OPERATIONAL EXPERIENCE GAINED WITH

THE FAILED FUEL ROD DETECTION SYSTEM

IN NUCLEAR POWER PLANTS

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ABSTRACT

Fuel assemblies containing defective fuel rods are releasing fission products and consequently have to be removed from further service in the core. Partially spent fuel assemblies can only be reinserted into the core after removal of the defective rods. Spent fuel assemblies have to be freed from these failed rods before being shipped to a reprocessing plant.

INTRODUCTION

Brown Boveri Reaktor GmbH (BBR) together with the Krautkrämer Company have developed a Failed Fuel Rod Detection System (FFRDS) which allows the location of failed fuel rods without dismantling the fuel assembly. The inspections are performed in the spent fuel storage pool. No disassembling such as removal of end fittings, pulling of rods or any special preparations of the fuel assemblies are necessary for the application of the FFRDS. For a subsequent repair, only the located failed fuel rods need to be extracted, i.e. intact fuel rods are not unnecessarily pulled.

SYSTEM DESIGN

The inspection technique uses ultrasonic pulses travelling from a transmitter to a receiver. The dimensions of transmitter and receiver are such that they can be inserted on both sides of the fuel rod row into the fuel assembly. If water is present between transmitter and receiver the ultrasonic signal received is characterized by a specific intensity and transit time proportional to the speed of the ultrasonic signal in water (Fig. 1).

However, if the signal passes through a fuel rod on its way to the receiver, the transit time of the signal is being reduced due to the higher velocity in metal as compared to water.

Furthermore, the intensity of the signal is reduced due to sound scattering at the cladding/water interfaces. If the rod is defective, i.e. containing some amount of water, the intensity of the signal is again reduced by additional sound scattering due to the water contained in the fuel rod.

When the ultrasonic probe is moved along a fuel rod row, two selected wall-through signals are received for each fuel rod, the first from the front half and the second from the back half of the fuel rod.

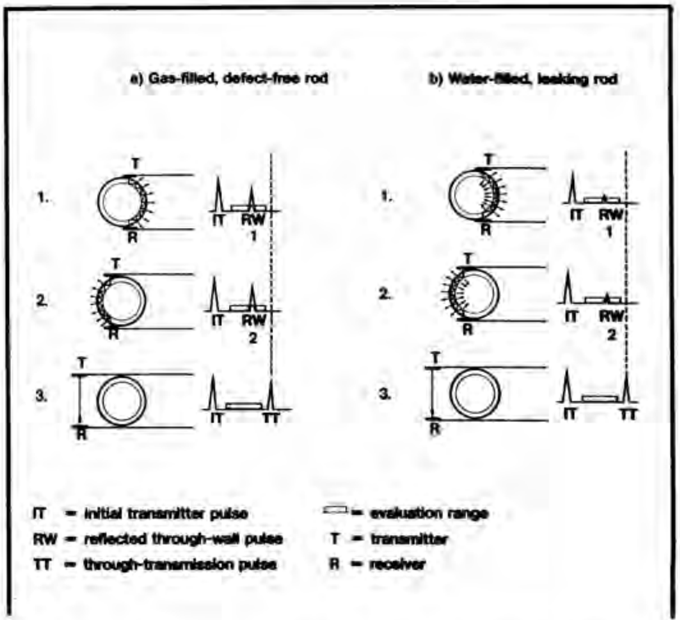

Fig. 1. FFRDS - The ultrasonic technique.

For recording the ultrasonic signals at the receiver, an X-Y-recorder is used which registers only the signals having a certain intensity. A typical recording of a PWR fuel assembly is shown in Fig. 2. The positions of the control rod guide tubes are marked with a circle, and the defective fuel rods are identified with an X. In both these cases, no peaks were recorded.

