IN-DEPTH ANALYSIS OF THE IN-CORE MEASUREMENTS

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ABSTRACT

An in-depth analysis of the in-core measurements, in particular the follow-up of the evolution of the flux maps and the deduced core nuclear parameters, may help in detecting anomalies and in identifying the related physical or modelling problems.

The purpose of this paper is to illustrate some cases met during flux map measurements in Belgian reactors. The corresponding analyses allowed to take corrective actions in order to address the identified deficiencies. Two types of parameters are to be studied in depth:

- A fine analysis of the as-recorded axial shapes has allowed to visualize and identify the two following problems i.e. deposit of cruds on the upper part of assembly and progressive deficiency of an in-core detector.
- The analysis of the evolution of core parameters derived from flux maps such as axial-offset, radial power tilts, background activity, can also reveal some modelling defaults, physical problems or detector instability. We can mention for instance corrosion, assemblies deformation or a defective detector.

This paper presents also method to determine the position of the end of the fissile columns for shortened assemblies in order to use only power representation signal. This is specially useful for shortened assemblies, such as MOX FAs.

Various examples of anomalies encountered in the Belgian PWRs are given in this paper. The diagnosis and the corrective action taken (if any) are explained.

1. INTRODUCTION

An in-depth analysis of the in-core measurements, in particular the follow-up of the evolution of the flux maps and the deduced core nuclear parameters, can contribute to detecting anomalies and identifying the related physical or modelling problems.

The purpose of this paper is to illustrate some cases met during flux map measurements in Belgian PWR reactors. The corresponding analyses have allowed to take corrective actions in order address the identified deficiencies.

2. DESCRIPTION OF FLUX MAP MEASUREMENTS AND TREATMENT

The in-core measurement is achieved by means of non resident miniature moveable fission chambers . Three to five such chambers are introduced from the bottom of the core into 25 to 30% of the total number of fuel assemblies in ten successive operations. The measurement starts from the top of the core and the chambers are pulled down to the bottom.

The electric stream they produced under irradiation is proportional to the neutron flux; it is recorded every 8 mm. A last measurement is recorded out of the flux, it gives the background activity.

The first treatment of this rough information consists in validating the records and averaging them into a limited number of equidistant point (50 to 75 points depending on the plant and the acquisition system).

The resulting information is first visually analyzed and then sent to the RABBIT code where the following successive main operation are performed:

- axial reposition and ,if needed, extension of the flux traces based on the theoretical position of grids deflexion
- reconstruction of the axially incomplete measurements from symmetrical and neighbouring ones
- calibration of the signal performed from calibration measurements (cross calibration are all the successively into the same) or if not available from symmetrical measurement
- analysis and correction of time dependant deviations from deviation measurements: the first measurement is performed a second time at the end of the campaign
- deviation between measurement and theoretical values and interpolation to non instrumented assemblies
- calculation of the 3D power distribution and parameters addressed by the technical specifications.

3. AXIAL SHAPES

A fine analysis of the as-recorded axial shapes has allowed to visualize and identify the two following problems i.e. deposit of cruds on the upper part of the assemblies, and the progressive deficiency of an in-core detector.

