Gamma Spectrometry for Burn-up Determination of Spent Fuel Assemblies at the Paks NPP

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Abstract. VVER-440 fuel assemblies sunk in the loading pit were measured by gamma spectrometry. The assemblies were moved to the front of a 1.6 m long collimator built in the concrete wall of the pit in the reactor block and lifted down and up under water for scanning by the refuelling machine. The HPGe detector was placed behind the collimator in an outside staircase. The measurements involved scanning of the assemblies along their length of all the 6 sides, at 5–12 measurement positions side by side. Axial an azimuthal burn-up profiles were taken up in this way. Assembly groups for measurements were selected according to their burn-up (10–45 $GW \cdot d \cdot t^{-1}U$) and special positions (e. g. control assembly, neighbor of control assembly). The ratio of the activities of Cs-134 to Cs-137 was found to be proportional to the burn-up. Activity ratios were evaluated by intrinsic efficiency calibration. Burn-up differences were well observable between assembly sides looking at center and opposite directions. Also, burn-up profiles are different for control assemblies and normal fuel assemblies. Uncertainty is around 3%. Taking into account irradiation history and cooling time, the ratio Cs-134/Cs-137 shows good correlation with declared burn-up.

1. INTRODUCTION

To validate the calculation of burn-up from the reactor parameters an independent measurement method would be useful. If the results of the measurement correspond with calculated values, the safety margin could be decreased in the calculation, thus the assemblies could be used for higher power output. In Paks NPP, each reactor block has a collimator built in the wall of the loading pit. So a high resolution detector placed behind the collimator and by hanging up a spent fuel assembly in front of the collimator, gamma spectra can be taken.

2. THEORETICAL BASIS

Production of Cs-137 is linearly proportional to the neutron fluence, i.e. the number of U-235 nuclides undergoing fission. Cs-134 is produced in two steps: first the fission product Cs-133 is produced, then Cs-134, by neutron capture. The alternative way (direct Cs-134 production from fission of U-235) is of lower probability by orders of magnitude. The production of Cs-134 is almost proportional to the

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square of neutron flux. If the activity of Cs-134 and Cs-137 is known, the burn-up can be calculated as:

$$BU = k(A_{Cs\text{-}134}/A_{Cs\text{-}137}) \quad (2.1)$$

Why is it useful to follow this complicated way of determining burn-up instead of the simpler way of determining the activity of Cs-137?

Count rate measured by the detector coming from Cs-137 content in the assembly depends on many coefficients. These are as follows: the gamma yield (I_g factor), self absorption in the loading material (enriched uranium), absorption of construction materials (zircon tubes, assembly wall), gamma absorption by the water from the assembly to the wall of the loading pit and by the collimator, distance coefficient, efficiency of the detector. Some of them are well known or measurable (I_g factor, distance coefficient, efficiency of detector), others can be calculated with acceptable precision and some of them can be only estimated.

Cs-134 has two strong peaks at 605 keV, I_g=97.6%, and at 796 keV, I_g=85.5%. Cs-137 has one peak at 662 keV, I_g=85.1%. From the two peeks of Cs-134 one can determine the relative efficiency of detection of the of 662 keV line gamma line by intrinsic calibration. In this way the geometry dependent parameters will be eliminated. For dependence of the activity ratio on the distance see Fig. 2.1.

