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Re-evaluation of Assay Data of Spent Nuclear Fuel obtained at Japan Atomic Energy Research Institute for validation of burnup calculation code systems

Kenya Suyama [a,*], Minoru Murazaki [b,1], Kiyoshi Ohkubo [b], Yoshinori Nakahara [c,2], Gunzo Uchiyama [b]

[a] Office of International Relations, Nuclear Safety Division, Ministry of Education, Culture, Sports, Science and Technology – Japan, 3-2-2 Kasumigaseki, Chiyoda-ku, Tokyo 100-8959, Japan
[b] Fuel Cycle Safety Research Group, Nuclear Safety Research Center, Japan Atomic Energy Agency, 2-4 Shirakata Shirane, Tokai-mura, Ibaraki 319-1195, Japan
[c] Research Group for Analytical Science, Nuclear Science and Engineering Directorate, Japan Atomic Energy Agency, 2-4 Shirakata Shirane, Tokai-mura, Ibaraki 319-1195, Japan

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ABSTRACT

The isotopic composition of spent nuclear fuels is vital data for studies on the nuclear fuel cycle and reactor physics. The Japan Atomic Energy Agency (JAEA) has been active in obtaining such data for pressurized water reactor (PWR) and boiling water reactor (BWR) fuels, and some data has already been published. These data have been registered with the international Spent Fuel Isotopic Composition Database (SFCOMPO) and widely used as international benchmarks for burnup calculation codes and libraries.

In this paper, Assay Data of Spent Nuclear Fuel from two fuel assemblies irradiated in the Ohi-1 and Ohi-2 PWRs in Japan are shown. The destructive assay data from Ohi-2 have already been published. However, these data were not suitable for the benchmarking of calculation codes and libraries because several important specifications and data were not included.

This paper summarizes the details of destructive assay data and specifications required for analyses of isotopic composition from Ohi-1 and Ohi-2. For precise burnup analyses, the burnup values of destructive assay samples were re-evaluated in this study. These destructive assay data were analyzed using the SWAT2.1 code, and the calculation results showed good agreement with experimental results. This indicates that the quality of destructive assay data from Ohi-1 and Ohi-2 PWRs is high, and that these destructive assay data are suitable for the benchmarking of burnup calculation code systems.

1. Introduction

The isotopic composition, or assay data, of irradiated spent nuclear fuels is important data for studies on the nuclear fuel cycle and reactor physics. These data are used not only for the safety assessment of spent nuclear fuels and radioactive waste but also for the validation of burnup calculation codes and associated libraries.

In particular, in the community of nuclear criticality safety researchers, the importance of isotopic composition is highly recognized because of the concept of burnup credit. Several international benchmark studies were conducted to validate the burnup calculation codes in the Expert Group of Burnup Credit Criticality Safety (EGBUC) of the Working Party on Nuclear Criticality Safety (WPNCS) of the Nuclear Science Committee (NSC) in the Nuclear Energy Agency (NEA) of the Organization for Economic Co-operation and Development (OECD) (DeHart et al., 1996; Okuno et al., 2002). The working group also initiated the activity to gather isotopic composition data into the Spent Fuel Isotopic Composition Database (SFCOMPO) (Naito et al., 1993). The SFCOMPO has been operated by the OECD/NEA since 2001 with a mission to distribute spent fuel isotopic composition data throughout the world (Suyama et al., 2003).

