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Risk Assessment Due to Postulated Accidental Releases of UF_6And Emergency Preparedness to Mitigate its Consequences.

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ABSTRACT: *Uranium Hexafluoride UF_6 is a material used in the various processes which comprise the front end of the nuclear fuel .Confinement of UF_6 is a very important safety requirement since this material is highly reactive and presents safety hazards to humans. This paper deals with risk assessment in case of release of UF_6 inside process confinement buildings. Distance dependent RASCAL computer model is used to predict concentrations of UF6, Hydrogen Fluoride and Uranyl Fluoride inside Manufacturing Pilot Plant (FMPP), facility, as well as to evaluate source terms released to the atmosphere calculated . The results can be used to define adequate protective measures and regulations to mitigate accident consequences for emergency plan in identity with the role of Egyptian Nuclear and Radiation Regulatory Authority (ENRRA).*

I. Introduction

UF_6 is a volatile solid. It may present both chemical and radiological hazards. Since the primary hazards from the release of UF_6 are chemical, while the radioactivity aspects present secondary hazards (chronic effects). In the nuclear industry UF_6 is handled in all three states during processing stages in the fuel cycle. All three phases, solid, liquid and gas, coexist at 64°C (the triple point)[1]. It is essential to control the physical state of UF6 at all times. When restricted volumes such as traps and containers are filled with UF_6, allowance must be made for the volume changes which arise over the working temperature range to avoid rupture. An important UF_6 reaction is that When UF_6 is released into the atmosphere, it reacts with the moisture in the atmosphere to form a cloud of Uranyl fluoride ($U0_2F_2$) and hydrofluoric acid (HF), i.e.,

$$UF_6 + 2H_2O \rightarrow UO_2F_2 + 4HF \quad [2].$$

This cloud usually appears as a visible gray white fog. The HF is a corrosive and irritating acid vapor that can severely harm the lungs and skin if exposed in sufficient concentration. Therefore, safety analyses for uranium fuel fabrication facilities should also address the potential hazard resulting from this chemical composition [3]. The $U0_2F_2$ forms a particulate, which is very soluble in the lungs, and can be carried away by the wind and deposited, onto the ground. 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 $1g/m^3$ are visible [4]. The hazards from release of UF_6 are mainly inhalation of and ingestion of HF and UO_2F_2. The hazards of exposure to hydrolyzed UF_6 are greater than those involved in the combined exposure to UO_2F_2 and HF because the UF_6 hydrolysis reaction occurs at sensitive tissues. It has been estimated that intakes of 10-25 mg UO_2F_2 within a short period (30 min) can induce renal damage in a normal adult, while 50% lethality is expected for an intake of 200 mg [5]. In uranium fuel fabrication facilities, only low enriched uranium (LEU) is processed. The radiotoxicity of the processed LEU in fuel fabrication facilities is low, and thus any potential off-site radiological consequences following an accident would be expected to be limited [3].

Health effect due to HF exposure:

Hydrogen fluoride is a colorless fuming corrosive liquid which boils at 20°C. It is one of the strongest oxidizing agents known and it is considered to be one of the most destructive inorganic agents to human tissue [6]. Table 1 refers to human hazards effect due to different periods of exposure. The 2nd, 3rd and 4th values of air concentration of HF are applicable to workers exposed in routine conditions, such as workers at F_2 production facilities or UF_6 production or enrichment facilities in normal conditions of operation. In these cases the problem is chronic exposure to HF. The 5th values of Table 1 refer to acute exposure to HF for short periods of time. These values could be used as` guidance in emergency planning as well as for making safety decisions (e.g. if accident analysis indicates that the exposure of the most exposed person can exceed the value given, more stringent safety conditions would be required). In case of acute exposure to HF, the health hazards are the induction of pneumonitis and pulmonary edema. Table 1 indicates that significant health effects can be expected after an integrated exposure of an adult in excess of 13 mg HF/m^3 for over 30 minutes.