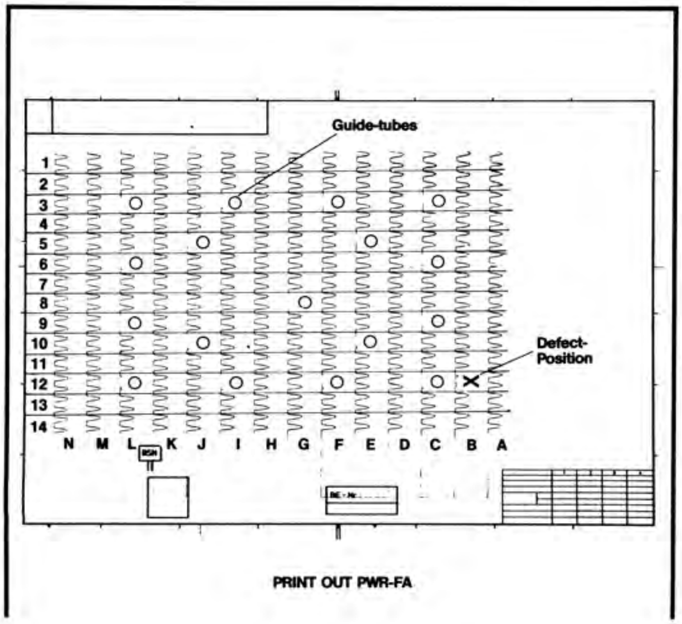

Fig. 2. FFRDS-Typical plot of defective fuel assembly.

SYSTEM DESCRIPTION

The FFRDS consists of the following components:

- an ultrasonic probe with separate transmitter and receiver which can be inserted into the fuel assembly lanes,
- a manipulator for moving the ultrasonic probe (Fig. 3),
- a control system to drive the probe (Fig. 4; electronic cabinet, right side)
- an ultrasonic system with recording device (Fig. 4; electronic cabinet, left side).

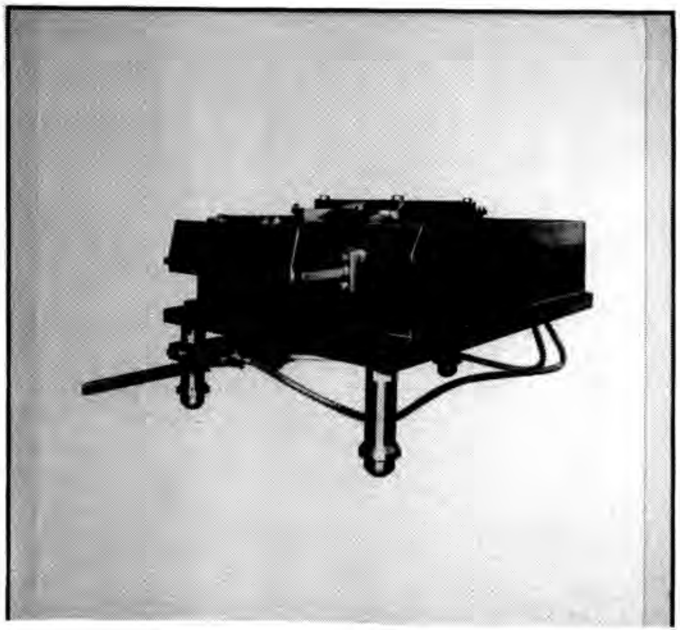

Fig. 3. FFRDS - Manipulator with US-probe.

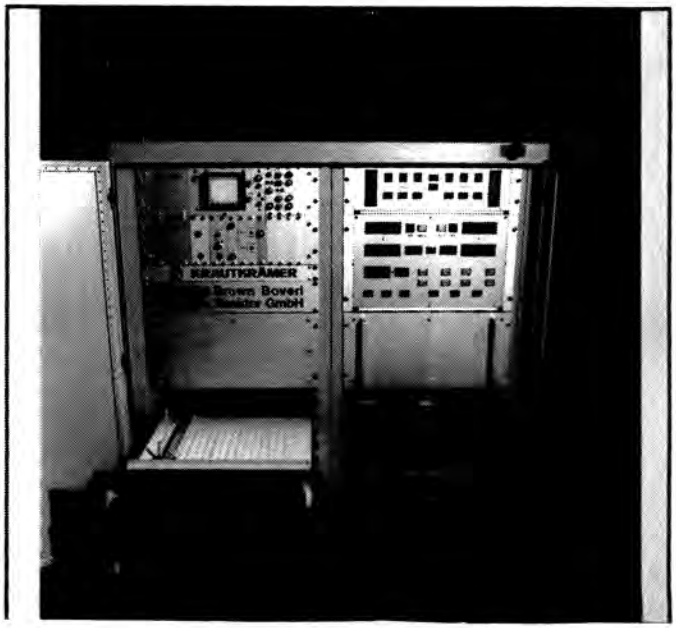

Fig. 4. FFRDS - Electronic Cabinet.

Fig. 5 shows the mechanical drive system (the manipulator) of the FFRDS. The probe is located below the manipulator.

In Fig. 7, one can see the probe travelling through the first row of fuel rods during the inspection of a fuel assembly.

