BASALA: Advanced BWR MOX Core Physics Experiments

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ABSTRACT

An experimental program, BASALA, will be implemented in the EOLE critical facility in order to measure the main neutronic parameters of high moderation 100% MOX BWR cores loaded with 9x9 fuel assemblies within the framework of collaboration between NUPEC, CEA, COGEMA and their associated industrial partners. The obtained data will be used for validation and improvement of the core analysis scheme for those cores. The experimental program comprises two core configurations with different lattice pitch representing hot operating and cold condition. The hot core configuration has a reference core that is designed for measurements on basic core characteristics and variation cores for measurements on Gd2O3-UO2 fuel rods and different void condition. The cold configuration has a reference core and variation cores on Gd2O3-UO2 fuel rods, control blades, soluble boron and different temperature condition. Main measurement items are a critical core size, radial and axial power distribution by gamma spectrometry. The experiments will be completed in 2002.

1. INTRODUCTION

Recycling of plutonium in PWR was decided in France in 1985 and the first mixed oxide (MOX) reload was introduced in the St.-Laurent plant in 1987. In Japan, good performances have been obtained in MOX fuel demonstration programs with a small number of assemblies in PWR and

BWR, and batch size use of MOX fuel will start in the near future. The recycling of plutonium in light water reactors is expected to continue for several decades. As medium and long term development, core concepts have been studied for enhancing consumption of plutonium with adopting higher moderation ratio than the conventional fuel lattice on the basis of 100 % MOX fuel cores for PWR [1], [2] and BWR. [2] These studies require validation that current calculation schemes have similar accuracy for high moderation 100% MOX cores to that for UO2 cores in LWR.

In 1995, NUPEC, CEA and their associated industrial partners decided to undertake an experimental program, MISTRAL [3-5], that aimed at measuring the main neutronic parameters of the high moderation 100 % MOX LWR. Four core configurations have been investigating: the three configurations are devoted to the fundamental parameters of high moderation MOX LWR cores and the last one was specially focused on PWR mock-up cores.

Following the MISTRAL program, NUPEC, CEA, COGEMA and their associated industrial partners decided to launch a new experimental program, BASALA (Boiling water reactor Advanced core physics Study Aimed at mox fuel LAttice), that is focused on high moderation BWR mock-up cores. The experiments will be performed in the EOLE facility at the Cadarache Center from 2000 to 2002. NUPEC is conducting this study on behalf of the Japanese Ministry of International Trade and Industry (MITI).

This paper presents the core configurations, measurement parameters and experimental techniques of this program.

2. BASALA Program

2.1 EXPERIMENTAL FACILITY

The experimental program will take place in the EOLE facility at the Cadarache Center. The facility consists of:

An outer cylindrical aluminum vessel (diameter = 2.3 m and height = 3 m) with a stainless steel over-structure that is able to contain various types of cores and related structures.

An inner cylindrical vessel (diameter = 1 m and height = 1 m) containing the core consisting moderator (light water), fuel and related structures in this experiment.

Control rods (four safety clusters and one pilot rod) linked to the over-structure. The location and the composition of these rods can be adjusted as required by the studied cores.

Water circuits that are used to fill up and empty the inner vessel with moderator, introduce soluble boron and control the moderator temperature between 5°C and 85°C.

A modern and computerized equipment is utilized for the performance and the data treatment of measurements.

2.2 BASALA PROGRAM

(1) CORE CONFIGURATIONS

The fuel rods available in the facility are used for the experiments. Those are similar to those used in the PWR power reactor, except for the fuel height (h ~ 80 cm). There are four types of plutonium content (2.5 %, 4.3 %, 7.0% and 8.7 %). The fuel pellets are composed of mixed dioxide of plutonium and depleted uranium, and are cladded by zircaloy cladding. On the basis of the fuel rod specification, fuel rod pitches and over-cladding of the fuel rods are designed to simulate BWR cores that have the features of high moderation, 100 % MOX and 9x9 fuel assemblies. Those features are consistent with the advanced core design study. [2]

Figure 1 shows an outline of the BWR 9x9 fuel assembly with a control blade that was used as a basis in the core design study and a target of simulation in the experiments.

