NEW CZT MEASUREMENT DEVICE
COMPARISON WITH EMECC MEASUREMENTS IN EDF PWRs

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The reduction of collective radiation exposure is an important objective for EDF and for all nuclear power plant operators. One of the tools for studying the impact of chemistry, operation and plant design parameters on radiation fields is the measurements campaigns of contamination in PWRs.
Consequently, for over 30 years, EDF has performed gamma spectrometry measurements with CEA and its EMECC system, with more than 200 campaigns in EDF plants and also about 70 campaigns in collaboration with other operators.
In addition to EMECC campaigns, EDF have been carrying out a new dose rate measurement program since 2006 based on a InSpector 1000 portable analyzer with a semi-conductor CZT (Cd-Zn-Te) probe allowing a dose rate range from 0.1 to 10 mSv/h without cooling and energy range from 300 keV to 1.8 MeV.
Comparison with EMECC results, more accurate but also more difficult to handle, shows that the CZT device is able to satisfactorily quantify the main radionuclides contribution to dose equivalent rate.
The first feedback analyses confirm that CZT is a pertinent complementary tool to understand contamination mechanisms on EDF fleet (as well as other operators) and consequently to reduce doses. Further upgrade to the CZT device are planned in order to allow surface activity deposition measurement including widespread use of a bigger probe to improve sensitivity, calibration with specific geometries conversion coefficients.

I – Reminder of the context and the need for a gamma spectrometer

EDF has the goal to bring the results for both individual and collective dosimetries in all its PWR nuclear power plants to the same level as that of the best international operators [1]. Within the scope of the ALARA Project, a plan of actions to control the source term in order to reduce the normal and incident-induced abnormal contaminations in the circuits has been validated by the Company Management Head [2].
As from 2006, this plan includes a priority action to provide to the power plants Risk Prevention Services a portable CZT gamma spectrometer, inSpector 1000-CZT, for analysis of activity deposition in ex-core surfaces. This simple and practical tool is an aid to diagnosing circuit contamination for use by the Risk Prevention Service and is a complement to the volume activity analysis of the main reactor coolant loop piping carried out by the chemists. The spectral resolution of the CZT detector is greater than that of NaI and less than that of ultra-pure Ge and meets industrial requirements.

II – The objectives of CZT measurements made on the circuits in nuclear plants

The primary objective of the CZT gamma spectrometer to be carried out by the Risk Prevention Service is to allow each nuclear plant:

- to characterize the contribution of radionuclides 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.

The second objective is to assess the efficiency of cleansing remedies [3].
Starting in 2006, an information system is implemented with a newsgroup named "CZT spectrometer for use by the Risk Prevention Service" and a feedback network called "user PEX-CZT".

III – Main characteristics of the CZT spectrometer for the Risk Prevention Service

The CZT gamma spectrometer developed by CEA & EDF, and commercialized by Canberra for use in nuclear plants, has five main components:

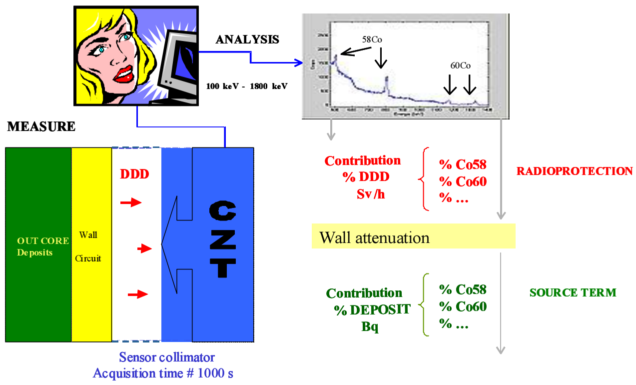
- a set of 3 CZT interchangeable probes (Ritec) of varying sensitivity;
- a cable between the probe and the electronic measurement chain part;
- the electronic measurement chain;
- a laptop PC;
- a probe collimator and its tripod support.

