Internal Doses at Enusa Juzbado Fuel Fabrication Plant. Estimation and Application Alara Criteria

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Summary

An ALARA program has been applied at „Fábrica de Juzbado“ (Nuclear Fuel Fabrication Plant) to reduce the radiological exposure and for a best estimation of internal doses. As a consequence of this program the internal doses are very low. We have made a statistical study of air sampling concentration and internal dose values finding that they can be fitted to the probability distributions. Using these distributions we have applied simulation techniques to forecast the future intake and their uncertainties. An improved method for normal and lognormal censured distribution is used to take into account lower level detection (LLD) values. To make this study we have developed several *Mathematica* (Wo99) programs. These methods can be useful to design and conduct the air control monitoring and the bioassay programs introducing statistical criteria to determine when an air control monitoring or bioassay is required and the frequency in the application.

Introduction

„Fábrica de Juzbado“ is a factory where uranium fuel assemblies to light water reactors are made. This process requires manipulating powder of enriched uranium oxides (mainly UO_2, and a little percentage of U_3O_8). The enrichment of ^{235}U varies between 0.71% and 5%. Hood and glove boxes are used for handling the uranium, but small amounts of radioactivity may be released into the room air as airborne. „Ceramic Area“ is the working area where there is a potential radiological hazard for internal contamination. The intake of workers of Ceramic Area is estimated with fixed air samples. Besides, there is alpha continuous air monitoring but it is not used to estimate internal doses, they are applied to detect accidental high unexpected concentrations of airborne radioactivity.

A bioassay program is applied. The workers are periodically monitored with lung counter and urine samples are taken.

An ALARA program has been applied to reduce the uranium airborne concentration and the radiological exposure. More effective methods are applied for a best estimation of internal doses.

We have made an statistical study of air sampling concentration and the internal doses values. We have found that these can be fitted to the probability distributions. Using these distributions we have applied simulation techniques (La98) to forecast the future intake and their uncertainties. An improved method for normal and lognormal censured distribution is used to take into account lower level detection (LLD) values. All these methods can be useful for the design and the conduct of the air control monitoring and for the bioassay programs introducing statistical criteria to determine when an air control monitoring or bioassay is required as well as how often should be applied.

ALARA application

According to ALARA criteria many protected actions to reduce internal exposure have been taken in Fábrica de Juzbado:

- Reduction of uranium airborne in Ceramic Area: Improvement of the ventilation, better confinement hood and glove boxes for handling the uranium
- Reduction of the fabrication lifetime and the storage of uranium oxide
- Automation of the process: sintered pellet loading at grinder equipment, pellet inspection, rod loading, etc.
- Staff training

The investment during the past five years to improve both quality and to reduce the doses has been approximately 2 millions of Euros.

In the year 2000 the Spanish legislation will include the new dose limits established by the European Union directive: „Basic rules of Health Physics relative to the protection of workers and the population against the risks from the ionizant radiation" (May 13, 1996)

One of the requirements to take into account is the establishment the new dose limits lower than the present ones. Juzbado Plant is in a good position to accomplish these limits due to the efforts to minimise the doses.

Furthermore, the estimation of internal doses and the measure of the surface contamination have been improved. The goals are: a) To detect unusual level of surface or environment contamination as soon as possible to permit a faster intervention, b) To improve the comfort of worker avoiding the use of respirators and other protection clothes.

The reduction of dose has a high cost for the companies. We think that where the low level of doses is guaranteed individual controls could be relaxed, but in many occasion the Health Physics regulations are not enough precise. In this sense, we have developed a method introducing statistical criteria to determine when an air control monitoring or bioassay is required and the frequency for their application.

Figure 1 shows the evolution of the internal collective doses at Fabrica de Juzbado. Since 1994 has been improved the method.

