FAMOS III, BURN-UP MEASUREMENT SYSTEM SUITABLE FOR LA HAGUE ACCEPTANCE CRITERIA CONTROL

by

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Fuel Assembly Monitoring System (FAMOS) was developed to set up a NDA method for the characterization of light water reactor fuel assemblies. The applied active/passive monitoring system made total characterization of fuel assemblies possible, without any previous knowledge of fuel assembly data or reactor operating data. FAMOS III measurement system was especially developed for the determination of fuel assembly burn-up which is suitable for the control of the acceptance criteria in the so-called La Hague measurements.

Key words: fuel assembly monitoring system, NDA method, burn-up determination, acceptance criteria, La Hague measurements, end of fuel assembly

INTRODUCTION

Fuel Assembly Monitoring System (FAMOS) was developed at Karlsruhe Research Center (FZK), Germany, in order to set up a NDA method for characterization of light water reactor fuel assemblies [1]. Application of an active/passive monitoring system enables full characterization of fuel assemblies without any previous knowledge of fuel assembly data or reactor operating data.

Subsequent optimization has resulted in the development of systems that are easily operated and maintained, called FAMOS II and FAMOS III. FAMOS III system was especially developed for the determination of fuel assembly burn-up [2, 3, 4], which proved to be suitable for the control of acceptance criteria in La Hague measurements, especially for the end of the fuel assembly (50 cm). In addition to passive neutron measurement, gross gamma detection is carried out to determine cooling time. This detector is also used to improve the determination of the axial burn-up gradient. This measurement system can be used for Uranium and MOX fuel assemblies. The system can be used in the analysis of the first core and the last core as in NPP Stade. In such circumstances, a few special characteristics of fuel elements have to be taken into account. In the first core different initial enrichments have near be taken into account. In the last core the fuel elements have different and lower burn-up values compared with normally burned ones This special characteristics area is taken into account by data evaluation in FAMOS code.

A new analysis procedure was applied to improve the accuracy for the measurements at NPP Philippsburg, NPP Isar II and NPP Stade. The phenomenological model commonly used in the analysis procedures of burn-up meters [1, 2] results in higher uncertainty when fuel assemblies have different irradiation history. KORIGEN burn-up code [5] was therefore used and the analysis procedure adapted.

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METHOD

Burn-up measurement of reactor fuel assemblies is carried out in the fuel assembly storage pond by detecting the passively emitted neutrons and gammas. To obtain representative emission values, two neutron detectors and two gamma detectors are installed around the fuel assembly.

Inherently emitted neutrons are counted during passive neutron measurements. An explicit relationship exists between neutron emission rate and burn-up value. In the past this relationship was described by a phenomenological model and the decay of radioactive isotopes calculated only in respect to the cooling time assuming the same irradiation history for all fuel assemblies. In the new version of data analysis, the relationship and the decay of radioactive isotopes are calculated with KORIGEN burn-up code in order to take into account specific data of each individual fuel assembly, *i. e.*, the geometry of the fuel assembly, the initial enrichment, the irradiation history, the cooling time and the boron concentration in the cooling water of the pond. In nuclear power plants these parameters are available from the fuel assembly data card.

Neutrons and photons are detected at different axial positions of the fuel assembly by moving the fuel assembly in an axial direction step by step. At first, burn-up is determined in the central region and then at the end of the fuel assembly. When using the data from the central region of the fuel assembly the neutron and the gamma counts are used. In this region the burn-up is nearly constant and no special corrections with respect to axial burn-up gradients are needed.

At the end of the fuel assembly, a large change of burn-up occurs because of axial power density change in the reactor core. For this region, two analysis procedures are performed. In the first, only neutron counts are considered and analyzed by using KORIGEN as described above. Power density is varied assuming the same irradiation history. In the second one, only gamma counts are considered and analyzed using the linear relationship between burn-up and gamma counts. Since gamma ray can be exactly collimated, the gross-gamma measurement allows a high spatial resolution. High accuracy, therefore, results in determining local burn-up especially at the end regions of the active zone. For burn-up declaration the lowest value of burn-up is printed on the protocol. This is conservative when criticality safety must be considered.

MEASUREMENT SYSTEM

In principle, high radial burn-up gradients cannot be excluded, so the measurement system consists of two neutron detectors and two gross-gamma detectors placed around fuel assembly.

