ANALYSES OF POSTULATED ACCIDENTAL RELEASES OF UF_6 INSIDE PROCESS BUILDINGS

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ABSTRACT

Uranium Hexafluoride is a material used in the various processes which comprise the front end of the nuclear fuel cycle (conversion, enrichment and fuel fabrication). Confinement of UF_6 is a very important safety requirement since this material is highly reactive and presents safety hazards to humans. The present paper discusses the safety relevant aspects of accidental releases of UF_6 inside process confinement buildings. Postulated accidental scenarios are analyzed and their consequences evaluated. In-plant releases rates are estimated using computer code predictions. A time dependent homogeneous compartment model is used to predict concentrations of UF_6, Hydrogen Fluoride and Uranyl Fluoride inside a confinement building, as well as to evaluate source terms released to the atmosphere. These source terms can be used as input to atmospheric dispersion models to evaluate consequences to the environment. The results can also be used to define adequate protective measures for emergency situations.

1. INTRODUCTION

A major concern in nuclear fuel cycle facilities is the potential for accidental release of uranium hexafluoride. The UF_6 is a reactive substance which reacts with water forming HF and UO_2F_2. The HF is a highly corrosive substance and the UO_2F_2 is very toxic. A sudden release of UF_6 inside a building or to the atmosphere could conceivably cause undesirable health effects to workers and the public in general.

The present paper discusses a methodology for assessing UF_6 release inside buildings. Time dependent homogeneous models are used to evaluate concentrations and the source term to inside a building and to the atmosphere. A brief description of UF_6 basic properties and health hazards is presented. Potential release scenarios are also briefly discussed. A simple time dependent homogeneous model is presented for the particular case of constant UF_6 flow rate. UO_2F_2 deposition is considered in this model.

Three release scenarios typical to uranium conversion, enrichment, and fuel fabrication plants are analyzed: a catastrophic rupture of an overfilled cylinder; a rupture in a pig tail; and a rupture in a liquid UF_6 transfer piping.

2. UF_6 BASIC PROPERTIES AND HAZARDS

Uranium Hexafluoride is the substance most suitable for use in the fuel cycle facilities processes because of its exotic physical properties. It can be handled at reasonable temperatures and pressures, and the relatively light fluorine atoms facilitate the separation of ^{235}U from the ^{238}U. At atmospheric pressure, and below 57 °C, UF_6 is a volatile, white, crystalline solid, which easily sublimes by the application of heat. Liquid UF_6 can exist only in pressurized conditions (pressures greater than 1.5 atmospheres and temperatures above 64 °C), thus any process handling liquid UF_6 is above atmospheric pressure.

2.1. Hazard Related Properties

When UF_6 changes from solid to liquid phase it will suffer an expantion of about 33%. This large volume expantion may cause catastrophic failure of overfilled containers resulting in the instantaneous release of liquid UF_6 to inside a building or to the atmosphere. The accident at Sequoyah Fuels in 1986 occurred while an overfilled 48Y cylinder was being heated in a steam chest. The rupture had 1.32 meter in length resulting in a massive release of UF_6 to the environment. The release lasted for about 40 minutes.

It is known that liquid UF_6 in contact with hydrocarbons can initiate an explosive reaction. So care has to be taken to avoid the presence of hydrocarbons in cylinders, vacuum pumps and other process equipment which may be in contact with liquid UF_6.

If UF_6 comes in contact with water, it will decompose immediately to highly corrosive hydrogen fluoride (HF), and to uranyl fluoride (UO_2F_2) which is formed as a solid particulate compound. This exothermic reaction can be written in the form

$$UF_6 + 2\,H_2O \rightleftharpoons UO_2F_2 + 4\,HF + 50{,}5\ \text{kcal} \tag{1}$$

When released to the atmosphere, gaseous UF_6 reacts with moist air to form a cloud of UO_2F_2 and HF. This cloud usually appears as a visible gray white fog. If a release occurs inside a building this fog may impair escape from the release area or may difficult planned emergency actions. A dense fog was observed, for example, at the Hanau conversion plant, in 1987, during a UF_6 release from an autoclave. The distance of sight was about 10 cm /1/. It has been reported that UO_2F_2 concentrations as low as $1 g/m^3$ are visible and visibility is less than 90 cm /2/.

2.2. UF_6 Health Hazards

The primary health and safety hazard of UF_6 at fuel cycle facilities is associated with the exposure to UF_6 hydrolysis products HF and UO_2F_2. HF is an extremely corrosive substance that causes severe skin burns, damage to the eyes, and lung injury when inhaled. UO_2F_2 is a water soluble compound, which in addition to being radioactive can also have toxic chemical effects. If ingested or inhaled, it will enter the bloodstream and will act primarily on the kidneys.

Early chemical effects from acute exposures to UF_6 have been reported by Mc Guire/3/. For a 70 kg person it is reported that: an intake of about 10mg of soluble uranium appears to produce no detectable transient or permanent health effects; the threshold for permanent renal damage is about 40mg of uranium intake; and an intake of 230 mg of soluble uranium seems to produce 50% lethality.

The effect from acute exposure to HF is a function of the HF concentration and the exposure time. The criterion suggested in NUREG-1391/3/ uses a relationship based on the IDLH (Immediately Dangerous to Life and Health) value of 25 mg/m^3. The IDLH is defined as the concentration that for a 30 minutes exposure would not cause any escape impairing symtoms or any irreversible health effects. The equivalent concentration - time effect relationship, for exposure times other than 30 minutes, is given by the following expression:

$$C = 25 \cdot \left(\frac{30}{t} \right)^{1/2} \qquad (2)$$

Where t is given in minutes and C is given in mg/m^3.

For other exposure guidelines, such as the ERPG (Emergency Response Planning Guidelines), a similar relationship may be established. The 1 hour equivalent HF concentration in the lung (ppm by volume) can be written as

$$C_{1hour} = C(t) \cdot \left(\frac{t}{3600} \right)^{1/2} \qquad (3)$$

Where

C_{1hour} = 1h equivalent concentration (ppm);
C (t) = average concentration for duration t (ppm);
t = duration of the exposure (s).

