EDF MEASUREMENT PROGRAM FOR SOURCE TERM REDUCTION

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ABSTRACT

Dose reduction during outages is a strategic purpose for EDF (productivity gains, nuclear acceptability and respect of regulation). The reach of these main purposes is correlated to source term reduction and, thus, contamination characterization and dose rate measurements.
In a first part, this paper will present EDF dose performances in 2009 (collective and individual doses) in comparison to international results.

In a second part, a focus will be done on EDF strategy concerning dose rate measurements and contamination characterization (radionuclides identification). Indeed, EDF has put in place a global monitoring program including in particular:

- *deposited activity with EMECC device,*
- *main contributors to dose rate with CZT device,*
- *dose rate measurements.*

For each kind of device, the main characteristics and the standard measurement points will be illustrated.

Moreover, specific measurement campaigns were also achieved in order to monitor actinides activity level in case of cladding defect on a fuel rod.

Finally, as a part of the Source Term Reduction project, all these measurements are or will be used afterward for the analysis of several optimization procedures currently carried out in EDF units such as zinc injection, new chemical Boron/Lithium management, new fuel managements, primary pumps stopping criteria decrease,... in order to quantify their efficiency on dose rate decrease.

I – Introduction

The reduction of collective dose is a constant challenge for all nuclear power plant operators, EDF included. Two different ways exists in order to reduce collective dose. The first one consists in a better organization of the outage (time spent in control area, biological shielding, …) and the second one in improving the radiological state of the unit and the efficiency of the source term reduction operations (corrosion and fission products). The first step for source term reduction is to put in place a measurement strategy in order to characterize not only dose rates but also deposited activities on walls (surface activity and hot spots). This strategy have to be elaborated in order to determine the performances of each units of the French fleet, to compare their performances and the associated good practices and finally to monitor the influence of new operational procedures (zinc injection, boron/lithium management, optimized SG tubes pre-oxidation and cleaning, …).

A general review of the EDF RP results in 2009 is done in section II. Moreover, section III describes the dose rate measurement strategy in place on the EDF French fleet whereas section IV details the contamination measurement strategy (EMECC campaigns and CZT program).

II – EDF dose performances in 2009

II.1 – Collective dose per unit

The average collective dose per unit in 2009 is 0.69 for the French fleet (0.79 for 900-series units and 0.57 for 1300-N4-series units).

