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RISK ASSESSMENT OF AN URANIUM ISOTOPIC ENRICHMENT PLANT

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1. Introduction

The risk associated with operating a uranium isotopic enrichment plant (UEP) is essentially linked to uranium hexafluoride - UF_6, which is toxic, radioactive and highly reactive compound with various substances. UF_6 accidental releases in UEP can occur from different ways, such as piping rupture, valve failure during transfer of UF_6 or from cylinders, cylinder rupture during heating or accidental fire [1].

For case of UF_6 release in gas form, the reaction (usually within one or two minutes) with water vapor present in the air, releases heat due to the exothermic reaction and forms small particles of uranyl fluoride (UO_2F_2) (diameter 1 to 10 µm) and hydrogen fluoride gas (HF) [2].

In order to try to avoid UF_6 accidental releases, an operational risk assessment for UEP is presented in this paper. The tool that will be used to assist in the identification of hazard scenarios in a UF_6 subsystem is defined as regulation bases. The Preliminary Hazard Analysis (PHA) method is used as a tool to identifying hazard scenarios. The real operational data of the typical UEP was used. PHA is a simple and inductive analysis method whose objective is to identify the hazards, situations and hazards events that can cause damage to a particular activity, installation or system [3]. It is useful when there is a need for a broad identification and overview of hazards.

After identifying the hazard scenarios, the risk was quantified based on the assessment of frequency and severity. The risk categorization had the purpose of pointing out the scenarios whose importance can be classified as an important safety item. The results show that the proposed methodology is a promising way to solve this problem type.

2. Methodology

The methodology was initially based on the identification of hazard scenarios and filling out the PHA spreadsheet. Risk quantification was performed based on estimated frequency and severity calculation. The approach for calculating the operational failure frequency followed the methodology proposed by.

Failure rates were brought from [5] and were used to calculate failure probabilities. The estimated operating time of the equipment is considered in the concept of risk by calculating the probability of a failure event, according to Eq. 1 [6].

$$P_f = 1 - e^{-\lambda t} \tag{1}$$

A typical equipment failure rate was used for each scenario, as well as an annual estimate of the equipment operating time. The operating frequency is given by Eq. 2:

$$F_{op} = \frac{number\ of\ times\ \text{the operations performed}}{year} * \frac{duration\ of\ an\ operation}{operation} \tag{2}$$

The frequency of radiological risk is given by Eq. 3:

$$F = F_{op}P_f \tag{3}$$

The severity referring to the radiological risk is defined as the effective radiation dose, that is, the radiological impact is expressed in terms of radiation dose [7]. The effective dose was calculated by Eq. 4 adapted from [8]:

$$D_{ef} = \frac{QAfRT}{V} \tag{4}$$

Where:

Q - released radionuclide mass [kg];
A - radionuclide specific activity [Bq/kg];
f - Compromised effective equivalent dose conversion factor due to radionuclide inhalation [Sv/Bq], [11];
R - respiration rate, [m^3/s];
T - operator contact time with the plume inside the room [s];
V - room volume [m^3].

The assessment of internal exposure in workers is based on prospective exposure parameters such as duration of exposure, concentration of radionuclides in the breathing zone, and type of radioactive aerosol materials. The specific activity A was calculated by equation 5, as defined [9].

$$A = 0.4 + 0.38E + 0.0034E^2 \tag{5}$$

Where:

A - specific activity [$\mu Ci/g$]
E - percentage of uranium enriched in U^{235}

Equation 6 defines the radiological risk as defined [4].

$$R = C_R(FD_{ef}) \tag{6}$$

Then:

C_R - radiological risk coefficient [Sv^{-1}], [10].

3. Results and Discussion

The criterion proved to be very effective in identifying and categorizing the plant's risk. It will be used to define the important safety items. The identified scenarios presented a very different order of magnitude.

The scenarios that describe the UF_6 isotopic recomposition system RBI1, RBI3, RBI4 and RBI10 showed a very low risk. May be left out of the list of important safety items. They are cylinder valves, pipe sections and a sample collection system.

The rest of the scenarios represent more than 99% of the total risk. They will be considered in the list of important items for safety and therefore they will have a differentiated maintenance approach.

Table I presents the frequency quantification, risk and severity results found with the methodology proposed.

Table I: quantification of radiological risk as a function of frequency and severity

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Scenario	Frequency, /year	Effective dose [Sv]	Coefficient of radiological risk [Sv^{-1}]	Risk, /year
RBI1	8.13E-06	1.12E-01	4.00E-02	3.6E-08
RBI2	3.34E-03	1.12E-02	4.00E-02	1.5E-06
RBI3	2.94E-03	5.60E-03	4.00E-02	6.6E-07
RBI4	8.13E-06	3.43E-01	4.00E-02	1.1E-07
RBI5	3.41E-03	3.43E-01	4.00E-02	4.7E-05
RBI6	2.85E-03	3.43E-01	4.00E-02	3.9E-05
RBI7	3.41E-03	3.43E-01	4.00E-02	4.7E-05
RBI8	1.10E-01	1.71E-01	4.00E-02	7.5E-04
RBI9	1.10E-01	1.71E-01	4.00E-02	7.5E-04
RBI10	4.29E-03	1.71E-03	4.00E-02	2.9E-07
RBI11	1.10E-01	1.71E+00	4.00E-02	7.5E-03
RBI12	1.10E-01	1.71E+00	4.00E-02	7.5E-03

4. Conclusions

This article presents a new methodology frequency quantification, risk and severity in case of accidental release of UF_6 in a UEP. A structured risk assessment focused on the plant's reality is very important for the plant and for the licensing bodies. The results show that the methodology is simple and easy to implement in a nuclear industrial installation. The application of the method identified areas where the risk is quite high, such as scenarios RBI11 and RBI12 in Table I, due to the high severity (effective dose). These two scenarios together represent 90% of the risk pointed out in the entire system. The failure of these instruments can lead to an increase in pressure inside cylinder 30B, with the possibility of rupture of the cylinder, valves or piping with the release of UF_6.

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