To evaluate the percentage of the exposed persons who would suffer fatality if exposed airborne HF the concept of Toxic Load (TL) can be used

$$TL = \int C^n (t) dt \qquad (4)$$

Where n=1 for HF; and C (t) is the HF concentration.

Using probit as the dose –response correlation (from Lees/4/)

$$\Pr = -26.36 + 2.854 \cdot \ln(TL) \qquad (5)$$

(20000 < TL < 150000)

The percentage of fatality would then be given by the expression

$$P = 50 \cdot \left[1 + \frac{(\Pr - 5)}{|\Pr - 5| \cdot erf\left(\frac{|\Pr - 5|}{\sqrt{2}} \right)} \right] \qquad (6)$$

This percentage is visualized in Fig 1 as a function of the Toxic Load

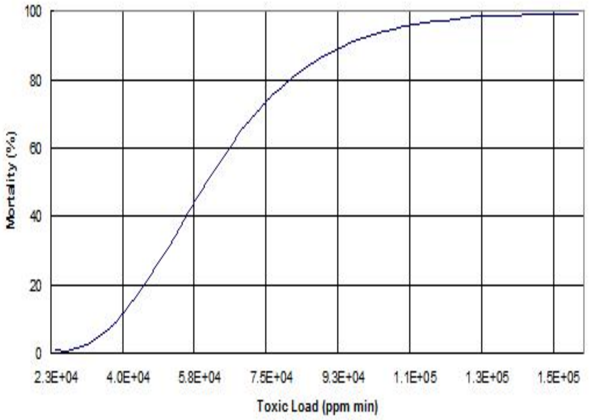

Figure 1. Percentage of fatalities versus the toxic load.

Credible events resulting in a UO_2F_2 intake or HF exposure in such levels that can endanger the life of a worker or result in irreversible health effects are classified as high consequence events in the performance requirements criteria of 10CFR 70.61 /11/.

3. UF_6 RELEASE SCENARIOS

Nuclear fuel cycle facilities can release UF_6 to the atmosphere as a result of unintentional events. The most serious events are those in which liquid UF_6 or pressurized UF_6 gases are released from failures in process equipments, piping or storage cylinders.

Breaches from a solid UF_6 container is not considered a major hazard. Solid UF_6 is not in a readily dispersible form, it undergoes a slow solid reaction with moist air. Usually, the solid reaction product plugs the breach.

A UF_6 release from a system operating under vacuum (such as in an enrichment cascade) is also a minor problem. In this case, a breach allows the external moist air to react with the UF_6, and most of the UF_6 and reaction product would be retained inside the container or piping.

There are various potential UF_6 release scenarios that can possibly be postulated for a nuclear fuel cycle facility. Siman Tov/5/ identifies and discusses several potential UF_6 accident scenarios. They are grouped into four major headings: UF_6 cylinders failures; UF_6 process equipment failures; nuclear criticality events; and operator errors. A total of 25 scenarios were identified, ranging from high consequences events, such as the hydraulic rupture of an overfilled cylinder, to a small size release as a cold trap failure. Most of these scenarios occur inside buildings.

The environmental source term is a function of the pathway followed by the UF_6 released inside a building as schematically shown in Fig 2.

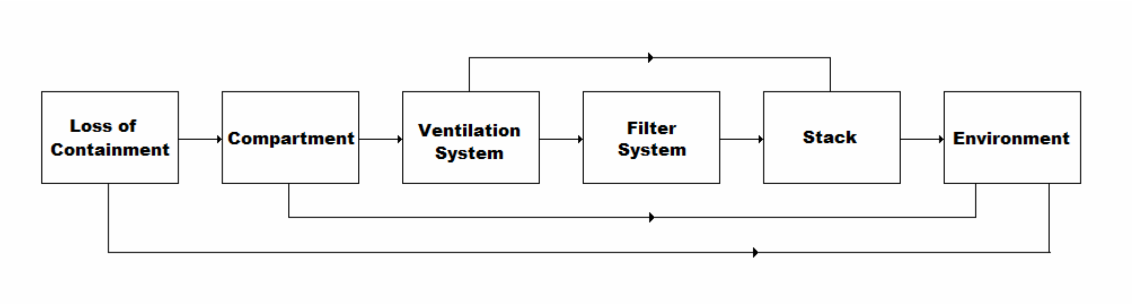

Figure 2. UF_6 release pathways (adapted from Siman Tov /5/).

A high consequence event could be originated from a breached cylinder, process vessel, or piping, followed by a direct release of UF_6 to the atmosphere (bypassing the confinement of the building and the associated ventilation system). This event, associated with unfavorable meteorological conditions, could lead to a bounding scenario, resulting in the highest exposure to UF_6 or its hydrolysis products HF and UO_2F_2.

Bounding scenarios are normally used in the safety analysis of nuclear fuel cycle installations for licensing purposes. They are events of very low probability of occurrence and they are conservative so as to maximize the consequences of UF_6 exposure.

Bounding scenarios can be postulated using basic design data of a plant. First, the safety analyst must identify process equipments which may contain pressurized UF_6 (liquid or gas) and then select a convenient scenario or scenarios (using Siman Tov list, for example). The selection of a scenario or scenarios can be based on deterministic or probabilistic criteria. In a deterministic approach the analyst could simply select the event which would result in the maximum quantity of UF_6 released to the atmosphere, without taking into consideration any mitigation effect provided by the building or systems that could limit the quantity released, and the frequency associated with the event.

A probabilistic approach would consider the frequency category of the event. A criterion normally used in safety analysis is shown in Table 1. The safety analyst can use this table to select one bounding event for each frequency category for detailed analysis. Obviously, in this approach the analyst must have means to supply the probabilities or frequencies of the postulated scenarios.

