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Material Category of TRU Bearing Materials at SFR Fuel Fabrication Facility

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1. Introduction

According to the 6th Atomic Energy Commission of ROK government held in 2016, R&D project to develop SFR fuel fabrication technology using transuranic(TRU) metal ingot produced from pyro-processing facility will continue so that it is deployed at Gen-IV SFR and TRU metal fuel fabrication facility will be constructed by 2025 [1]. Fuel fabrication facility using TRU bearing material other than laboratory scale has not been constructed so far and there are no safeguards criteria for TRU metal fabrication facility. IAEA safeguards criteria only addresses the facility that handles MOX fuel composed of mixed plutonium and uranium dioxide. TRU material including higher contents of minor actinide has never been addressed in IAEA safeguards criteria. Therefore, safeguards approach for TRU metal fuel fabrication facility need to be developed.

Development of safeguards approach and measures applicable to TRU metal fuel fabrication facility begins with how to define TRU material in terms of safeguards since safeguards requirements depend upon the nuclear material category of the nuclear material [2].

In this paper, material category of TRU bearing material at SFR fuel fabrication facility has been reviewed in terms of safeguards as a starting point in facilitating development of safeguards approach for TRU bearing SFR fuel fabrication facility.

2. Safeguards Analysis on Material Category of TRU Bearing Materials

The feed nuclear material of SFR fuel fabrication facility are U and U/TRU metal ingot produced from pyro-processing facility. The process and product materials is metal in the form of U/TRU/RE/Zr. Basically U/TRU metal ingot and other material in the form of U/TRU/RE/Zr does not have much difference other than U contents because U/TRU metal ingot is melted and diluted by U metal ingot and Zr to meet required fuel specification. Therefore, analysis of material category in this paper is focused on the TRU material consisted of plutonium and other minor actinide regardless of different physical form in the fabrication process.

2.1 Material category of TRU material in reference documents

Direct use material refers to the nuclear material that can be used for the manufacture of nuclear explosive devices without transmutation or further enrichment [3]. Plutonium in spent reactor fuel fall into this category [3]. Therefore, it is obvious that plutonium bearing TRU material in which significant fission products have been removed from pyro-processing facility is direct use material.

However, there are different views on whether TRU material is irradiated or unirradiated material. Technical report of KINAC written by J.K. Jeon analyzed that U/TRU metal ingot is an irradiated direct use material so inspection frequency will be less than those of required at reprocessing facility. Main reason for that is time consuming to separate pure plutonium will be close to the time required to reprocess spent fuel considering essential equipment and process required to separate rare earth fission products from TRU material [4].

On the other hand, the IAEA mentioned frequency of inventory verification of pyro-process product material in State without broader conclusion is 12 times as plutonium from PUREX [5]. Even it didn't define directly material category of TRU material, it can be inferred that the IAEA views TRU materials as unirradiated direct use material given that timeliness goal for inventory verification is one month.

US DOE also describes the over-arching objective of metallic pyro-processing fuel fabrication line is the detection of the diversion of 8 kilograms of separated plutonium within one month of diversion [6].

2.2 Conversion time of TRU material

Conversion time is the time required to convert different forms of nuclear materials to the metallic components of a nuclear explosive device [3]. The conversion time estimates applicable at present are provided in table 1 [3].

According to the table 1, TRU material corresponds to category of Pu in other miscellaneous impure compounds. Then conversion time is maximum 3 weeks. Given that conversion time of Pu in irradiated fuel is minimum 1 month, less than 1 month of conversion time of TRU material is regarded as appropriate.

Unirradiated direct use material is direct use material which does not contains substantial amounts of fission products and it requires less time and efforts to be converted to component of nuclear explosive devices than irradiated direct use material such as plutonium in spent fuel that contains substantial amount of fission products [3].

Beginning material form	Conversion time
Pu, HEU or ^{233}U metal	Order of days (7-10)
PuO_2, $Pu(NO_3)_4$ or other pure Pu compound; HEU or ^{233}U oxide or other pure U compounds; MOX or other non-irradiated pure mixtures containing Pu, U(^{233}U+$^{235}U \geq$ 20%); Pu, HEU and/or ^{233}U in scrap or other miscellaneous impure compounds	Order of weeks (1-3)[a]
Pu, HEU or ^{233}U in irradiated fuel	Order of months (1-3)
U containing < 20% ^{235}U and ^{233}U; Th	Order of months (3-12)

Table 1. Estimated material conversion times for finished Pu or U metal components

Therefore, TRU materials of SFR fuel fabrication facility in which significant amount of fission product is removed from electro-refining and winning process of pyro-processing facility should be considered as unirradiated direct use material.