Table1. Health hazard effect due to HF exposure for different periods:

	Source	**Effect**	**Concentration Air (mg HF/m^3)**	**Exposure time (min)**
CHRONIC EXPOSURE	National Institute for Occupational Safety and Health (NIOSH)	Short term exposure limit (STEL)	5	15
	NIOSH	Threshold limit value (TLV)	2.5	480
	Occupational Safety and Health Administration (OSHA)	Permissible exposure limit (PEL)	2	480
ACUTE EXPOSURE	National Research Council NIOSH/OSHA	Emergency exposure limit	13.3	10
		Immediately dangerous to life or health (IDLH)	13.3	30

II. Material and Method

In this study a postulated scenario is UF6 release during operating system of different stages . At 12:30 p.m. after operating system were preheat to evaporate UF6 from solid to gaseous phase and during hydrolysis process, after the gaseous UF6 is added to the water, a solution of uranyl fluoride and hydrofluoric acid is formed (figure 1) it is postulated that one valve in production line was opening resulting failure in this valve, the amount of UF_6 in cylinder before operation was 20Kgm in solid phase, and the enriched value of U was 19.75%.

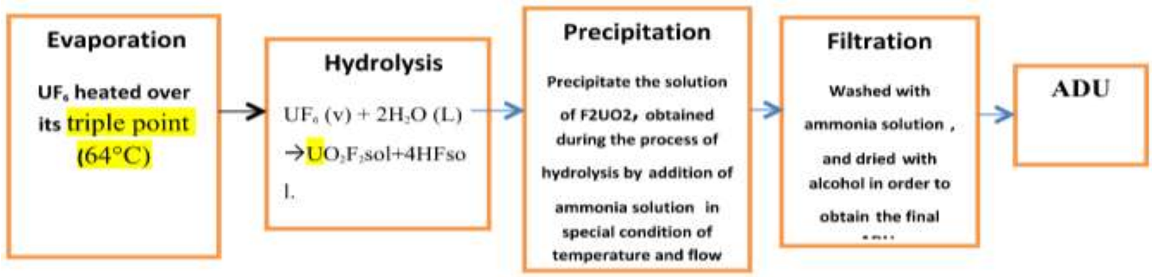

Fig 1 .Flowchart of different processes in wet area.

UF_6 Parameters in RASCAL **Model Assumptions and Equations**

The following assumptions were made in the development of the UF_6 parameter in the result model.

1. The UF6 plume is released at or near ground level. (Elevated releases are not modeled.)
2. An initial UF6 control volume is defined by the UF6 release rate and density.
3. The initial cross section of the UF6 control volume is square with

$$A_{UF6} = Q'_{UF6}/\rho_{UF6} 2u \qquad (1)$$

Where

A_{UF6} =cross-sectional area (m^2),

Q'_{UF6} = UF_6 release rate (g/s),

ρ_{UF6} = UF_6 density (g/m3),

u = wind speed at 1 m (m/s),

If the release includes HF and UO2F2 in addition to UF6, the area of the initial control volume is given by

$$Acv = \frac{V'_{UF6}+V'_{HF}+V'_{air}}{u} \qquad (2)$$

where

V'_{UF6} = the release rate of UF_6 (m3/s)

V'_{HF} = the release rate of HF (m3/s)

V'_{air} = the volume flow of air that would be needed to generate the HF flow from a reaction of the air with UF_6 (m3/s)

u = wind speed at 1 m (m/s).
4. There is no diffusion of the UF_6 plume.
5. Deformation of the UF_6 control volume is determined by gravitational slumping of the UF_6.
6. The rate of change of the UF6 control volume is given by

$$\frac{dw_{UF6}}{dt} = k\left[g\,\frac{\rho_{UF6}-\rho_{air}}{\rho_{UF6}}\,H_{UF6}\right] \quad (3)$$

Where:
w_{UF6} = UF_6 control volume width (m),
t = time (s),
k = a slumping constant (dimensionless),
g = gravitational constant (m/s^2),
ρair = density of air (g/m^3),
HUF_6 = thickness of the control volume (m).