Table 1. Frequency Categories

	Frequency Category	Frequency (/yr)	Definition
1	Likely	>1.0E-02	May be expected to occur once or more during the lifetime of the facility
2	Unlikely	1.02E-02 to 1.0E-04	Not expected but may occur during the lifetime of the facility
3	Extremely unlikely	1.0E-04 to 1.0E-06	Will probably not occur during the lifetime of the facility
4	Not credible	<1.0E-06	Has extremely low probability of occuring

In deriving the source term inside a building the safety analyst may adopt different approaches depending on the objective of the analysis. One approach normally found is to assume that an instantaneous release of liquid UF_6 from a container will flash to vapor. The initial vapor fraction can be easily estimated using enthalpy balance, or can be obtained directly from tables or Figures available in NUREG-6410 /6/, for example. It can be also assumed that all UF_6 vapor will react with moist air producing HF and UO_2F_2. Additionaly, it can be assumed that all the UF_6 reaction products will be released directly to the atmosphere or, if an emergency ventilation system is available, they would first pass through filters or scrubbers before being released to the atmosphere.

The approach just decribed, although conservative, is simplistic and gives little additional information other than a conservative source term. Many important release scenarios inside buildings, such as failure of a pig-tail, piping, or a cylinder valve, may not result in an instantaneous release. Deriving source term for these scenarios would require methods capable to describe the multi phase transient conditions of UF_6 inside containers. Furthermore, an evaluation of the source term to the atmosphere should take into account the ventilation system and the reaction of the UF_6 with the existing moisture in the air pumped inside the building. Also, it would be interesting to estimate UO_2F_2 deposition that may occur onto the floor and equipment surfaces following a UF_6 release. A layer of UO_2F_2, for example, was observed to cover the floor and equipment at the Hanau fuel fabrication plant accident in 1987 /1/.

The current paper addresses some of these questions by following an approach schematically shown in Fig 3. Source terms are defined for each step of the analysis. The first source term (ST1) corresponds to the material contained in cylinders, process vessels or piping (material at risk). This step defines the material quantity available for release and process or storage conditions. Only part of ST1 may be released to the building since some UF_6 may be retained inside the containers. In the present paper the quantity (ST2) of UF_6 effectively released to the building atmosphere is assumed to form a homogeneous mixture over the entire building. This mixture reacts with moist air producing UO_2F_2 and HF. Part of the UO_2F_2 formed is deposited on the floor and equipment surface. The airborne material is exhauted from the building through the ventilation system blowers (ST3). The ventilation ducts may still retain some UO_2F_2 so the material reaching the filter system is defined as ST4. The material (ST5) leaving the filter system is the atmospheric source term.

The source term ST1 can easily be estimated by considering the quantity of the UF_6 contained in cylinders, process vessels or piping; the process or storage conditions; and the potencial failure mode to be considered in the analysis. The evaluation of the ST2 and ST3 source terms require specific models to simulate the time-dependent conditions inside containers and buildings.

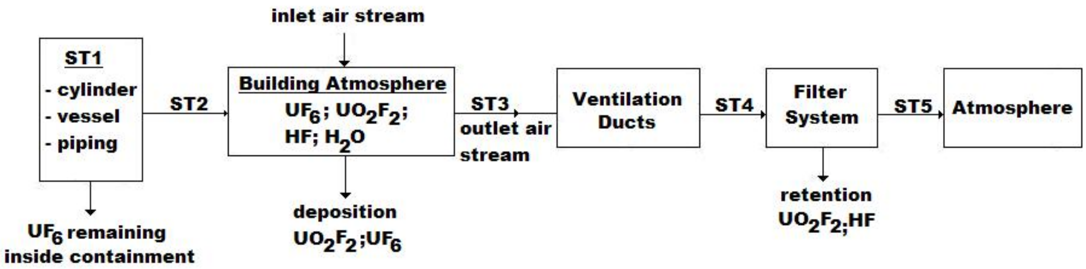

Figure 3. Source Term Definition.

A very simple model can be derived for a constant release rate of UF_6 inside a building. The time-dependent concentration can be evaluated by using the following equation:

$$\frac{dC(t)}{dt} = \frac{Q_{UF_6}}{V} - \frac{Q \cdot C(t)}{V} \tag{7}$$

Where:
Q_{UF6} = Constant UF_6 release rate (kg/s);
V = Compartment free volume (m^3);
Q = Compartment ventilation rate (m^3/s).

Assuming, additionally, that all UF_6 will react with moist air available in the compartment and that the UO_2F_2 deposition rate is constant, the following equations can be written for t < T (where T duration of the release).

- UO_2F_2 Concentration (C_{UO2F2})

$$\frac{dC_{UO_2F_2}(t)}{dt} = \frac{0{,}88 \cdot Q_{UF_6}}{V} - \frac{Q \cdot C_{UO_2F_2}(t)}{V} - \frac{C_{UO_2F_2}(t) \cdot \upsilon \cdot A}{V} \tag{8}$$

Where:
υ = Constant deposition rate (kg/s);
A = Deposition area (m^2).

- UO_2F_2 Deposited (M_{UO2F2})

$$\frac{dM_{UO_2F_2}(t)}{dt} = C_{UO_2F_2}(t) \cdot \upsilon \cdot A \tag{9}$$

- HF Concentration (C_{HF})

$$\frac{dC_{HF}(t)}{dt} = \frac{0{,}23 \cdot Q_{UF_6}}{V} - \frac{Q \cdot C_{HF}(t)}{V} \tag{10}$$

Solving these equations result:

$$C_{UO_2F_2}(t) = \frac{0{,}88 \cdot Q_{UF_6}}{V}\left(1 - e^{-\frac{(A \cdot \upsilon + Q)}{V} \cdot t}\right) \tag{11}$$

$$M_{UO_2F_2}(t) = \frac{0{,}88 \cdot A \cdot \upsilon \cdot Q_{UF_6}}{(A \cdot \upsilon + Q)^2} \cdot \left[A \cdot \upsilon \cdot t + Q \cdot t + \left(-1 + e^{-\frac{(A \cdot \upsilon + Q)}{V} \cdot t}\right) \cdot V\right] \tag{12}$$

$$C_{HF}(t) = \frac{0{,}23 \cdot Q_{UF_6}}{Q}\left(1 - e^{-\frac{Q}{V} \cdot t}\right) \tag{13}$$

For t > T, the concentrations are given by the following expressions:

- UO_2F_2 Concentration

$$C_{UO_2F_2}(t) = C_{UF_6}(T) \cdot e^{-\frac{(A \cdot \upsilon + Q)}{V} \cdot (t - T)} \tag{14}$$