3.1. CRUD DEPOSIT

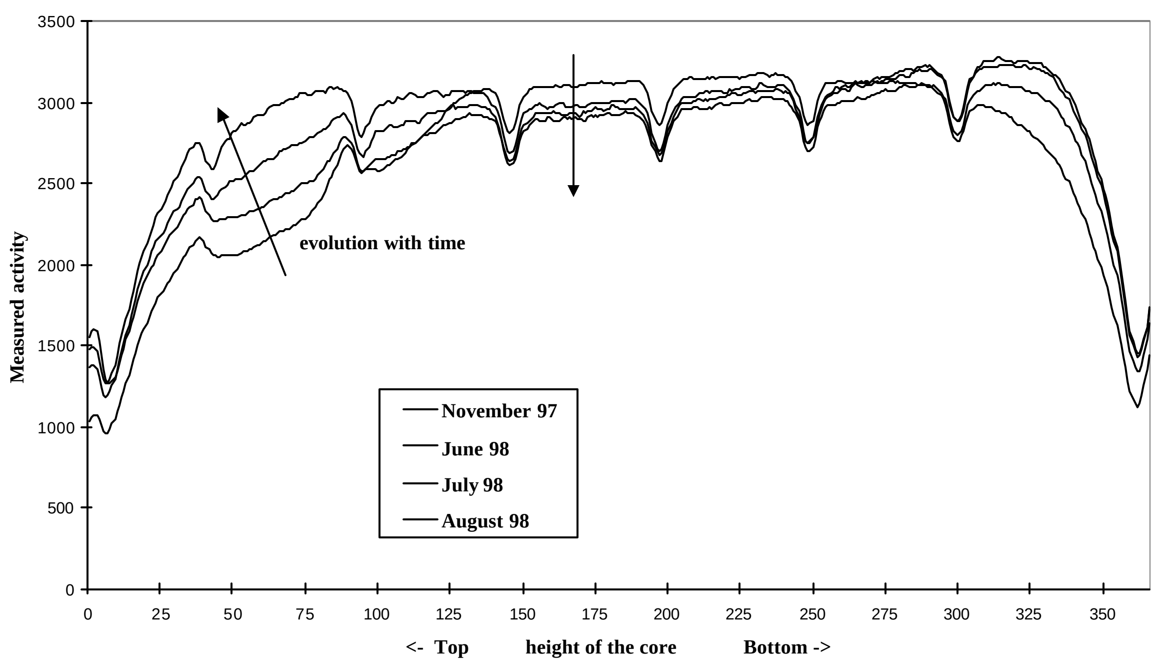
At the beginning of a cycle of a reactor operated in 15 month cycles with MOX , the critical boron concentration at HZP was high (about 2200 ppm). After 2 months of operation, the analysis of the axial traces indicated a significant depression of the flux trace occurring between the 3 upper spacer grids for only 4 fuel assemblies as shown in figure 1. These 4 spent fuel assemblies of old design were stored in the pool during a few cycles before being reloaded for a last irradiation cycle. That anomaly did not occur on all the other fuel assemblies. The analysis and following of the global average axial-offset, as well incore as excore did not exhibit that anomaly because of the very limited number of affected assemblies.

That phenomenon was easily identified as crud deposit on the upper part of the assemblies. Various irradiation characteristics of those assemblies were favourable to crud deposits i.e. high power because of assembly position in the central part of the core and because of a recent power uprate of the plant, high boron concentration (> 2000 ppm) at BOC required for a long cycle, a lower flow rate inside those old design fuel assemblies.

The axial shape analysis has allowed to follow-up the evolution of the phenomenon (figure 1) which remained limited to the 4 concerned assemblies and which progressively disappeared during the cycle with the decrease of the boron concentration and with the burnup effects becoming dominant.

During the whole cycle, no safety parameter was affected and no corrective action was required namely thanks to the fact that the phenomenon has been showed to be limited.

Figure 1
Evolution of the profile of the axial-shape of an assembly with crud's with time

