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**Source Term Evaluation for UF₆
Release Event in Feed Facility
at Gaseous Diffusion Plants**

S. H. Kim
R. P. Taleyarkhan

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**SOURCE TERM EVALUATION FOR UF_6 RELEASE EVENT
IN FEED FACILITY AT GASEOUS DIFFUSION PLANTS**

prepared by

S.H. Kim
R.P. Taleyarkhan
Engineering Technology Division
Oak Ridge National Laboratory

Prepared by the
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831-8045
managed by
LOCKHEED MARTIN ENERGY SYSTEMS, INC.
for the
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SOURCE TERM EVALUATION FOR UF_6 RELEASE EVENT IN FEED FACILITY AT GASEOUS DIFFUSION PLANTS

ABSTRACT

An assessment of UF_6 release accidents was conducted for the feed facility of a gaseous diffusion plant (GDP). Release rates from pig-tail connections were estimated from CYLIND code predictions, whereas, MELCOR was utilized for simulating reactions of UF_6 with moisture and consequent transport of UO_2F_2 aerosols and HF vapor through the building and to the environment. Two wind speeds were utilized. At the high end (Case 1) a wind speed of $\sim 1\text{ m/s}$ (200 fpm) was assumed to flow parallel to the building length. At the low end (Case 2) to represent stagnant conditions a corresponding wind speed of 1 cm/s (2 fpm) was utilized. A further conservative assumption was made to specify no closure of crane and train doors at either end of the building. Relaxation of this assumption should provide for additional margins. Results indicated that, for the high (200 fpm) wind speed, close to 66% of the UO_2F_2 aerosols and 100% of the HF gas get released to the environment over a 10-minute period. However, for the low (2 fpm) wind speed, negligible amount ($\sim 1\%$ UO_2F_2) of aerosols get released even over a 2 hour period.

1. INTRODUCTION

All cascade feeding is performed by transferring UF_6 gas from a cylinder through a heated line into the appropriate point in the cascade that contains the same assay material as the material being fed. The feed material is received in a large cylinder which is placed in steam-heated autoclaves during feed operations. The feed facility houses multiple autoclaves and allows the train to port UF_6 cylinders in and out of the building. Also the crane moves in and out of the building to transfer cylinders between the building and outdoor storage lot. To allow this train and crane access, large openings with motor-operated rolling doors are installed on both sides of the building, as seen in Fig. 1. Figure 2 illustrates a simplified plan view of X-343 at the Portsmouth Gaseous Diffusion Plant. As seen in the figure, the building is 140-foot long, 63-foot wide, and about 43.3-foot high. There are auxiliary facilities attached on the side of the building such as men's and women's locker rooms, electrical room, and air-conditioned operator room. The X-343 facility contains seven steam-heated autoclaves. All seven units are designed for feed or vapor-phase sampling operations, and are connected to the cascade feed headers. Three of the seven autoclaves have seven-foot diameters and the remaining four autoclaves have six-

foot diameters. If a cylinder requires sampling, it is picked up with the overhead crane and placed into a feed and sampling autoclaves. The cylinder is then heated, sampled, weighed, and returned to storage with the overhead cylinder. After analysis of samples is done, cylinders are sequentially moved to one of the feed autoclaves where they are heated, the cylinder contents (UF_6) are vaporized, and transferred to the cascade through a manifold system of three feed headers, metering stations, and cascade feed piping. A flexible piping, called "pigtail", is provided between the cylinder and a manifold system of feed headers. This pigtail connection is the most vulnerable piece of equipment in the UF_6 feed operations. More than one-half of all major UF_6 releases have occurred at the pigtails. For the current study, therefore, UF_6 is assumed to be released through broken pigtails to the atmosphere in the feed facility.