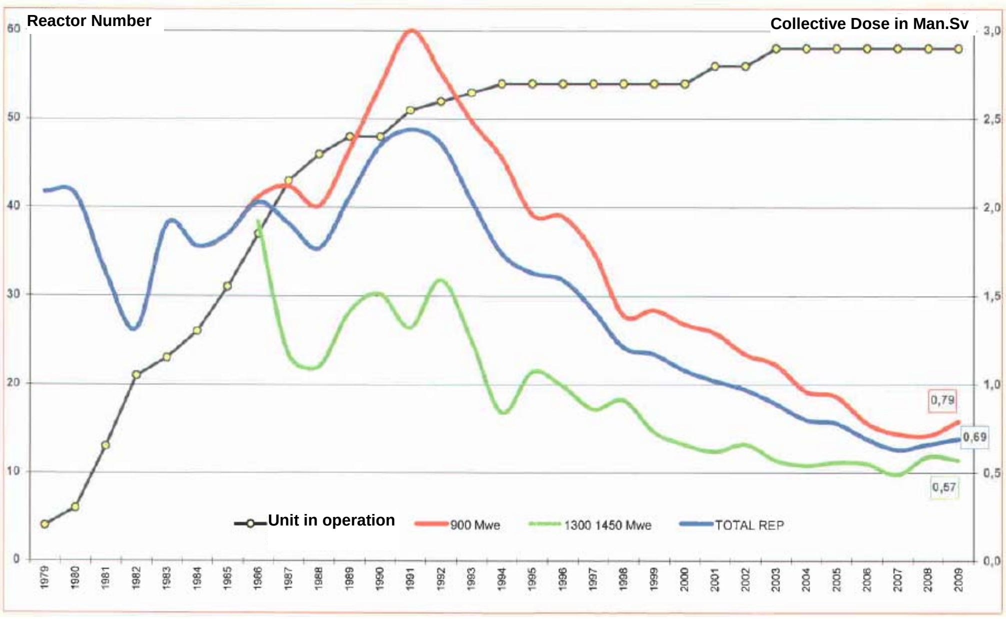

Figure 1: French fleet collective dose since 1979

As shown on figure 1, one can observe that the collective dose slightly has increased for 2 or 3 years due to important workings during outages mainly on steam generator. An action plan has been put in place at EDF in order to reach the 2010 RP objective: a collective dose of 0.65.
However, compared to the other important PWR fleets in the world (Germany, Japan, USA), France shows the lower collective dose per unit in 2009 (table 1).

Country	France	USA	Japan	Germany	Belgium	Spain	Sweden	Switzerland
Collective dose (Man.sv)	0.69	0.70	1.49	1.05	0.37	0.72	0.92	0.36
Unit number	58	69	23	11	7	6	3	3

Table 1: 2009 collective dose - International comparison

II.2 – Individual dosimetry

In 2009, the individual dosimetry on the French units has significantly decreased. In fact, 67% of the workers exposed to radiation received less than 1 mSv and less than 1% of the workers received more than 10 mSv. Furthermore, there was no worker in 2009 exposed to dose higher than 20 mSv and one can count 2 workers with dose higher than 16 mSv over the 12 last months.
In 2009, as in 2008, the highest average individual dose concerns “calorifugeage” activity (3.20 mSv). This worker category is the only one which increases in 2009 mainly due to an important number of ten-year outages in 2009.

III – EDF strategy for dose rate measurements

III.1 – RCS Index

This historical RCS index, carried out on the French fleet since the startup of all units, is adapted from the SRMP measurement program proposed by EPRI. This program contains 3 points per loop located on hot leg, cold leg and cross-over leg (figure 2). The RCS index is calculated as the average over 9 points for a 900-series unit (3 points × 3 loops) or over 12 points for a 1300-series unit (3 points × 4 loops). Those measurements must be performed by the Radiation Protection department of each unit only before oxygenation (internal EDF procedures) but all units can choose to perform or not measurements after oxygenation if need be in order to detect a possible over-contamination.