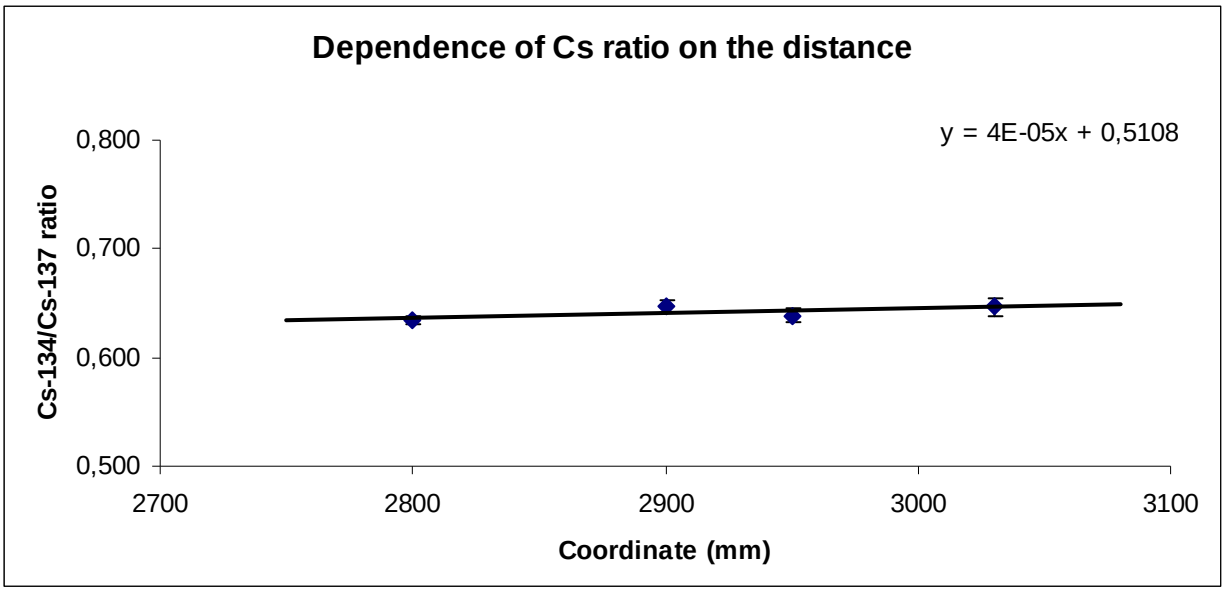

FIG. 2.1. Cs-134/Cs-137 activity ratio vs. distance.

This method can be used with linear, logarithmic, or polynomial fitting. The polynomial fitting would be the best, but more peaks of the same isotope would be needed. Unfortunately, other peaks of Cs-134 come with much lower yields, so their uncertainties are higher. Thus they do not improve but reduce the trustiness of the fitting. The remained two methods differ from each other by 3% in calculating the activity ratio Cs-134/Cs-137. Considering the uncertainty around 1% of the peak areas, this uncertainty is acceptable now.

3. MEASUREMENTS

The collimator built into the south wall of the loading pit is looking to the centre, its axis is almost parallel with the axis of the "carriage" of the refuelling machine The field of vision of the collimator at the measuring distance is about 200 mm horizontal and 15–20 mm vertical. The distance coordinate does not represent the real distance of the assembly to the detector, but the "carriage" coordinate of the refuelling machine does it. The real distance was 1800–2000 mm, depending on the gamma activity of the assembly. "Bridge" and "carriage" coordinates of the refuelling machine were measured from a base point (south-west corner of the podium). The vertical coordinate was given by the length of the refuelling machine's "rope", which lowers the assembly down. To match this coordinate to the assembly, the endpoints of uranium loaded into the pin was determined first, by measuring the peak of Cs-137. The ends of the loading were where it decreased hardly. The average value of the two endpoints was the vertical coordinate of the pin's centre. The code, (C-porka developed by the Reactor Physics Departement of Paks NPP) which calculates the burn-up and production of isotopes for pins, divides each pin in 48 nodes by assembly length, 41 among them contains fuel. If there had been enough time, each node would be measured. Mainly 9 nodes (5–12) measurement were used to characterize the typical burn-up profile. Two from the bottom end of the pin to the plateau, 5 from the plateau and 2 from the plateau to the top end of the pin. A typical burn-up profile with measured values is shown in Fig. 2.2.

