MEASUREMENTS ON SHORT TIME COOLED PWR FUEL WITH A FORK DETECTOR

Howard Menlove, Douglas Reilly, Richard Sieblist
Los Alamos National Laboratory-Safeguards Assay Group
P.O. Box MS E540 Los Alamos, NM 87545 USA (+1505) 667-2448

Olga Y. Mafra, Gevaldo Almeida, Luis Rovere
Agencia Brasileiro-Argentina de Contabilidade e Controle de Materiais Nucleares-ABACC
Av. Rio Branco, 123 - 5o. andar 20040-005 Rio de Janeiro-RJ BRAZIL (+5521) 2213464

Emmanuel Gryntakis
International Atomic Energy Agency - IAEA/SGOA1
Wagramerstrasse 5, P. O. Box 200 A-1400 Vienna, AUSTRIA (+431) 2360-1942

Osvaldo Calzetta Larrieu
Centro Atomico de Bariloche - CAB
C.C.961 - (8400) S. C. de Bariloche- Rio Negro ARGENTINA (+549) 444-5100

Abstract

The Fork detector has normally been used to measure gamma rays and neutrons from irradiated fuel assemblies to verify the consistency of burn up declarations. An unusual series of measurements was conducted with a Fork detector on PWR fuel in the storage pond of the Angra-1 Nuclear Power Station. This fuel had cooled only 41 days and had burn-ups in the range of 16 to 31 GWd/tU. Despite the intrinsically low sensitivity of fission chambers to gamma rays, a special adjustment and calibration was necessary to reduce the contribution of gamma-ray pile-up to the neutron count rate. This was necessary because of the high gamma flux from short-lived nuclides in the fuel, which could, otherwise, alter the neutron to gamma-ray counting ratio, the basis for the burn-up determination. The measured results, expressed as a plot of the ratio neutron and gamma-ray counting rates versus the gamma-ray counting rate showed very distinct data clusters for each burn-up. This made it possible to confirm the irradiation cycle history of the fuel assemblies.

1. Introduction

At the present time, there is no NDA equipment or related method, capable to verify uranium or plutonium in irradiated fuel elements, an obstacle caused mainly by the low gamma and neutron emission rate of these nuclides, compared to those ones produced by other actinides and fission products present in the spent fuel element. As result of that, those elements have to be verified and quantified by calculation or other indirect methods, making using of the very same cause of the *trouble* to solve it, i.e., the measurement of the *spurious* high gamma and neutron emission rates.

A device that uses this approach is the *Fork Detector*, developed to measure gross gamma-ray and neutron emission, from which, both burnup and cooling time can be inferred. Even when the cooling time is not known, or when the fuel elements had been submitted to a discontinuous and irregular irradiation cycle, it's still possible to differentiate between discrete burnups and initial enrichment from irradiated-fuel assemblies, and verify the consistency of reactor fuel burn-up declarations, as outlined on section 3. This equipment, was used to measure some 41 days-cooled spent fuel elements at the storage pond of the Brazilian Angra I Nuclear Power Station.

2. Equipment and Methods

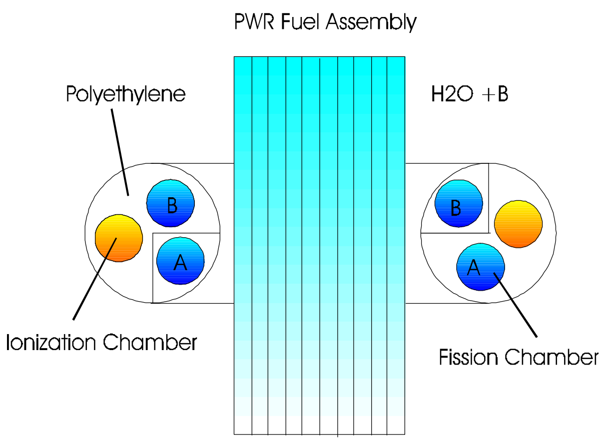
The Fork Detector has been developed [1] at Los Alamos National Laboratory, and since then additional improvements on equipment, data, as well as on its using has been done [2-5].