2. MODELING DESCRIPTION

UF_6 was assumed to be released through 0.875"-dia broken valve fitting on a pigtail from the cylinder of which internal pressure was about 88 psia and vapor temperature was 240F. The transient mass rate of UF_6 release was calculated by R. Schmidt using the CYLIND code for 5-min and 30-min releases. For the current study, however, only a 5-min release case has been considered. Because of the large pressure difference between internal cylinder pressure and atmospheric pressure, the code predicted UF_6 vapor release as choked flow. As seen in Figure 3, UF_6 was predicted to be released as vapor at about 1.7 ~ 2 kg/s (~4.5 lb/s) over a 5-min period. Once the UF_6 vapor is released, because of the choked condition at the break, it will rather widely spread out, and interact with atmospheric moisture while seeking the lowest elevation to settle down because it is much denser than air (~12 times as dense). Unreacted UF_6 vapor will settle down on the floor while reaction products, UO_2F_2 and HF, will become buoyant, separated from the unreacted UF_6 vapor cloud, and entrained with bulk air flow. If heat loss from the UF_6 vapor cloud to the floor is significant, the UF_6 vapor will be partially aerosolized and fall down on the floor. At the same time, the UF_6 vapor cloud will experience a chemical reaction with atmospheric moisture at its surface, and thus continuously be stripped off by overlying air flow. However, in our case, the rate of UF_6 vapor release is rather small, and the cloud is expected to spread widely. It is expected, therefore, that most of the released UF_6 vapor get reacted with atmospheric moisture in the course of spreading and settling

down on the floor.¹ Even if a layer of UF_6 vapor cloud forms on the floor, its heat transfer characteristics to the surroundings (including the floor) is very poor because of its low thermal conductivity (i.e., 0.003 Btu/hr-ft-F versus 0.26 for air and 0.46 for water), timing for aerosolization of UF_6 vapor due to thermal conduction/convection may be much longer than that due to its depletion caused by surface chemical reaction with atmospheric moisture. Having these in mind, the MELCOR model has been developed to capture stated-behavior of UF_6 vapor upon being released. Rather than modeling the entire building, only a section of the building near the opening is modeled. Figure 4 illustrates a control volume diagram modeled with MELCOR. Flow paths between control volumes are shown as arrows in the figure. Control volumes, 111 through 115 and 102, represent volumes where UF_6 vapor cloud settles, undergoes a chemical reaction with atmospheric moisture, and its reaction products, UO_2F_2 and HF , transport or settle on the floor. Distance from the wall to the closest autoclave is 28 feet, as can be seen in Figure 2. We assume that the area between the wall and the closest autoclave (from which we assume that UF_6 vapor gets released) becomes involved in UF_6 vapor settling and its chemical reaction with atmospheric moisture. Also assumed was that the UF_6 vapor is released symmetrically such that the mirror region of the autoclave (i.e., another side of the autoclave away from the wall) is also involved in the UF_6 vapor release. Consequently, the floor size of the control volumes, 111 through 115 and 102, was assumed to be 58' x 63'. The control volumes, 111 through 115, were modeled as thin layers with 0.4 m height each to provide a means to force the UF_6 vapor to stay close to the floor. Even though the UF_6 vapor is released at a certain height, we assume that the released UF_6 vapor gets settled onto the floor immediately upon being released. Therefore, the UF_6 vapor was assumed to get released into the lowest control volume, cv-111. The UF_6 vapor will fill cv-111 first, and then react with the moisture there. Unreacted UF_6 vapor will overflow to cv-112 and react with the moisture there, and so on. Unreacted UF_6 vapor is heavy cloud and very immobile. Therefore, the model assumes no direct transport of the UF_6 vapor cloud from the settling control volumes (cv-111 through -115) to the environment (cv-902). Hence, no direct flow path was modeled between cv-111 through -115 and cv-902. Instead, the flow from those control volumes was modeled to pass through cv-102 which is the upper volume of the UF_6 release area, in order to transport into the environment (cv-902). The control volume 901 represents the volume of the feed building which is not affected by UF_6 .

¹ To chemically react 2 kg/s of UF_6 vapor, about 0.2 kg/s of H_2O is needed. Assuming 60% of humidity, it means that ~12 m³/s of air is needed to completely react. If UF_6 vapor spreads over 12 m² area (~2 m radius) assuming 1 m/s of air velocity, it will be completely reacted before it spreads down onto the floor. This is a conservative assumption and was made since we have not conducted a spreading assessment.

vapor release and transport. This volume provides air into the control volumes where the released UF_6 vapor transport occurs. To bound the problem, two values of wind speed were considered. The conservative first case assumed a constant wind velocity of ~ 1 m/s (200 fpm). Consequently, air was assumed to blow into the building through the train and crane openings at 1 m/s (200 fpm). Since air flow area increases from the opening size ($23' \times 20'$ for train door and $9.3' \times 58.8'$ for crane door) to total building cross section area ($63' \times 43.3'$) before the air enters the affected control volumes, 1 m/s (200 fpm) of velocity was scaled down to 0.36 m/s (72 fpm) of velocity for flow paths from cv-901 to cv-111 through -115 and -102. The second case assumed a low (close to stagnant) wind speed of ~ 1 cm/s (2 fpm).

