Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 17-18, 2018

Review on Definition of Damaged Spent Nuclear Fuel for Dry Storage

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1. Introduction

As Kori Unit 1 was permanently shut down, decommissioning of NPP became urgent task in Korea. Management of spent nuclear fuel (SNF) which is generated during decommissioning has come to the fore on the important issue. The occurrence of damaged SNF can be increased due to high burnup and extended fuel cycle which can improve efficiency of NPPs. Currently, where dry storage is required as the wet storage becomes saturated, domestic definition and classification of damaged SNF is required. However, domestic definition on damaged SNF is vague and there is no classification in Korea. Therefore, it is necessary to review definition and classification of damaged SNF by country for derivation of domestic standard [1].

2. Definition and Classification Standards

2.1 Definition and classification standard of Damaged SNF by country

Foreign definition and classification of damaged SNF are managed without consistent principle by policy of each country. But general standard isn't defined in many countries. Only few countries define damaged fuel as can be seen in Table 1. The International Atomic Energy Agency (IAEA) has defined damaged fuel if fuel doesn't perform its own function. Fuel assembly containing fuel rods with pinhole or hairline crack in cladding can release fission gases (Xe, Kr) during operation. But if we can detect fission gases and handle assembly without non-standard handling, it can be considered as intact fuel [2]. In USA, SNF that can meet all fuel-specific and system-related functions is defined as undamaged. In other words, if fuel rod with pinhole or hairline crack can meet fuel-specific and system-related function, it can be defined as defective but undamaged fuel [3]. In Germany and Japan, any rod with a cladding breach is defined as damaged. In France, fuel assembly susceptible to spread fissile material is defined as damaged [5]. Overall, the definition of damaged SNF depends on the situation in each country. Countries which have reprocessing policy (Japan, France, and Germany) give a strict definition. On the other hand, countries which don't have reprocessing policy give a vague definition.

Table. 1. Definition of damaged SNF by country

List		Definition
IAEA[2]		• **Damaged**: Any SNF that requires non-standard handling to demonstrate compliance with applicable safety, regulatory or operational requirements • **Defect**: Any unintended change in the physical as-built condition of the SNF with the exception of normal effects of irradiation(e.g. elongation due to irradiation growth or assembly bow).
USA	**NRC (ISG)** [3]	• **Damaged**: Any fuel rod or fuel assembly that cannot fulfill its fuel-specific or system-related functions • **Undamaged**: SNF that can meet all fuel-specific and system-related functions • **Intact** : Any fuel that can fulfill all fuel-specific and system-related functions, and that is not breached.
	ANSI [4]	• **Damaged Fuel** : Spent nuclear fuel with known or suspected cladding defects greater than a pinhole or hairline crack.(Cladding Damage, Level I, II)
France[5]		• **Damaged Fuel**: Fuel assembly susceptible to spread fissile material. There is no containment by the cladding of radioactive material, pellets
Germany[5]		• **Damaged**: any rod with a cladding breach; any assembly with rods removed • **Intact**: fuel assemblies discharged from the reactor without failure indications from the online monitoring system or in subsequent sipping tests
Japan[5]		• **Damaged**: any rod with a cladding breach; any assembly with rods removed

2.2 Classification of USA

The NRC concluded that the combination of the presence of high temperature and oxygen of exposed fuel pellet could lead to the oxidation of UO_2. Oxidation of UO_2 to U_3O_8 can result in spalling and powdering of the irradiated fuel segments. Therefore, the NRC evaluated that it is concerned about handling of spent fuel though sealing under transportation is suitable [6].

Although the NRC board decided DD-84-9 later, the NRC published Interim Staff Guidance No.1, Rev.2(ISG-1, Rev.2) owing to damaged SNF problem. ISG-1, Rev.2 classify SNF as (1) damaged (2) undamaged, and (3) intact and give fuel classification standard (performance criteria) [3]. Furthermore, American National Standards Institute(ANSI) indicates ANSI-N14.33 which writes engineering industry practice to help consumer dealing with damaged SNF. ANSI-N14.33 refers to guidelines and requirements of the NRC, and provides definition, classification and handling of damaged SNF for the industry [4].

2.3 Technical background of USA classification

During operation, fuel with pinhole is classified as damaged, but the definition of damaged fuel during storage or transportation is slightly different by country. The NRC judges that if fuel rod has only pinhole or hairline crack of less than 1mm, there is no possibility of causing contamination in the dry storage canister due to leakage of the fuel material and causing problems in terms of storage performance. ISG-1, Rev.2 state that fuel pellet can be divided into 25~35 pieces during operation. These pieces are 2 to 3 mm wide, so pellet fragment containing radioactive fission product can't leak through 1mm wide cladding defect [3]. Some of fission gases can leak out. But, there fission gases are inert gas, so that they are not responsive and small in quantity. Therefore, these fission gases can't contaminate the inside of dry storage canister [Fig. 1].

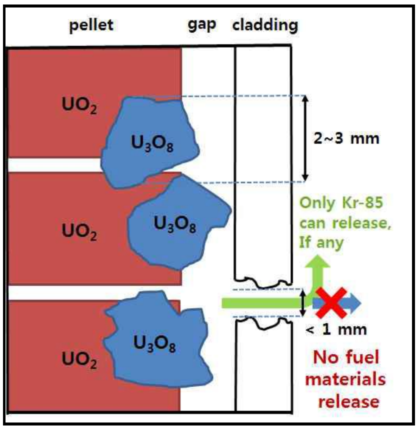

Fig. 1. Technical background diagram of ISG-1 Rev.2.