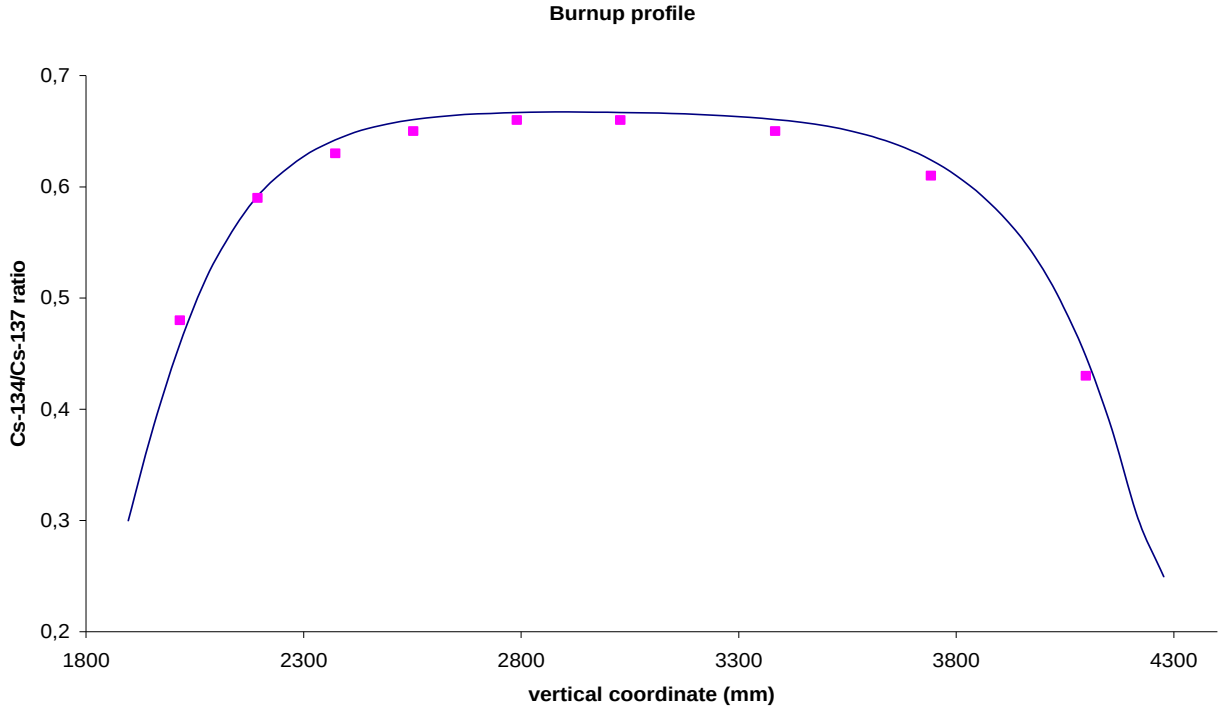

FIG. 2.2. A typical burn-up profile with measured values.

Six assembly groups were selected for the measurements, one of high burn-up (44 GW·d·t^{-1}U) and the second of low burn-up (10 GW·d·t^{-1}U). The third one was of normal burn-up (39 GW·d·t^{-1}U) and 3,8% initial enrichment, the fourth one was of 26 GW·d·t^{-1}U burn-up and 2,4% initial enrichment. The above groups consist of 6 assemblies, as the core is divided into 6 sectors. Their positions in each sector were the same. Two control assemblies and two of the neighbor of control assemblies were taken. Altogether 28 assemblies were measured. The measurements involved scanning of the assemblies along their length of all the 6 sides. To collect spectra, there are two methods: one is continuously moves the assembly and periodically save the data, and the other one measures determined positions, and fits a curve to the measured values. The first method is better for the unknown distribution of the material in the measured region. The precision of this method in each region is less, but the sum of the regions determines a not continuous distribution well. The second method gives more precise values for each measured position, but gives no information on between

the positions. This method is better to measure the continuous distribution of material. In this case the second method was chosen with 5–12 measurement positions side by side. Around 1200 spectra were collected. Axial and azimuthal burn-up profiles were taken in this way. Measuring time was 300 or 600 s by position. Spectra were evaluated automatically by a computer code including the intrinsic calibration method. Considering the short half life of Cs-134 (2.06 years), all the calculated values from the measurements were corrected for the first day of the measurements. Measurements took 5 weeks.

The different cooling time and burn-up of assembly groups give different measurement distance and time. The evaluation spectra of low cooling time assemblies are complicated because of the short half-life isotopes, mainly Zr-95 (724.2 keV and 756.7 keV $T_{1/2}$=64.02d). After 1.5 year it is decayed. Long cooling time (6 y or more) decreases the amount of Cs-134, increasing the uncertainty.