- UO_2F_2 Deposited

$$M_{UO_2F_2}(t) = \frac{M_{UO_2F_2}(T) \cdot Q + A \cdot \upsilon \cdot V\left[M_{UO_2F_2}(T) + C_{UO_2F_2}(T) \cdot \left(1 - e^{-\frac{(A \cdot \upsilon + Q)}{V} \cdot (t - T)}\right)\right]}{(A \cdot \upsilon + Q)} \tag{15}$$

- HF Concentration (C_{HF})

$$C_{HF}(t) = C_{HF}(T) \cdot e^{-\frac{Q}{V} \cdot (t - T)} \tag{16}$$

The source term ST3 for UO_2F_2 and HF can then be evaluated by the expression:

$$ST3(t) = Q \cdot C(t) \tag{17}$$

And the total mass released from the building is given by:

$$M = \int_0^t V \cdot C(t) \cdot dt \tag{18}$$

The method just described (Model 1) is applicable to constant release rate (ST2) and assumes that all UF_6 will react with moist air to produce UO_2F_2 and HF. In more general situations, however, the UF_6 source term ST2 will be time-dependent. For these cases other methods should be used to describe the transient conditions inside UF_6 containers and process buildings. As shown later in this paper Model 1 can be easily adjusted to simulate time dependent source terms inside buildings. By dividing the time dependent source term into convenient time intervals, and using an average source term for each interval, it is also possible to simulate the transient conditions with reasonable results.

To estimate time-dependent ST2 and ST3 source terms the current paper also uses the calculational methods developed by Williams /7, 12/ (Model 2). An adapted version of the CYLIND/12/ computer program was used to simulate breaches in cylinder and process vessels. The time dependent concentrations of Model 2 are evaluated using the building ventilation model available in /7, 12/. The postulated scenarios are analyzed using both models and the results of Model 1 are benchmarked against Model 2.

4. POSTULATED UF_6 RELEASE SCENARIOS

As shown in Section 3 of this paper various potential accident scenarios involving UF_6 release can be postulated for a nuclear fuel cycle installation: failure of a storage cylinder; failure of a process vessel; pipe rupture; valve leak or failure; failure of flexible piping connections etc. Many of these events can be found in the Safety Analysis Report (SAR) of operating and proposed installations.

A worst case scenario that can be found in SARs is the catastrophic failure of an overheated or overfilled cylinder inside an autoclave during UF_6 liquefaction. It is assumed that the autoclave also ruptures releasing liquid UF_6 inside the building. A substantial fraction of liquid UF_6 flashes to vapor, and the entire flashed vapor reacts immediately with moist air forming HF and UO_2F_2. No credit is given to the building ventilation system and filters. This scenario can be found, for example, in the SAR of the Claiborne Enrichment Center (CEC)/8/. In the case of CEC, the scenario to occur would require failure of at least nine safety layers. Simultaneous failure all these layers are considered not credible thus the postulated scenario falls into the Frequency Category 4. Nevertheless, the consequences of the scenario are analyzed in detail to assess public exposure. This scenario is also postulated in the SAR of the National Enrichment Facility (NEF) as referenced in /9/.

Scenarios involving dessublimer and cylinder rupture have been postulated for uranium conversion plants. At the BNFL Springfields uranium conversion plant, for example, the worst case scenario was considered to be the rupture of a 20 ton capacity dessublimer, failure of 48Y filled cylinders and the total collapse of the process building. Based on operational features of the plant it was concluded that about 14.8 ton of liquid UF_6 would be available for release to the atmosphere. An additional scenario was postulated for a 14Y cylinder filled with 12.5 tons of liquid UF_6. It was assumed a valve failure resulting in a release of 7.5 ton of UF_6 vapor to the atmosphere/10/.

Scenarios involving UF_6 releases inside fuel fabrication facilities can also be postulated. These facilities handle liquid UF_6 as feed material to produce uranium dioxide. UF_6 is liquefied in autoclaves and transferred to process equipment through piping systems. If a breach occurs, gaseous UF_6 can be released from the piping.

This paper presents an assessment of three UF_6 release scenarios postulated to occur inside a process building. For comparison all three scenarios have the same quantity of material at risk (2277 kg of liquid UF_6).

4.1. Catastrophic Rupture of a 30B cylinder and the Autoclave: Scenario 01

It is assumed that a 30B cylinder being heated inside an autoclave is overpressurized and fails. The autoclave then fails releasing UF_6 into the process building. This accident could be caused by overheating a cylinder filled with its maximum capacity or by heating an overfilled cylinder.

It is assumed that 2277 kg of liquid UF_6 is released into the building. A quantity of 1276 kg of UF_6 becomes airborne and the remaining solid UF_6 is dumped onto the floor. The UF_6 vapor is released within 5 minutes at a constant rate of 4.253 kg/s (Source term ST2). The UF_6 vapor reacts immediately with moist air forming HF and UO_2F_2.

4.2. Breach of the piping connecting the autoclave to a Process Equipment: Scenario 02

It is assumed that, at the beginning of a feeding operation, a breach occurs in the external flexible piping that connects the autoclave to a process unit. The autoclave contains a 30B cylinder filled with 2277 kg of liquid UF_6. The autoclave heater is shut off, but no further action is taken to stop the release.

4.3. Rupture of the liquid UF_6 transfer piping of a 3000 kg Vertical Storage Vessel: Scenario 03

It is assumed a complete rupture of the piping connecting an intermediate UF_6 storage vessel to a filling station. It is assumed that 2277kg of liquid UF_6 is available for release through the breach.

In some SARs, the first scenario is usually classified as not credible since many safety layers must fail for the accident to occur. The other two scenarios should fall at least into the Frequency Category 3 (Extremely unlikely) since they are considered as high consequence events.

The scenarios analyzed in this paper can be postulated for any of the nuclear fuel cycle facility - conversion, enrichment, or fuel fabrication. The differences between the consequences for each plant would be mainly related to the inventory available for release, the construction characteristics of the plant, the dimensions and physical lay-out of the process building, and the type of ventilation and filtering systems. Scenarios one and two are found in the SARs of some enrichment plants. Scenario three is typical of a

UF_6 conversion plant. Intermediate storage vessels may be used to store raw UF_6 produced in the fluorination unit of a conversion plant.