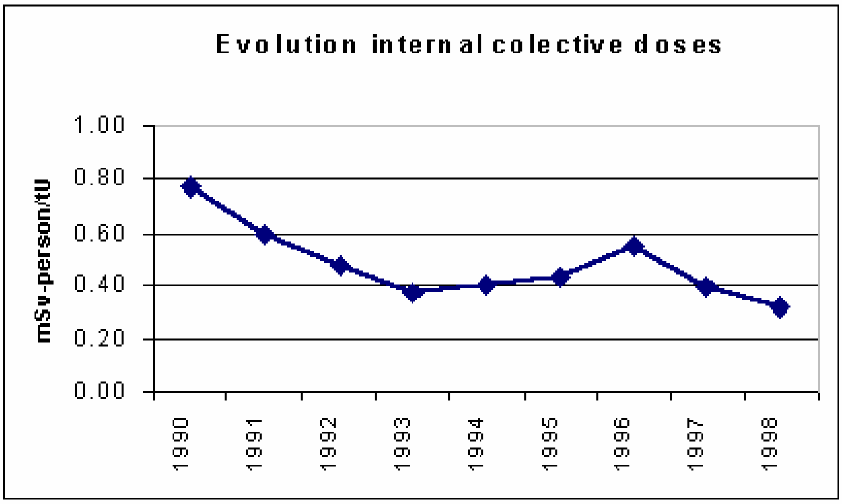

Figure 1 Internal collective doses evolution at Fabrica de Juzbado. They are normalised with the number of tU fabricated each year.

Estimation of intake with air sampling

We are going to describe how the intake for people working in Ceramic Area is estimate.

The uranium radioisotopes air concentrations are periodically monitored with air samplers. Samples are taken from the drawing air, using a pump, through a paper filter where the airborne is collected. Air samples are fixed in locations strategically located in the workplaces (Figure 2). Samples (filters) are usually taken every 8 hours (at the same time that the workers change shift) in the area where the powder materials are handled, whereas others area samples are taken daily (each 24 h.) or once a week. Since the airborne radioactivity expected in these areas is exclusively due to uranium powder, samples are counted for alpha radioactivity using scintillation ZnS. In some operations where the maximum level of airborne uranium concentration (DAC) could be exceeded (i.e. cleaning equipment's) individual respirators are used. A double system to cut the flow through the filter is applied when the respirator is used, in this way it is possible to take into account the respirator in the estimation of the intake.

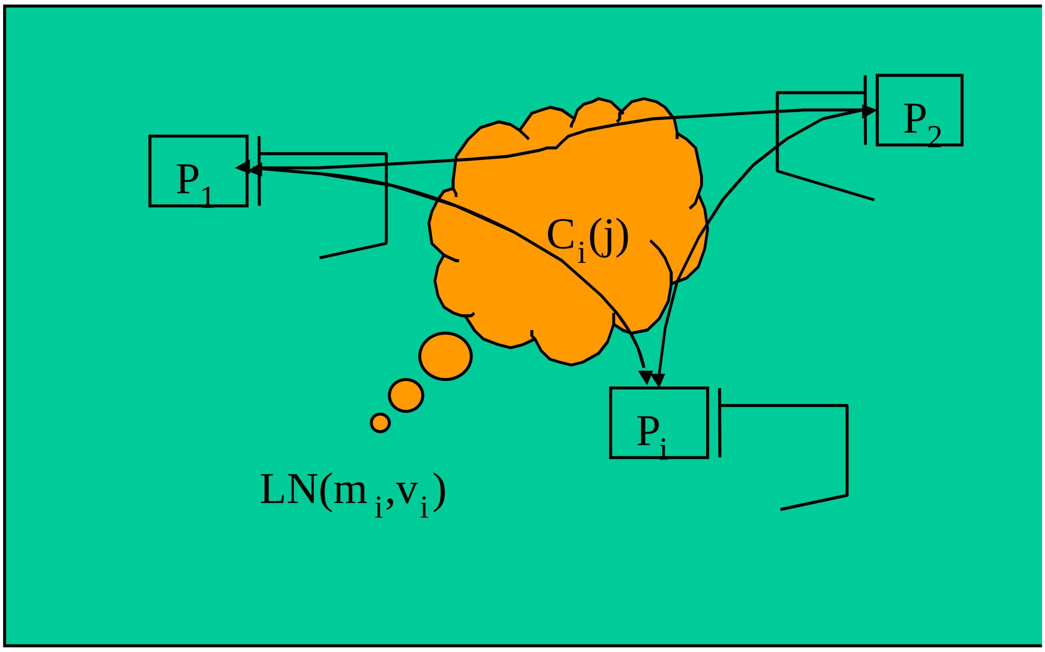

Figure 2 Worker moving in an area with air sampling fixed in points P_i. We have found that daily concentration C_{id}, can be fitted to the lognormal distribution LN(m_i,v_i)

The concentration C_{id} the working day d at point i is given by

$$C_{id} = A_{id} / (r\,T) \tag{1}$$

A_{id} is the measured activity in filter from air sample i the working day (shift) d.