The program consists of two core configurations with different fuel rod pitches:

BWR-Hot: Core configuration simulating hot operating condition of high moderation 100 % MOX BWR cores loaded with 9x9 fuel assemblies,
BWR-Cold: Core configuration simulating cold condition and further higher moderation cores.

The experiments of BWR-Hot include a reference core and variation cores. The configuration of the reference core of BWR-Hot is schematically shown in Figure 2. The core consists of 9x9 assemblies with a water rod area in the middle of the assembly. The center part of the core is a test zone surrounded by a driver zone. Figure 3 shows a configuration of the fuel assembly in the experiments. The diameter of the over-cladding and the fuel rod pitch and the assembly pitch are determined to be 10.2, 11.3 and 114.1 mm respectively in order to represent moderation ratio of the original 9x9 fuel assembly in terms of gross and local aspects. The two large water rods are simulated by 7 water tubes of 10.2 mm in diameter. In the test zone, the assemblies are composed of the four types of MOX fuel rods with the lower plutonium content at the assembly periphery facing water gaps. The driver zone is mainly loaded with 7 % MOX.

One of variation cores (Hot-Poison) is dedicated to the study of burnable poison fuel rods: two assemblies diagonally located in the test zone include 8 or 16 Gd2O3 (2.5 %)-enriched UO2 (4.9 %) fuel rods per assembly. Figure 4 shows the location of 16 Gd2O3-UO2 fuel rods in the assembly. The other variation core (Hot-Void) is designed for the measurements related to void effect. In this core every fuel rod of the four assemblies in the test zone is attached with a thick over-cladding (11.25 mm in diameter) in the full length in order to simulate higher voided area in the core center. The third variation core (Hot-Water rod) is dedicated to the measurements on a high moderation lattice. In this core, each assembly in the test zone has 8 fuel rod replaced by the water tubes of 10.2 mm diameter in addition to the 7 water tubes in the middle of the assembly. Figure 5 shows the location of water tubes in the assembly.

The experiments of BWR-Cold also include a reference core and variation cores. The configuration of the reference core of BWR-Cold is schematically shown in Figure 6. Fuel rod and lattice pitches are 13.5 and 135.5 mm respectively and different from the BWR-Hot reflecting water density difference between hot operating and cold conditions.

One of variation cores of BWR-Cold (Cold-Poison) is dedicated to the measurements on burnable poison fuel rods (Gd2O3-UO2) same as BWR-Hot. The other variation core (Cold-Control blade) is designed to the measurements on control blade worth. In this core, a control blade is inserted in the water gaps of four assemblies in the test zone. Measurements are conducted for two types of absorber materials, B4C cladded by stainless steel tubes and Hafnium plates. The other variation core (Cold-Boron) is dedicated to soluble boron worth. In this core, concentration of boron is varied from 0 (reference core) to 600 ppm and measurements are conducted at 4 different concentrations of boron. The other variation core (Cold-Temperature) is designed for the measurements on core temperature effect. The moderator temperature is adjusted to 10, 20, 30, 40, 50, 60, 70 and 80 °C in the measurements.

(2) MEASUREMENT ITEMS

Measurement items are summarized in Table I.

Measurement items in the hot reference core are:
> Critical core size,
> Radial and axial power distribution with using gamma-spectrometry,
> Reactivity measurements of Gd2O3-UO2 rods, void and water rods with using modified source method (MSM).

Measurement items of Hot-Poison, Hot-Void and Hot-Water rod cores are:
> Critical core size,
> Radial (and axial) power distribution with using gamma-spectrometry.

Measurement items in the cold reference cores are:
> Critical core size,
> Radial and Axial power distribution with using gamma-spectrometry,
> Reactivity measurement of Gd2O3-UO2 rods, control blades, soluble boron, and temperature effect with using modified source method (MSM).

