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REVIEW OF DOSE CRITERIA FOR TRANSPORTATION OF PACKAGES IN KOREA

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ABSTRACT

Radioactive materials packages are classified into Type-L, Type-IP, Type-A, Type-B, Type-C, Fissile material and Uranium Hexafluoride packages in Korea. Transportation of packages may result in radiation dose to nearby residents. In order to transport packages, it is necessary to establish radiological criteria. In Korea, dose criteria were established as for Type-L, Type-A, Type-B(U) and Type-C packages. The objective of this study is to review the dose criteria for the packages and packaging in Korea. In Korea, dose criteria for the packages and packaging is specified in Nuclear Safety and Security Commission Notice(NSSC) 2017-56. Dose level under routine conditions of transport shall not exceed 2 mSv/h at surface, and 0.1 mSv/h at 2 m from packages or overpacks. For Type-L package, dose level at surface shall not exceed 5 μSv/h which is a requirement for the Type-L packaging. The packaging Type-B and Type-C have to meet the requirement 10 mSv/h at 1 m from the surface of the package after specified test which is to ensure the package retain sufficient radiation sheilding in the accident conditions. The worldwide countries applies IAEA rationale and regulations for the safe transport of radioactive material. However, differences with the laws and regulation systems for safe transport packages of each countiries were identified. IAEA recommanded radiation dose rate level by following reason. For excepted package, the 1961 Edition of the Transport Regulation set in 0.1 mSv from 0.15 mSv which is a radiation detection limit with sensitive x-ray film. For Type-A package, 2 mSv/h at surface is derived calculatively by considering transport index and criticality safety index. For Type-B(U) package, recommanded level would retain sufficient shielding to ensure with the maximum radioactive contents that the package is designed to contain. For Type-C package, provides similar levels of protection for the air mode when compared to a Type-B(U) package in a severe surface mode accident. This study reviewed the dose criteria and rationales of other countries and IAEA Regulation for the Safe Transport. Based on this information, it will contribute to improve the regulatory system in accordance with the transportation of radioactive material in Korea.

INTRODUCTION

International Atomic Energy Agency (IAEA) specifies the transport packages used to transport radioactive materials and sets requirements for each package [1]. IAEA has provided the requirements that must be met for radioactive material packages to protect persons, property, and the environment from the effects of radiation when transporting radioactive materials and to ensure safety. These requirements include (1) containment of radioactive contents, (2) control of external radiation dose, (3) prevention of dangerous conditions, and

(4) prevention of heat damage. In addition, the IAEA proposed the following 3 actions to achieve these 4 requirements: (1) The performance criteria should be applied to the packages. (2) The maintenance conditions should be applied to the packages in consideration of the characteristics of the radioactive contents. (3) The approval procedure for the packages should be passed within the regulations of each country. Therefore, the IAEA categorized transport packages based on the physical form and radioactivity of the radioactive contents and provided requirements for each type of transport. Internationally, each country has established and operates technical criteria for radioactive material on the rationales of the above principles.

The regulatory framework for the transport of radioactive materials is important to maintain coordination between international organizations and countries for the ease of transport of packages. The regulatory framework for domestic transport package has been established with reference to international organizations and international regulatory systems to maintain international harmonization. However, there is a lack of research on the rationale for each criteria. Therefore, in order to establish a safety regulation system for the transport packages in accordance with the international criteria, it is necessary to investigate overseas criteria and to analyze the rationale of the establishment.

The technical criteria for radioactive materials in Korea include radiation dose rate criteria, radioactivity criteria, and load criteria. The scope of this study is the dose rate criteria applicable to general criteria, Type-L, Type-IP, Type-B, and Type-C packages. In this study, current criteria of radiation dose were investigated and the rationales of the criteria were analyzed.

INVESTIGATION ON DOMESTIC PACKAGE DOSE CRITERIA

In Korea, dose criteria for the packages were specified in Nuclear Safety and Security Commission Notice (NSSC) 2017-56. Table 1 shows radiation dose criteria for radioactive material package written in korean law. The radiation dose level under routine conditions of transport shall not exceed 2 mSv/h at surface, and 0.1 mSv/h at 2 m from packages or overpacks. For Type-L package, the radiation dose level at surface shall not exceed 5 μSv/h which is a requirement for the Type-L packaging. The packaging Type-B and Type-C have to meet the requirement 10 mSv/h at 1 m from the surface of the package after specified test which is to ensure the package retain sufficient radiation shielding in the accident conditions.