A cross section view of the Fork Detector is sketched on Fig.1. There, one can see 2 fission chambers A and B, and 1 ionization chamber in each branch of the fork. To count neutrons in the very high gamma dose of the irradiated fuel, the fission chambers were modified to be insensitive to gamma pile-up. The modification included:

a) - removal of the cadmium near the fission chambers.
b) - increasing the discrimination level for neutrons versus gamma.
c) - setting 2 discrimination levels (A and B) to verify the absence of gamma pileup.

The removal of the cadmium was to increase the efficiency of the fission chambers, and the gain was a factor of 3.4 for the Fork in air.

Figure 2 shows a diagram of the fission chamber spectrum with the two discrimination levels set well above the alpha pileup threshold. One pair of tubes was wired together for neutron channel A (0.40 of Ro) and another pair for the channel B (0.20 of Ro) where Ro is the normal threshold setting for the fission chambers. The ratio A/B can be used to verify the absence of gamma pileup into channel A or B.



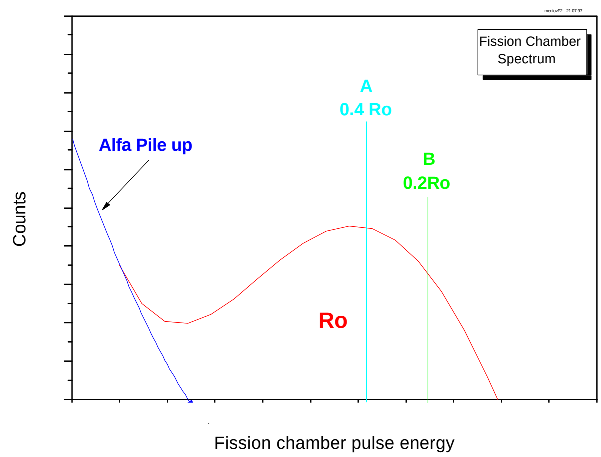


Fig.1 - Diagram of modified Fork detector cross section. The Cd was removed from the interior of the CH2 insert.

Fig .2 - Fission chamber pulse height spectrum showing the high discrimination levels for channels A (0.40 R_o) and B (0.2 R_o).

2.1. Check of the modified equipment

Prior to its calibration and use, the Fork Detector was tested to verify whether the chosen approach to avoid the problems associated with the high gamma flux worked properly. Tests with older fuel assemblies gave the same A/B ratio = 2.04 that was measured using calibration assemblies. For the hot assemblies (41 days) this ratio increased to ≈ 2.4. This increase was independent of the neutron rate and was the same for all of the high gamma dose assemblies, showing that the effect was not from gamma pileup. It was assumed that the A/B ratio shift, was from a small gain reduction, because of the high ionization current in the fission chamber.

To correct for this gain reduction, assuming that discriminator level A lays on the center of a relatively flat region, e.g., the gain shift would cause the same absolute reduction on A and B, then the measured A+B neutron rates should be multiplied by the factor f = 3(2.Q-1)/(2.Q+1), where Q is the ratio $(A/B)/(A_o/B_o)$, and A_o/B_o the original ratio. For this case where A_o/B_o =2, and the measured A/B for short-cooled assemblies reached 2.4, then Q=1.2, and f=1.23, i.e., the measured neutron rates should be increased by about 20%, as it was actually done.

This corresponds to a gain shift of circa 14% determined as (Q-1)/(2Q-1), considering the value of A as reference or about 6% when one takes R_o as reference 0.4(Q-1)/(2Q-1).

2.2. Calibration

The new modified Fork Detector was calibrated relative to three of the older fuel assemblies that were in the Angra I storage pool. These assemblies had been measured with a standard Fork Detector in 1986. The fuel assemblies that were re-measured are listed in Table I.

