MULTIFACTORIAL ANALYSIS OF OCCUPATIONAL OUTAGE DOSES DISPERSION IN THE FRENCH NPPs 1998-2002

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Introduction

Since 1992, many improvements have been achieved at EDF in terms of reducing occupational radiological exposures. Many efforts have been done in several areas, but without knowing what are the factors that have most influenced these results. It would therefore be of interest now to know more about that in order to be able to decide where to invest with an optimal efficiency to further improve occupational radiological protection.

Objectives and methods

At the request of EDF, CEPN has performed an in depth statistical analysis in order to reveal the respective influence of factors explaining outage doses dispersion in France, and therefore to determine which factors are still potential levers for continuing improvement of occupational radiological protection. The study has been first carried out among more than 137 outages corresponding to the period 1998 – 2000; the period has then been expanded with two extra years 2001 and 2002, which has allowed studying 226 outages. Eleven qualitative variables and 39 quantitative variables were selected to take into account reactors design features (10 variables), characteristics of the operation of the plants (15 variables), and characteristics of the shutdown (15 variables), and of the outages themselves (13 variables) (see annexes 1 and 2). Many of these variables are similar to variables requested in the so-called level 2 questionnaire of ISOE (materials and components, primary water chemistry and contamination levels, hot spots…).

Most of the results from the first study have been confirmed in the second one; therefore, we will here present the results on the five years period, proposing an analysis of the evolution between the three first years and the recent period only in a few cases when the results of the first period have not been confirmed. The main differences between the first step and the second, is that the impact of some variables that was not significant became significant, as the size of the samples had increased.

The study has been performed for the outages sample as a whole as well as for each type of French Pressurised Water Reactors and for each major type of outages (simple refuelling outage (ASR), short maintenance outage (VP) and long decennial outage (VD)).

To achieving the previous objectives, CEPN has performed a statistical study in two steps: an analysis of the qualitative variables influence on outage doses, followed by an analysis of correlations between doses and each quantitative variable. All calculations have been performed using STATGRAPHICS Plus software.

Results

- Analysis of the influence of the qualitative variables on outage doses dispersion.

This study confirmed the very important impact of the design on the collective dose level during outages. Among the 5 years analysed, doses from the 900 MWe units are 30% higher than those of the 1300 MWe units. The same gap may be observed for the simple refuelling outages (ASR) as well as for the short maintenance outages (VP). It is even more important between the two types of reactors (40%) for the ten years outages (VD).

The study confirms a statistically significant impact of SG tubes material and fabrication as well as of SG channel head electropolishing on outage dose.

It is interesting to see that there is no relationship between the use of MOX fuel and outage doses, which let consider that there is no significant impact of the MOX fuel on the source term.

One may have expected that, on the 900 MWe units, the type of reactor boron and water make up system might have had an impact on the level of the doses: actually, there are two systems for the cover of the tank corresponding to that system, one with air under the cover and one with nitrogen under the cover; it was therefore suspected that any bore injection in the system with air, will have introduced oxygen into the primary circuit, leading to oxidation and contamination. This is not verified, or at least there is no significant difference with those reactors with nitrogen under that tank cover.

Qualitative Variables	Total sample	Outage type			900 MWe				1300 MWe			
		ASR	VP	VD	All	ASR	VP	VD	All	ASR	VP	VD
Reactor type	+	+	+	+								
Outage type	+				+				+			
Presence of hot spots	+	+	+		+	+	+		-		-	
Use of MOX fuel	-	-	-	-	-	-	-	-				
Large tasks	+	-	+	-	+		+	-	+		+	-
SG tube material	+	+	+	+	+	+	+	-	+	-	-	
SG tubes manufacturer	+	+	+	-	+	-	-	-	-	-	+	-
Electropolishing SG channel head	+	-	+						-	-	+	
SG Type	+	+	+	+	+	-	-	-				
Reactor boron and water make-up system	+	+	+	+	-	-	-					

+ Significant relationships since the first step of the study; + new significant relationships with increased size of the sample in the second step. The blocks in black are those where any analysis should be avoided (a priori not meaningful). The blocks with – are those where no relationship is significant.

- Analysis of the influence of the quantitative variables on outage doses dispersion.

Moreover, to study relationships between dose and quantitative variables, doses from units with hot spots have been normalised by dividing them with a 1.3 factor, as a 30% extra dose has been pointed out as a significant average impact resulting from these hot spots on outage doses.

Furthermore, due to the influence of the reactor type and outage type on doses, most analysis have been performed successively on the total sample, samples by type of outages, samples by type of reactors, samples crossing the previous variables (when enough data exist in the sub-samples). This has allowed comparing more homogeneous reactors as regards these variables.