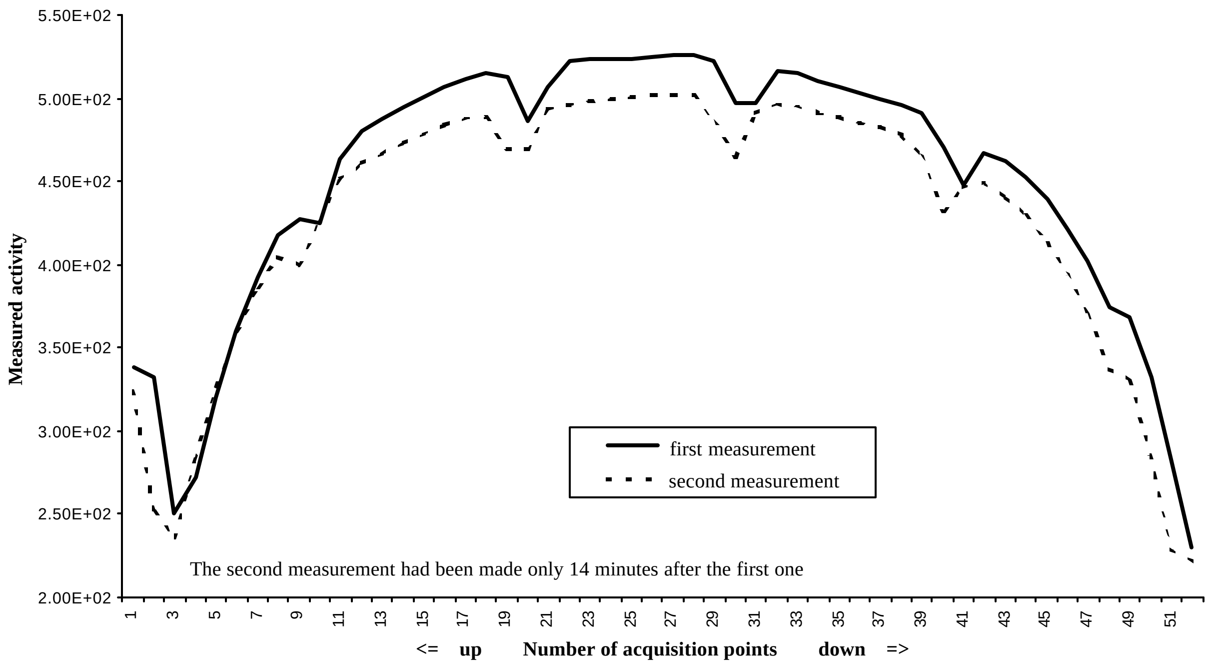


3.2. DEFECTIVE DETECTOR

The comparison of the two successive flux measurements carried out with the same detector on the same fuel assembly demonstrated a stepwise discrepancy in the flux trace. The deviation occurred only with one detector at constant power. Hence, it was inferred that the discrepancy originated from a defective detector signal and not from a possible drift during flux measurements. Direct action was taken to restart the flux map measurement using only the three valid detectors. After investigation of the electronic system, it was decided to replace without delay the defective detector.

The two successive flux measurements on the same assembly as shown in figure 2, exhibit an average deviation of about 4 %.

Figure 2
Successive measurements of the same assembly => defective detector



4. EVOLUTION OF CORE PARAMETERS

The analysis of the evolution of core parameters derived from flux maps such as Axial-Offset, radial power tilts, background activity, can also point out some modelling defaults, physical problems or detector instability.

4.1. ASSEMBLY DEFORMATION

In the cores affected by an excessive assembly bowing phenomenon, the fresh fuel assemblies are loaded under control rods (even at the centre of the core) in order to avoid or at least to delay possible incomplete rod insertion (IRI). The loading pattern is the checkerboard type. The loading of bowed burnt fuel assemblies adjacent to fresh fuel assemblies leads to the increase of some inter-assembly water gaps and to the disappearance of other such gaps. As all the large water gaps are located at the same side of the fresh assemblies, a radial power tilt occurs in the core. Indeed, in a core quadrant, the large water gaps will be closer to the core centre than in the opposite quadrant where they will be oriented to the core periphery.

When the core deformation is S-type, the power tilt is opposite in the upper part and in the lower part of the core, and the corresponding axial-offset becomes significantly different quadrant per quadrant.