Table I - Calibration Assemblies

				Old Neutron Rates (counts/sec)			
ID	Burnup MWd/tU	Cooling Time to 96-04-26	Initial Enrichment (%)	Correction to 90-10-24	Correction. to 96-05-26	New Fork (A+B) counts/s	Efficiency Ratio (new /old)
A15	15937	3752d	2.104	45.5	36.8	91.3	2.48
A16	13954	3752d	2.104	27.2	22.0	56.4	2.56
B32	556	4636d	2.610	~0.16	NA	0.18	NA

The assembly B32 has a such low burnup that most of the neutron counts are from Pu-240 and U-238. It is not clear that the 1986 data had a zero neutron background and an alpha pulse background rate ≥0.02 counts/sec would significantly change the results. Thus, assembly B32 was not used in the calibration.

The average results from assemblies A15 and A16 give the efficiency ratio of the new Fork Detector, to the old one of 2.52. This is consistent with the introduced Fork modifications.

2.3. ORIGIN-2 Calculations

The neutron and gamma emissions from the irradiated fuel depend on the irradiation history and initial enrichments. The ORIGIN-2 Burnup calculations has been used to correct the measured data to a standard enrichment and irradiation history. The selected *standard three year cycle* was the following:

365d irradiation Þ 50d cooling Þ 365 d irradiation Þ 50 d cooling Þ 365 d irradiation Þ 41 d cooling

with a 3% initial enrichment. The fuel assemblies in strata A, B and F were corrected to above three year cycle and initial enrichment to correct for the variable irradiation histories and initial enrichments.

3. Results

3.1. Uncorrected Data

All of the measured fuel assemblies were measured at their midpoints by lifting the assemblies part way out of the storage grid. On of the hot assemblies was scanned from the midpoint to the top and exhibited the expected neutron and gamma profiles. For recently discharged fuel (41d cooling time), it was not necessary to make any corrections for gamma or neutron decay for the measurement time interval of 3 hours.

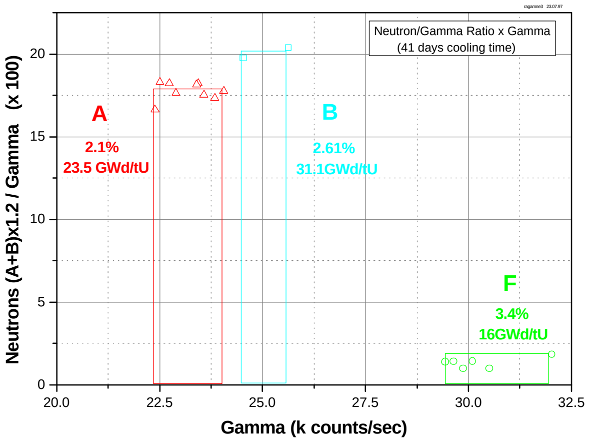
Figure 3 shows the ratio neutron/gamma as function of the gamma rate to illustrate the clustering of strata A, B and F. These strata have their own separate clusters because of the distinct burnup levels and initial enrichments. The lower the enrichment, the higher the neutron rate for a given burnup. The production of Cm-244 (the source of neutrons) begins with neutron capture in U-238, the burnup begins with the fission in U-235. The gamma come from the fission products so one get more neutrons per gamma ray from the lower enrichment. Fuel assemblies with higher enrichments have higher fission rates in the core and thus higher gamma rates, for the short cooling time of the assemblies

3.2. ORIGIN-2 Corrections

The ORIGIN-2 burnup code was used to correct the measured neutron rates to a *standard* irradiation history and initial enrichment. The standard cycle was arbitrarily defined as three one year irradiations with 50 days for each reload and fuel with an initial enrichment of 3%.

Each of the fuel stratum were calculated for the declared given irradiation histories and enrichments as well as standard irradiation history and enrichment for their burnup. The ratio of these calculations were used to correct the neutron rates A, B and F.