One major difficult in modeling a UF_6 release inside a process building is to define which compartment volume should be considered for analysis. A real plant is divided into various process units each of which is located at separated areas, but not physically isolated from each other. Thus, if a UF_6 release were to occur in one unit, it could spread to others making the modeling more complicated. Spatial effects may become apparent and they should be taken into account in a more sophisticated analysis. The computational programs used in the present paper are based on lumped models to describe time dependent concentrations inside buildings, so they may not be suitable for cases in which spatial effects are an important part of the analysis. In the present work, however, these lumped models are used as a screening tool to generate source terms and to estimate concentrations and exposure to UO_2F_2 and HF. The process units involved in a postulated UF_6 release are modeled as a single homogeneous compartment having an equivalent free volume. To account for UO_2F_2 deposition an equivalent deposition area is also estimated. The ventilation system is of the induced draft type, connected to a battery of filters before exhausting to the atmosphere. In this paper a building of typical dimensions is used to illustrate the analyses. The data used in the simulations are given in Table 2.

Table 2. Building Data

- Building free volume	5800 m^3
- Ambient Temperature	30 ^oC
- Ambient Pressure	101.4 kPa
- Relative Humidity	80 %
- Exhaust Rate	16 m^3/s

5. RESULTS

5.1. Scenario 01: Catastrophic Rupture of Cylinder and Autoclave

The results for Scenario 1 are shown in Figures 4 through 9. Assuming an unmitigated accident, it will last for about 30 minutes.

Fig. 4 shows the time dependent uranium and HF concentrations. As a result of a relatively high ST2 source term the uranium and HF concentrations will increase rapidly reaching a maximum at 300 seconds (100 g/m^3 for U and 33 g/m^3 for HF). The average concentrations for uranium and HF are 28.5 g/m^3 and 9.6 g/m^3, respectively. An average concentration of 28.5 g/m^3 results in a uranium intake of 300 mg in less than a minute (assuming a breathing ratio of $3.33*10^{-4}$ m^3/s). Fig. 5 shows the uranium intake during the first 2 minutes of the UF_6 release.

The HF concentration of 9.6 g/m^3 is well above the IDLH and ERPG-3 guidelines (IDLH = 25 mg/m^3; equivalent ERPG = 35ppm). Fig. 6 shows the HF toxic load for the first five minutes of the release, which can be confronted with Fig. 1 to assess the consequences of HF exposure.

These results show that an unprotected person standing in the vicinity of the release point would be exposed within a few minutes to lethal uranium and HF concentrations.

Fig. 7 shows the UO_2F_2 mass deposited inside the building. It is estimated that about 3.55 kg will be deposited along the entire transient. The mass deposited is a function of the deposition rate (0.1 mm/s).

Figure 8 shows the mass flow rate of the exhausting stream (ST3). Since there is enough moist air, only HF and UO_2F_2 will be released to the filtering system. The average mass flow rate for UO_2F_2 and HF are 0.61 kg/s and 0.16 kg/s respectively. It is estimated that about 1100 kg of UO_2F_2 and 260 kg of HF will be released to the filtering system (Fig. 9). If no credit is given to filters about 850 kg of uranium would be released to the atmosphere. Assuming a filtering system with 99.9% efficiency, the source term ST5 to the atmosphere would be minimal.

Figs. 4, 7 and 9 also include results of the simplified model (model 1) described in Section 3 for benchmarking with the computational model of Williams (model 2). As seen the results coincide. In this particular case – constant UF_6 mass flow rate and full UF_6 reaction with moist air – it is obvious that both compartment models are reduces the same set of equations described in Section 3.

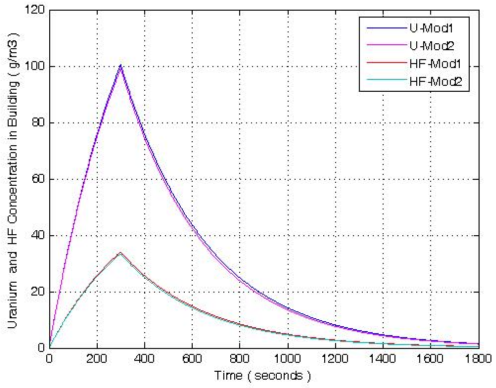

Figure 4. Uranium and HF Concentration in Building.

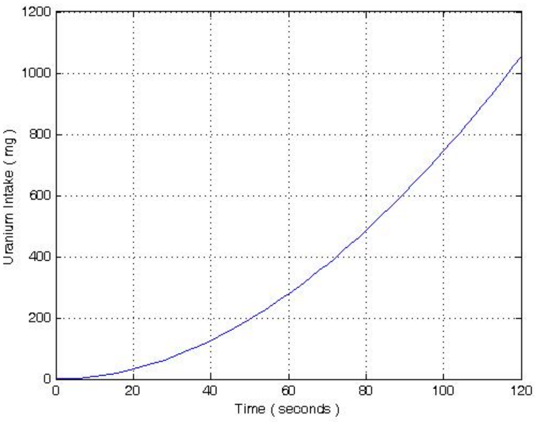

Fig.5: Uranium Intake.

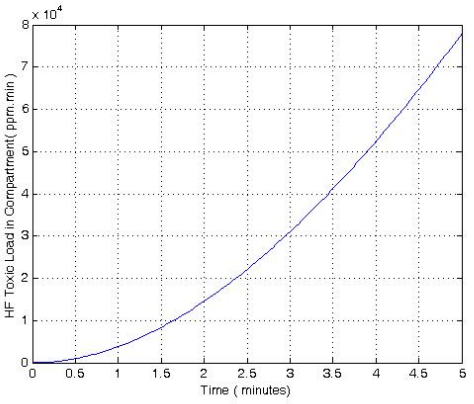

Figure 6. HF Toxic Load in Building.