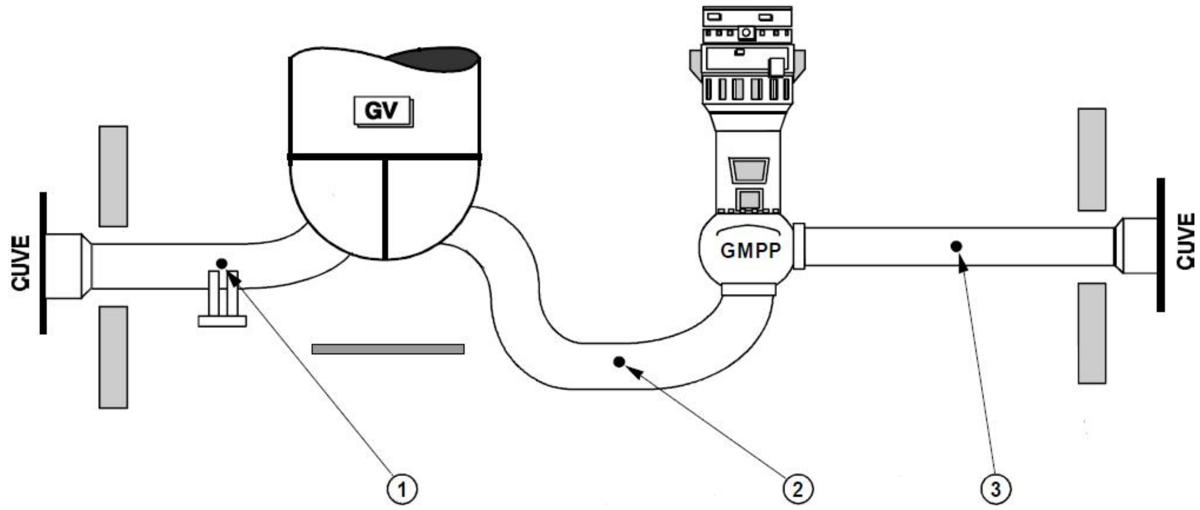

Figure 2: Localization of RCS index measurement points

RCS index evolution as a function of cycles is presented on figure 3 for 900-series, 1300-series and N4-series. One can observe that 900-series units RCS index decreases drastically and becomes closer and closer than the latest units (N4 series). That can be explained by the continuous progress obtained on source term (optimized shutdown procedures to avoid over-contamination after oxygenation, modified chemistry deployment on each units) and design improvements from the oldest units to the latest ones (SG tubing in alloy 690 replacing alloy 600) **/1/** .

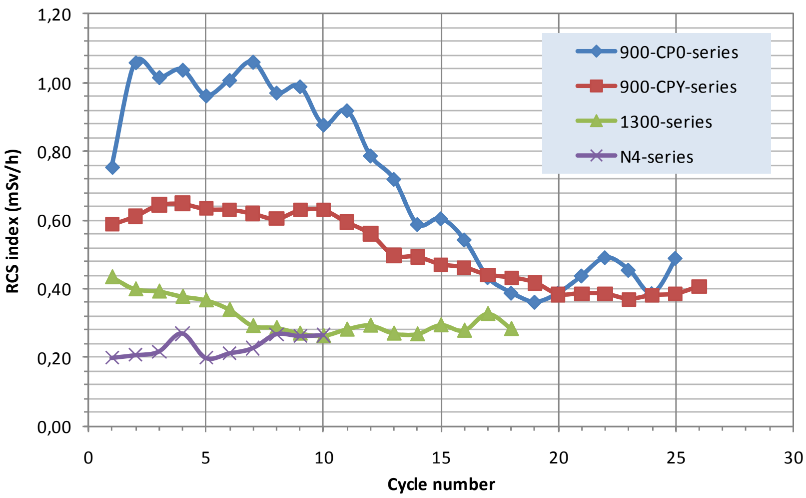

Figure 3: RCS index evolution on the French fleet until 2009

III.2 – RB index

RCS index, followed since the first startup of each French NPPs, is particularly useful to compare the dose rates near primary pipes between several units but does not give any information about the global radiological state of the reactor building.
For that purpose, a new Reactor Building Index (RB Index) has been created and will be set up on the whole EDF fleet between 2010 and 2011. This index is based upon a cartography including

approximately 40-50 measurement points in order to follow the radiological state of the reactor building and its main systems (RHRS, CVCS, RCS, VDS, PZR, SIS, Steam Generators and RFCTS). This index will not be detail in this paper because a specific paper on that subject is also proposed in ISOE 2010 /**2**/.

IV – EDF strategy for contamination characterization

In addition to dose rates measurements, contamination characterization is also achieved by gamma spectrometry (EMECC campaigns and CZT program).

IV.1 – EMECC campaigns

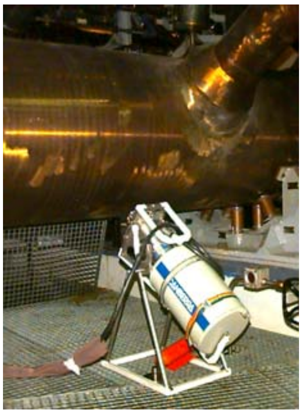

Figure 4: EMECC device

EMECC campaigns (performed by CEA /**3**/) have been commissioned for more than 30 years on French fleet units in order to better characterize contamination mechanisms. At the same time, EDF has also commissioned and financed EMECC campaigns on foreign units (Doel, Sizewell, Trillo during the 4 last years) with the contribution of several European operators in order to compare different good international practices.
That device allows non destructive surface activity by gamma spectrometry (HP germanium detector cooled by liquid nitrogen) based on a photon flux measurement converted in activity with the help of a pre-computed transfer function (MERCURE code). A very large range of geometries can be measured as primary circuit (cold and hot side steam generator tube bundle, hot, cold and cross-over legs), CVCS (letdown line, regenerative heat exchangers), RHRS (heat exchanger, piping), …