T is the time during which the air flows, r, is drawing to the filter the day d (We assume that T and r are constants and equal for all working days).

The worker stays every day in n different points. He registers the time Δt_{id} that during the working day d has been at point i. The intake for this worker the day d is

$$I_d \approx \nu \sum_{i=1}^{n} C_{id} \Delta t_{id} \tag{2}$$

where ν is the worker's breathing rate, which we assume constant and equal for all workers. (We chose „≈" better than „=" because C_{id} is already the *average* concentration at i for all the day d and not during Δt_{id}. Furthermore if the worker has used a respirator at Δt_{id} a reduction factor is applied to estimate C_{id}).

Substituting eq(1) in (2) we obtain

$$I_d \approx \frac{\nu}{r\,T} \sum_{i=1}^{n} A_{id}\ \Delta t_{id} \tag{3}$$

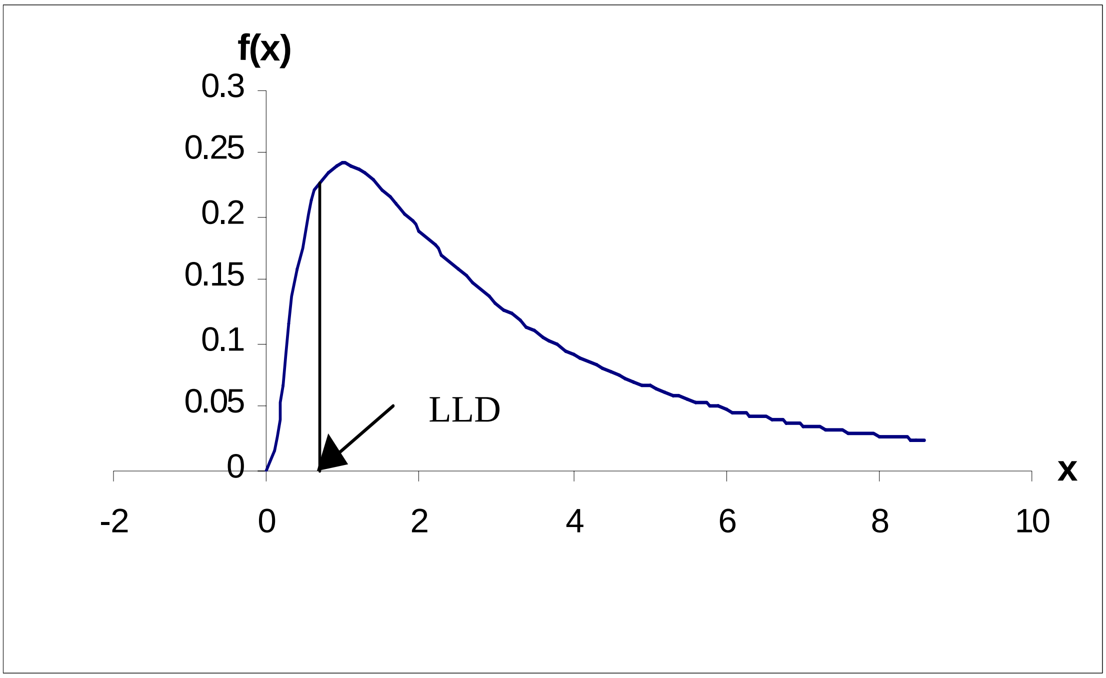

Figure 3 Censored lognormal distribution, x is a random variable that represent the daily average uranium concentration C_d. Some values are censored because they are bellow that the lower detection limit (LLD).

Simulation applicated to estimate the potential radiological hazards

The standards require that monitoring of intake of radioactive material and bioassay programs should be applied depending on radiological hazards but they do not establish precise criteria how this radiological hazards should be evaluated. For instance: Monitoring of intake of radioactive material is required by 10 CFR 20.15028(b) if the intake is 'likely' to exceed 0.1 ALI (annual limit on intake), but how the hazard to exceed 0.1 is evaluated?

We have developed a statistical method to evaluate these hazards (Sa98a and Sa98b). We have used the data of our plants but we consider that it can be applied to others radioactive facilities.

We suppose a group of *m* workers moving daily, during a long time, between *n* points in an area (Fig. 3) where the average daily concentration C_{id} in each point was measured. We don't consider the points where either the workers stay a negligible time nor the time for moving between points.

