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Radiological Risk Analysis on D-UF6 Sampling System

Jeong-Guk Kim *, San Chae, Jongjin Kim, and Won-Hyuk Jang
Korea Atomic Energy Research Institute, Integrated Radwaste Management Center
989Bungil 111, Daedeokdaero, Yuseong-gu, Daejeon, 305-353, Korea
**Corresponding author: jungkim@kaeri.re.kr*

1. Introduction

Korea Atomic Energy Research Institute (KAERI) has a plan to stabilize the depleted UF_6 (D-DF_6), which has been stored since 1980s, into more stable forms such as oxide [1]. The total amount of about 185 tons has been managed in sixteen 48Y-type cylinders. The defluorination of D-UF_6, which is one of the most promising stabilization processes, needs the sampling operation to check the state of 48Y cylinders and the isotopic composition of D-DF_6 for safety analysis regarding to transportation. Therefore, a radiological risk analysis according to the designed sampling system has been reviewed by modeling and analytical calculation in this article.

2. Sampling System

The sampling system was designed to sample only several grams of D-UF_6 from the 48Y cylinder. The D-UF_6 is stored as an equilibrium state of gas-solid under room temperature condition. So, a small amount of D-UF_6 can be sampled by using cold trapping from 48Y cylinder.

Sampling process is composed of 3 steps; 1) pre-sampling step, 2) sampling step, and 3) post-sampling step. Sampling will be performed in mockup building, which is now storing the D-UF_6 cylinder. A process block diagram of sampling system is shown in Fig. 1. The volumes of Box-1 and Box-2 are 55 m^3 and 90 m^3, respectively.

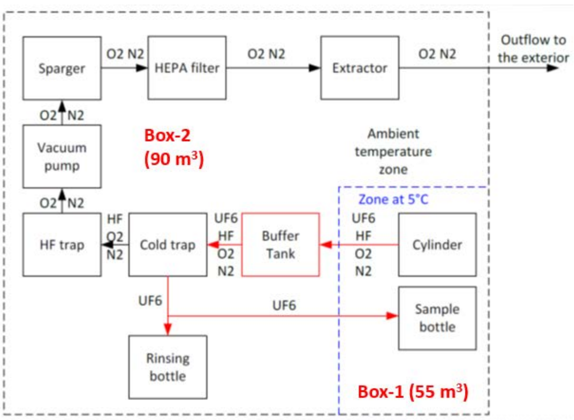

Fig. 1. Process block diagram of sampling system.

3. Radiological Risk of Sampling System

The sampling system has three kinds of risk classifications such as nuclear risks, internal non-nuclear risks, and external non-nuclear risks [2]. Each risk has 3, 6, and 7 sub-risks, respectively. Among those 16 risks, the most important risk is considered as the risk of dispersion of radioactive and toxic substances.

The dispersion of radioactive substances may be come from leakage scenarios resulting from a single failure (operator failure) or a failure of equipment containing D-UF_6. Some of these scenarios are considered as follows:

- the leak from a cylinder after connection or disconnection with the needle valve open,
- the leak from a transfer pipe with D-UF_6 at sub-atmospheric pressure inside a box.

The scenario is relating to leak in Box-1, when a cylinder is connected or disconnected with needle valve open. If a needle valve in a cylinder is opened directly to the atmosphere inside the box, the D-UF_6 leakage flow would be zero, and then reach an equilibrium rapidly.

In the case of a leak with the needle valve open, and assuming a failure of the air extraction system, the mass of D-UF_6 obtained inside the box after several hours will be reached at an equilibrium state.

4. Modeling and Risk Analysis

4.1 Modeling

After several hours, the model for Box-1, where connected directly to 48Y cylinder, so would be most high activity when the cylinder is connected or disconnected with needle valve open, can be represented as shown in Fig. 2. This scenario means that the needle valve is opened directly to the atmosphere inside the Box-1, and then the UF_6 leakage flow through the orifice would be zero during the first minute, and would reach equilibrium within a few minutes at about 9 mg/min. Box-1 has a volume of 55m^3 and a renewal rate of 2 (air renewal takes place through the cleaning ducts at a rate of 90 m^3/h).

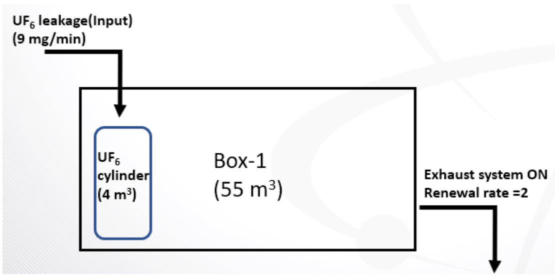

Fig. 2. Model description for leak in Box-1.

The mass balance of the model can be expressed as Equation (1).

$$V \frac{dC(t)}{dt} = Q_{in}C_{in} - Q_{out}C_{out} \quad (1)$$

where, V [m^3] is the volume of Box-1, C [mg/m^3] is the concentration of D-UF_6, Q [m^3/min] is the air flow rate, and the subscripts “in” and “out” mean input and output streams, respectively. In equilibrium state, Q_{in} is almost the same as Q_{out}, and $C(t)$ is also the same as C_{out}, so the solution of Equation (1) is shown as Equation (2).

$$C(t) = K_1\ (1 - exp(-K_2\ t)) \quad (2)$$

where, K_1 [mg/m^3] and K_2 [min^{-1}] mean the linear factor coefficient and the exhausting flowrate factor coefficient, respectively.

4.2 Risk analysis

After about 3 hours of leakage, the concentration of D-UF_6 in Box-1 reaches a maximum concentration of 0.177 mg/m^3, which is equivalent to 1,077 Bq/m^3, and then this equilibrium state continues, as shown in Fig. 3. According to attached Table 3 of the Standards for Radiation Protection, in Notification of the Nuclear Safety and Security Commission [3], the annual limit on intake (ALI) for radioactive nuclide U-234, 235, 236, and 238 is 30,000 Bq/m^3. For maximum operation time for 3 months (about 500 hours), the radioactivity in Box-1 due to leakage is calculated as 1,077 Bq/m^3, only 3.6 % of ALI. The derived air concentration (DAC) in Box-1 is calculated as 4.425 Bq/m^3, which is 44 % of the permissible limit in the notification.

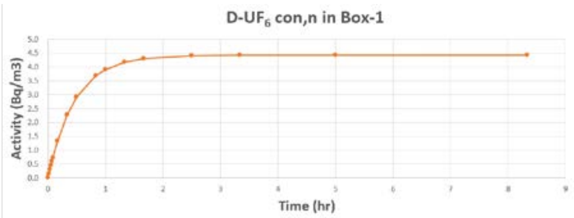

Fig. 3. D-UF_6 concentration in Box-1 after leakage.

5. Conclusions

A radiological risk analysis was performed on the sampling system necessary for stabilizing D-UF_6, which has been stored for decades. This sampling system has a risk such as the leak from a cylinder after connection or disconnection with the needle valve open or from a transfer pipe with D-UF_6 at sub-atmospheric pressure inside a box. These risks were modeled and analyzed, resulting in less than 5% of ALI and 45% of DAC.

REFERENCES

[1] Choi, J.-W. et. al., “Consideration on the Stabilization Method of D-UF_6”, KAERI/RR-4267/2017, 2017.

[2] G. Marge, Jc Schiano De Cola, C. Comte, “Safety Evaluation-KAERI –Detailed design”, ORANO, 2020.

[3] Nuclear Safety and Security Commission (NSSC), “Standards for Radiation Protection”, Notification No. 2019-10, NSSC, 2019.