FAMOS III (Fig. 1) can be installed on the fuel assembly storage rack or on the delivery station in the pond. There is adequate space for both lowering the fuel assembly into the monitoring system and for good positioning of the fuel assembly in the monitoring device. A leading-in unit protects the detectors and enables easy positioning

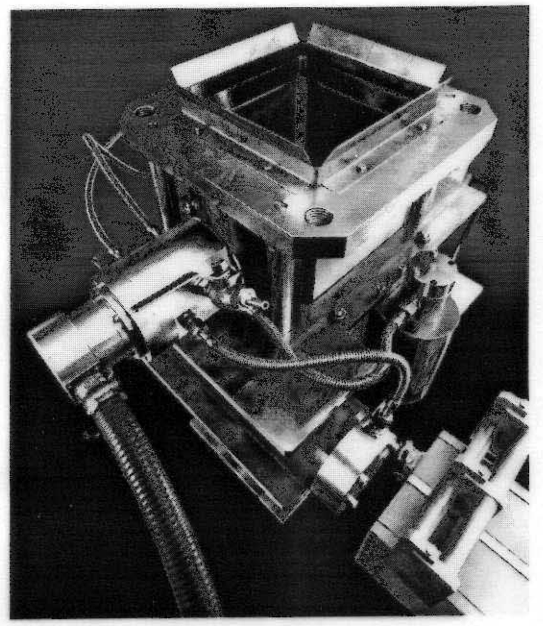

Figure 1. Measurement head

of the fuel assembly with a crane. The dimensions of the rack system are comparable with the dimensions of the pedestal plate and the fixing devices.

The fuel assemblies are inserted into the monitor from above. The movement through the system is carried out sequentially. The operation of FAMOS III is controlled by a PC using a control menu.

The measuring equipment is located outside the pond and is adapted to the rough operating surroundings. The cables connecting the detectors and the electronics are gathered in a tube which can be fixed to the pond wall. A separate set of electronics is installed for each detector.

ADVANCED CALCULATION METHOD

The burn-up calculation approach must be carefully selected when using a phenomenological model and it is necessary to check its application in a series of calibration measurements. Furthermore, the input parameters are different for fuel assemblies at the power station: They depend on the specifics of the assay *i. e.*, on the type of fuel, irradiation history, operating parameters during irradiation phase *etc*. These parameters must therefore be determined for each application. In addition, simplification must be also assumed, *i. e.*, the change of the axial burn-up profile at the end of the fuel assemblies is described with the same parameter as the burn-up in the central region of the fuel assembly, or the decay of isotopes is described without an explicit consideration of the cooling cycles between irradiation cycles.

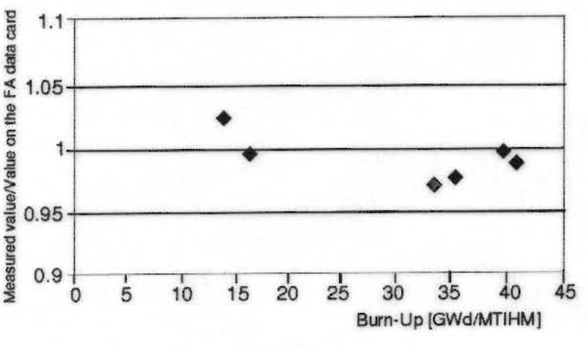

Figure 2. Mean burn-up ratio measured at NPP Stade

Because of such disadvantages of the phenomenological models, the determination of burn-up values is carried out with the KORIGEN code. This code is commonly used to determine the relevant data of irradiated fuel assemblies which are used in German reactors. The code is qualified for calculations needed in the field of safety assurance. Hereby, the parameters, *i. e.*, burn-up and cooling time are varied until the photon emission rate and the neutron emission rate come into agreement with the measured data. The phenomenological model can be used to select the starting parameters to accelerate the analysis procedure.

Figure 2 shows typical results of the measurements. The ratio between the measured value and the value on the fuel assembly (FA) data card is analyzed. Fuel burn-up is measured in units of the gigawatt day (GWd) per metric tonne of initial heavy metal (MTIHM). The data points show very good agreement. The experimental error is in the range between –5% and +5%.

CONCLUSION

The measurements at NPP Philippsburg, NPP ISRA II and NNP Stade have shown that the required accuracy was met and the acceptance criteria at La Hague given by the French authority could be satisfied. Therefore, FAMOS III is a qualified burn-up measurement system which is accepted by the French authorithies.

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ФАМОС III, СИСТЕМ ЗА МЕРЕЊЕ ИЗГАРАЊА ГОРИВНИХ ЕЛЕМЕНАТА ПОГОДАН ЗА КОНТРОЛУ ЛА ХАГ КРИТЕРИЈУМА

ФАМОС (Fuel Assembly Monitoring System) – систем за мерење изгарања горивних елемената, развијен је у Центру за нуклеарна истраживања Карлсруе, Немачка, а користи се за недеструктивну анализу горивних елемената лаководних реактора. Потпуна карактеризација горивних елемента без претходног познавања података о горивним елементима и начину рада ректора могућа је на основу примене активног/пасивног мониторинга. Даља унапређења резултовала су системима ФАМОС II и ФАМОС III, једноставним за употребу и лаким за одржавање. ФАМОС III посебно је развијен за одређивање степена изгарања горивних елемената и погодан је за контролу критеријума при тзв. Ла Хаг мерењима, нарочито на крајевима горивних елемената (50 cm).