Figure 4 shows the data after the ORIGIN-2 corrections. One can see that all the data lies close to the standard curve. The deviation from the curve is probably caused by the rough approximations to the irradiation histories that were used for strata A an B. An additional ORIGIN-2 calculation was performed for the case of fresh fuel being introduced into the core in February 1994. Thus, at shut down in March 1996, the burnup would be ~ 10 GWd/tU but the gamma dose would be similar to other fuel with 41 d cooling. Figure 4 shows also the expected neutron rates for fuel with the lower burnup. None of the measured fuel in strata A, B and F have neutron rates consistent with the low burnup assumption.



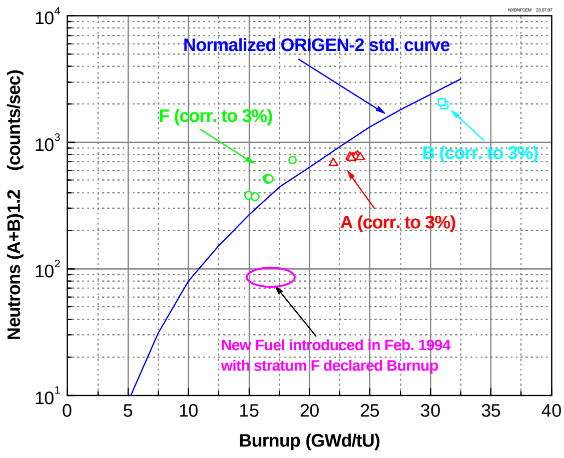


Fig.3 - Measured neutron to gamma ratios versus gamma for strata A, B, and F.

Fig.4 - Neutrons rates versus burnup after corrections using ORIGIN-2 code to standard irradiation cycle and 3% enrichment.

4. Conclusions

The following conclusion can be made from the measurement campaign involving the short-cooled spent fuel elements:

a) - The calibration of the Fork agreed well with the measurements from 1986. The efficiency increase was approximately a factor 2.
b) - The Fork worked satisfactorily in the high gamma dose corresponding to 41 d of cooling time.
c) - There was no gamma pileup into the neutron channel but there was a small gain reduction from the high ionization current. The gain shift was approximately constant and correspond to about 6% for all the fuel with a short cooling time.
d) - All of the neutron and gamma data was reproducible and internally consistent.
e) - The raw data neutron and gamma ratios demonstrated the consistency of the strata A, B, and F and the absence of any outlier fuel assemblies.
f) - The ORIGIN-2 calculations corrected all of the measured data to a standard neutron versus burnup reference curve.
g) - No outlier fuel assemblies were measured having a burnup deficit.
h) - The assembly and installation of the Fork in the pool required 1.5h and the calibration and measurement with the 21 assemblies required 3.5 h.

References

[1] - Phillips, J.R., Halbig, J.K., Bosler. G.E., *Passive neutron measurements and calculation of irradiated PWR fuel assemblies*, Safeguards and Nuclear Material Management (Proc. 3rd. ESARDA Ann.Symp. Karlsruhe, 1981), CEC Joint Reasearch Centre, Ispra, (1981) 169.

[2] - Phillips, J.R., Bosler, G.E., Halbig, J.K., Klosterbuer, S.F., Menlove H.O., *Nondestructive Verification with minimal movement of irradiated light-water reactor fuel assemblies.* LA-9438-MS (ISPO -172) (1982).

[3] - Rinard P., *A spent fuel curve for safeguards application of gross-gamma measurements.* LA-9757-MS (ISPO - 195) (1983).

[4] - Carchon,R. et al. *ION-1 Fork measurements on pressurized water reactor spent fuel assmblies,* International Symposium on Nuclear Material Safeguards. IAEA, (1986).

[5] - Hsue,T.S., Menlove, H.O., Rinard, P..M., *Design of a new portable fork detector for research reactor spent fuel.* LA-12892-MS UC-70 (1995).