2.3 Material attractiveness of TRU material

Material category of the nuclear material is a function of the attractiveness level of the nuclear material with respect to use in nuclear explosive device [2]. In this section, material attractiveness of TRU material is discussed based on the previous studies.

LANL assessed attractiveness of material associated with a MOX fuel including TRU material using the following formula [7]:

$$FOM_1 = 1 - \log_{10}\left(\frac{M}{800} + \frac{Mh}{4500} + \frac{M}{50}\left[\frac{D}{500}\right]^{\frac{1}{\log_{10} 2}}\right) \quad (1)$$

- M = Bare critical mass (kg)
- h = Heat content (W/kg)
- D = Dose rate of 0.2M at 1 m (rad/h)
- S = Spontaneous fission neutron production rate (n/s/kg)

Figure 1 shows the effect of diluting TRU from UREX with incremental fractions of the lanthanides in spent fuel ranging from zero to one using FOM_1. The retention of the lanthanides with TRU reduces the FOM_1 but the FOM_1 decrease with increasing burn-up [7].

Figure 2 shows FOM_1 for a range of mixtures of U, TRU and fission products from conceptual advanced pyro-process recycle facility [7]. Addition of increasing quantities of either U or fission products reduces the FOM_1.

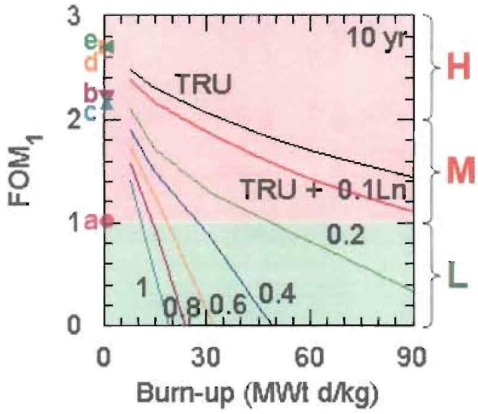

Figure 1. The FOM1 of TRU plus various fractions of the Lanthanides in Spent Fuel ranging from 0 to 1 Versus Burn-up

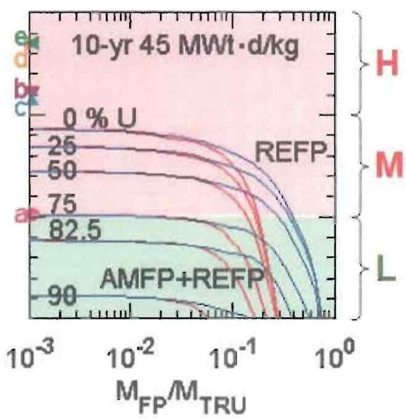

Figure 2. the FOM_1 of PYROX material Versus ratio of fission product mass to TRU mass for various Uranium concentrations (%)

LANL concluded that the TRU bearing product displays the same characteristics as UREX TRU and TRU + Ln, which are potentially attractive for use in a nuclear weapon or nuclear explosive device.

Target	U.S. NRC (proposed)	U.S. DOE	FOM_1
	A-C	A-E	Value (B-E)
Spent fuel	B	D	-∞ (E)
U ingot	C	E	-∞ (E)
TRU ingot	A	B	~1.5 (C)

Table 2. Attractiveness level results when applied to pyro-processing

Chanki Lee et al, compared attractiveness level of pyro-processing materials using several approaches. Table 2 [8] shows the results of the attractiveness level analyses. He concluded that all methods consistently indicate that TRU ingots are the most attractive target in pyro-processing [8].

Based on the previous studies, TRU materials that are attractive for use in nuclear weapon is analyzed as category I material according to the INFCIRC 225/Rev.5. and it is certain that category I material needs the high level of safeguards to protect against unauthorized removal of nuclear material.

3. Conclusions

The material categorization is the basis for safeguards nuclear material against diversion of nuclear material that could be used in a nuclear explosive device. Material category of TRU bearing materials are review in terms of safeguards. The IAEA and U.S. DOE view TRU material as unirradiated direct use material. Conversion time of TRU material is less than one month. TRU material is classified into category I by material attractiveness. Overall TRU bearing material at SFR fuel fabrication facility is defined as unirradiated direct use material in safeguards point of view. Therefore, safeguards approach for SFR fuel fabrication facility using TRU material should be developed based on the material category of TRU as unirradiated direct use material.

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