The measurement can be performed as if the primary circuit is full or empty, because the volume activity contribution can be easily removed. That point can be important in case of a high volume activity in the primary coolant which can notably affect the measurement result and lead consequently to a wrong analysis.
Deposited activities can be measured in a range from 1 MBq/m² up to 100 GBq/m² with a counting time depending on the detection accuracy: 30 minutes for current high activity radionuclides (^{60}Co, ^{58}Co) up to 1 hour for the other ones.
The EMECC program has to be defined before the beginning of each campaign according to its specific aim. As an example, a typical EMECC program performed in 2009 in a 4-loop unit is presented in table 2 and figure 5.

Measurement points	Before oxygenation	After oxygenation
RCS – Hot leg – Loop 1	1	2
RCS – Hot leg – Loop 2	3	4
RCS – Crossover leg – Loop 1	5	
RCS – Crossover leg – Loop 2	6	
RCS – Cold leg – Loop 1	7	8
RCS – Cold leg – Loop 2	9	10
RCS – SG hot side – Loop 1	11	12
RCS – GG cold side – Loop 1	13	14
RCS – SG hot side – Loop 2	15	16
RCS – SG cold side – Loop 2	17	18
RCS – Bypass line – Loop 1	19	20
CVCS – NRHE	21	

Table 2: Example of a EMECC program performed in 2009 on a EDF 4-loop unit

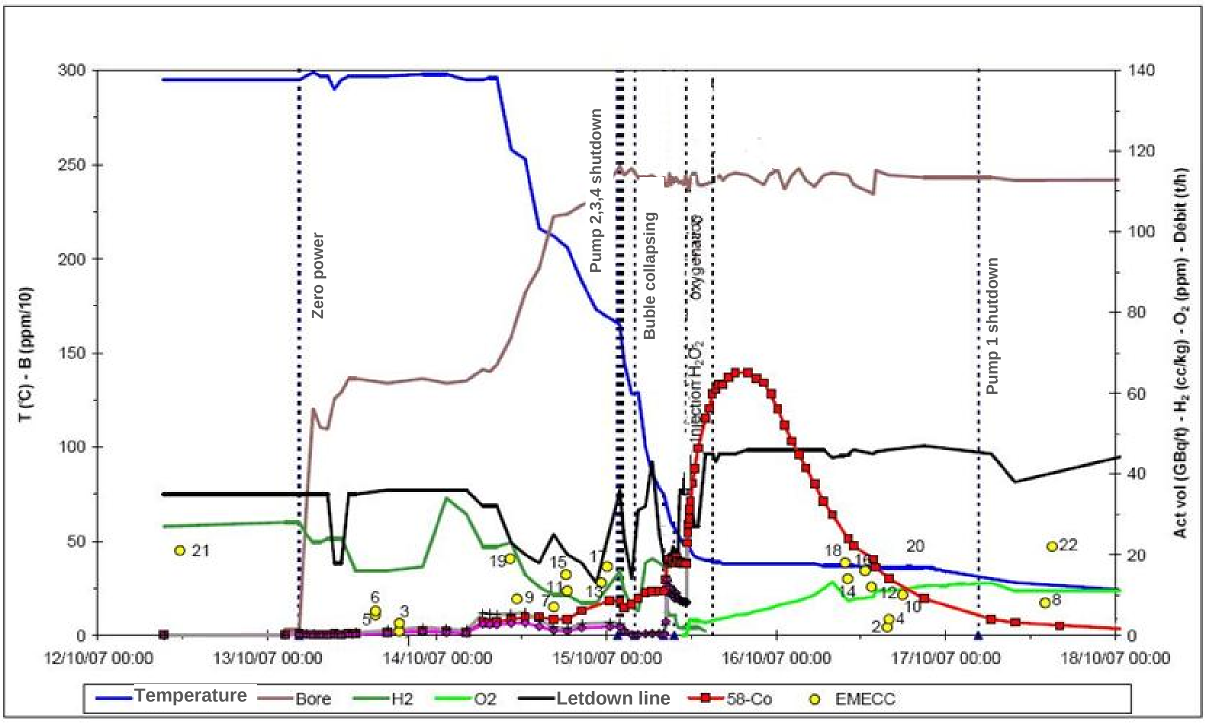

Figure 5: Measurement point localization during shutdown

As an illustration, the evolution over cycles of ^{60}Co surface activity deposited on hot legs and steam generator tubes is shown respectively on figure 6a and 6b for one unit representative of each EDF fleet sub-series.

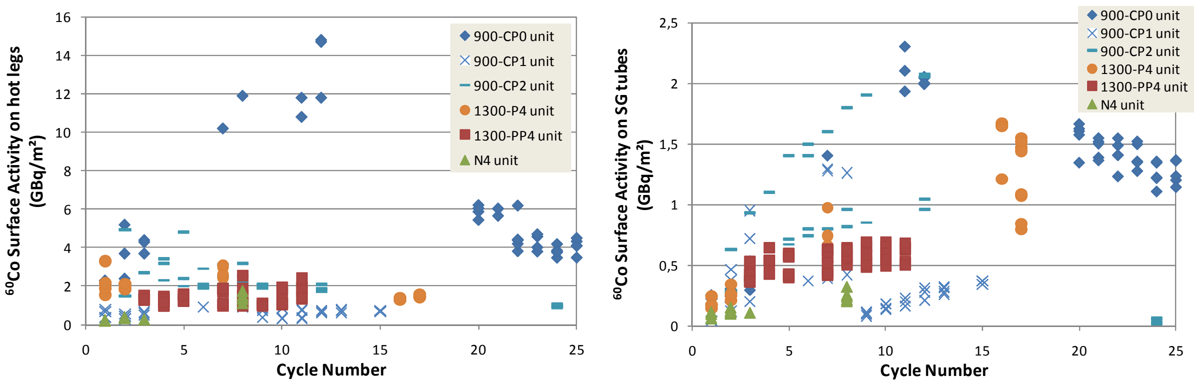

Figure 6: Evolution of ^{60}Co deposited activities on hot legs (6a) and steam generator tubes (6b)