Considering the difficulties in obtaining destructive assay data of spent nuclear fuel, and in order to revise the SFCOMPO by adding new data to it, the OECD/NEA/NSC/WPNCS decided to launch a new expert group for Assay Data of Spent Nuclear Fuel (EGADSNF) in 2006. For this purpose, the authors began to review past postirradiation examination (PIE) activities carried out at the Japan Atomic Energy Research Institute (JAERI) to find data that had not been registered in the current SFCOMPO. We found that PIEs were carried out in JAERI for the fuels from Ohi-1 and Ohi-2 PWRs in Japan and the numerical data of the samples from Ohi-2 had already been published in 1994 (Adachi et al., 1994) but the current SFCOMPO does not include destructive assay data from the Ohi-1 and Ohi-2. We also found that destructive assay data from Ohi-1 and Ohi-2 were not suitable for the benchmarking of burnup calculation systems because (i) several important specifications and data were not included in the reference by Adachi et al., 1994,

* Corresponding author. Present address: Fuel Cycle Safety Research Group, Nuclear Safety Research Center, Japan Atomic Energy Agency, 2-4 Shirakata Shirane, Tokai-mura, Ibaraki 319-1195, Japan. Tel.: +81 29 282 5834; fax: +81 29 282 6479.
E-mail address: suyama.kenya@jaea.go.jp (K. Suyama).
[1] Present address: Tokyo Nuclear Services Co., Ltd., 1-3-5 Taito-ku, Tokyo 110-0016, Japan.
[2] Retired.

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i.e., name of reactors of Ohi-2 was not opened, atomic percent was only shown for assay data of neodymium isotopes, and the history of the boric acid concentration was not opened, (ii) the method to evaluate the burnup values was not suitable for precise burnup analysis, and (iii) in the case of the destructive assay data from Ohi-1, not only several important specifications and data of measured isotopic composition analysis but also the initial isotopic composition of uranium pellet except for ^{235}U were not included in the reference by Inoue et al., 1994.

This paper presents the "new and reviewed" destructive assay data from Ohi-1 and Ohi-2, including the isotopic composition and other required specifications of spent fuels in addition to associated data such as the initial fuel composition and specific power distribution. The analysis of these data was carried out using a burnup calculation code SWAT2.1, driving a continuous-energy Monte Carlo code (MVP) and a point burnup calculation code (ORIGEN2.2); the calculation results are presented in this paper. This analysis reveals that the qualities of these destructive assay data are as high as those of previously opened destructive assay data such as those from theTakahama-3 PWR (Nakahara et al., 2000).

2. Postirradiation data of pressurized water reactor (PWR) 17 × 17 fuel assemblies

In a series of PIEs for PWR fuels conducted at the Japan Atomic Energy Research Institute (JAERI), a dataset from the Takahama-3 PWR of the Kansai Electric Power Co., Inc. is one of the most famous destructive assay data (Nakahara et al., 2000). We found that other PIEs for PWR 17 × 17 fuel assemblies have also been conducted, and their data had been published in 1994 (Adachi et al., 1994; Inoue et al., 1994). These PIEs were carried out for a G13 fuel assembly (average burnup 45GWd/t) irradiated during four cycles in the Ohi-1 PWR (1100 MWe) and for an I7G fuel assembly (average burnup 31.5GWd/t) irradiated during two cycles in the Ohi-2 PWR (1100 MWe) of the Kansai Electric Power Co., Inc. Ohi-1-G13 and Ohi-2-I7G are of the same assembly geometry as Takahama-3, but they have lower ^{235}U initial enrichment, namely 3.2 wt.%.

Overview of PIE and numerical experimental data (isotopic composition obtained by destructive assay) from the Ohi-2 I7G assembly and the experimental procedure have already been shown (Adachi et al., 1994). The remarkable points of the destructive assay data from the Ohi-2 PWR were that the data from the UO_2–Gd_2O_3 fuel pins were considered and the isotopic ratios of gadolinium isotopes were measured. However, these data from Ohi-2 have not been analyzed and have not become well-known following their publication. This may be because they have not yet been archived in the SFCOMPO database because the name of the power reactor was not shown in the report by Adachi et al., 1994. Another reason may be because the sampling positions of these destructive assay data are not suitable for a single pin-cell model or for point burnup calculation code systems. The isotopic composition data from the Ohi-1 G13 assembly have not yet been shown in any published report. In 1994, Inoue et al. presented experimental data only from a fuel behavior analysis viewpoint. The destructive assay data from the Ohi-1 G13 assembly has a high burnup of approximately 52GWd/t.