Measurement items of Cold-Poison, Cold-Control blade and Cold-Temperature cores are:
> Critical core size,
> Radial (and axial) power distribution with using gamma-spectrometry.

3. MEASUREMENT TECHNIQUE

The efficient experimental techniques [6] available in the EOLE facility is used during the BASALA program same as the MISTRAL program.

3.1 GAMMA SPECTROMETRY

Integral gamma scan technique is applied to perform the measurements of radial and axial fission rate distribution in the core. It consists of using a germanium diode to count the gamma rays emitted by the fission products contained in the fuel rod shortly after irradiation. Consequently, the integrated counting rate (on the whole energy range) is proportional to the fission rate occurring in the fuel rod during the irradiation. A second diode is used to take into account time decay of gamma rays. The experimental uncertainty obtained is estimated to be ± 1 % (1ó) on a single measured fuel rod.

Measurements of individual gamma peaks are also used for specific radioactive decay of fission products such as ^{140}La, ^{92}Sr and others. This technique is applied to power distribution measurements in mixed cores loaded with both MOX and UO2 fuel rods.

3.2. REACTIVITY MEASUREMENTS

Reactivity measurements are performed using two kinds of experimental techniques: divergence and the MSM technique.

(1) DIVERGENCE TECHNIQUE

The residual reactivity of a given core is obtained by using the divergence technique which consists of measuring the doubling time (period) of the flux level in the core. Using the Nordheim equations, the period is directly connected to the reactivity of the core. This technique is used to measure small reactivity effects that are lower than the pilot rod efficiency. The experimental uncertainty is estimated to be ± 1 ¢(1ó).

(2) MSM TECHNIQUE

This method is used to perform reactivity effect measurements in sub-critical situations. One can link the sub-critical level of the core in a given sub-critical configuration to the counting rate of fission chambers. This technique can be used to measure all kinds of negative reactivity effects. The uncertainty linked to the MSA technique amounts to ± 2% (1ó) of the measured reactivity worth.

CONCLUSIONS

This paper describes the BASALA experimental program that has been decided within the framework of collaboration between NUPEC, CEA, COGEMA and their associated industrial partners. The program is devoted to the measurements of the physical parameters of the high moderation 100% MOX BWR cores loaded with 9x9 assemblies. The core configurations, the measured parameters and the experimental techniques used during this program have been decided. The experiments will be completed in 2002.

ACKNOWLEDGEMENTS

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Table I . Summary of Measurement Items in BASALA

Core Configuration	BWR-Hot	BWR-Cold
Reference Core	CS, PD	CS, PD
Poison Rod (8, $16Gd_2O_3$-UO_2)	CS, PD, MSM	CS, PD, MSM
Void	CS, PD, MSM	-
Water Rod (8 additional rods)	CS, PD, MSM	-
Control Blade (B_4C, Hf)	-	CS, PD, MSM
Boron (0 – 600 ppm)	-	MSM
Temperature effect (10 – 80 °C)	-	CS, MSM

CS: Critical Size, PD: Power Distribution,
MSM: Reactivity Measurement by MSM with Reference Core