Aerosols in the current study need to be characterized and specified in MELCOR input for the aerosol transport calculations with consideration of aerosol growth by agglomeration, condensation, etc. Aerosol size is assumed to be a log-normal distribution between $0.4 \mu\text{m}$ and $2.5 \mu\text{m}$ diameter. In the current model, the aerosol size range is binned into five sections, and in each section, one aerosol component is assumed to represent aerosols in that section since we have a single component aerosol (UO_2F_2) in the current study. Also assumed was 1.85 for the dynamic shape factor and 2.25 for the agglomeration shape factor. For aerosol particle density, $6,375 \text{ kg/m}^3$ was used for the current study.

3. RESULTS AND ANALYSIS

The MELCOR model was executed for the UF_6 vapor release (from 100s until 400s representing a 5 min release duration, as depicted in Figure 3) until 1000s into transient. First 100s before the UF_6 release was necessary to establish a steady-state condition. Results for this 5 min release case are shown in Figures 5 through 12.

Figure 5 shows atmospheric temperature variations of affected control volumes. The control volume 111 is exposed to sensible energy carried by the released UF_6 vapor (about 240F) and to chemical reaction energy (about 0.32 MJ/kg of UF_6 reacted). As seen in the figure, atmospheric temperature of cv-111 that is the volume into which the UF_6 vapor is released, is highest, $\sim 520\text{F}$ during the UF_6 release period. The control volume, cv-102, is seen not to be affected much by the UF_6 vapor release. Its temperature increase (very slight in magnitude) is mainly due to air convection. Figure 6 illustrates mass flow rates between the affected control volumes. Numbers in the legend box represent control volume index.

As seen in the figure, flow rates as going up through the upper control volumes, increase since the upper control volume has more flow as air coming in from cv-901 in addition to air/vapor/aerosol mixture flowing from the lower control volume. Mass reaction rates of the UF_6 vapor with atmospheric moisture in various control volumes are shown in Figure 7. The control volume 111 has the highest UF_6 reaction rate since the UF_6 vapor is released into this particular volume. Almost no UF_6 reaction is seen in cv-102. Figure 8 shows variations of vapor and aerosols released from the feed building to the environment. The UF_6 release magnitude is almost zero. About 320 kg of UO_2F_2 aerosol and ~125 kg of HF vapor were predicted to be released into the environment. These numbers represent ~66% of all UO_2F_2 aerosol mass and ~100% of HF mass produced from the chemical reaction between the UF_6 vapor and the atmospheric moisture. Figure 9 illustrates variation of UF_6 vapor mass in various control volumes at the end of each time step. Variations of UO_2F_2 aerosol mass and the UO_2F_2 mass settled in various locations are shown in Figure 10 and 11, respectively. Because aerosols are advected to cv-102 from the lower control volumes (cv-111 through cv-115), cv-102 was predicted to contain a substantial amount of the UO_2F_2 aerosols before the aerosol magnitude diminishes due to the release into the environment. Figure 11 shows aerosol deposition onto the floor. Aerosols settle due to gravity onto the floor or fall out once they grow to reach a critical size (in the current study, 2.5 μm diameter is the maximum aerosol size as explained in the previous chapter). Figure 12 shows the variation of HF mass distribution in various locations. Again the vapor is advected from the lower control volumes into the upper one, cv-102 was predicted to contain substantial amount of the vapor before the HF vapor gets released into the environment.

To examine the effect of stagnant (or very stable) atmospheric condition for the UF_6 release accident, another MELCOR run was executed for the same UF_6 release scenario but with 1 cm/s (2 fpm) of far-field wind velocity. The results are presented in Figures 13 through 19 for the transient until 7,000s. Because of the very weak air flow, the atmospheric temperature of cv-111 where the UF_6 vapor gets released, increases up to 850K. It is shown in Figure 15, that a negligible amount of UO_2F_2 (~4 kg) was predicted to be released into the environment. In the same figure, HF is shown to keep being released into the environment, and expected to do so until all available HF mass is completely released into the environment.