Table 1 shows a summary of the characteristics of these PIE samples. Tables 2 and 3 show the main parameters of the Ohi-1 and 2 PWRs and those of the G13 and I7G fuel assemblies, respectively. In the report of Adachi et al., 1994, the name of reactor name

Table 2
Main parameters of Ohi-1 and Ohi-2 PWRs (Adachi et al., 1994; Inoue et al., 1994).

Reactor name	Ohi-1	Ohi-2
Type of reactor	PWR	PWR
Power [MWth]	3423	3423
Number of loops	4	4
Core equivalent diameter [m]	3.37	3.37
Active height [m]	3.66	3.66
Number of assemblies	193	193
Inlet temp [deg.]	289	289
Outlet temp [deg.]	325	325

Table 3
Main parameters of G13 and I7G fuel assemblies (Adachi et al., 1994; Inoue et al., 1994).

Reactor name	Ohi-1	Ohi-2
Assembly name	G13	I7G
Fuel assembly rod array	17 × 17	17 × 17
Fuel pellet diameter [mm]	8.05	8.05
Clad outer diameter [mm]	9.50	9.50
Clad inner diameter [mm]	8.22	8.22
Clad thickness [mm]	0.64	>0.59
Clad material	Zry-4	Zry-4
Number of rods	264	264
Fuel rod pitch [mm]	1.26	1.26
Gadolinia content [wt.%]	N.A.	6.0

Table 1
Main parameters of destructive assay data from Ohi-1 and Ohi-2 PWRs (Adachi et al., 1994; Inoue et al., 1994).

Reactor name	Ohi-1			Ohi-2		
Assembly name	G13			I7G		
Irradiation period	Dec. 1982 to Dec. 1987			Jul. 1984 to Feb.1987		
Number of irradiation cycle	4			2		
Assembly Average Burnup [GWd/t]	45			31.5		
Sample name	91E07	89G01	89G03	89G05	89G08	89G10
FIMA% [a]	5.539	2.283	3.068	2.680	3.205	4.098
Burnup [GWd/t] [b]	53.20	21.92	29.45	25.73	30.77	39.34
New estimation of FIMA [%][c]	5.401	2.211	2.950	2.585	3.129	3.981
New estimation of Burnup[d] [GWd/t]	52.434	21.465	28.717	25.137	30.172	38.496
Fuel type of sample	UO_2	UO_2–Gd_2O_3	UO_2–Gd_2O_3	UO_2–Gd_2O_3	UO_2	UO_2
Fuel pin position in the assemblies	N13	C5	C5	O13	F4	F4
Sample axial height from the bottom of active length [mm]	1128	267	737	733	265	738
^{235}U enrichment [wt.%]	3.2	1.7	1.7	1.7	3.2	3.2
Fuel Pellet Density	95% T.D.	95% T.D.	95% T.D.	95% T.D.	95% T.D.	95% T.D.
Gd_2O_3 content [wt.%]	N.A.	6.0	6.0	6.0	N.A.	N.A.

[a] Adopted fission yield data of ^{148}Nd is that of the thermal fission of ^{235}U. Samples from I7G assembly were shown in Adachi et al. (1994).
[b] GWd/t/FIMA [%] is 9.6. Data from I7G assembly were shown in Adachi et al. (1994).
[c] Re-evaluated FIMA% using effective fission yield values considering the cumulative fission numbers of ^{235}U, ^{238}U, ^{239}Pu, and ^{241}Pu and with correction of ^{148}Nd amount by the effect of neutron-induced reactions of ^{147}Nd and ^{148}Nd.
[d] Adopted conversion factors from GWd/t/FIMA[%] are re-evaluated considering the numbers of fission of ^{235}U,^{238}U,^{239}Pu, and ^{241}Pu and their cumulative fission yield.