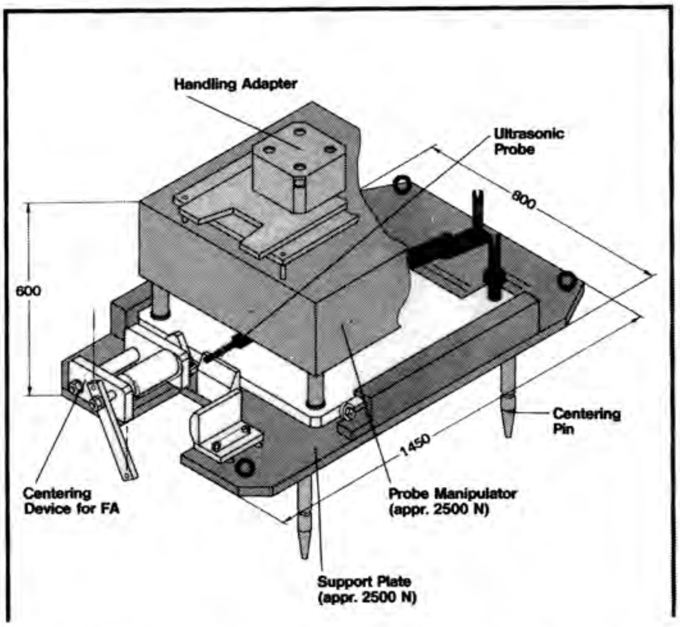

Fig. 5. FFRDS - Testing device, manipulator with support plate.

Fig. 7. FFRDS - Test Equipment.

Figure 6 represents in detail the ultrasonic probe. Transmitter and receiver are mounted at the ends of two parallel rods and are dimensioned in a way that the probe can be inserted on both sides of a row of fuel rods inside a fuel assembly.

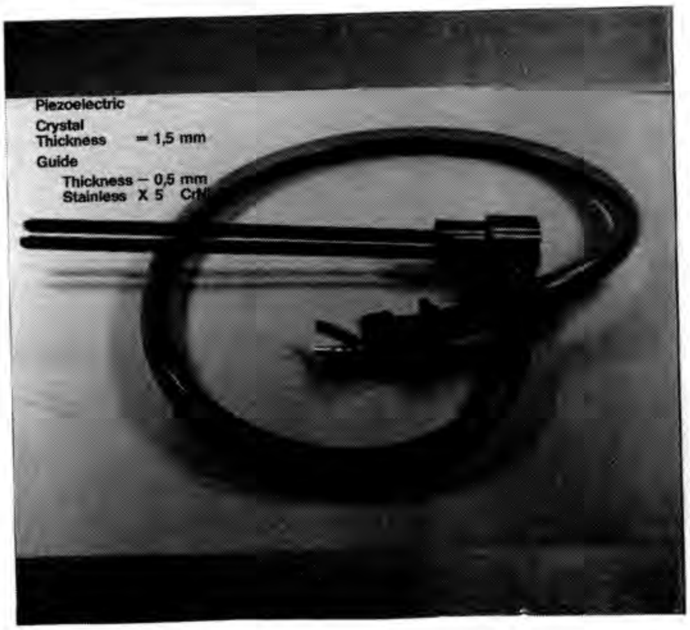

Fig. 6. FFRDS - Ultrasonic probe.

In order to get around the thicker guide tubes which are present in the fuel rod bundles of PWR fuel assemblies, the ultrasonic probe is of flexible design. Because of its flexibility the probe will not damage the fuel assemblies to be examined. In addition, an overload indicator is included in the mechanical manipulator. Maneuvering and measuring processes are controlled by the combined evaluation and control electronics. During the automatic measuring process inside a row of fuel rods, manual maneuvering of the ultrasonic probe to another fuel rod row is precluded by an electronic interlock device. The results are being recorded and simultaneously displayed to the operating personnel on a monitor. In addition, the travelling path of the ultrasonic probe can be observed by means of a television camera.

Application and Handling

The FFRDS has been developed for the examination of irradiated fuel assemblies. These fuel assemblies can only be examined under water. Therefore, the inspection of the fuel assembly with the FFRDS will be performed in the fuel assembly storage pool. (See Fig. 8).