The isotope activity ratio values, calculated for the pins from the burn-up, needs to be averaged for the whole assembly. It's not a simple average of course, because of the distance correction (smaller part) and self-absorption correction of the other pins (main part). This calculation was performed by the code MCNP at Paks NPP. The calculation gives different values side by side, depending on the surroundings of the assembly (i.e. working/control assembly and its situation to the centre of the core). In the calculation of the decay of isotopes was corrected to the first day's measurement.

4. RESULTS

Upon representing the ratios by sides and matching the core sector and turning degrees, burn-up differences were well observable between assembly sides looking at the centre of core and opposite to it.

Azimuthal profiles of the 39 GW·d·t^{-1}U burn-up group at the centre of pins are seen in Fig.4.1.

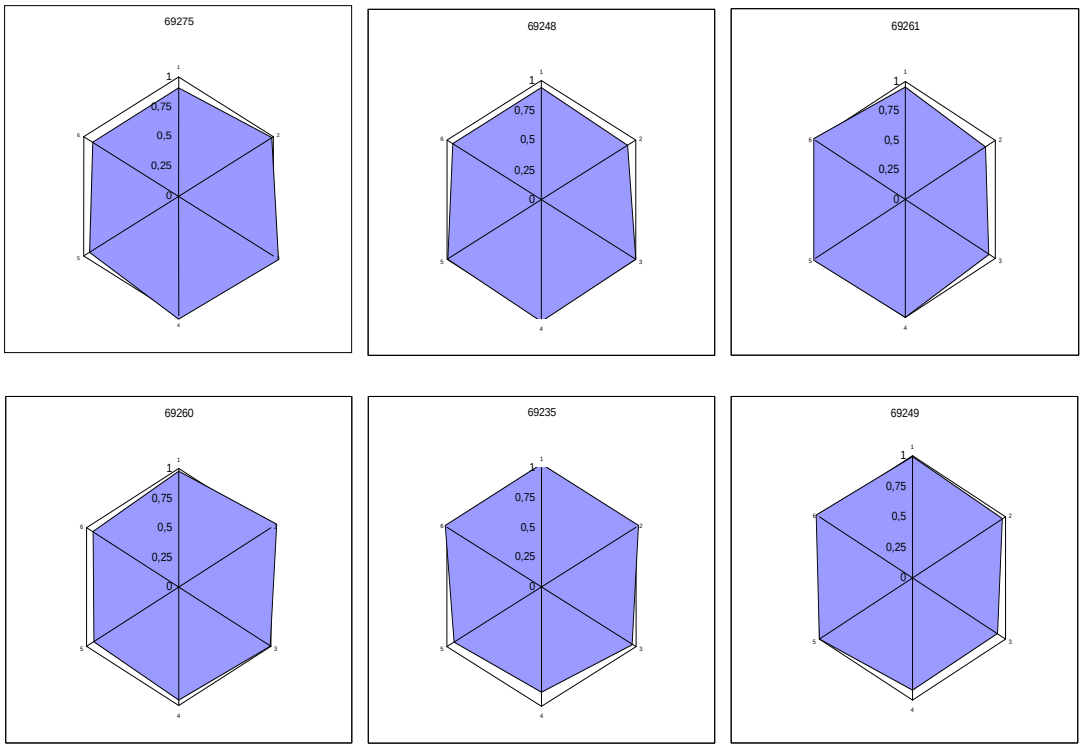

FIG. 4.1. Azimuthal profiles of the 39 GW·d·t^{-1}U burn-up group at the centre of pins.

Also, burn-up profiles are different for control and normal “working” fuel assemblies, see Figs 4.2–4.3.

