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CONVERGENCE ANALYSIS BETWEEN THE EXPERIMENTAL DATA AND CALCULATION RESULTS OF THE SPENT FUEL BURNUP IN THE PRESSURIZED WATER REACTOR

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Abstract

Using a burnup credit as safety criteria in a spent nuclear fuel (SNF) criticality calculations required accuracy isotopes composition preparation approach. Comparisons between calculation results and existing experimental data are one effective way for this calculation approach development. Moreover some studies devoted to determination of the SNF isotopes composition do not provide the information about the fuel irradiation history, cooling time at all. In this case some complicacy can appear during initial data preparation and calculation results interpretation. In present work the verify calculations for ^{137}Cs concentration proposed dependence were made use experimental data for several pressurize water reactor (PWR) and boiling water reactor (BWR) spent fuel assembly. The calculations of the ^{137}Cs concentration using the proposed formula have a good agreement with the experimental data, which is available to the authors.

Keywords

spent nuclear fuel, Monte-Carlo criticality calculation, burnup credit, SCALE computer codes system, ^{137}Cs concentration

1. Introduction

In various studies related to the determination of the fuel burnup and cooling time of the SNF the conclusions, that a lowest experimental error is obtained in the methods based on a ratio of activities of the isotopes ^{106}Rh/^{137}Cs, ^{144}Pr/^{137}Cs and ^{134}Cs/^{137}Cs, are made. However, these methods require the knowledge about the cooling time of the specific fuel assembly (FA), which can be unknown.

In studies [0, 0] and others, a conclusion, that the isotopes activities ratio of ^{134}Cs/^{137}Cs and ^{144}Pr/^{137}Cs gives an opportunity to detect the fuel burnup and cooling time in a range of 0.5 - 5 years with a 5% error, was made. In case of usage of γ-lines area ratio of ^{106}Rh/^{137}Cs and ^{134}Cs/^{137}Cs, the detection error of the fuel burnup and cooling time does not exceed 10%, as asserted in [0].

Taking into account the relatively small half-life periods of ^{134}Cs, ^{106}Ru (parent for ^{106}Rh) and ^{144}Ce (parent for ^{144}Pr) and different isotopes output under the ^{235}U and ^{239}Pu fission, can to show that under the same burnup the activities ratios shown above can vary by 5 - 10%. Also those activities ratios depend on initial fuel enrichment.

Moreover some studies devoted to determination of the SNF isotopes composition do not provide the information about the cooling time at all, that makes employment of the discussed ratios impossible. For example in report [0], the experimental data from study [0] is shown and indicated that provided measurement error is about 7% for each fuel burnup and the isotope concentration, but the fuel depletion conditions and cooling time are unknown.

Thus in case of absence of the accurate data about the history of the FA operation due to various reasons, a comparison of the isotope composition calculation results and experimental data may results in the wrong conclusions about the initial and boundary conditions approaches during the developing of the calculational scheme and performing calculations

2. Spent Fuel Assembly Cooling Time Consideration

The change of the ^{137}Cs isotope concentration with the fuel burnup is linear and almost independent from any kind of factors, such as reactor power level, coolant/moderator density, fuel type, etc. In study [0], the variation of the isotope concentration of ^{137}Cs for various reactor types was analyzed and the following dependence for the ^{137}Cs concentration was proposed:

$$c_{137}\left[\text{kg/t(U)}\right] = 3.9\cdot 10^{-5}\cdot e^{-\lambda_{137}\tau}\cdot burn \qquad (1)$$

where:
λ_{137} – ^{137}Cs decay coefficient, sec; burn – fuel burnup, MW·day/t(U); τ – effective FA operation time, sec, which is calculated using the burnup, as following:

$$\tau = \frac{burn\cdot Mu}{\bar{q}\cdot 1000}\cdot 24\cdot 3600 \qquad (2)$$

where:
burn – current fuel burnup, MW·day/t(U); Mu - metallic uranium mass per fuel assembly, kg.
$\bar{q}$ – average single FA power, MW:

$$\bar{q} = \frac{Q_r}{N_{fa}} \qquad (3)$$

where:
Q_r – thermal reactor power, MW; N_{fa} – number of FAs in the core.

In principle in this dimension of the ^{137}Cs concentration do not depend from "heat" neutrons reactor type.

Using the experimental data for PWR and BWR FA presented in SFCOMPO (Spent fuel composition Database), a verification of the dependence (1) was performed.

The dimension of "effective day" in tables input just mark what the downtime get by calculation. The downtime was calculated as:

$$t = -\frac{\ln(c/c_0)}{\lambda} \qquad (4)$$

where:
c_0 – ^{137}Cs concentration calculated using dependence (1), which are value for uploaded fuel; c – ^{137}Cs concentration which presented for sample; λ – ^{137}Cs decay coefficient, sec.

Recalculate burnup profile use formula (1) as:

$$burn = \frac{c_{137}}{3.9\cdot 10^{-5}e^{-\lambda\tau}e^{-\lambda t}} \qquad (5)$$

where:
c_{137} – ^{137}Cs concentration which presented for sample; λ – ^{137}Cs decay coefficient, sec; τ – fuel assembly operation time; t – cooling time for samples.

Using the dependence (1), the ^{137}Cs concentration and the cooling time for presented samples were determined and compared with the experimental data. The results of comparisons are presented in Appendix A (Table 1 - 5).

3. Summary and Conclusions

Some verification calculations for dependence (1) were made and shown what proposed formula have a good agreement with the experimental data, which is available to the author. Will show what some aspects for the experimental samples history can be describe. It is a effective cooling time and sample burnup profile. So the dependence can be useful in case of unknown conditions for experimental samples and for preliminary experimental data preceding if all conditions known.