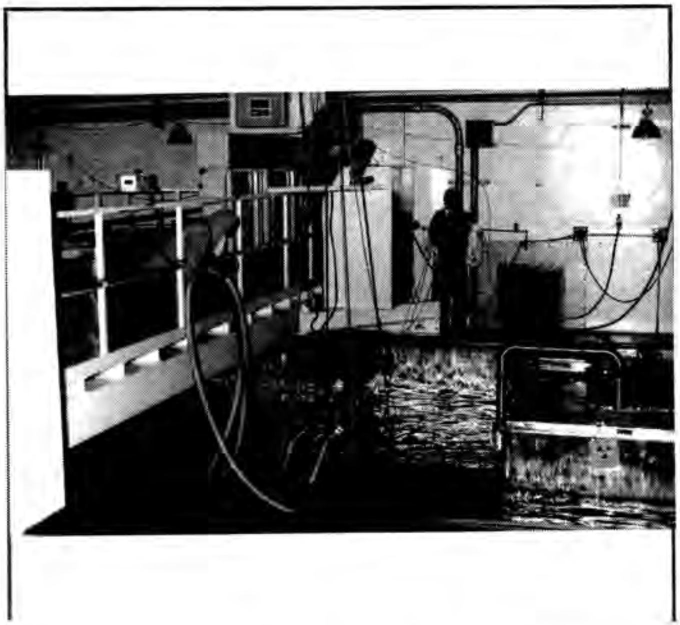

Fig. 8. FFRDS - Lowering of manipulator and supportplate into the fuel storage pool.

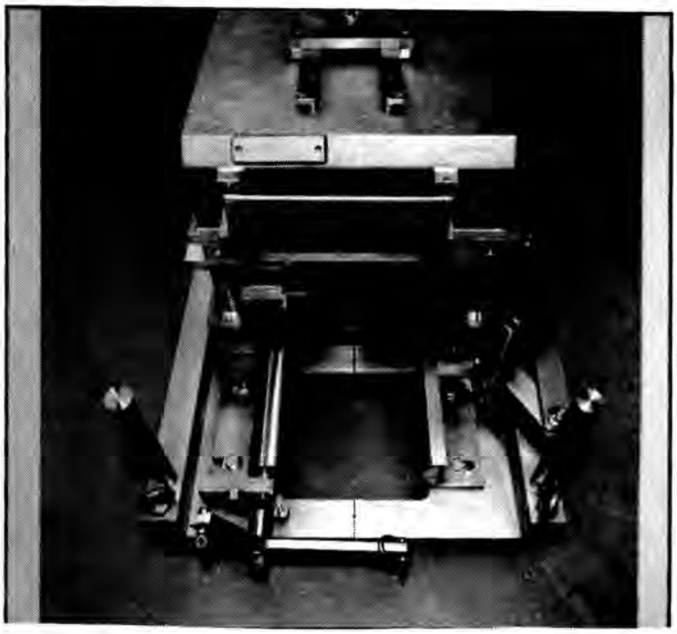

Fig. 9. FFRDS - Manipulator with Support plate.

The mechanical unit (support plate plus probe manipulator) will be placed on top of a fuel assembly storage rack. Guiding pins will assure the exact positioning of the support plate with respect to the storage rack pitch, thus allowing the selected fuel assembly to be operated with the fuel assembly handling machine. The fuel assembly to be examined is suspended from the grapple of the refueling machine directly above the corresponding position of the support plate.

During the measurement, the fuel assembly is still held by the handling machine or crane and is axially positioned by an eccenter locking mechanism at the support plate. The vertical location of the fuel assembly is adjusted in such a way that the ultrasonic probe can enter the water channels of the fuel assembly preferably between the lower spacer grid and the lower end fitting.

The support plate as well as the handling adapter of the probe manipulator will be designed to meet the interfaces in a specific plant. So no additional or special tool should be necessary to install and use the FFRDS besides the tools available in the plant. Evidently the FFRDS could also be integrated into a permanently installed station (see Fig. 9).

OPERATION

Disassembly or removal of end fitting or pulling of rods and prior preparation of the fuel assemblies are not required for the application of the FFRDS. For a subsequent repair, only failed fuel rods which have been located need to be extracted, i.e. intact fuel rods are not pulled unnecessarily.

Two experienced people are needed for the handling of the FFRDS; in addition, personnel for the handling of the fuel assemblies is required. According to experience, approximately 2 hours are needed for the handling and examination of one PWR fuel assembly.

The evaluation of the recorded ultrasonic signals will take place immediately after the measurement. So the positions of the failed fuel rods will be identified directly after the inspection.

Based on the experience gained during tests performed, the following values can be considered as average measuring speeds

- PWR fuel assemblies: approximately 6 minutes
- BWR fuel assemblies: approximately 4 minutes.

EXPERIENCE

A total of 800 fuel assemblies, PWR as well as BWR (i.e. more than 160,000 fuel rods), have been inspected. Fuel assemblies of up to 35,000 MWd/tU burnup were examined. The inspections were made both on irradiated fuel assemblies that had been in a storage pool for about four years and of fuel assemblies just after shutdown. Water was positively detected in the fuel rod plenum and in the fuel region of more than 300 rods.