7. The slumping constant has a theoretical value of 1.4 ≈ ($2^{\frac{1}{2}}$) but may be given a lower value to account for surface resistance or to tune the model. A value of 1.3 is used as default in the current version of the UF_6 model in RASCAL.
8. Air is entrained into the UF_6 control volume only through the top. Entrainment through the sides is negligible because after only a few seconds the area of the top of the volume is much larger than the area of the sides.
9. The rate of entrainment of air into the UF_6 is given by

$$\frac{dV_{air}}{dt} = u_e\, w_{UF6}\, u \quad (4)$$

where
V_{air} = air entrainment rate (m3/s),
u_e = an entrainment velocity (m/s).
11. The water available for reaction with UF_6 is determined by a combination of the water vapor in the entrained air and precipitation entering the UF_6 control volume.
12. The water available for reaction is given by

$$m_{H2o} = \rho_{H2O}\, V_{air} \;\; + p_r\, w_{UF6} 6u\Delta t \;\; \rho_{H2ol} \quad (5)$$

Where, Δt = the duration of the time step (s)
m_{H2o} = the rate at which water becomes available for reaction (g/s),
ρ_{H2O} = density of water vapor in the ambient air (g/m^3),
p_r = precipitation rate (m/s),
ρ_{H2ol} = density of liquid water (g/m^3).
13. The reaction between UF_6 and water is assumed to occur at the top of the UF_6 control volume. The volume of UF_6 involved in the reaction is subtracted from the UF_6 control volume, and the masses of air, HF, and UO_2F_2 are added to the HF/UO_2F_2 control volume. The volume of the HF/UO_2F_2 control volume is increased by the volumes of the air and HF. The UO_2F_2 formed in the UF_6/H_2O reaction is present as small particles that are assumed to have negligible volume. The temperatures and volumes of the control volumes are adjusted to conserve enthalpy in a constant pressure reaction.
14. Potential heat exchange with the ground and possible reaction of UF_6 with water on the ground surface are assumed to be negligible.
15. The ground is assumed to be a sink for UF_6 that may be deposited on the ground. Any UF6 condensing in the UF6 control volume is assumed to deposit on the ground. In addition, 25% of the UO_2F_2 formed in the UF_6/H_2O reaction is assumed to deposit at the time of the reaction, unless the UF_6 is released in a fire. Wet deposition of UF_6 is not modeled because all water entering the UF_6 control volume is assumed to react with UF_6 to produce HF and UO_2F_2.
16. If UF_6 is released within a building, the UF_6 is assumed to react with water vapor within the building and the release to the environment is assumed to consist of only HF and UO_2F_2. In this instance, thermodynamic calculations are not included in RASCAL also the plume rise is not included the transport and dispersion calculations .

Atmospheric Conditions:

The weather data for facility sit, consists of wind speed 9.3 Km/h, wind direction at 45^oNorth south, air temperature 22^oC, air pressure 1019 Pa and humidity 22%

Dispersion and Deposition of HF and UO_2F_2

The UF_6 model works in two stages. In the first stage, the model calculates the spread of UF_6, the conversion of UF_6 to HF and UO_2F_2, and the plume rise of the HF and UO_2F_2. The products of this stage are UF6, HF, and UO_2F_2 source terms and the plume rise of HF and UO_2F_2, all as a function of distance from the release point, with HF and UO_2F_2 release fraction through building 0.23 and 0.88 respectively. In the second stage, a straight-line Gaussian model is used to calculate airborne concentrations and deposition of HF and UO_2F_2 at receptors on a polar grid. The distance calculated dependent source terms in the first stage are used as long as UF_6.

III. RESULT AND DISCUSSION

Release through buildingwith release fraction 0.6:

The results for pipe leakage Scenario are shown in table 2. Assuming an unmitigated accident. Release start at 10:30 am end at 11:30 am last for about 1 hour. Table 2 show equivalent RASCAL calculated results 7:30 p.m , after 8 hours from the end of release.

Table 2 equivalent RASCAL calculated results for 8 hours after the end of release

meter	10	20	30	40	50	60	70	80
HF Conc – Avg (ppm)	2.2E+00	6.5E-01	3.0E-01	1.7E-01	1.1E-01	7.6E-02	5.6E-02	4.3E-02
HF Deposition (g/m²)	8.3E-02	2.4E-02	1.1E-02	6.4E-03	4.1E-03	2.9E-03	2.1E-03	1.6E-03
U Exposure ((g-s)/m³)	1.1E+02	3.2E+01	1.5E+01	8.5E+00	5.4E+00	3.8E+00	2.8E+00	2.1E+00
U Intake (mg)	3.7E+01	1.1E+01	5.0E+00	2.8E+00	1.8E+00	1.3E+00	9.3E-01	7.1E-01
U TEDE (Sv)	1.1E-02	3.3E-03	1.5E-03	8.7E-04	5.6E-04	3.9E-04	2.9E-04	2.2E-04
U Deposition (g/m²)	9.3E-01	2.8E-01	1.3E-01	7.2E-02	4.6E-02	3.2E-02	2.4E-02	1.8E-02

Fig. 2 represents the average of HF concentrations at different distances. It is clear that the highest HF concentration at 10 meters from release point. The HF concentration of 2.2 PPm is well below the IAEA ERPG-2 guidelines (equivalent ERPG = 25ppm). Fig. 3 shows the dependence of uranium and HF deposition on distance.