4. CONCLUSION

The UF_6 vapor was assumed to be released through a 0.875"-dia broken valve fitting on a pigtail from the cylinder in the feed facility, X-343, of the Portsmouth Gaseous Diffusion Plant. The release rate was predicted using the CYLIND code, to be about 1.7 ~ 2 kg/s over a 5-min period. The MELCOR model was developed to calculate the UF_6 behavior, its reaction with the atmospheric moisture, transport and settling of its reaction products, UO_2F_2 and HF, and the source term magnitude. Flow paths between control volumes were modeled carefully to capture possible air flow patterns. A conservative value of 1 m/s (200 fpm) of wind velocity at far-field was scaled to 0.36 m/s at the entrance of each control volume based on air mass flow conservation. Assuming instantaneous spreading of the released UF_6 vapor on the floor where released and also a constant availability of outside wind flow of 1 m/s, the model predicted that 100% of the UF_6 vapor reacts with the moisture, ~66% of UO_2F_2 and ~100% of HF are predicted to be released over ~10 minutes into the environment if the doors (train and crane access doors) do not shut. When the far-field wind velocity was assumed to be 1 cm/s (2 fpm), almost none of the aerosols were predicted to be released into the environment, and HF vapor was predicted to be released over a long period of time.

It is a normal operating practice to shut the doors once such a UF_6 release accident is recognized. Assuming that the doors shut within 5 minutes (as may be reasonably expected), the source term amount will likely be reduced substantially such that even with 1 m/s (200 fpm) wind speed, ~70% of UO_2F_2 aerosols and ~50% of HF are retained within the feed facility building. Again, if only limited UF_6 vapor spreading takes place, the degree of the chemical reaction will also be limited and the releases will take place over longer period of time, thereby, providing more time for accident mitigation and containment.

Figure 1. A Schematics of Feed Facility Building, X-343, of the Portsmouth GDP

Figure 2. Simplified Plan View Drawing of X-343 of the Porthmouth GDP

Figure 3. Mass Rate of UF₆ Vapor Released into the X-343 Feed Facility

Figure 4. MELCOR Nodalization for Source Term Evaluation from Feed Facility

Figure 5. Variation of Average Temperature of Control Volumes (far-field wind velocity=1 m/s)

Figure 6. Mass Flow Rates Between Control Volumes (Numbers in Legend Box Indicate Control Volumes) (far-field wind velocity=1 m/s)

Figure 7. Mass Reaction Rate of UF_6 Vapor and Atmospheric Moisture in Various Control Volumes (far-field wind velocity=1 m/s)

Figure 8. Mass Source Term of UO_2F_2 , HF and UF_6 Released into the Environment (far-field wind velocity=1 m/s)

Figure 9. UF_6 Vapor Mass Variation at the End of Each Time Step
(far-field wind velocity=1 m/s)

Figure 10. UO_2F_2 Mass Variation in Various Control Volume Atmosphere
(far-field wind velocity=1 m/s)

Figure 11. Mass of UO₂F₂ Aerosol Settled or Fall-out onto the Floor from Each Control Volume (far-field wind velocity=1 m/s)

Figure 12. HF Mass Variations in Control Volumes (far-field wind velocity=1 m/s)

Figure 13. Variation of Average Temperature of Control Volumes (far-field wind velocity=1 cm/s)

Figure 14. Mass Reaction Rate of UF_6 Vapor and Atmospheric Moisture in Various Control Volumes (far-field wind velocity=1 cm/s)

Figure 15. Mass Source Term of UO₂F₂, HF and UF₆ Released into the Environment (far-field wind velocity=1 cm/s)

Figure 16. UF₆ Vapor Mass Variation at the End of Each Time Step (far-field wind velocity=1 cm/s)

Figure 18. Mass of UO_2F_2 Aerosol Settled or Fall-out onto the Floor from Each Control Volume (far-field wind velocity=1 cm/s)

Figure 17. UO_2F_2 Mass Variation in Various Control Volume Atmosphere (far-field wind velocity=1 cm/s)

Figure 19. HF Mass Variations in Control Volumes
(far-field wind velocity=1 cm/s)

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