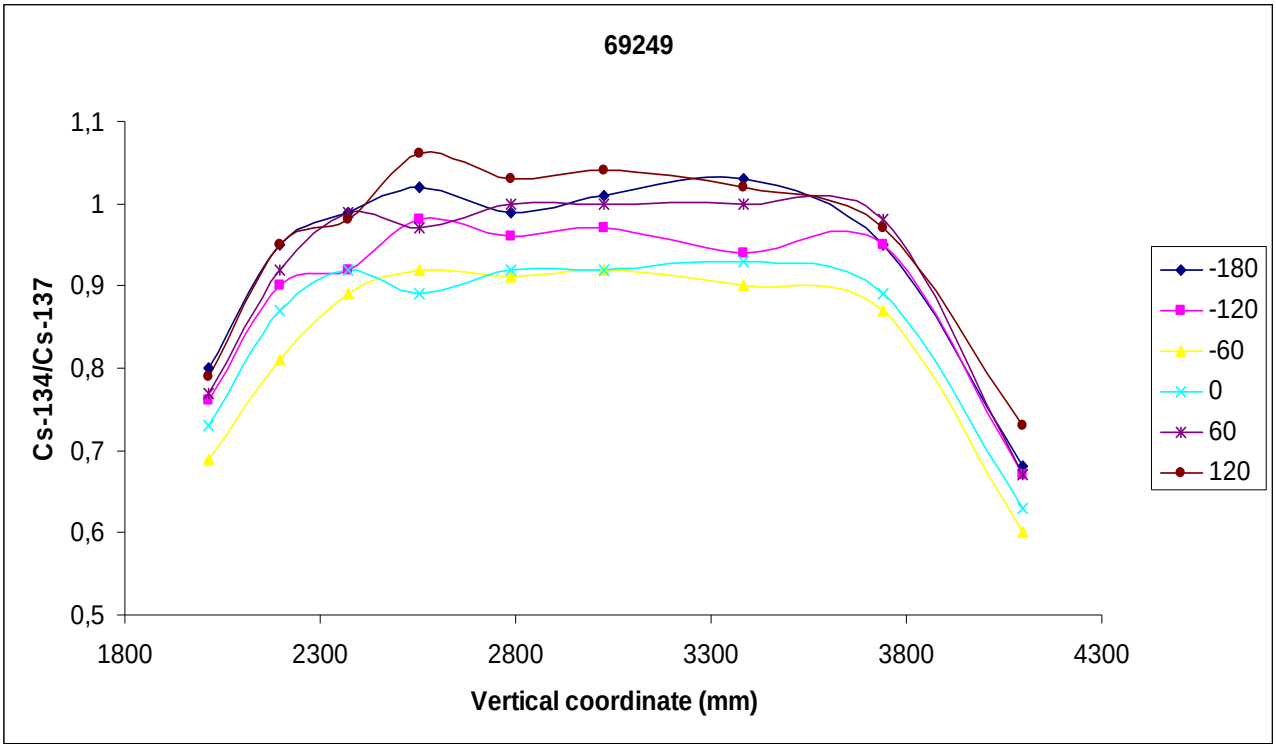

FIG. 4.2. Burn-up profile of a working fuel assembly.