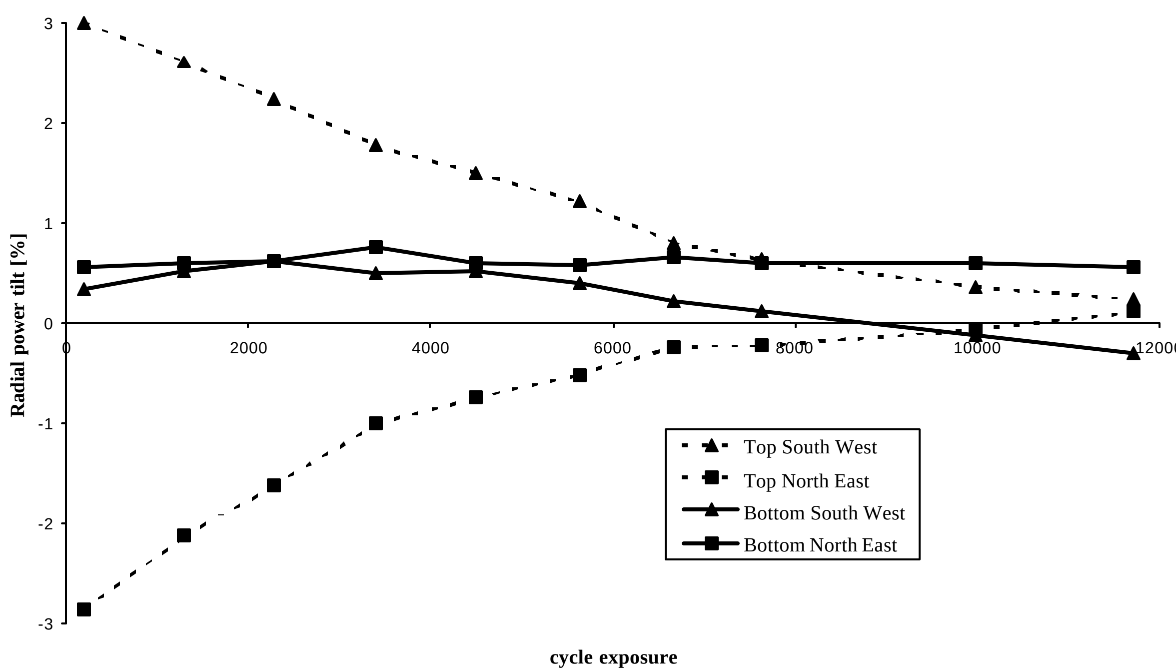
That effect gradually disappears with exposure because of a possible bowing of the fresh fuel assemblies and because the burnup effects become dominant; a reversal of the evolution may reveal a complete vanishing of the gaps (i.e. a similar deformation of fresh assemblies as old ones). That is overly compensated by exposure redistribution.

Figure 3 gives an example of power tilts in the upper and lower part of a core which presented an S-type assembly deformation. In case of not-deformed fuel assemblies, the radial in the upper and in the lower part remain in the range of ± 0.5 %.

The follow up of this parameters seems to be a good indicator of the evolution of the core deformation.

Different corrective actions are underway to avoid IRI and to straighten progressively the affected cores.

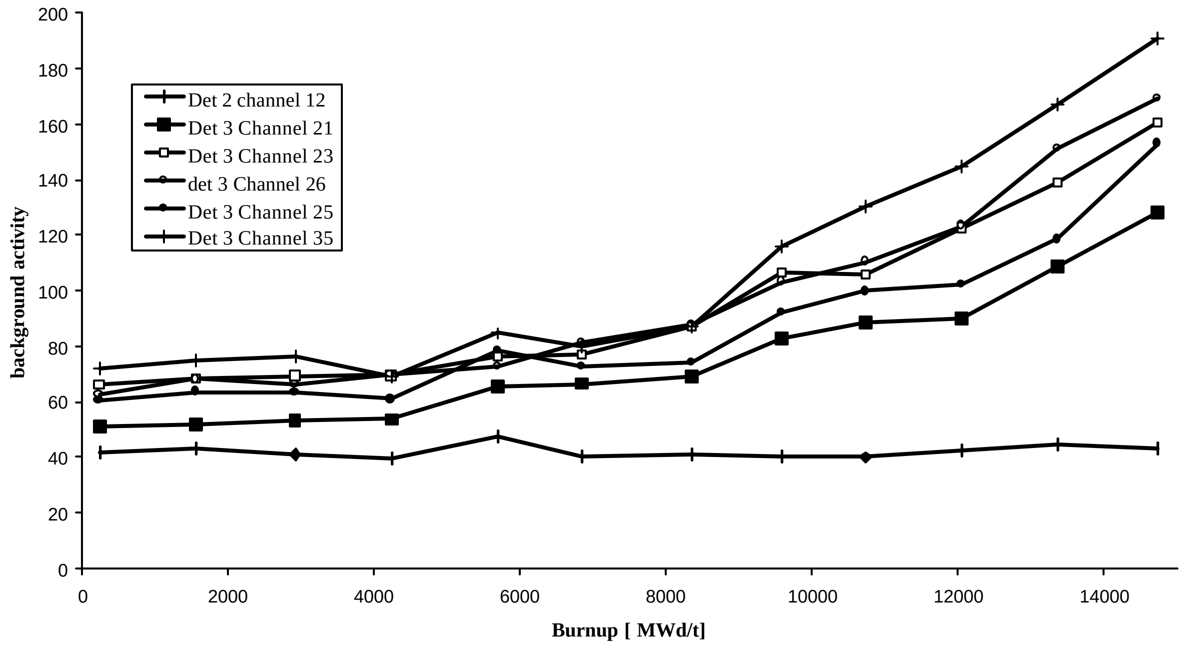
Figure 3
Difference between top and bottom of the radial power tilt