Table 1. Radiation dose criteria for radioactive material package in Korea

Package type	Dose criteria	Condition
General transportation criteria	2 mSv/h	Surface
	0.1 mSv/h	Apart 1 m from surface
	10 mSv/h	Surface (exclusive use)
Type-L package	5 μSv/h	Surface
Type-B, C packages	10 mSv/h	Apart 1 m from surface (after specified test)
Type-IP package	10 mSv/h	External radiation level at 3 m from the unshielded material or object

INVESTIGATION ON OVERSEAS PACKAGE DOSE CRITERIA

Generaly, most countries applies IAEA rationales and regulations for the safe transport of radioactive material. However, differences with the laws and regulation systems for safe transport packages of each country were identified. In this section, radiation dose criteria for the IAEA, the US and Japan were reviewed.

IAEA

The IAEA proposed dose criteria for radioactive material transport packages in IAEA SSR-6. Package type criteria in Korea, the US, Japan are similar with those proposed by IAEA. Table 2 shows IAEA dose criteria for radioactive material package.

Table 2. IAEA dose criteria for radioactive material package [1]

Package type	Dose criteria	Condition
General transportation criteria	2 mSv/h	Surface
	0.1 mSv/h	Apart 1 m from surface
	10 mSv/h	Surface (exclusive use)
Excepted package	5 μSv/h	Surface
Type-B, C package	10 mSv/h	Apart 1 m from surface (after specified test)
Type-IP package	10 mSv/h	External radiation level at 3 m from the unshielded material or object

United States

In the US regulatory system, package type of excepted package is equivalent to the Type-L package in Korea. In addition, Type-C package is not classified in the classification system. Therefore, U.S. regulation doesn't define Type-C package criteria. Table 3 shows U.S. dose criteria for radioactive material package.

Table 3. U.S. dose criteria for radioactive material package [2]

Package type	Dose criteria	Condition
General transportation criteria	2 mSv/h	Surface
	0.1 mSv/h	Apart 1 m from surface
	10 mSv/h	Surface (exclusive use)
Excepted package	5 μSv/h	Surface
Type-B package	10 mSv/h	Apart 1 m from surface (after specified test)
Type-IP package	10 mSv/h	External radiation level at 3 m from the unshielded material or object

Japan

In Japan regulatory system, Type-C package is not classified in the classification system. Therefore, The Japan regulation doesn't define Type-C package criteria. Table 4 shows the Japan dose criteria for radioactive material package.

Table 4. Japan dose criteria for radioactive material package [3]

Package type	Dose criteria	Condition
General transportation criteria	2 mSv/h	Surface
	0.1 mSv/h	Apart 1 m from surface
	10 mSv/h	Surface (exclusive use)
Type-L package	5 μSv/h	Surface
Type-B package	10 mSv/h	Apart 1 m from surface (after specified test)
Type-IP package	10 mSv/h	External radiation level at 3 m from the unshielded material or object

Comparison

In the case of the radiation dose criteria of domestic radioactive materials package, they are substantially similar to the technical criteria of the IAEA, the US, and Japan. However, the IAEA and the United States managed as excepted package which meets the same packaging conditions for domestic Type-L packages. Also, in the US and Japan regulatory systems, Type-C package is not classified in the classification system. Therefore, the US and Japan regulations do not define Type-C package criteria.

ANALYSIS RATIONALES FOR SETTING THE TRANSPORT PACKAGE DOSE CRITERIA

Korean radioactive material transport package dose criteria was established based on the IAEA criteria. The rationales for setting the radiation dose rate criteria for radioactive material packages set by the IAEA were specified in the published report [4].

General transportation criteria

The IAEA has stated that the radiation dose rate on the outer surface of the package should not exceed 2 mSv/h. The IAEA has established the above provisions to reduce unnecessary or uncontrolled radiation exposure during the transport process [4]. The criteria was established based on the IAEA's assessment of the radiological impact of transporting radioactive materials and the results of surveys conducted by transportation worker [5]. As a result of the surveys carried out by transportation worker, it was found that the workers who carried out major works related to transportation at the pier were exposed from the packages for the longest time. The workers were estimated to perform the following tasks: unscrew the bolts to separate the packages from the train, perform measurements at 2 m from the surface of the package, and attach the crane beam to the package. It was noted that these tasks took 30 minutes per day to perform. When the radiation dose was assessed by the data, it was considered that transport worker carrying such packages for 30 minutes a day, held close to the body, would not exceed the permissible dose of 1 mSv per 8 hour working day. Following equation shows calculation of 2 mSv/h on surface criteria:

$$1\ \text{mSv/day} \div \frac{1}{2}\ \text{hour/day} = 2\ \text{mSv/hour} \qquad \text{(Eq. 1)}$$

The IAEA proposed that the radiation dose rate at a point 1 m from the outer surface of the package should not exceed 0.1 mSv per hour. IAEA has set out the rationale for setting the packaging criteria of the package at a distance of 1 m from the external surface in the IAEA TS-G-1.1 report. According to the document, the radiation dose rate criteria were set

considering the influence of the undeveloped x-ray film rather than considering the radiation effects of the human body.