The advanced functions of this equipment give the user indispensable elements for real time spectrum analysis, in particular:

- real time acquisition, display and storage of the gamma spectrum ;
- identification of the 10 main nuclear plant radionuclides: Co58, Co60, Ag110m, Sb124, Sb122, Cr51, Fe59, Mn54, I131 and Cs137 ;
- calculation of the contribution of the radionuclides to the dose rate outside the circuits expressed as a % of Sv/h;
- calculation of the contribution of the radionuclides to the activity deposition inside the ex-core circuits surfaces expressed as a % of Bq.

The following diagram shows the measurement principle of the CZT gamma spectrometer for dose analysis giving 2 results: the dose-rate % (Sv/h) and/or the activity deposition % (Bq).
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.



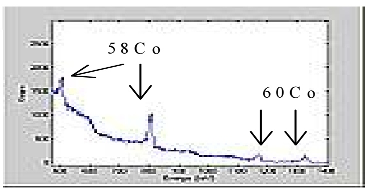
It identifies the gamma radionuclides in the energy range from 100 to 1800 keV for exposures from 0.5 to 150 mGy/h.

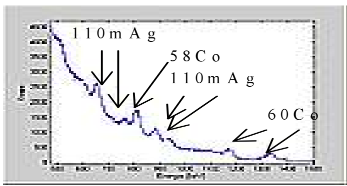
The spectral resolution is approximately 15 keV at 600 keV and 25 keV at 1300 keV..
Approximately 15 minutes is necessary for the acquisition of a spectrum with an exposure of 1 mGy/h, without a probe collimator.

Given as examples, the following spectrums are obtained using a CZT probe for a Reactor Coolant loop piping and for a heat exchanger for the chemical and volume control (CVCS) purification circuit polluted by silver.

System hot leg

Activity deposition
- Co58 : 63%
- Co60 : 37%





Chemical and volume control system heat exchanger

Activity deposition:
- Co58 : 44%
- Co60 : 16%

The spectrums measured by the power plants usually present important contributions in Co58, Co60 and Ag110m with quite important pipe thicknesses. Because of these radionuclides gamma energies, the spectrums often thin down at low energies (below 500 keV). These errors are minimized when contributions to dose equivalent rates (DER) are considered.

Thereafter analyses will then be based on DER contributions. This is entirely coherent with the interest and the possibility of the CZT which is aimed to be a radiation protection tool rather than a characterization and fine metrology tool.

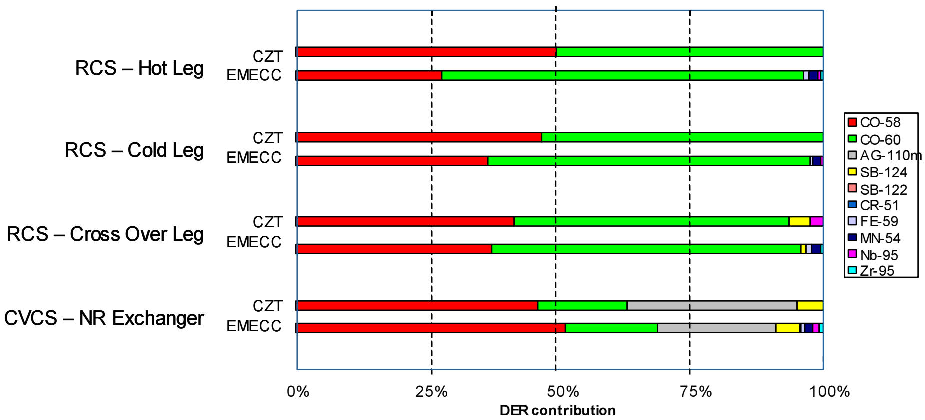
IV - Comparison of EMECC / CZT measurements

The EMECC spectrometry measurements campaigns are performed by CEA [4]. These campaigns with Ge probes allow having finer quantitative analyses than CZT measurements. A study carried out by CEA and EDF concluded that:

- the CZT device permitted to identify the main radionuclides (contributions to the total dose rate greater than 10 %) in agreement with germanium spectrometer;
- the measurement uncertainty is greater or CZT than germanium spectrometer;
- the estimation of minority radionuclides (contribution lower that 10 %) is risky because of a lack of precision.