4.2. DEFICIENT DETECTOR

The follow-up of the evolution of the background activity of the detectors (signal recorded when detector is out of flux) can also indicate possible deficiency related to a detector. Figure 4 gives an example of a detector background activity evolution compared with normal (constant) evolution (detector 2). The background activity increase in absolute value with time has indicated a deficiency in the electronic system of the detector, which has been repaired.

Figure 4
Evolution of the noise with time
=> Detector 3 defective



5. REDUCED ACTIVE LENGTH OF MOX ASSEMBLIES

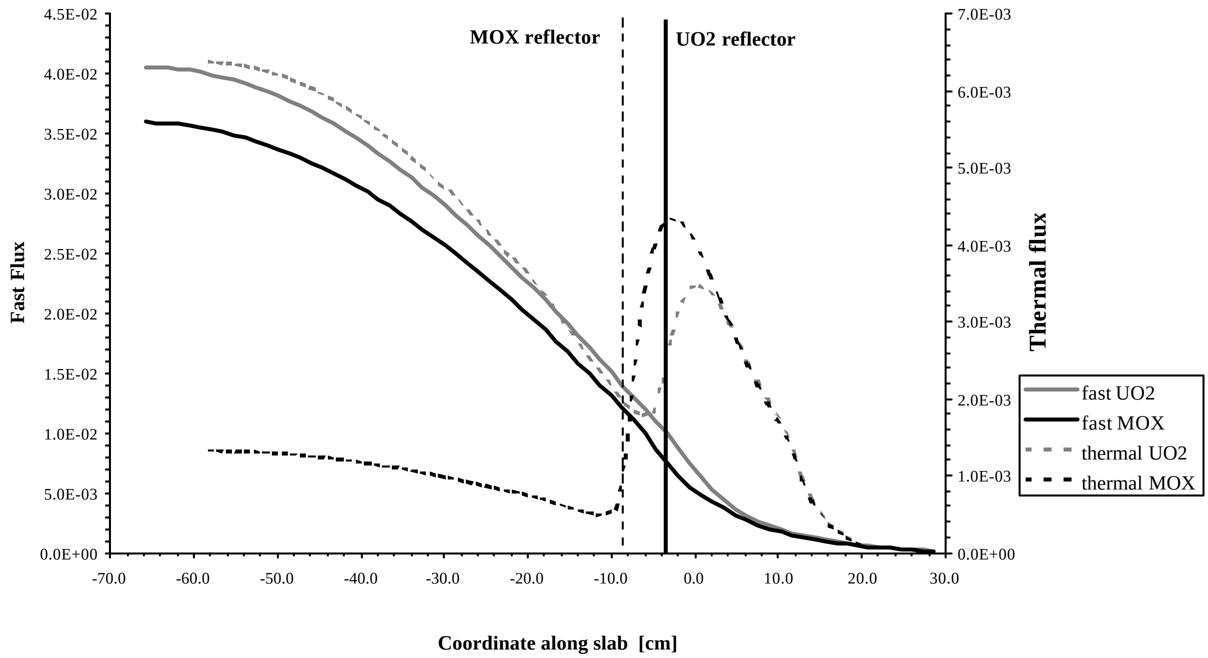
Comparatively to the Uranium assemblies, the active length of the MOX assemblies has been reduced by 4 pellets (4*1.15 cm) in order to increase the plenum volume for accommodating fission gas release.