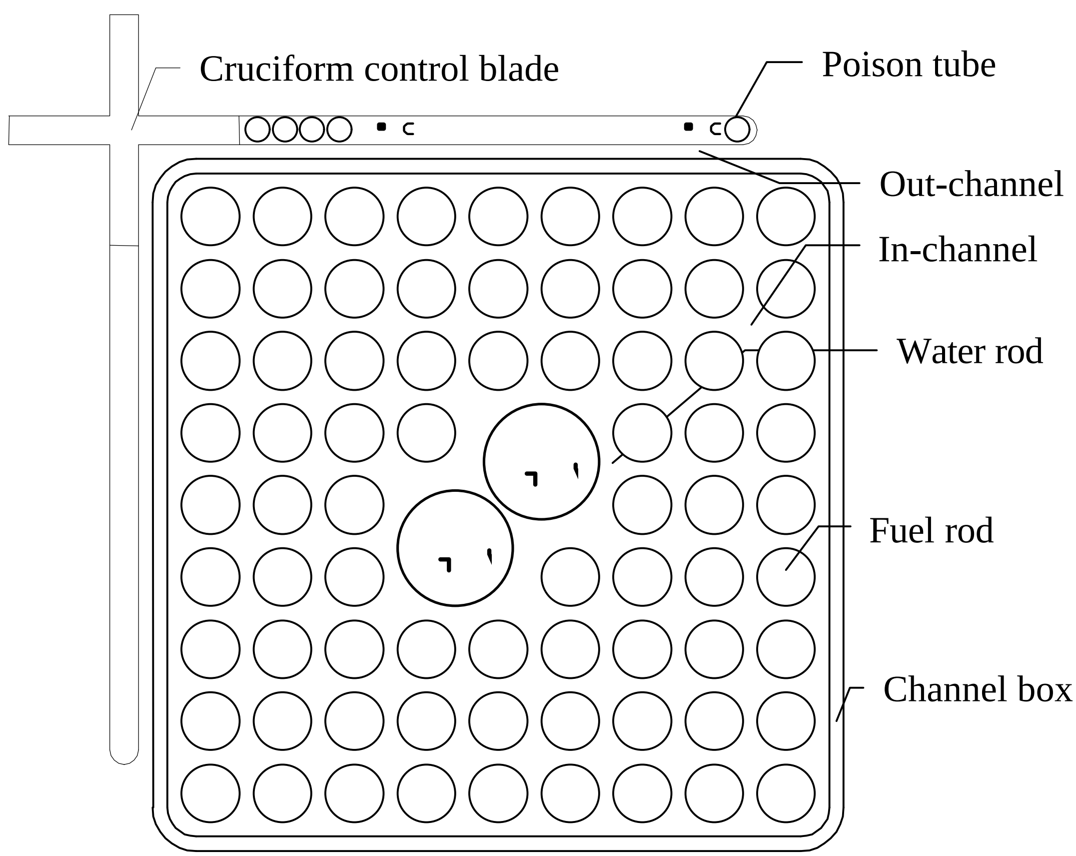

Figure 1. Outline of BWR 9x9 Fuel Assembly

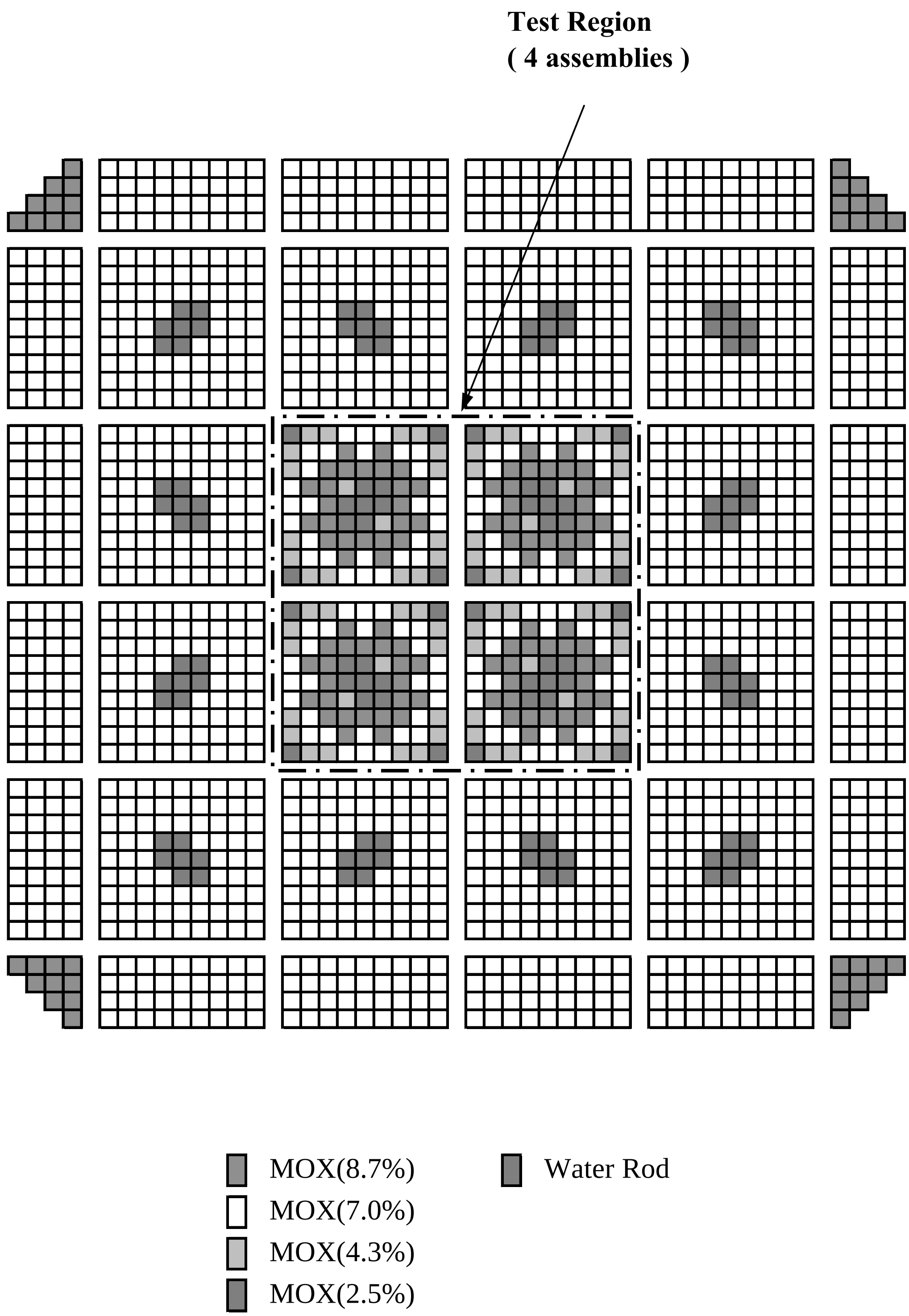

Figure 2. Core Configuration of Reference Core in BWR-Hot