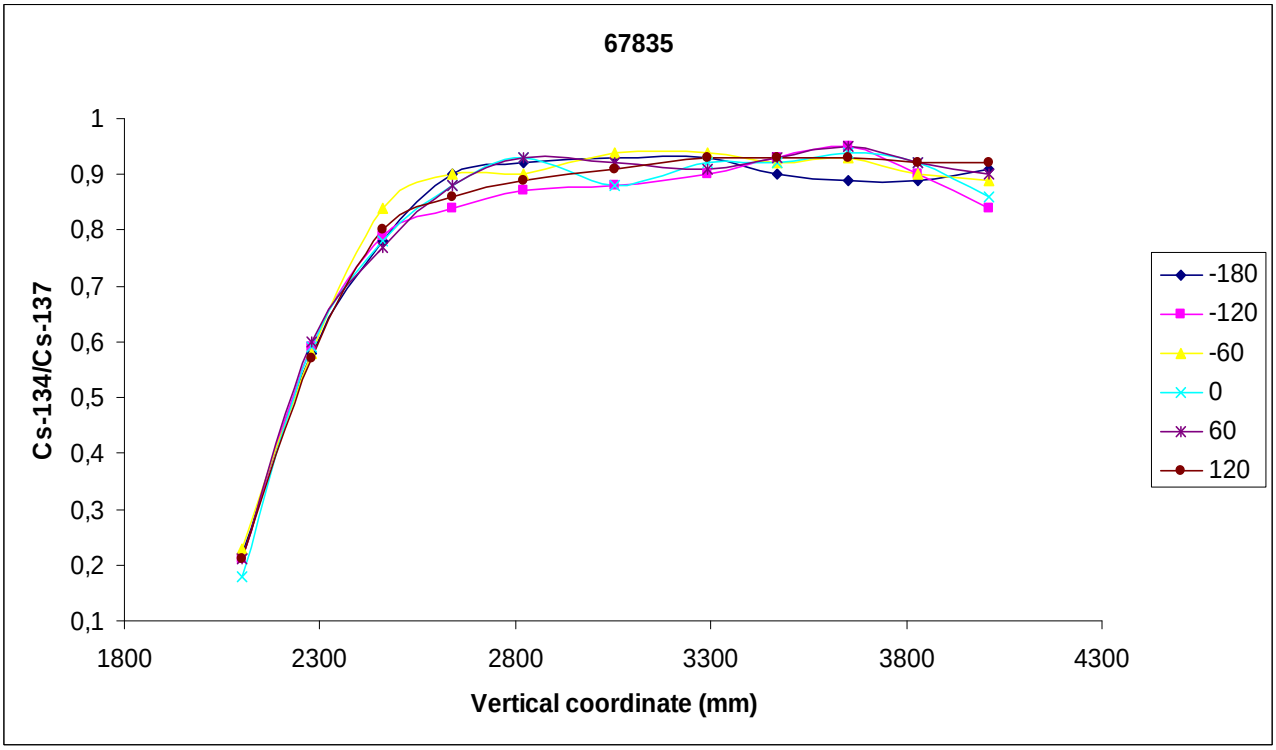

FIG. 4.3. Burn-up profile of a control fuel assembly.

To compare calculated results based on the measurements and the burn-up, the ratio Cs-134/ Cs-137 shows good correlation see Fig. 4.4.