The radiation exposure for uranium Exposure, intake and value of absorbed dose (TEDE) during the accident due to the UF_6 release through building was represented in figure 4 and figure 5respectively.

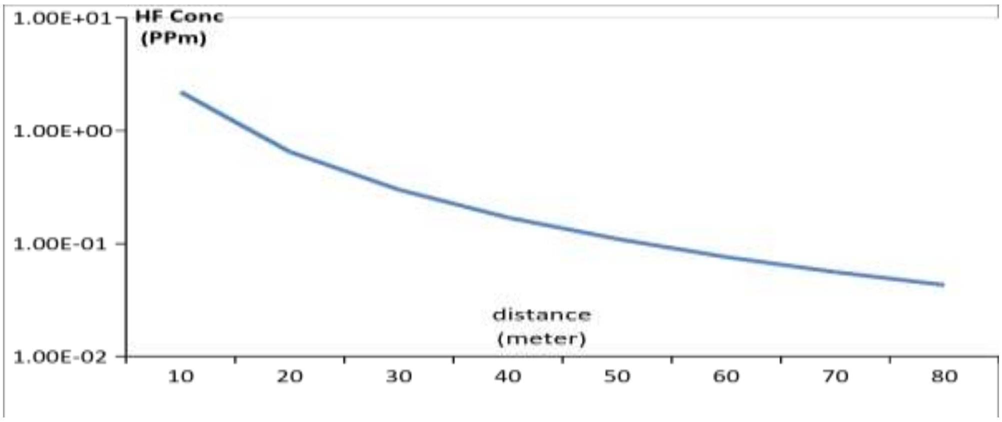

Fig (2) Distance dependent HF concentration

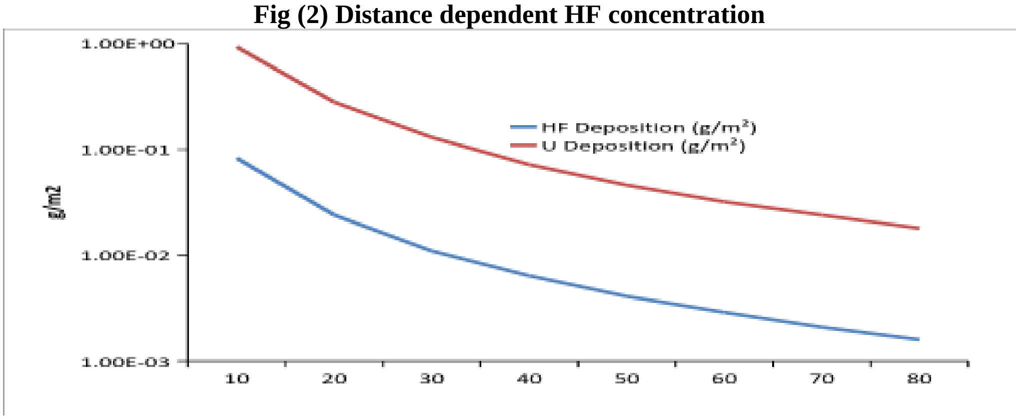

Fig.3. Relation between distance and deposition of U and HF.