The in-core code used to process the flux map measurements considered the same active length for all the fuel assemblies. Just above the top of the MOX fuel assemblies of reduced length, the code was deducing a fictitious power from the detector response taken in the upper reflector. Such a treatment led to exceed significantly but fictitiously the FQ LOCA limit.

Because of the reduced FQ LOCA limit at the top of the core and because of the high reflector effect on MOX fuel and despite the inaccuracy of the measurement at the ends of the fissile length, the Belgian Safety Authorities requested to verify the LOCA limit along the whole active length. For such a verification it is necessary to locate accurately the end of the fissile column from the fine distribution of the detector response at the top of MOX assembly.

The determination of the end of the MOX fissile column was based on the position of the minimum of the thermal flux, and hence of the detector activity close to the reflector. The distance between the end of the fissile column and this minimum was evaluated from slab transport calculation in various conditions (boron concentration, burn-up, enrichment, …) and fixed conservatively at 5 cm (see figure 5).

Figure 5
Flux comparisons in MOX-UO2 configuration



The detector response signal is recorded every 8 mm and is automatically analyzed, filtered and condensed to produce every 64 mm an average value automatically transmitted to the in-core code. Such data are too rough to determine the minimum and the fine distribution. The solution was to a
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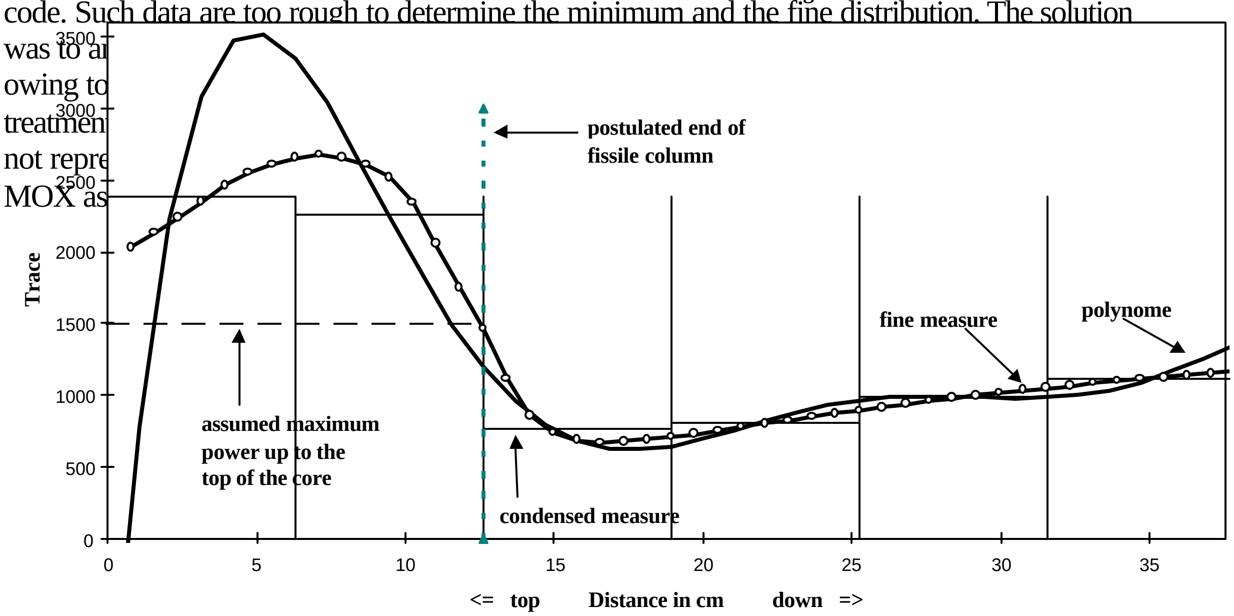
Figure 6
Determination of the end of the active length



6. CONCLUSION

The given examples illustrate that an in-depth analysis of the in-core measurements can contribute to detecting anomalies which can occur during a cycle, to identifying the root cause of such anomalies and to taking corrective action if necessary.