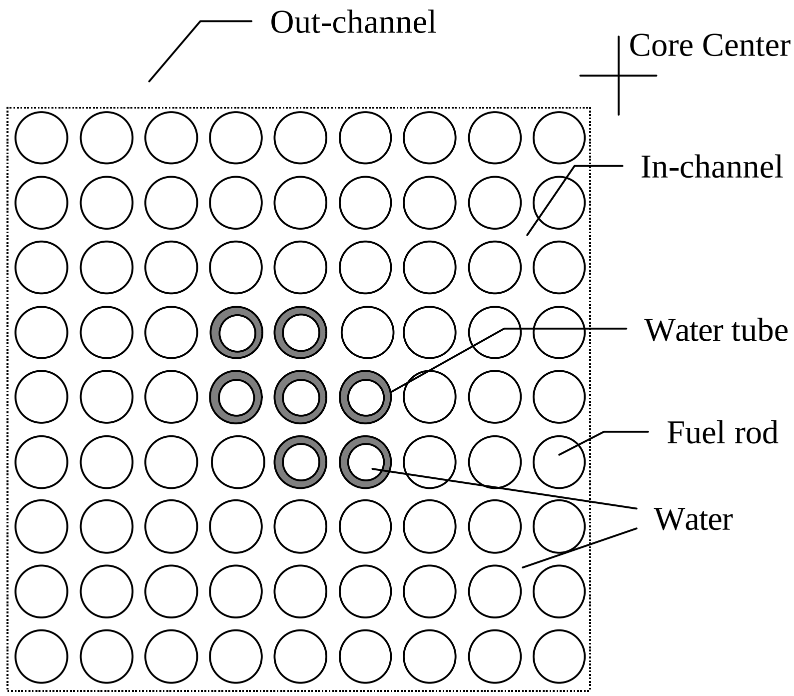

Figure 3. Configuration of Fuel Assembly in Experiments

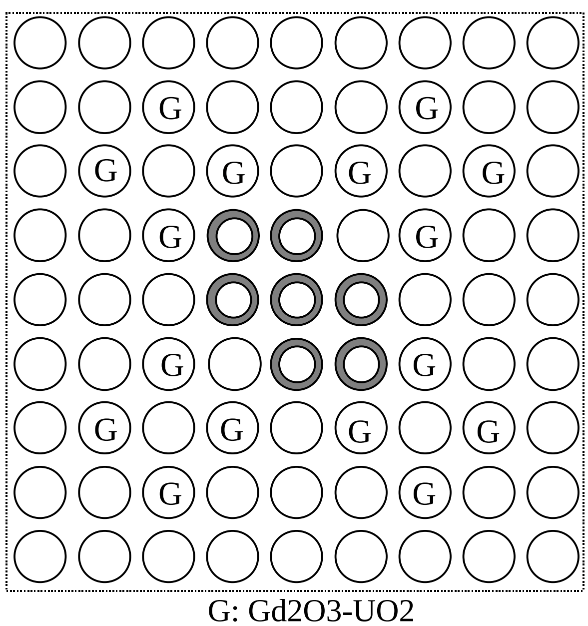

Figure 4. Location of Gd2O3-UO2 Fuel Rods