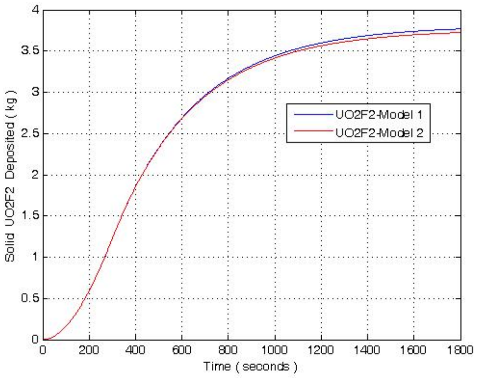

Figure 7. Solid UO_2F_2 Deposited.

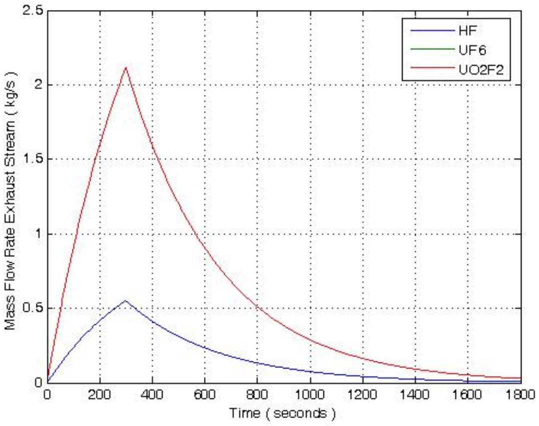

Fig.8: Mass Flow Rate Exhaust Stream.

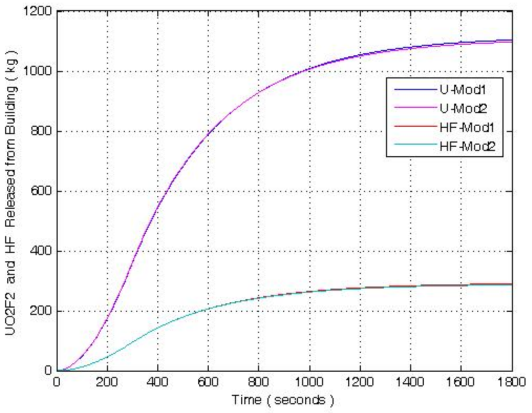

Figure 9. UO_2F_2 and HF Released from Building.

5.2. Scenario 02: Rupture of External Feed Line of an Autoclave

Results for the scenario postulated at the feed line of the autoclave are shown in Figs 10 through 17. Since it is assumed that no action is taken to stop the release, the transient lasts for about one hour. The mass balance inside the cylinder was calculated using the CYLIND/12/ computer program and the results are illustrated in Fig. 10. As shown, about 1000 kg of solid UF_6 remains inside the cylinder, which means that 1277 kg is released to the building (ST2). Fig. 11 illustrates the mass flow rate of UF_6 released from the rupture, as shown the UF_6 is released in both solid and gaseous states. Relatively high flow rates are observed at the initial moments of the transient (~ 2.7 kg/s in the initial 60 seconds). This is explained by noticing that the UF_6 liquid line is slightly above the cylinder valve line, which means that liquid can be expeled from the rupture. After the initial 60 seconds only gaseous UF_6 is released and the mass flow rate rapidly decreases from 2.7 kg/s to 1 kg/s. After about 900 seconds the UF_6 triple point is reached inside the cylinder and the flow stabilizes to a rate of about 0.32 kg/s. The release stops when the temperature inside the cylinder falls below the triple point, at approximately 3000 seconds. The mass flow rate illustrated in Fig.11 is used as the source term ST2 to simulate the time dependent conditions inside the process building.

Figs. 12 illustrate the time dependent uranium and HF concentrations inside the building. In the first 400 s the concentrations rapidly rises as a result of a high ST2 source term. At the triple point conditions ST2 tends to a constant flow rate of 0.32 kg/s and the concentrations also tends to stabilize.

Fig. 12 also shows a comparison between both models. To apply Model 1 the source term shown in Fig. 11 was divided into seven convenient time intervals each of which with a constant source term. Then the differential equations presented in Section 1 were solved for each time interval using the appropriate initial conditions and source terms. As shown the results are comparable.

Similar to Scenario 01, the average concentrations of HF and UO_2F_2 are well above safe limits, ~3.8 and ~11.5 g/m^3 respectively. For one hour release the HF has an equivalent IDLH equal to 17.6mg/m^3 and an ERPG-3 of 50 ppm. Fig. 14 presents the HF toxic load showing high values of exposure within the first 20 minutes. The average concentration of 11.5 g/m^3 produces a uranium intake of 300 mg in less than two minutes (Fig. 13).

As in the previous scenario an unprotected person would be exposed within a few minutes to lethal uranium and HF concentrations.

Fig. 15 shows the cumulative UO_2F_2 mass deposited inside building. About 3.55 kg of UO_2F_2 will be deposited during the transient time. Again it is assumed a constant deposition rate of 0.1 mm/s.

The ST3 source term is shown in Fig. 16. About 1100 kg of UO_2F_2 and 260 kg of HF will be released to the filtering system as shown in Fig. 17. Assuming that the filters have an efficiency of 99.9% the source term ST5 to the atmosphere would also be minimal.

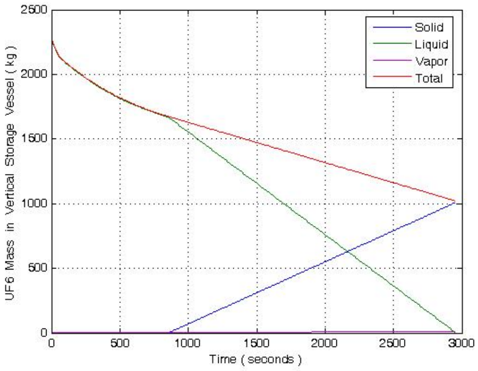

Figure 10. UF$_6$ Mass in 30B Cylinder.

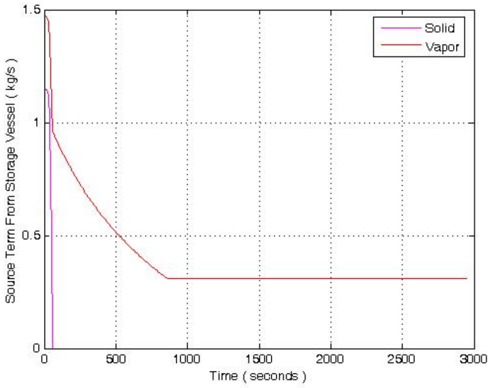

Figure 11. UF$_6$ Release Rate from 30B Cylinder.

