Compararisons on Categorization Criteria of Nuclear Facilities Based on Radiological Effects

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1. Introduction

There have been constructed and operated a lot of nuclear facilities, including nuclear power plants, research and test reactors, or fuel cycle facilities. Prior to construction and operation of these facilities, licensees should prepare and submit safety analysis reports to obtain regulatory approvals. In addition, radiological emergency preparedness and response plans should be established based on contents of safety analysis reports. In order for that, radiation doses to workers or public should be assessed in case of emergency scenario of nuclear facilities from potential release among radionuclide inventories. Here, different emergency response would be expected for each licensed facility. Such variety in radiological hazards of nuclear facilities has been categorized in a graded manner by different regulatory bodies. In this paper, such categorization methods for nuclear facilities were investigated and compared, which have been suggested by the International Atomic Energy Agency (IAEA) [1, 2], Nuclear Regulatory Commission (NRC) [3] and Department of Energy (DOE) [4, 5] of U.S.

2. Facility categorization methods

IAEA and U.S. define emergency classes, including alert, site area emergency, and general emergency. Each class corresponds to possibilities of radiological effects near facility, on-site, and off-site, respectively. Accordingly, in terms of facility requirements on emergency preparedness, U.S. DOE (DOE-STD-1027 [4, 5]) defines Hazard Categories 1—3, while IAEA GS-G-2.1 [1] defines Threat Category I—V. Each category of a facility implies a possible emergency class.

Quantitative criteria (thermal power and radionuclide inventory) for categorization of nuclear reactors and other nuclear facility types (e.g., fuel cycle facilities), which were set based on reasonably conservative assumptions, are shown in Tables 1 and 2. TQ refers to threshold quantity for given radionuclides, and U.S. DOE defines individual TQs for Hazard Categories 2 and 3. Notably, a nuclear reactor cannot be classified as level below Threat Category III or Hazard Category 2. It means that release of nuclear materials in a nuclear reactor would have possibility to make onsite radiological effects regardless of thermal power. Radionuclide inventory criteria for other facility types are not applicable to all categories.

Table 1. Categorization criteria for nuclear reactor.

Possible Radiological Effects	IAEA		U.S. DOE	
	Threat Category	Thermal Power (MW)	Hazard Category	Thermal Power (MW)
Off-site	I	> 100	1	≥ 20
	II	> 2 & ≤ 100		
On-site	III	≤ 2	2	< 20

Table 2. Categorization criteria for other nuclear facility types.

Possible Radiological Effects	IAEA		U.S. DOE	
	Threat Category	Nuclide Inventory	Hazard Category	Nuclide Inventory
Off-site	I	10^4 A/D_2	1	N/A
	II	10^2 A/D_2		
On-site	III	10^{-2} A/D_2	2	Category 2 TQ
Near Facility	N/A		3	Category 3 TQ

Because above categorization criteria are applicable to judge facility with possible onsite radiological effects, these criteria were compared and analyzed in detail.

3. Comparison of categorization criteria

Firstly, categorization criteria for reactor thermal power are 10 times larger for U.S. DOE than IAEA, which means that U.S. DOE has relevantly higher upper limit in nuclear fuel inventory. Applying empirical inverse square law in terms of radiological dispersion tendency, U.S. DOE facilities could have about 3.2 times farther emergency planning distance range than those of IAEA at maximum, assuming same dose criteria.

Other than nuclear reactor facilities, categorization criteria for radionuclide inventory are based on derived radioactivity values such as A/D_2 and TQs. These values are summarized in Table 3. U.S. NRC radionuclide inventory criteria to require emergency preparedness, based on 10 mSv effective dose at site boundary, were additionally referenced in NUREG-1140 [3].

Table 3. Radionuclide inventory criteria (in Bq) for major selected radionuclides.

Radionuclide	IAEA	U.S. NRC	U.S. DOE
H-3	2.00E+13	7.40E+14	1.11E+16
C-14	5.00E+11	1.85E+15	5.18E+16
Co-60	3.00E+11	1.85E+14	7.03E+15
Sr-90	1.00E+10	3.33E+12	8.14E+14
I-131	2.00E+09	1.85E+11	6.66E+13
Xe-133	2.00E+12	3.33E+16	6.66E+16
Cs-137	2.00E+11	1.11E+14	3.29E+15
U-238	Unlimited	3.70E+11	8.88E+12

A total of 8 radionuclides were selected and compared based on their radiological importance. The maximum differences between methods were up to above 10^6 times. In most cases, IAEA categorization criteria were the strictest, and those of U.S. DOE were the most relaxed. Although above criteria were all derived to categorize nuclear facilities which have potentials for onsite emergency, variety in radionuclide-specific values arose from intrinsically inconsistent assumptions in radiation exposure pathways (Table 4).

For example, IAEA set A/D_2 values from 4 exposure scenarios from indoor release of dangerous sources that can affect workers [2]. In contrast, both U.S. categorization criteria were calculated from atmospheric dispersion of released radionuclides that can affect public at distances from facility. IAEA and U.S. methods have adopted different release fraction, dose criteria, and dose conversion coefficient.

Table 4. Assumptions for derivation of radionuclide inventory criteria.

	IAEA*	U.S. NRC	U.S. DOE
Pasquill Stability Class	Indoor Release Scenario (10^3 larger coefficient than [3])	F	D
Wind Speed (m/s)		1	4.5
Inhalation Rate (m^3/s)		2.66E-4	3.5E-4
Release Fraction	10^{-1}**	10^{-4}~10^{0}	10^{-3}~10^{0}
Dose Criteria (mSv)	10~100***	10	
Dose Conversion Coefficient	ICRP-60	ICRP-26	

* Model parameter values in inhalation scenarios.
** Except exposure scenarios from contamination by noble gases.
*** RBE-weighted red marrow absorbed dose.

While both are conservative, U.S. NRC and U.S. DOE assumed different atmospheric conditions. U.S. DOE modified U.S. NRC assumptions for atmospheric conditions after technical consideration of inaccuracy in Gaussian plume dispersion model and generally different site boundary of licensed facilities between two institutes. Material release rates for each chemical type were also updated to be relatively practical and simplified.

4. Conclusion

In this paper, hazard categorization methods for nuclear facilities were investigated and compared. IAEA, U.S. NRC, and U.S. DOE methods had different categorization criteria from each other because of different upper range settings, exposure scenarios, and environmental conditions for radiological release and dispersion from inventories. Even though these are set based on technical considerations, such findings imply that calculation results for same facility would be largely different. Thus, in order for these methods to be effective, model parameter values should be adjusted carefully in a site-specific way. Verification of methods by comparison with computer codes and experimental results, as well as emergency action levels, would be necessary.

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