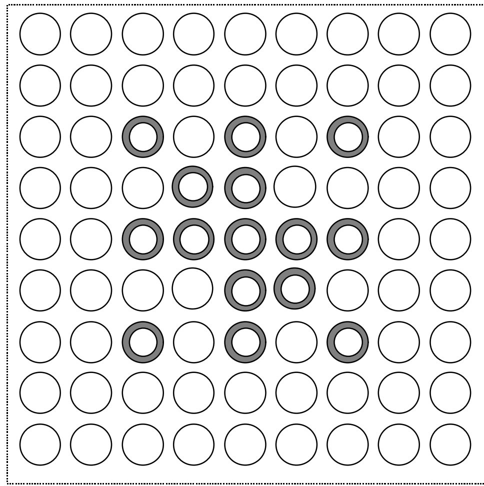

Figure 5. Location of Water tubes

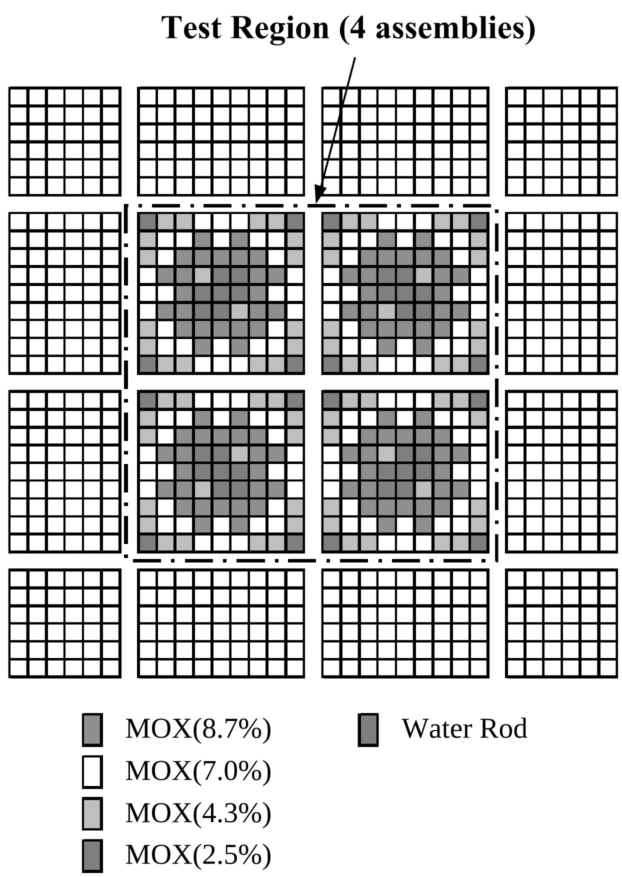

Figure 6. Core Configuration of Reference Core in BWR-Cold