The daily intakes I_d^k of each worker *k* are

For $k = 1$ $\{ I_1^1, I_2^1, \ldots, I_d^1, \ldots\}$
For $k = 2$ $\{ I_1^2, I_2^2, \ldots, I_d^2, \ldots\}$
… … … … …
For $k = m$ $\{ I_1^m, I_2^m, \ldots, I_d^m, \ldots\}$ (4)

The total intake I_D^k for each worker during a period of *D* days -usually *D* = number of working days of a year- is

$$I_D^k = \sum_{d=1}^{D} I_d^k \qquad (5)$$

and the average, $\hat{I}_D$, and standard deviation, s_D, of $\{ I_D^1, I_D^2, ..., I_D^m \}$ are:

$$\hat{I}_D = \frac{\sum_{k=1}^{m} I_D^k}{m} \quad (6)$$

$$s_D = \sqrt{\frac{\sum_{k=1}^{m}\left(I_D^k - \hat{I}_D\right)^2}{m-1}} \quad (7)$$

with a confidence interval of mean given by:

$$I_D = \hat{I}_D \pm t_{1-\alpha/2,m-1}\, {}^{s_D}\!/\!_{\sqrt{m}} \quad (8)$$

where $t_{1-\alpha/2,\, m-1}$ is the *t*-Student with to a given of significance a and *m* -1 degrees of freedom

We are interested in evaluating the probability *p* that any worker of these group intakes an amount *I* lower than the limit of intake *L* in the period [0,D]. We have into account that { I_D^1, I_D^2, ..., I_D^m } values follow a Normal distribution. In effect: $I_1^D = D\,\hat{I}_1$, $I_2^D = D\,\hat{I}_2$, …, $I_m^D = D\,\hat{I}_m$ and according to the Theorem Central of Limit the averages of a population follow a Normal Distribution. Therefore $P(I = L) = \alpha = p$ is given by

$$\hat{I}^D + z_{1-\alpha}\, s_D = I_L \leq L \quad (9)$$

where

L Limit of intake, usually *L* is a fraction f of ALI.

z_{1-a} z factor of a normal standard N(0,1) with one side level of signification a (e.g.: a= 0.05 $z_{0.95}$ = 1.649).

In many occasions we have only the daily intake I_d^k values of a few workers and a statistical requirement to apply (9) is that $m \geq 30$. Besides the quality of A_{id} (activity measured in filter) values is better than I_d^k. Therefore we are interested in evaluating the hazard of an area and not of a specific worker. For this reason we have used a Monte Carlo simulation to estimate the daily intake $I_d^{(k)}$ (we denote the worker by (*k*) instead of *k* to indicate that it is a simulation). We can simulate $I_d^{(k)}$ substituting in (2) C_{id} for $f_i^{(d)}[c]$ and Δt_{id} for $g_i^{(d)}[w]$.

$$I_{\mathrm{k}}^{(\mathrm{d})} = \nu \sum_{i=1}^{n} f_i^{(d)}[c]\, g_i^{(d)}[w] \quad (10)$$

where $f_i^{(d)}[c]$ and $g_i^{(d)}[w]$ are (seudo)random density function that, respectively, represent C_{id} and Δt_{id} values. For this reason, we need to find an appropriated density function to that fits the experimental values { C_{id}} and the { Δt_{id}}.

We have found that { C_{id}} values has a good fit to many points to the lognormal $LN(m_i,s_i)$ distribution given by

$$LN(\mu_i,\sigma_i) \equiv \begin{cases} f_i(c) = \dfrac{1}{\sigma_i\, c\sqrt{2\pi}}\,\mathrm{Exp}\left[-\dfrac{1}{2}\left(\dfrac{\ln c - \mu_i}{\sigma_i}\right)^2\right] & \text{if } c > 0, \\ f_i(c) = 0, \text{ in otherwise} & \end{cases} \quad (11)$$

where

$$\hat{\mu}_i = \frac{1}{N}\sum_i \ln C_{id}$$

$$\hat{\sigma}_i^2 = \frac{1}{N}\sum_i (\ln C_{id} - \hat{\mu}_i)^2$$

, *N* is the total number of data of the point *i*.