2.3.1 Origen-ARP Code Analysis

Through the Origen-ARP Code, we evaluate the accumulation of radioactive elements and nuclides in SNF after 3 to 5 cycles [7]. Table 2 summarizes the most radioactive elements and nuclides. Fig. 2. also shows the change in radio-activity with the storage time of the main nuclides. These results show that all of the major radionuclides produced by nuclear fission during nuclear operation are nuclides of the remaining elements in the nuclear fuel material, and that only Kr-85 is the only gaseous nucleus that can escape through the defect. But, the amount of Kr-85 gas is not large when SNF be loaded into the dry storage cask, because Kr-85 gas escaped through the hairline crack continuously during the wet storage period and released again through the vacuum drying process, which is the initial stage of dry storage. Therefore, unless the nuclear material in the nuclear fuel cladding tube is so fine that the nuclear fuel material can't escape hairline crack, the NRC may not consider the contamination in dry storage canister during long-term dry storage of spent fuel from the Origen-ARP Code evaluation. It means that ISG-1 Rev2 is technically very reasonable.

Table 2. Radioactivity of main nuclides

Nuclide	Radioactivity	Nuclide	Radioactivity
Np-239	7.74E+06	Sb-125	9.93E+03
U-237	7.25E+05	Eu-154	8.63E+03
Ru-106	6.40E+05	Cm-244	4.52E+03
Rh-106	6.40E+05	Pu-238	4.00E+03
Cs-134	2.02E+05	Eu-155	3.51E+03
Pm-147	1.86E+05	Am-242	2.38E+03
Pu-241	1.66E+05	Te-125m	2.15E+03
Cs-137	1.35E+05	H-3	7.15E+02
Ba-137m	1.27E+05	Pu-240	5.86E+02
Y-90	9.73E+04	Sm-151	5.18E+02
Sr-90	9.56E+04	Pu-239	3.71E+02
Cm-242	5.98E+04	Am-241	1.75E+02
Kr-85	1.22E+04		

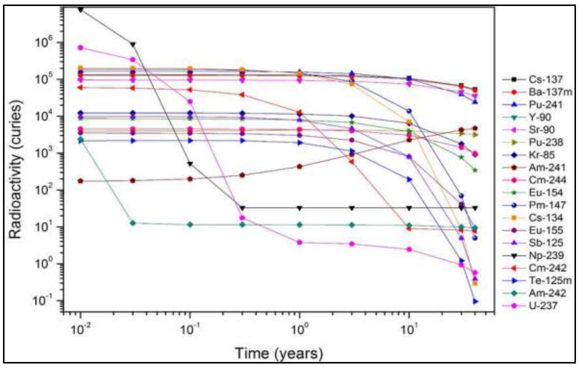

Fig. 2. Change in Radioactivity with storage time

2.3.2 UO_2 pellet oxidation

If hairline crack exists in the fuel rod, oxygen may penetrate into pellet. The fact that U_3O_8 or U_3O_7 generated by oxidation can be pulverized is some arguments. Therefore, we reviewed advanced research material. If fuel pellet oxidize, UO_2 is converted into U_3O_8 or U_3O_7. In this process, about 33% swelling occurs. At this time, fuel is pulverized into grain size particle by hoop stress. [8, 9, 10]. However, the long-term dry storage conditions of SNF are stored in a canister filled with helium gas, which is an inert gas, so that oxidation of UO_2 can't occurs in this environment. And temperature of fuel pellet is usually 200 ℃ [11]. In this temperature, oxidation of fuel pellet rarely occurs. Fig. 3 shows advanced research result which utilize irradiated and un-irradiated UO_2 pellet and powder to measure rate at which UO_2 is oxidized to U_3O_8 by the temperature in air atmosphere. This research shows that oxidation rate decreases sharply with decreasing temperature [12]. Especially, around 200 ℃ oxidation proceeds at a very slow rate in air atmosphere. In dry storage condition, pellet temperature is low and SNF is stored in a canister filled with helium gas. Therefore, UO_2 pellet oxidation rarely occurs in this condition [9].

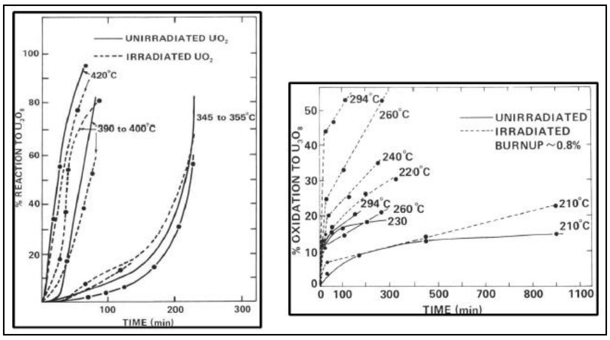

Fig. 3. UO_2 oxidation in air by temperature

With this result, the NRC states that fuel rods with only pinhole or hairline crack within 1mm can't contaminate the inside of dry storage canister. So they judged this fuel as "Defective but Undamaged" fuel.

3. Conclusions

Domestic nuclear fuel is based on the design of US type fuel, and domestic long-term storage management policy is similar with US policy. However, there's no clear definition or classification of damaged SNF in Korea. Therefore, we should develop a domestic standard in order to prepare dry storage by referring to the US standard.

Acknowledgement

This Research was funded by Korea Hydro and Nuclear Power Co. (KHNP) [Project Name: Long-term Management of LWR Damaged SNF for Dry Storage]
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