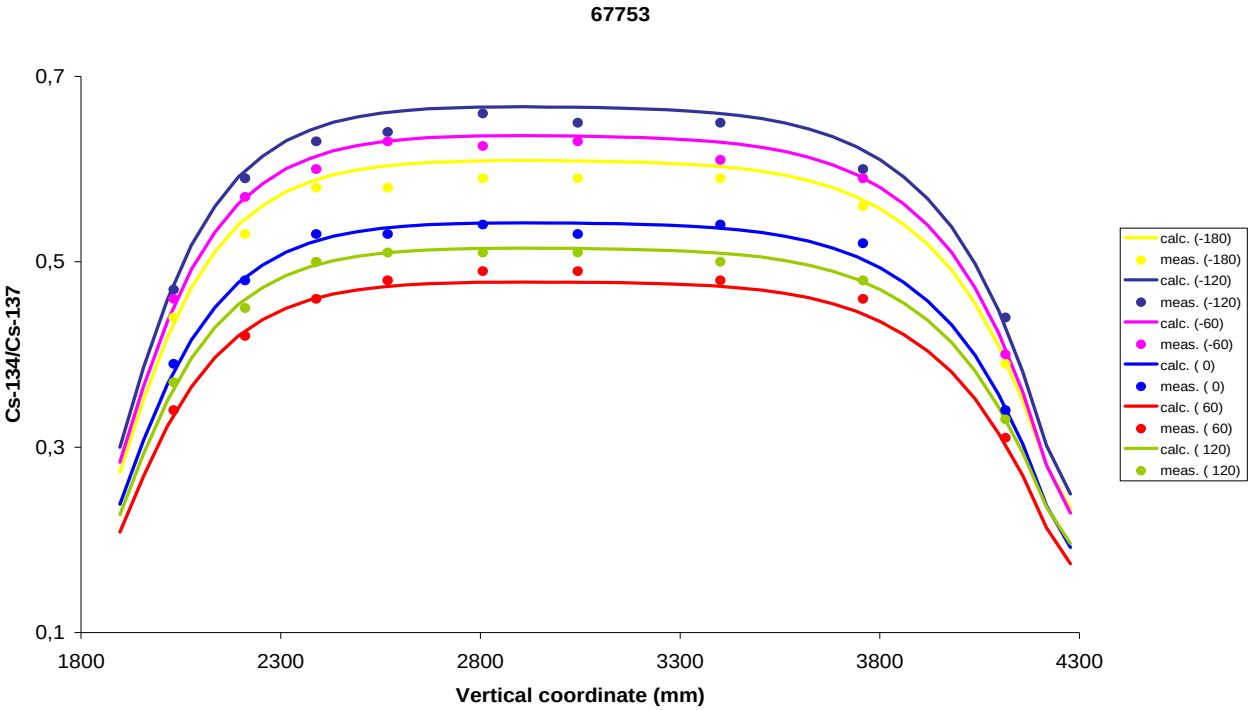

FIG. 4.4. The Cs-134/Cs-137 ratio from measurements and calculation.

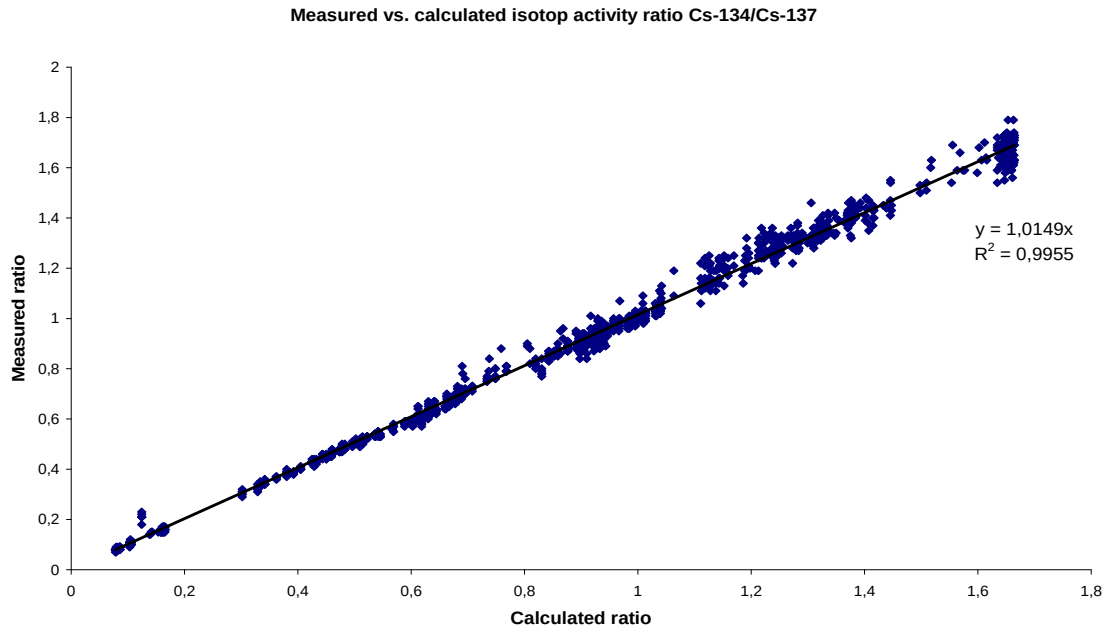

FIG. 4.5. Measured vs. calculated activity ratio Cs-134/Cs-137.

When representing the measured Cs-134/Cs-137 ratio as a function of the ratio calculated from the reactor parameters for the whole data sets, the correlation is significant, see Fig. 4.6.

5. SUMMARY

By this method the burn-up of assemblies can be determined. Uncertainty of the method is around 4%. To decrease the uncertainty the measurement time should be increased by decreasing the number of measured positions and/or assemblies. For the best results 2–4 years old assemblies are to be measured.

The method should be checked at other ponds in Paks NPP first. It's also planned to modify the detector system to measure ponds without built-in collimator, to be able to use the method for other reactors too.

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