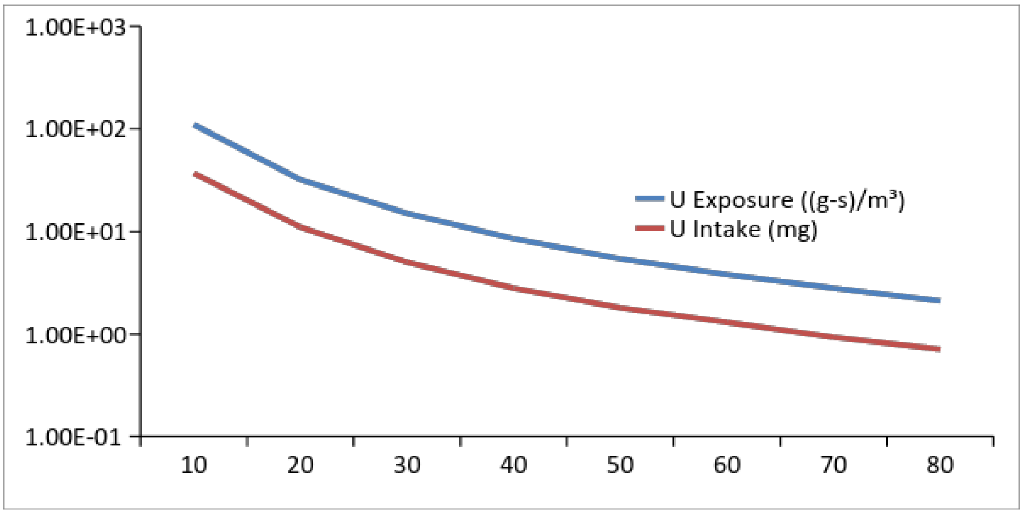

Fig.4 Relation between distance & radiation exposure and intake Uranium

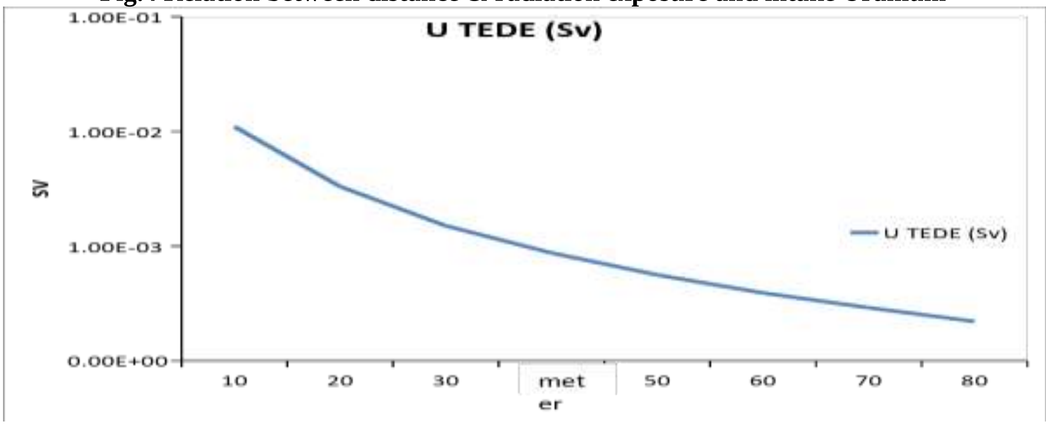

Fig.5 Relation between distance & U- TEDE

From figure 3 and 4 it is obvious that the intake value of U is 37 mg at distance 10 meter from release point and 11 mg at 20 meters from release point which are well above the guidance ERPG-2 guidelines (ERPG = 10 mg). The value of U (TEDE) is 1.1 rem at 10 meter from the release point is well above the ERPG-2 guidelines(EPRG=1 rem). These results show that an unprotected worker standing in the vicinity of the release point would be exposed within a few minutes to lethal uranium intake and high TEDE.

For release fraction 1 (means the valve complete leakage). The U-intake increases by24 mg for 10 meters, where TEDE increase by 0.8 rem. Then if the release fraction increases, it means the increase in the risk percentage for the person stand in the vicinity of the release point. Table3 represent result data due to release fraction 1.

Table 3: release due to fraction at different distance results:

METER	10	20	30	40	50	60	70	80
HF Conc – 1h Eq (ppm)	3.6E+00	1.1E+00	4.9E-01	2.8E-01	1.8E-01	1.3E-01	9.3E-02	7.1E-02
HF Conc – Avg (ppm)	3.6E+00	1.1E+00	4.9E-01	2.8E-01	1.8E-01	1.3E-01	9.3E-02	7.1E-02
HF Deposition (g/m²)	1.4E-01	4.1E-02	1.9E-02	1.1E-02	6.8E-03	4.8E-03	3.5E-03	2.7E-03
U Exposure ((g-s)/m³)	1.8E+02	5.4E+01	2.5E+01	1.4E+01	9.1E+00	6.3E+00	4.6E+00	3.6E+00
U Intake (mg)	<u>6.1E+01</u>	<u>1.8E+01</u>	8.3E+00	4.7E+00	3.0E+00	2.1E+00	1.6E+00	1.2E+00
U TEDE (Sv)	<u>1.9E-02</u>	5.6E-03	2.6E-03	1.5E-03	9.3E-04	6.5E-04	4.8E-04	3.7E-04
U Deposition (g/m²)	1.6E+00	4.6E-01	2.1E-01	1.2E-01	7.7E-02	5.4E-02	4.0E-02	3.0E-02

Release direct atmosphere:
Table 4 represents results data of release of directed to atmosphere using RASCAL Code.