The inspection process has been highly automated and inspection time for one fuel assembly including handling and redundant inspection is less than one hour.

No loss of ultrasonic probe sensitivity due to radioactive irradiation has been experienced.

The fuel rod inspections made to date have verified the inspection principle and confirmed the evaluation method to the extent that failed fuel rods can be located within a very short time. Generally, the method can be used whenever water has entered into a defective rod. So far, the FFRDS has been employed to locate failed fuel rods only. However, the same system is capable of detection of failed neutron absorber rods.

FUTURE OUTLOOK

Presently, efforts are being made to employ the FFRDS as an alternative to the sipping test. During several occasions the FFRDS was utilized during refueling as a substitute for the sipping test. Comparison of results of the two methods demonstrate the superiority of the FFRDS inspection technique.

In all cases, the defective fuel assemblies could be identified during the inspections.

In summary, the FFRDS exhibits the following advantages over sipping tests:

- detection of defective fuel assemblies and localization of individual failed fuel rods in one step,
- clear identification of a failed fuel rod irrespective of its burnup,
- applicability even after long periods of storage in the spent fuel storage pool,
- saving in time.

Another perspective is offered by the integration of the FFRDS into an inspection stand. Such an arrangement provides for shortening the total inspection cycle by allowing to handle one fuel assembly from the core or fuel pool and transport it to the station, where a second one is being inspected.

This setup provides for a rotation of 360° and a vertical displacement of the fuel assembly. Routine inspection equipment can be mounted on the movable platform.

A summary of fuel inspection services is shown in the reference list which includes all major designs of fuel assemblies.

TABLE I

Reference-List January 1985

Date Mon./Yr.	Location/ Country	Fuel Design/ Fuel Supplier	No. of FA's	Type of Inspection
10-11/79	Laboratory/FRG	PWR 17 x 17/BBC-BBR	1	Out-of-pile Qualification
12/79	NPP Biblis B/FRG	PWR 16 x 16/KWU	3	In-pile Qualification
05/80	NPP Biblis B/FRG	PWR 16 x 16/KWU	4	Service
06/80	NPP Biblis B/FRG	PWR 16 x 16/KWU	1	Out-of-pile Demonstration (TÜV)
08/80	NPP Unterweser/FRG	PWR 16 x 16/KWU	12	Service
09/80	Centre d'Etudes Nucléaires/F	PWR 17 x 17/Framatome	3	Out-of-pile Demonstration
04-05/81	NPP Würgassen/FRG	BWR 7 x 7/KWU	17	Service
06/81	NPP Biblis B/FRG	PWR 16 x 16/KWU	27	Service
02/82	Kumatori Works/J	PWR 15 x 15/NFI	2	Out-of-pile Qualification
02/82	NPP Takahama/J	PWR 15 x 15/W/MHI	5	Service
06/82	NPP Bugey 2-5/F	PWR 17 x 17/Framatome	10	Service
11/82	NPP Biblis A/FRG	PWR 16 x 16/KWU	4	Service
11-12/82	NPP Biblis B/FRG	PWR 16 x 16/KWU	4	Service
01/83	NPP Neckarw./FRG	PWR 15 x 15/KWU	11	Service
02/83	NPP Doel 2/Belg.	PWR 14 x 14/Framatome	104	Service
02-03/83	NPP Surry/USA	PWR 15 x 15/W	105	Service
06/83	NPP Doel 2/Belg.	PWR 14 x 14/Framatome	30	Service
09/83	NPP Doel 2/Belg.	PWR 14 x 14/Framatome	126	Service
10/83	NPP Millstone 2/USA	PWR 16 x 16/W (CE-type)	32	Service
10/83	NPP Turkey Point/USA	PWR 15 x 15/W	32	Service
11/83	NPP Würgassen/FRG	BWR 7 x 7/KWU	3	Service
11/83	NPP Philippsb./FRG	BWR 7 x 7/8 x 8/KWU	22	Service
03/84	NPP Tihange/Belg.	PWR 15 x 15/Exxon	94	Service
03/84	NPP Farley/USA	PWR 15 x 15/W	14	Service
05/84	NPP Calv. Cliffs/USA	PWR 15 x 15/CE	7	Service
08/84	NPP Doel 2/Belg.	PWR 14 x 14/Framatome	121	Service
09/84	NPP D. C. Cook 2/USA	PWR 15 x 15/W	20	Service
10/84	NPP Kori/Korea	PWR 14 x 14/W	23	Service