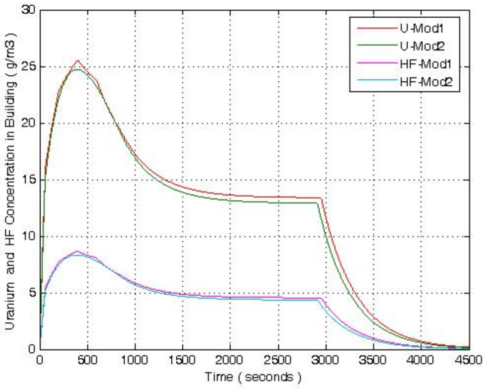

Figure 12. Uranium and HF Concentration in Building.

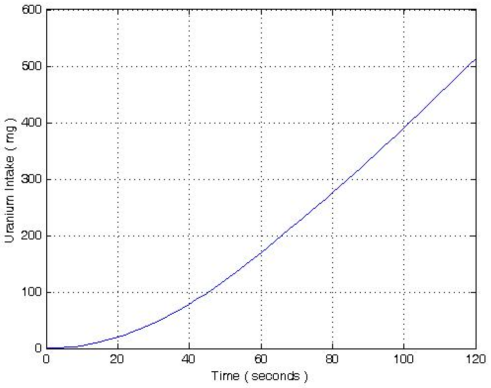

Figure 13. Uranium Intake.

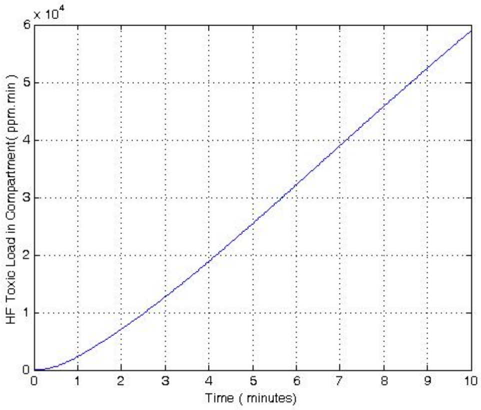

Figure 14. HF Toxic Load in Compartment.

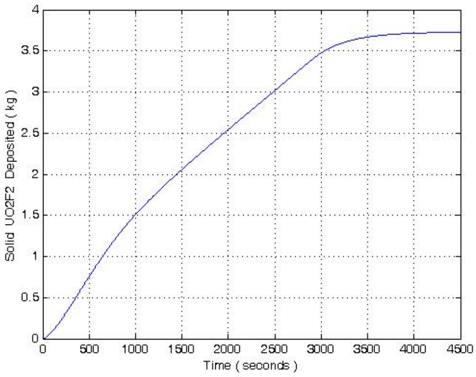

Figure 15. Solid UO$_2$F$_2$ Deposited.

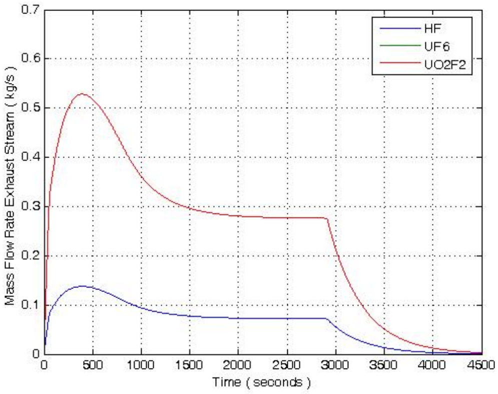

Figure 16. Mass Flow Rate Exhaust Stream.

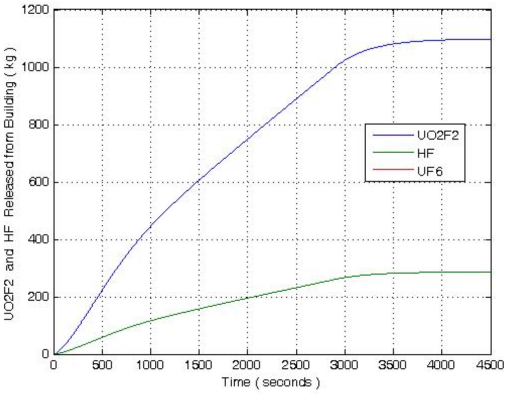

Figure 17. UO$_2$F$_2$ and HF Release from Building.

5.3. Scenario 03: Rupture of the liquid UF_6 transfer piping of a 3000 kg Storage Vessel

Results for this scenario are shown in Figs. 18 through 22. Again the mass balance inside the UF_6 storage vessel was calculated using the CYLIND/12/ computer program; the results are given in Fig. 18. As shown, the entire content of storage vessel is released into the building (2277 kg of liquid UF_6). Fig. 19 illustrates the mass flow rate of UF_6 released from the rupture. In this case UF_6 is released in both solid and gaseous states during about 700 s. The solid UF_6 is assumed to be dumped onto the floor and takes no further part in the simulation.

Fig. 20 shows the time dependent uranium and HF concentrations. The transient lasts for about 40 minutes. As expected, the concentrations exhibit similar time dependent behavior as for Scenario 1. In this case the average concentrations for uranium and HF are ~21.0 g/m^3 and ~7.2 g/m^3 respectively. The UO_2F_2 and HF released to the filtering system are about the same as in the previous two cases.

As in the previous two scenarios, the same high consequences are observed for UO_2F_2 intake and HF exposure.

In the present paper it was assumed a deposition velocity (DV) of 0.1 mm/s. Using this value the total mass deposited woud be about 3.55 kg of UO_2F_2 as shown in Fig. 21. The 0.1 mm/s value was taken from experimental studies that indicate a settling velocity of this order of magnitude. Williams /12/, however, uses a much higher DV (1 cm/s) resulting in a much higher UO_2F_2 mass deposition as shown in Fig. 22. It appears, however, that for the size of the UO_2F_2 particulate (1-3 microns), the 0.1 mm/s seems to be more appropriate.