In 1947, a research study found that the criteria of radiation dose to fogging the x-ray film after developing unexposed x-ray film due to radiation was 0.15 mSv. Therefore, the 1961 regulation of the IAEA proposed that the maximum exposure time of 24 hours for the transport of radioactive materials should not exceed 0.1 mSv. The radiation dose rate of 0.1 mSv/h was set at 1 m based on a distance of 4.5 m (15 feet) and a transport time of 24 hours between the general radium containing parcels and the ordinary parcels used in 1947 by the US railroad company Express Company. That is, a radiation dose rate of 0.1 mSv/h at 1 m is calculated to be equivalent to a radiation dose of 0.1 mSv at 4.5 m for 24 hours. Following equation shows calculation of 0.1 mSv/h on 1 m from the surface criteria:

$$0.1\ \text{mSv} \div 24\ \text{hour} \times \left(\frac{4.5\ m}{1\ m}\right)^2 \cong 0.1\ \text{mSv/hour} \qquad \text{(Eq. 2)}$$

The IAEA has stated that in the case of exclusive transport, the radiation dose rate on the outer surface of the package should not exceed 10 mSv per hour [1]. To convert a distance of 0.1 mSv/h from the distance of 1 m to a distance of 10 cm, the distance is reduced to 1/10. Therefore, the radiation dose rate is 100 times higher according to the law of reciprocal of distance and dose. Following equation shows calculation of 10 mSv/h on surface in the case of exclusive transport criteria:

$$0.1\ \text{mSv/hour} \times \left(\frac{1\ m}{0.1\ m}\right)^2 = 10\ \text{mSv/hour} \qquad \text{(Eq. 3)}$$

Criteria on Type-L package

IAEA TS-G-1.1 report specifies the rationale for the calculation of packaging criteria for Type-L package. Limitations on the radiation dose rate of excepted packages are derived based on the handling procedure of the package, and exposure time of the film.

The dose criteria for the surface of excepted package was set considering the influence of the unexposed photographic film rather than the radiation effect of the human body. As a result of evaluating the radiation effect on the x-ray film in 1947, it was confirmed that when the radiation dose exceeding 0.15 mSv, the film becomes fogging after the development. This phenomenon was judged to interfere with the use of the film and make a false diagnosis.

According to the 1961 edition of the transportation regulations, a dose limit of 0.1 mSv was set for exposure time of up to 24 hours, which was the time when the package is transported by train to avoid fogging after film development. In the calculation, the criteria of 0.005 mSv/h were set as the limit of radiation dose rate by rounding the applied exposure time of 24 hours to 20 hours. Following equation shows calculation of 0.005 mSv/h on surface criteria:

$$0.1\ \text{mSv} \div 20\ \text{hour} = 0.005\ \text{mSv/hour} \qquad \text{(Eq. 4)}$$

Criteria on Type-B package

IAEA TS-G-1.1 specifies the technical criteria of the Type-B package. According to the document, the 1973 revised edition of the regulations stipulated that the radiation level at 1 m from the surface of a Type-B package should not exceed 100 times the value that existed before the accident condition tests, had the package contained a specified radionuclide. This requirement constituted an unrealistic design constraint in the case of packages designed to carry other radionuclides. Therefore, since the 1985 edition of the regulations, a specific maximum radiation level of 10 mSv/h has been stipulated, irrespective of radionuclide.

Previously, the maximum radiation level in the design of the package was set at the surface of the package and at a distance of 1 m. However, after the test for the accident condition has been carried out, when the package is loaded at the maximum permissible concentration, it shall not exceed the limit of 10 mSv/h at a distance of 1 m from the surface.

Criteria on Type-C package

According to the IAEA TS-G-1.1, the Type-C package provides a similar level of protection compared to serious accidents of the Type-B package. To achieve this goal, limitations on the radiation dose rate and the radioactivity of the contents were required for Type-B accident conditions and Type-C tests. Therefore, the technical criteria of the Type-C package is set to be the same as the technical criteria of the Type-B package.