The measurement points for EMECC and CZT "programs" are not all equivalents. The closest measurement points are the one situated on the hot leg and on the CVCS non-regenerative heat exchanger. The comparison points (measurements before oxygenation) are presented for a nuclear power plant with steam generator tubes made of nickel based alloy: Figure 1.

Figure 1 : Plant with I-600 TT Steam Generator tubing : Alloy 600



The comparison between EMECC and CZT measurements lead to the following observations:

- the CZT measurements are coherent with gaps between CZT and EMECC of about 10 %,
- the biggest gaps on cold and hot legs can be explained by the absence of collimator for CZT device compared to EMECC and therefore perturbation of the measurement by the direct environment. The CZT analysis tends to overestimate the Co58 contribution with respect to Co60.

Measurements can be performed at different times and different water levels which need to be taken into account in the comparison. In contrary with EMECC analysis, it is not possible with CZT analysis to substract volume activity contribution.

Conclusion :

- Correctly used and in a goal of radiation protection, the CZT technology is able to obtain quite satisfactory results for the main radionuclides. Below 10 % of DER contribution, the minority radionuclides are poorly estimated.
- The same analysis was conducted with an another plant equipped with Alloy 800 SG tubing. The results were also close between EMECC and CZT measurements. So the CZT reliability is established whatever the nature of SG tubing materials (Alloy 600 or Alloy 800).
- The EMECC measurements allow to obtain finer quantitative analyses. It represents the reference for analyses of activity contamination in EDF plants ex-core circuits.

V - CZT measurement programme to be carried out during shut down

Starting in 2006, EDF power plants proposed a CZT measurement programme in complement of dose equivalent rate (DER) cartography. The programme to be carried out systematically at the time of plant shutdown includes 8 points of measurement to determine the contribution to the DER of radionuclides deposition in the ex-core circuits: 3 points in the nuclear auxiliary building, 1 in the fuel building and 4 in the reactor building. Table 1 below gives the precise location of the measurements to be made.

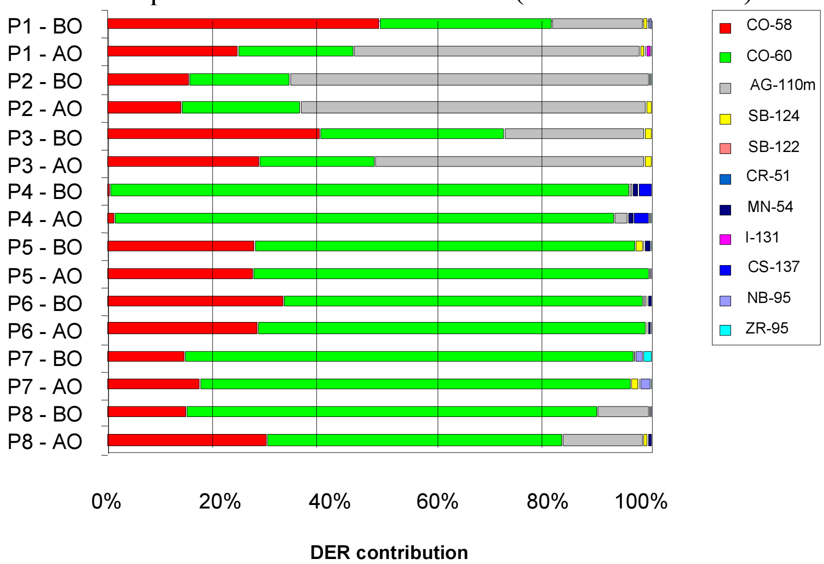
Table 1 - Shutdown programme - CZT measuring points before and after oxygenation