IV.2 – CZT program

As a matter of fact, EMECC campaigns are a very accurate way to characterize contamination in primary circuit but it clearly appears that the campaign number per year cannot exceed 10. There are 2 reasons explaining this limitation: in one hand, the CEA staff restricted capacity and in the other hand, a significant cost of each EMECC campaign.

Therefore, it is not possible to perform an EMECC campaign for every unit and every outage and this kind of characterization is necessarily dedicated to specific major issues for EDF (impact on contamination of SG replacement, primary pump stopping criteria, pre-oxidation and acid-reducing cleaning after SG replacement or new plant first start-up) and particularly those with undertaking toward Authorities (zinc injection, fuel management impact for instance).

In order to give a supplementary operational way to each Radiation Protection Departments in each unit, EDF have been carrying out a new dose rate measurement program since 2006 based on a semi-conductor CZT probe (Cadmium-Zinc-Tellurium).

General objectives of the CZT gamma spectrometer **/4/** consists in allowing each nuclear plant:

- to characterize the radionuclide contribution to the dose equivalent rates in order to take the relevant action with regard to reducing staff exposure doses (radiation protection),
- to produce a "point zero" contamination diagnosis (source term),
- to monitor the evolution of contamination from one cycle to the next,
- to identify as soon as possible any penalizing pollutants with regard to over-contamination risks,
- to assess the cleansing remedies efficiency **/5/**.