Table 4 Represents results data of release production directed atmosphere at different distance :

METER	10	20	30	40	50	60	70	80
HF Conc - 1h Eq (ppm)	7.1E+01	7.9E+01	4.0E+01	2.3E+01	1.5E+01	1.1E+01	7.8E+00	6.0E+00
HF Conc - Avg (ppm)	9.5E+02	1.1E+03	5.3E+02	3.1E+02	2.0E+02	1.4E+02	1.1E+02	8.1E+01
HF Deposition (g/m²)	2.0E-01	2.2E-01	1.1E-01	6.5E-02	4.3E-02	3.0E-02	2.2E-02	1.7E-02
U Exposure ((g-s)/m³)	6.9E+01	7.7E+01	3.9E+01	2.3E+01	1.5E+01	1.0E+01	7.6E+00	5.9E+00
U Intake (mg)	2.3E+01	2.6E+01	1.3E+01	7.5E+00	4.9E+00	3.4E+00	2.5E+00	2.0E+00
U TEDE (Sv)	7.1E-03	8.0E-03	4.0E-03	2.3E-03	1.5E-03	1.1E-03	7.9E-04	6.0E-04
U Deposition (g/m²)	5.9E-01	6.6E-01	3.3E-01	1.9E-01	1.3E-01	8.8E-02	6.5E-02	5.0E-02

These results show that an unprotected person standing up to 40 meter from the release point would be exposed within a few minutes to lethal uranium and HF concentrations. From table 3 it is clear that there is no hazard TEDE during release directed atmosphere.
Fig.6. represented relation between distance dependent plume temperature and its height above ground .