Comparison analysis for present dependence needs to be continued. Authors will be appreciated to other researchers for similarly study.

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APPENDIX A

Table 1. Deviation of ^{137}Cs concentration and cooling time from experimental data for Miham-3 samples (cooling time for all samples 5 years).

Sample #	*Reported burnup, MW·day/t(U)*	*Recalculated burnup, MW·day/t(U)*	*Burnup deviation, %*	*^{137}Cs concentration deviation, %*	*Effective cooling time, years*
86B02	8300	7738.05	-7.26	5.31	7.38
86B03	6900	6332.84	-8.96	8.35	8.80
86G03	15300	15024.03	-1.84	4.80	7.15
86G05	21200	21436.72	1.10	0.88	5.39
86G07	14600	14932.42	2.23	0.98	5.43
87C03	29440	29780.68	1.14	2.72	6.21
87C04	32300	33195.02	2.70	0.64	5.29
87C07	33700	34459.59	2.20	0.88	5.39
87C08	34100	34775.74	1.94	1.07	5.47

Table 2. Deviation of ^{137}Cs concentration and cooling time from experimental data for H.B. Robinson Unit 2 samples (^{137}Cs concentration for samples USAHB2PWR-5 and USAHB2PWR-6 not presented).

Sample #	*Cooling time, years*	*Reported burnup, MW·day/t(U)*	*Recalculated burnup, MW·day/t(U)*	*Burnup deviation, %*	*^{137}Cs concentration deviation, %*	*Effective cooling time, years*
USAHB2PWR-1	10.8	16020	15762	-1.63	3.25	12.2
USAHB2PWR-2	10.8	23810	23609	-0.85	0.90	11.2
USAHB2PWR-3	9.9	28470	26443	-7.66	6.26	12.7
USAHB2PWR-4	9.9	31660	30303	-4.48	2.75	11.1

Table 3. Deviation of ^{137}Cs concentration and cooling time from experimental data for Calvert Cliffs samples.

Sample #	*Cooling time, years*	*Reported burnup, MW·day/t(U)*	*Recalculated burnup, MW·day/t(U)*	*Burnup deviation, %*	*^{137}Cs concentration deviation, %*	*Effective cooling time, years*
UCASS1PWR-1	5.08	27350	26118	-4.72	4.50	4.96
UCASS1PWR-2	5.08	37120	35382	-4.91	4.68	6.09
UCASS1PWR-3	5.08	44340	43095	-2.89	2.81	6.02
UCASS1PWR-4	6.5	18680	18274	-2.22	2.17	5.89
UCASS1PWR-5	6.5	26620	26523	-0.36	0.36	5.95
UCASS1PWR-6	6.5	33170	32645	-1.61	1.58	7.18
UCASS1PWR-7	6.7	31400	30390	-3.33	3.22	5.73
UCASS1PWR-8	6.7	37270	35098	-6.19	5.83	7.55
UCASS1PWR-9	6.7	46460	46308	-0.33	0.33	6.07

Table 4. Deviation of ^{137}Cs concentration and cooling time from experimental data for Gundremmingen NPP unit A samples (cooling time 0 years for all samples).

Sample #	***Laboratory***	***Reported burnup, MW·day/t(U)***	***Recalculated burnup, MW·day/t(U)***	***Burnup deviation, %***	***^{137}Cs concentration deviation, %***
GERGUNBWR-1	Ispra	27400	24080	-13.79	16.02
GERGUNBWR-2	Ispra	25730	30693	16.17	-13.72
GERGUNBWR-3	Karlsrue	21240	22406	5.20	0.08
GERGUNBWR-3	Ispra	21240	21904	3.03	2.32
GERGUNBWR-4	Ispra	22250	22629	1.68	3.52
GERGUNBWR-5	Karlsrue	22970	25699	10.62	-6.24
GERGUNBWR-6	Ispra	23510	23020	-2.13	6.95
GERGUNBWR-7	Karlsrue	25190	27038	6.83	-2.25
GERGUNBWR-7	Ispra	25190	25726	2.09	2.71
GERGUNBWR-8	Ispra	19850	22168	10.46	-7.77
GERGUNBWR-9	Ispra	20300	21047	3.55	-0.12
GERGUNBWR-10	Karlsrue	14390	15854	9.23	-5.49
GERGUNBWR-10	Ispra	14390	15171	5.15	-0.95
GERGUNBWR-11	Karlsrue	15840	18232	13.12	-10.44
GERGUNBWR-12	Karlsrue	17490	19189	8.85	-5.52
GERGUNBWR-12	Ispra	17490	15881	-10.13	12.67

Table 5. Deviation of 137Cs concentration and cooling time from experimental data for Cooper NPP.

Sample #	***Cooling time, years***	***Reported burnup, MW·day/t(U)***	***Recalculated burnup, MW·day/t(U)***	***Burnup deviation, %***	***^{137}Cs concentration deviation, %***	***Effective cooling time, years***
USACOPBWR-1	5.35	33940	33543	-1.18	1.17	5.87
USACOPBWR-2	5.35	33070	32431	-1.97	1.93	6.21
USACOPBWR-3	5.35	18960	18805	-0.82	0.82	5.71
USACOPBWR-4	5.28	31040	30054	-3.28	3.18	6.69
USACOPBWR-5	5.28	29230	31997	8.65	-9.47	1.35
USACOPBWR-6	5.28	17840	18081	1.33	-1.35	4.70