Measuring points in the Nuclear Auxiliaries Building
P1 : Chemical and Volume Control System (CVCS) : Before purification **P2 :** CVCS : After purification. **P3 :** CVCS : Non regenerative exchanger.
Measuring point in the Fuel Building
P4 : Spent Fuel Pit Cooling and Treatment System (SFPCTS) at the junction of all the piping
Measuring point in the Reactor Building
P5 : Reactor Coolant System (RCS) : Hot Leg. **P6 :** RCS : Cold Leg. **P7 :** Safety Injection System (SIS) - After the RCS valve **P8 :** Residual Heat Removal System (RHRS) - Heat exchanger

The work load, acquisition and analysis of the CZT spectrums are estimated at a maximum of 30 hours per unit and per shutdown. It includes the inlet and outlet of the equipment into and out of the controlled area and the data entry into the national database.
The collective dose included for the entire systematic shutdown programme is in the region of 0.15 man.mSv
The harmonization of these measurements on all units is used to establish inter-unit comparisons and, for a single unit, to monitor the contamination over a period of time. The measurement system is also used to check the correct operation of oxygenation of the primary fluid during cold shutdown of the reactor.

V.1 - Statistical analysis of CZT measurements

The results obtained on all PWR plants between 2006 and 2007 (380 measurements) are shown below.



**BO: Before oxygenation - AO: After oxygenation*

This graph shows that the radionuclides that contribute to almost all the DER are Co60, Co58 and Ag110m. The relative contributions of the 3 radionuclides are highly variable depending on the different units and circuits.

a) Measuring points in the Nuclear Auxiliaries Building (CVCS): *P1, P2 and P3*

CVCS

In the above example, the measurements made on the chemical and volume control circuit highlight that in addition to Co58 and Co60, the chemical and volume control system often shows a high level of contamination by Ag110m.
The analysis of the results shows that there is a wide dispersion.
The non-regenerative heat exchanger and the downstream part of the purification chain usually present similar behavior although in different proportions. In fact there is a wide variety of behaviors depending on shutdowns: Ag110m can be present in varying quantities and radio-cobalt can increase or decrease in proportion after oxygenation. These elements prove that the measurements before and after oxygenation should be considered separately.
It is the comparison before and after oxygenation that is of interest and can be used to check that there is no significant recontamination.

b) Measuring point in the Fuel Building (SFPCTS)*: P4*

SFPC

On the pool side, when the unit is shut down, the handling of fuel releases hot spots (Co60 particles from deterioration of the stellite) that were fixed to it. In the absence of a containment barrier, they are dispersed in the circuits by the movements of water. The analysis of the feedback on pool drainage points show highly variable DER from one plant to the next (from 0.07 to 100 mSv/h), around 94% of which are generated on average by Co60. Since this measurement point is almost always dominated by Co60, it can be eliminated from the systematic measurement programme.

c) Measuring point in the Reactor Building (RCS, SIS, RHRS)*: P5 to P8*

RCS

The measurements made on the hot and cold legs of the primary circuit are similar and are not normally impacted by oxygenation. We recommend comparing them in order to make the measurements more reliable.
The average of the CZT measurements on the primary legs show contributions to DER of 30% for Co58 and 70% for Co60; this is in the range of expected values from the EMECC feedback.
Some units stray from this average and show a higher Co58 contribution. This is especially the case for units in which the steam generator was recently replaced.

SIS

The analysis for the point of measurement downstream from the reactor coolant system valve highlights a high contribution of Co60 to DER averaging 81%, the rest coming from Co58. These results are not much different from the reactor coolant system loops (P5 and P6) but with a higher Co60 contribution. In fact there is less circulation and the Co58 depositions are lower here. They are quite even in all the units with a standard variance of 15%.

RHRS

The Residual Heat Removal System shows the behaviour between that of the Reactor Coolant System circuits (P5 and P6) and that of the CVCS circuit downstream from the purification chain (P1).