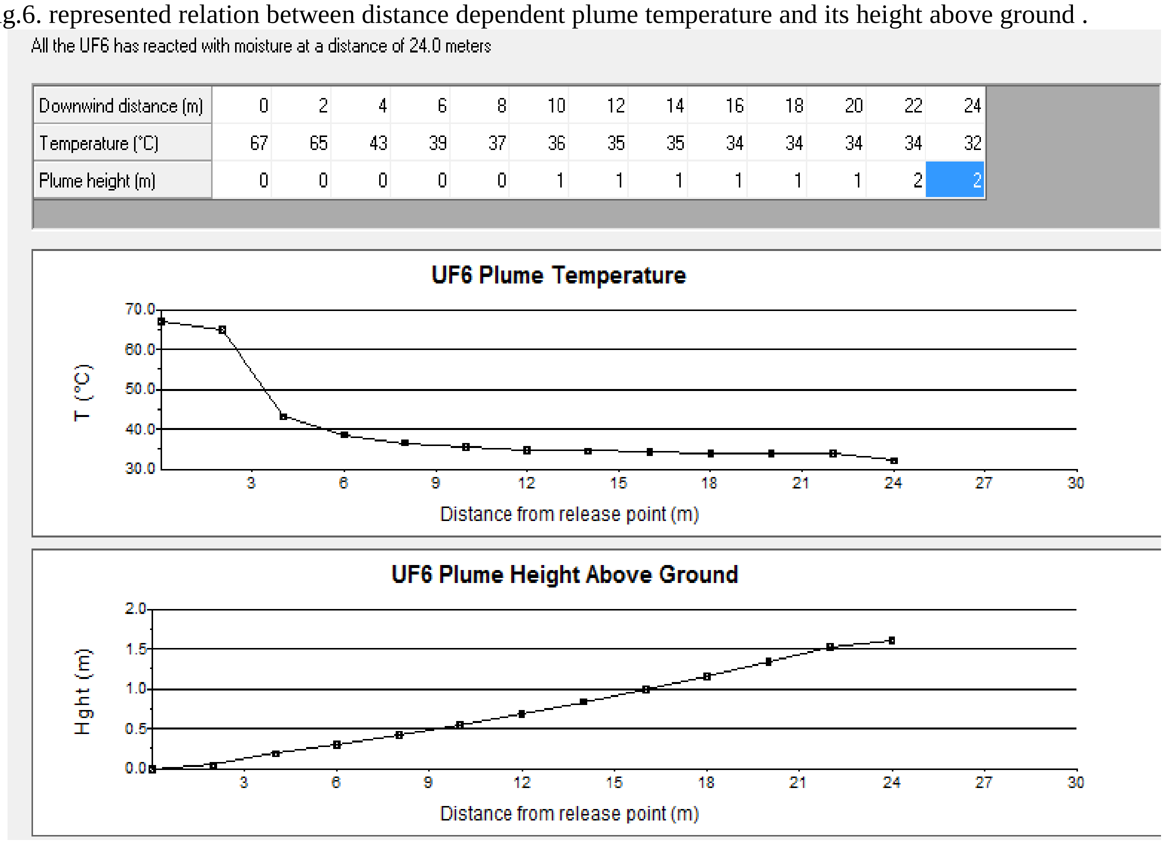

Fig.6. Relation between plume temperature and its height at different temperature.

It is clear that the maximum plume temperature 65 °C at 2 meter from the release point and the maximum plume hieght2 meter at 24 meter far away the release point, that mean worker is the most effective in these accident.

Emergency requirement to protect worker in fuel facility [7, 8]:
-For the use of glove boxes (for instance for the confinement of reprocessed uranium), specifications of design shall be commensurate with the specific hazards of the uranium fuel fabrication facility.

-The efficiency of filters and their resistance to chemicals (e.g. HF), high temperatures of the exhaust gases and fire conditions shall be taken into consideration
-Detectors shall be installed in areas with a significant chemical hazard (e.g. due to UF_6, HF) and with limited occupancy, unless it can be demonstrated that a chemical release is highly unlikely.
-For uranium fuel fabrication facilities, specific attention shall be paid to the qualification and training of personnel for dealing with radiological hazards (mainly criticality and contamination) and specific conventional hazards such as chemical hazards and fire hazards.
-To minimize the number of events occurring, close attention shall be paid to their prevention in anticipated operational occurrences, non-routine operations and secondary operations such as decontamination, washing and preparation for maintenance or testing.
-Close attention shall be paid to the confinement of uranium powders and the control of contamination in the workplace.
-Emergency arrangements shall be put in place for criticality accidents, the release of radioactive material and hazardous chemical materials, principally F_2, UF_6, HF and NH_3, and the spread of fires and explosions.
Emergency planning has been recognizes that equipment can fail and operators can make errors, therefore requiring safety systems to reduce the chances that malfunctions will lead to accidents that release radioactive and hazardous materials; and Recognizes that, in spite of these precautions, accidents can happen, therefore requiring high efficiency particulate air (HEPA) filters to prevent the release hazardous materials offsite.

Regulations

Fuel facility operators, licensed, have the responsibility to prevent serious accidents. The regulations require licensees to immediately notify ENRA of serious accidents. The licensee is required to develop and submit its emergency plan to the ENRA, after offsite emergency response organizations review the plan. Each licensee is required to invite offsite response organizations to participate in its exercises.

IV. CONCLUSION

From table 1, HF concentration though building it is clear that all result less than ERPG-2 20PPm, where in case of direct atmosphere concentration increase about three times through much long distance, though unprotected person affected.

Model results indicate that this release not affected on the public but workers are the most effective.
The control of UF_6 releases requires preplanning with respect to emergency procedures and equipment. Respiratory protective equipment, wooden plugs, patches, detection and alarm system, and some type of cooling mechanism should be available in areas where UF_6 is processed. Entry into dense clouds from UF_6 requires the use of protective clothing and breathing apparatus capable of preventing inhalation of HF and particulates. Skin protection is necessary to prevent burns. It is essential that all persons not properly trained and protected be evacuated from areas affected by the release.
If an emergency ventilation system is available, they would first pass through filters or scrubbers before being released to the atmosphere, these scenarios occur inside buildings.
Emergency arrangements shall be put in place for the release of hazardous chemical materials, principally F_2, UF_6, HF andNH_3, and the spread of fires and explosion

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