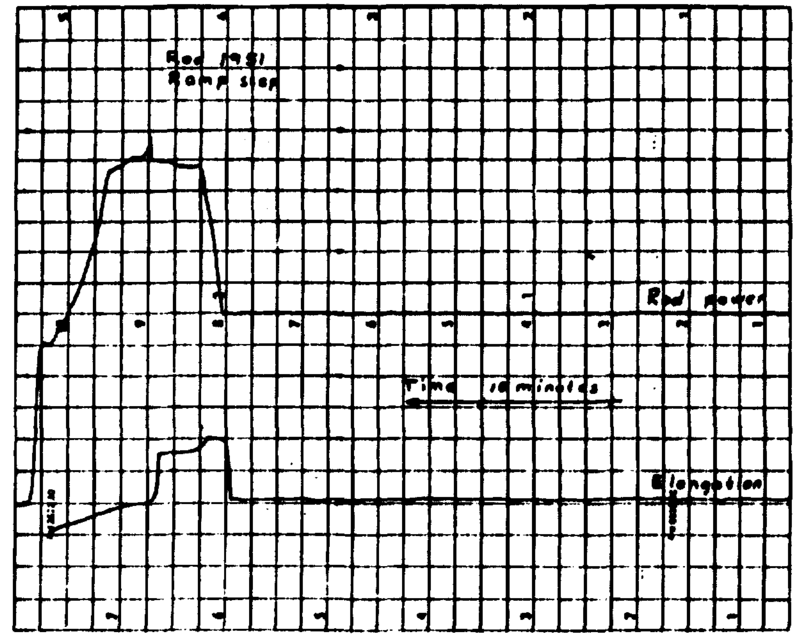

FIGURE 4 - RECORDER CHARTS FROM CASE OF ROD FAILURE

As the fuel temperature drops, stored energy is released to the coolant and measured as a spike in the thermal output of the rig. Simultaneously, the fuel column contracts and releases its axial straining force on the cladding, which therefore also contracts.

The duration of the power spike, as seen in Figure 3, is about 15 seconds, which fits the order of magnitude of the time constant for heat release from the fuel rod.

5. DISCUSSION

The observations of anomalies described in Section 3 have been evaluated in the light of the Studsvik experience described in Section 4.

The duration of the period of time of no observed increase in thermal output, 15 seconds, corresponds to the duration of the power spikes previously observed. Hence, the phenomenon could be related to storage of thermal energy in the fuel rod. Since, in the present experiments we are dealing with unfailed rods, the most likely explanation for any such increase in stored energy would be a decrease in the conductivity of the fuel-cladding gap, caused by an internal process in the rod. Such a process could very likely be fission gas release. The fact that the anomali occurs at about 40 kW/m, which is about the limit where thermally enhanced fission gas release could be expected, supports this assumption. Furthermore, the increase in rod elongation rate is consistent with the temperature increase of the fuel stack, which tends to axially strain the cladding tube through mechanical interaction.

The fact that the phenomenon was not observed in the annular fuel designs is explained by the prepressurization and/or the larger available internal volume, which both tend to accommodate the fission gas release without seriously degrading the gap conductance.

For the sphere-pac rods, the absence of the anomali is explained by the absence of a fuel-cladding gap.

Thus, the observed anomali are taken to depict the process of thermal feedback, quickly raising the fuel temperature in response to accelerated fission gas release. Furthermore, in view of the consistency of other Studsvik observations of power and elongation signal anomalies, it may be believed that the anomalies of the here discussed experiments, when observed in future experiments, can be consistently taken as indicators of thermal feedback.

6. CONCLUSION

During ramp tests of solid pellet, unprepressurized fuel rod designs, previously irradiated to 18 MWd/kgU, anomalies in the recorded thermal output signal and elongation detector signal were observed.

These observations have been explained in terms of thermal feedback. Similar occurrences may be looked for in future experiments as a useful method for nondestructively detecting accelerated fission gas release by thermal feedback.

THE STUDSVIK POWER TRANSIENT PROGRAMS DEMO-RAMP II AND TRANS-RAMP I

U. BERGENLID, G. LYSELL, H. MOGARD,
G. RÖNNBERG
Studsvik Energiteknik AB,
Nyköping, Sweden

Abstract

The Studsvik Demo-Ramp II och Trans-Ramp I are internationally sponsored research programs. The main objectives are similar in both programs: to study the effects on the PCI/SCC failure process of short time power transients, above the failure threshold where cladding failure (FP leakage) is expected to occur after a sufficient hold time. Demo-Ramp II is completed, whereas, at present, Trans-Ramp I is in progress. Test fuel rods of standard BWR design are used. The fuel rods have been base-irradiated in a power reactor (burn-up in the range 18 to 29 MWd/kg U) and subsequently ramp tested in the R2 reactor. Extensive examinations of the rods have been performed.

In the Demo-Ramp II program a large number of incipient cladding cracks were observed to be formed more rapidly than expected, based on previous knowledge. It was possible to operate one rod for a very short time above the failure threshold without SCC crack formation. One objective of the Trans-Ramp I program is to define more closely the power-time region above the failure threshold where the rods remain intact after power transients.