It is not surprising to find that the most important variable, which presents, by far, the highest correlation coefficients (more than 0.7), not only for the sample as a whole, but for each sub-sample by type of reactors (900 MWe or 1300 MWe) and even by type of outage for each type of reactor, is the time spent in controlled area. Having that in mind, it should be very important to create and follow up new variables that might influence the dispersion of these "time spent", and on which it may be expected to have an influence: percentage of mishaps, reworks, fortuitous works, work management, frequency and justification of controls… It is obvious that some doses (and money!) may still be saved in reducing the time spent in controlled area, as the impact of that variable remains significant even within homogeneous outages for the same type of reactor to explain differences in terms of doses. This comforts the expectations from ISOE a few years ago when issuing the book on "work management".

Another conclusion from that part of the study is that the time spent in the controlled area is a good estimate of the "actual exposed workload", contrarily to the length of the outage in terms of days, which was often referred to in the past as a good variable. Therefore, it seems very important in the future that the information on the time spent in the controlled area will be well followed both at the outage as a whole and at the task levels to allow performing useful benchmarking nationally and internationally.

That variable is therefore the first variable explaining outage doses dispersion. It is not possible to demonstrate that any other quantitative variable (but for a few very specific exceptions that will be pointed out later on) taken alone has a significant impact on the dose dispersion

One can then suppose that all other impacts are hidden by the influence of the time spent in controlled area. To remove that influence, a very efficient solution is the one proposed by our Spanish colleagues at Tarragona [1]: the elaboration of a ratio "outage dose divided by the time spent in controlled area" the so-called "dose index". That outage dose index might be considered as the average dose rate "used" during the outage as a whole.

All statistical correlations have then been performed between the remaining variables and the outage dose index to reveal the influence of other operating and outage variables. At that stage the impact of other variables becomes significant. The first of them is the radiological state of primary circuit (so called "indice de tranche" in the French plants). That variable is the average of a few dose rates measured on the cold and hot legs of the primary pipes in the SG containments with very precise conditions (positions, time after shutdown, circuit configuration…) in all French plants, following recommendations from the SMRP Programme of EPRI. That variable is nevertheless not as powerful as the time spent in the controlled area for explaining the outage doses dispersion, but one has to have in mind that radiological state of the primary circuit, by definition does not take into account the contamination of auxiliary circuits where (or in the vicinity of which) many works are performed. In that context the radiological state of primary circuit only becomes a very powerful variable (correlation coefficient higher than 0.7) for the ten years outages (VD) where much more work is performed on the primary circuit than during the other outages (on may even notice that for the ten years outages the radiological state of primary circuit is significant not only to explain the dispersion of the dose index but also to explain the dispersion of the outage doses themselves).

It is important to point out that even if cobalt 60 is very important during the first cycles, it remains a significant pollutant impacting dose rates and doses with ageing of the units as seen in the study for the 900 MWe units. It confirms the importance of stellite reduction programmes for that type of reactors as well as the importance of reducing CO_{59} content in the steels at both design and modification stages.

When analysing other radio-elements potentially contributing to dose through gamma emissions, some other become also significant contributors for the 1300 MWe units as cobalt is less important. It re-emphasises the importance of a circuit purification strategy not only focussed on cobalt, but also adapting the chemical specifications according to the type of pollutant (Ag, Sb…). EDF has developed such a strategy with all its partners (EDF headquarter departments, CEA, FRAMATOME). It will be now implemented.

The time spent in the controlled area by the health physicists appear also as an important variable for the 900 MWe units. The highest the time, the lowest are the doses with quite good correlations whatever the type of outage (ASR, VP or VD). The impact of this variable to explain the dispersion of doses has been even strengthened with the data from two the last two years. One may wonder why the same impact may not be observed on the 1300 MWe. An analysis of the data shows that the time spent in the controlled area by the health physicists is much more important (66% more) on the 1300 MWe units than on the 900 MWe units (75% more for the small outages ASR), with a smaller dispersion (the minimum values are between two and four time lower for the 900 MWe units depending on the year; the standard deviations are quite similar in absolute values, i.e. lower in relative values). Therefore the discrepancy between the two types of reactors is not surprising and one can then expect in the future that a global increase of the time spent in the controlled area by the health physicists in the 900 MWe units, particularly for those where that time is the lowest, will facilitate a reduction of the outage doses.

The time spent by the managers was also introduced as a potential variable to explain the dispersion of outage doses. Unfortunately the correlations are quite good but positive, of course it does not mean that the presence of the mangers is not useful, but clearly it just demonstrate that the longer are the outages, the highest the time spent in the controlled area by the managers and the highest the outage doses.