This real time acquisition device allows the identification of 10 main radionuclides likely to be found in NPPs (^{58}Co, ^{60}Co, ^{110m}Ag, ^{124}Sb, ^{122}Sb, ^{51}Cr, ^{59}Fe, ^{54}Mn, ^{131}I and ^{137}Cs) and the determination of the radionuclide relative contribution to outside pipe wall dose rates. The dose rates conversion into deposited activity is also possible thanks to a transfer function (code calculation) but very limited due to an incomplete geometry set. The CZT gamma spectrometer principle is reminded in figure 7.

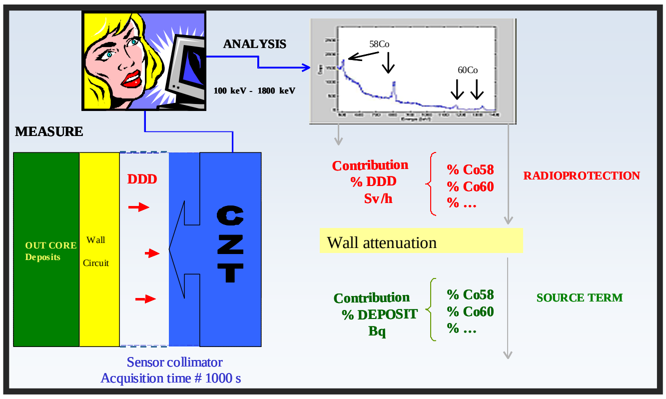

Figure 7 : CZT principle diagram

The equipment is shipped with 3 interchangeable CZT probes of varying sensitivity:

- ✓ 60 mm^3: 0.5 mGy/h - 10 mGy/h;
- ✓ 20 mm^3: 5 mGy/h - 100 mGy/h;
- ✓ 5 mm^3: 20 mGy/h - 150 mGy/h.

The gamma energy spectrum ranges from 100 to 1800 keV for exposures from 0.5 to 150 mGy/h depending on the used probe.

The spectral resolution is from 15 keV (at 600 keV) up to 25 keV (at 1300 keV).
Approximately 15 minutes is necessary for the acquisition of a spectrum with an exposure of 1 mGy/h, without any probe collimator.
The first feedback analysis (comparison with EMECC more accurate but also more difficult to handle) shows that the CZT device is able to satisfactorily quantify the main radionuclide contribution to equivalent dose rate.

CZT optimized program			
P1a	CVCS	Before purification system	Power operation
P1b			After fuel download
P2a	CVCS	After purification system	Power operation
P2b			After fuel download
P3a	CVCS	Exchanger	Power operation
P3b			After fuel download
P4a	RCS	Crossover leg	Hot shutdown
P4b			Pool flooding beginning
P5a	RCS	Hot leg	Hot shutdown
P5b			Pool flooding beginning
P6a	RCS	Cold leg	Hot shutdown
P6b			Pool flooding beginning
P7a	SIS	Valve	Hot shutdown
P7b			Pool flooding beginning
P8a	RHRS	Exchanger	Hot shutdown
P8b			Pool flooding beginning

Table 3 : CZT optimized program

Furthermore, the CZT "routine" program has been optimized recently in order to give an efficient basis for the contamination mechanism understanding. This program, containing 16 measurement points located on RCS, CVCS, SIS and RHRS (table 3), was proposed to all units as a prescript in 2010.
This device can also be used occasionally to characterize a possible unknown and unexpected contamination (hot spot) if need be.
Finally, technical modifications (collimator and accurate dose to activity conversion factors depending on geometry) are currently planned to improve deposited activities determination.

V – Conclusions

Source term reduction is an important matter of concern for EDF French fleet. In order to characterize radiological state of his reactor fleet, EDF is carrying out an important measurement program based on dose equivalent rate measurements (RCS index and RB Index) and contamination characterization (EMECC campaigns and CZT measurements).

References

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