We have represented the daily stay of every worker in each sampling point applying the uniform distribution, $U_i(0,T)$, given by:

$$U_i(0,T) \equiv \begin{cases} g_i(w) = \dfrac{1}{T} & \text{if} \quad 0 \le w \le T \\ g_i(w) = 0 & \text{otherwise} \end{cases} \tag{12}$$

where for every working day d must be verified å$^{m}_{i=1}$ $W_{id} = T$ (T is the total duration of a shift and $W_{id} = \Delta t_{id}$).

Therefore

$$I_{\mathrm{d}}^{(\mathrm{k})} = \nu T \sum_{i=1}^{n} \frac{U_i(0,T)^{(k)}}{\sum_1^n U_i(0,T)^{(k)}} \, LN\left[\mu_i, \sigma_i\right]^{(k)} \tag{13}$$

If the average staying time W_i. in each point is known and it does not have a big deviation we can apply the following simulation equation:

$$I_{\mathrm{d}}^{(\mathrm{k})} = \nu \sum_{i=1}^{n} W_i \, LN\left[\mu_i, \sigma_i\right]^{(k)} \tag{14}$$

Eqs (13) and (14) can be no conservative. One option more restrictive is to choose the point i with the highest concentration.

$$I_{\mathrm{d}}^{(\mathrm{k})} = \nu T \max_{1 \le i \le m} \left\{ LN\left[\mu_i, \sigma_i\right]^{(k)} \right\} \tag{15}$$

Example.- We have applied this procedure to a grinding workshop in Ceramic Area. The intake for worker moving in this workshop is estimated mainly by using tree sampling points(P_1, P_2 ,P_3) near a equipment. Also we have used two point more: one represents the grinding area concentration, P_A, an other, P_F , represents the time that the worker is out of the Ceramic Area.

We have used the real concentration values of one year. We have found that this point can be fitted to the following probability function: $f_1(a)$ = LN(3.261, 1.262), $f_2(a)$ = LN(3.836, 1.546), $f_3(a)$ = LN(2.710, 0.879), $f_A(a)$ = LN(2.132, 0.684), and $f_F(a)$ = LN(1.954, 0.715). We have simulated the daily intake I_d substituting these functions in eq(13) with D = 200 (the number of working days of a year), and m = 30. The solution is shown in Figure 4.

The average annual intake, $\hat{I}^{\mathrm{D}}$, is 102.8 Bq and the standard deviation, s_{D}, 17.7 Bq. Substituting in (9) I_{L} = 132 Bq and choosing L = 150 Bq (10% ALI for uranium with low enrichment) we obtain $I_{\mathrm{L}} < L$, and therefore the probability to exceed of 10% ALI in this area is <0.4%. According to 10CFR20.1502(b) neither individuals intake estimation are required, nor to make periodic bioassays (see point 2.1.2 Nu93).

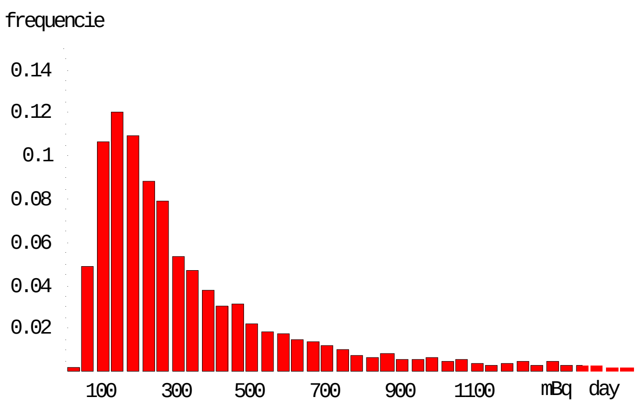

Figure 4 Distribution of daily intake of workers exposed to random concentration

Conclusions

An ALARA program has been applied at „Fábrica de Juzbado“ (Nuclear Fuel Fabrication Plant) to reduce the radiological exposure and for a best estimation of internal doses. As a consequence of this program the internal doses are very low. We have made a statistical study of air sampling concentration and internal dose values finding that they can be fitted to the probability distributions. Using these distributions we have applied simulation techniques to forecast the future intake and their uncertainties. An improved method for normal and lognormal censured distribution is used to take into account lower level detection (LLD) values. To make this study we have developed several *Mathematica* (Wo99) programs. These methods can be useful to design and conduct the air control monitoring and the bioassay programs introducing statistical criteria to determine when an air control monitoring or bioassay is required and the frequency in the application.

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