In a first time (three first years), the time spent in the controlled area by the individuals in charge of decontamination has appeared important for the 1300 MWe units. This is not any more the case when taking two more years. This does not mean that decontamination is not useful for reducing doses, but it just corresponds to an important reduction of the dispersion of the time spent during the different outages (by more than a factor 3).

As well as the impact of the qualitative variable “ type of reactor boron and water make up system”, some quantitative variables representatives of the number of rapid and important “load modifications” during the cycle, were introduced to check if the corresponding water movements may have introduced a significant oxidation and therefore an increase of the dose rates and doses. Correlations are no more significant with these variables than the impact of the qualitative variable. This comforts the conclusions of EMMEC measurements performed by the French Atomic Energy Commission that these load modifications cannot be significantly related to the outage doses.

Another variable has been introduced for checking the impact of the corrosion: the number of days during the cycle with “pH” lower than 6.9. It was expected that the higher that number, the higher the acidity and the corrosion in the primary circuit, the higher the dose rates nearby the primary circuit. What has been first observed is a difference of behaviour between the 900 MWe and 1300 MWe, as there is nearly two times more days for the 1300 MWe: 20 days ± 12 instead of 12 days ± 8 (but one has to have in mind that the fuel cycle is 18 months for the 1300 MWe while it is one year for the 900 MWe). Secondly, in most situations no significant correlation with either the dose index or the radiological state of primary circuit have been observed, but for the 1300 MWe during short outages only during the first period of the analysis (1998-2000) with both the radiological state of primary circuit and the dose index. The main characteristics of that sub-sample is that there has been an important increase of the average number of days between 1999 and 2000 (from 12 days to 23) with an increase of the dispersion, while it remains stable from 2000 to 2002. The example of this variable (and some of the previous) shows both: - that, even if some phenomenon’s are obvious (impact of acidity on corrosion…) the discrepancies between the units on the selected indicators are often not enough important to show significantly that they play a role for explaining the dispersion in terms of outage doses or dose index; - furthermore that it is not obvious to find good indicators.

Conclusion

The results presented here are just examples of what can be done with such a study both in France and at the international level with ISOE 2 data when fulfilled; they may be considered as preliminary results, they must be confirmed and validated.

Of course, some variables such as Zinc injection have not been studied here, as they were not relevant in France. Some others have not been kept such as biological shielding tons installed during the outage, as the information was not available in the French plants.

However that study has pointed out the interest of mixing qualitative and quantitative variables, the interest of mixing descriptive statistical analysis with the analysis of correlations between dose dispersion and other variables dispersions as well as there evolution with time.

ANNEX 1 - Qualitative Variables

Variables	Modalities
Design variables	
Type of reactor	900 MWe, 1300 MWe
Generation	Three generations for the 900 MWe and 2 for the 1300 MWe
Reactor boron and water make up system	Three modalities (with air, with nitrogen, floating cover)
Steam Generator Type	51A, 51B, 51BI, 51M, 4722, 6819
SG tube material	MA600, TT600, TT690
Electropolishing SG channel head	Yes, No
SG tubes manufacturer	Vallourec, Sandvick, Westinghouse
Operation variable	
MOX fuel used	Yes, No
Shutdown variables	
Outage type	Simple Refuelling outage (ASR), Partial checking outage (VP), Ten years outage (VD)
Large tasks	SGR, VHCR, …
Presence of hot spots	Yes, No

The first two variables correspond to the definition of the sister unit groups of the ISOE System.

ANNEX 2 - Quantitative Variables

Design variables
SG cobalt content (in ppm)
Number of standard fuel clusters
Number of fuel clusters with cladding
Operation variables
Average pH at cycle starting
Number of days with pH < 6.9
Average H_2 content (in ml/kg-TPN)
Cycle length (in equivalent fuel power days)
Number of abnormal operating situations (three set of modalities)
Fuel enrichment rate
Number of MOX assemblies
Age
Number of days with reduced power
Variables at outage start
Maximum values at the oxygenation peak (in MBq/t): - γ_{total}, - Ag110m, - Co58, - Sb124, - Co60, - Sb122, - Cr51, - rapport γ_{total}/Co58 Purification length since oxygenation peak (in hours)
Maximum values at the primary pumps stop (in MBq/t): - Co58, - Ag110m - Co60, - Sb124 - Cr51, - Sb122
Variables during shutdown
Managers collective dose
Health Physicists collective dose
Collective dose for decontamination
Total man-hours in controlled area
Total managers man-hours in controlled area
Total health physicists man-hours in controlled area
Total man-hours in controlled area for decontamination
Number of extra days when shutdown prolonged
Dose rate index nearby primary circuit (in 1E-2mSv/h)