It was judged that it would not exceed the limit of 10 mSv/h at a distance of 1 m from the surface when the package was loaded at the maximum allowable concentration after the test for the accident condition was carried out, and the applicable regulation would be sufficient to manage it.

Criteria on Type-IP package

The technical basis of criteria for Type-IP packages are specified in the IAEA technical basis for the IAEA regulations for the safe transport of radioactive material. Since the AG-144 advisory group meeting in 1977 was specified that low-level solid radioactive materials and low specific activity (LSA) materials which have low specific activity, so that the amount of radioactivity that can cause serious radiation risks under any circumstances during transport will not be absorbed to human. Therefore, it was pointed out that carrying out collision tests on low-level solid radioactive materials and packages containing LSA materials could lead to loss of shielding. Therefore, it was judged that it would be appropriate to add a restriction on external radioactivity, rather than requiring a special inspection for the two materials. Consequently, it was recommended not to exceed the radiation dose rate of 1 rem/h (10 mSv/h) at a distance of 3 m from the package so that it could be protected from excessive radiation level after the accident.

Criteria were set to ensure adequate radiation protection of the Type-IP package when an accident occurs. In the event of an accident, it is expected that the level of external exposure radiation dose will not increase significantly due to geometric changes in LSA materials and surface contaminated objects (SCO). As a result of the accident of the Type-IP package, it was essentially the same as the result of the accident involving the Type A package. The content of the Type A package is limited to the value of A_1, which is based on an external exposure dose rate of 100 mSv/h at a distance of 1 m. Following equation shows calculation of 10 mSv/h on 3 m from the surface criteria:

$$100\ \text{mSv/hour} \times \left(\frac{1\ m}{3\ m}\right)^2 \cong 10\ \text{mSv/hour} \qquad \text{(Eq. 5)}$$

The dose rate of 100 mSv/h at 1 m separation distance, which is the package contents of the Type-A package, was set considering the accidental radiological results. At the time of the accident, a reasonable assumption that a person would not be left for more than 30 minutes at a distance of 1 m from a damaged package was set to not exceed an effective dose of 50 mSv. Following equation shows calculation of 100 mSv/h on 1 m from the surface criteria:

$$50\ \text{mSv} \div 0.5\ \text{hour/accident} = 100\ \text{mSv/hour} \qquad \text{(Eq. 6)}$$

Conclusion

The regulatory framework for domestic radioactive material package has been established with reference to the regulatory framework of international organizations and foreign countries in order to maintain international harmony. However, there is a lack of research on the rationale for each criterion. Therefore, in order to establish a safety regulatory framework for transports that meets international criteria and is suitable for domestic situations, it is necessary to investigate the rationale of criteria and compare criteria with foreign countries. Therefore, in this study, the domestic radioactive material transportation criteria were investigated, and the rationales of the criteria were analyzed.

In the case of the radiation dose criteria of domestic radioactive materials package, they are substantially similar to the technical criteria of the IAEA, the US, and Japan. However, In the IAEA and the US regulatory system, package type of excepted package is equivalent to the Type-L package in Korea. In addition, in the US and Japan regulatory system, Type-C package is not classified in the classification system. Therefore, the US and Japan regulations do not define Type-C package criteria.

For the surface dose rate of 2 mSv/h, the criterion was established based on the results of the surveys conducted by the transport operators and the evaluation of the radiological effects of the transport of radioactive materials. At the point of 1 m from the outer surface of the package, the radiation dose rate criteria were set considering the effect of the unexposed x-ray film rather than considering the radiation effects of the human body. In the case of exclusive transport, the radiation dose rate at 1 m from the surface was converted to a distance of 10 cm from the package.

Radiation dose criteria for Type-L package criteria was set considering the effect of undeveloped x-ray film rather than considering the radiation effects of the human body. Type-B package criteria for the specific nuclide in the 1973 edition of the IAEA SSR-6 report was found to be unrealistic, and in the 1985 revision, the regulation was revised and set as the current regulatory criteria. Type-C package criterion provides the same level of protection as the Type-B package, so the same technical criteria as the Type-B package have been established. Technical criteria for Type-IP material are to be used for LSA materials and SCO which has low risk. Therefore, it was recommended not to exceed the radiation dose rate of 1 rem/h (10 mSv/h) at a distance of 3 m from the package so that it could be protected from excessive radiation level after the accident.

In this study, the status of technical criteria related to the transport of radioactive materials in Korea was investigated, and the rationales of the technical criteria were analyzed. It is expected that this rationale analysis data can be used to meet the criteria set by the international organizations and to amend the technical criteria to suit the domestic environment.

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