Figs. 20 and 21 also illustrate a comparison between Models 1 and 2. As shown the results are also comparable. In fact Case 3 is very similar to Case 1. Liquid spills tend to be fast transients having relatively high flow rates (ST2).

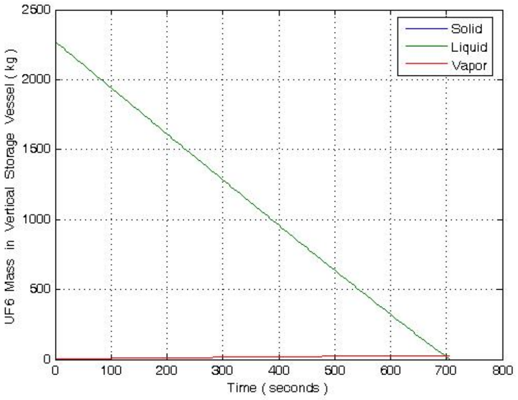

Figure 18. UF_6 Mass in Vertical Storage Vessel (kg).

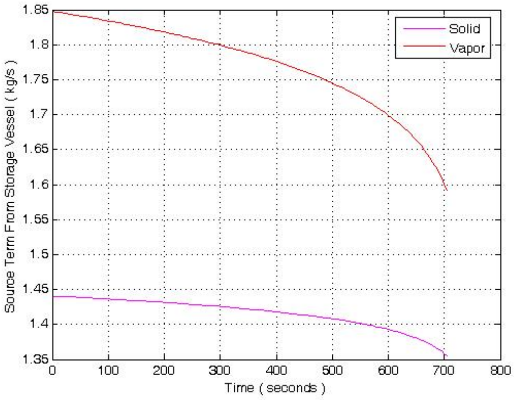

Figure 19. Source Term from Storage Vessel (kg/s).

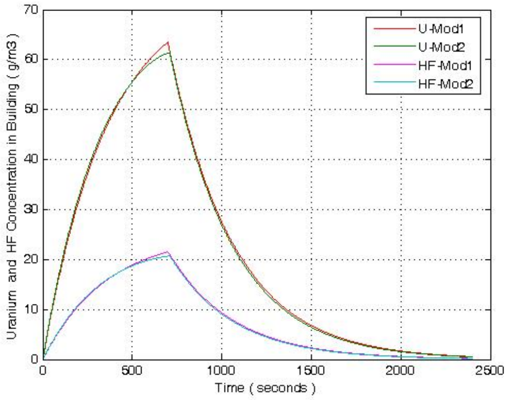

Figure 20. Uranium and HF Concentration in Building (g/m3).

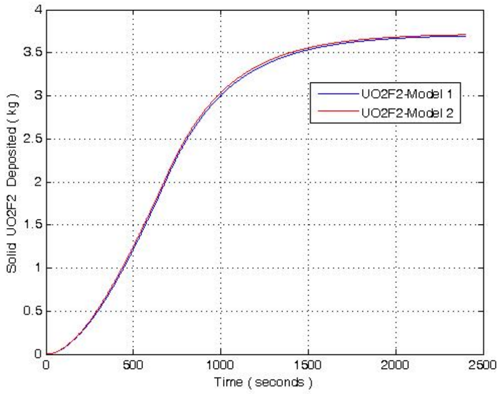

Figure 21. Solid UO_2F_2 Deposited.

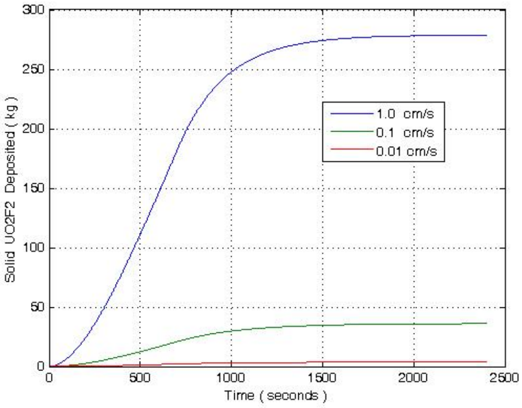

Figure 22. Mass Deposition as a Function of DV.

6. CONCLUSIONS

Table 3 presents a summary of the results for the scenarios investigated in this paper. The same inventory for the material at risk was used in the three scenarios (2277 kg of liquid UF_6). It was assumed that no action is taken to stop the event or to minimize its consequences. The only assumption made was that the ventilation system was secured during the entire transient.

Unmitigated consequence analyses as presented here are useful for identifying accident sequences that exceeds the performance requirements, and also to assess the adequacy of items relied on for safety. The scenarios analyzed in this paper are clearly of high significance, the three cases exceeded the consequence severity categories of 10 CFR 70.61/11/ (UO_2F_2 intake and HF exposure).

Due to the assumptions made, the overall results for the material balance in the three cases analyzed are about the same, despite of different transient duration time. The ST3 cumulative masses released to the filter system or to the atmosphere are: ~1100 kg of UO_2F_2; and ~260 kg of HF. About ~3.55 kg of UO_2F_2 is deposited onto the floor and equipment in the process building.

As shown in Figs. 4, 12, and 20 the UO_2F_2 concentration exceeds the value of 1 g/m^3. A thick white fog then should be expected to be present inside the process building for the most part of the transients analyzed.

The Model 1 described in Section 3 of this paper was benchmarked against Model-2 /12/. Provided the assumptions made for Model 1 are met, both models yield to comparable results. By dividing the time dependent source term into convenient time intervals, and using an average source term for each interval, it is possible to obtain a reasonable approximation of the source term ST2 generated by the CYLIND/12/ computer program. Thus the transient conditions simulated by Model 1 can be very close to the results produced by Model 2.

Table 3: Summary of the results

	Scenario 1	Scenario 2	Scenario 3
Release time (s)	Arbitrarily set to 300	~3000	~700
Transient time (s)	~1800	~4500	~2400
U mean concentration (g/m^3)	28.5	11.5	21.0
HF mean concentration (g/m^3)	9.6	3.8	7.2

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