- Before oxygenation, Co60 is the main, and almost exclusive contributor to DER (the other radionuclides having decreased) with an average of 75%.
- After oxygenation, Co58 and Ag110m recontamination is sometimes observed (which depositions are mostly on the cold parts). Co60 remains however the main contributor to DER with an average of 55%.

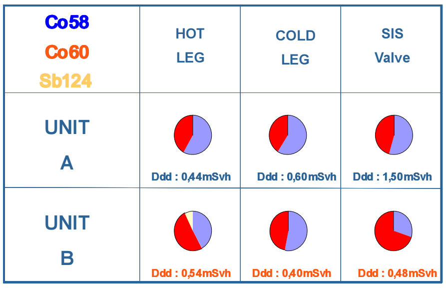
The same remarks as for the CVCS circuit apply, i.e., on the one hand high dispersion in the measurements and on the other the interest in comparing before/after oxygenation measurements. In the analysis this point should be used when considering evolution of the CVCS.

VII - Analysis and interpretation of the CZT results from nuclear plants

Besides monitoring of the state of contamination in the units, the systematic CZT measurement programme is used to define the impact of optimized operating conditions and/or specific malfunctions. The examples described below are the result of preliminary feedback from the plants and are a concrete illustration.

VII.1 - Optimization of primary chemistry and purification in operational phase

The results obtained on two plants of equivalent age and design, plant A and B, showed that the depositions can be different; this can be explained by the different operating conditions in both plants.

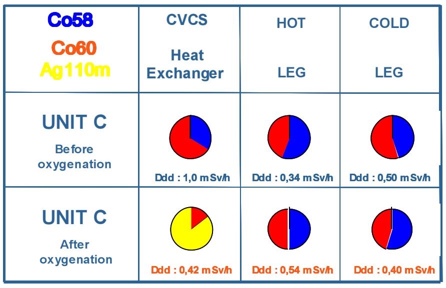


In this particular case, plant A operates with a higher primary pH and a purification circuit with a finer filter; this can partly explain the differences found in Co60 content.
The analysis of these differences forms part of a global study within EDF to optimize practices and reduce doses in all units.

VII.2 - Malfunction : by-passing purification during reactor shutdown

The following table highlights the recontamination by Ag110m of the CVCS circuit, in unit C, a 900 MW unit, due to the by-pass before the oxygenation phase of the filter and resin purification on the primary circuit during reactor shutdown.

The differences in the before and after shutdown spectrums highlight an over-contamination by Ag110m of the heat exchanger on the auxiliary purification circuit in the chemical and volume control system.
It is also noted that contamination of the reactor coolant system primary circuit loops is not affected by this malfunction. This confirms that Ag110m has a special affinity for the auxiliaries heat exchangers [5].



VIII – Use of CZT device for the purification of polluted power plants units

EDF Purification Engineering Unit proposes to set up a CZT measurement programme in addition to the programme carried out during shut down in order to monitor the radiological characterization of the units pollution as well as the efficiency of the decontaminations implemented.
The CZT measurements are input data used to elaborate decontamination processes. For the units needing purification, target circuits RHRS/CVCS, NVDS (nuclear island vent and drain system) and LWPS (non-recycled liquid waste treatment system) tanks, pools have been identified. It has been shown that they can be efficiently decontaminated which leads to significant gains in terms of doses to personnel in the concerned zones.

IX – Conclusions and perspectives

Since 2006, the EDF nuclear plants are equipped with the Cd-Zn-Te gamma spectrometer (CZT) for analysis of the radionuclides depositions inside the ex-core circuits at the origin of the doses.

The CZT spectrums obtained by the Risk prevention Service are indispensable in the diagnosis of circuit contamination as are the analyses of water conducted by the chemists. The first results obtained in the plants show the relevance of the tool in the understanding of contamination phenomena, the investigations to be conducted for prevention, the impact of malfunctions on over-contaminations (pollution). Further technical changes to the CZT device are planned in order to allow deposited activity measurement including widespread use of a bigger probe to improve sensitivity, calibration with specific geometries conversion coefficients.

The implementation of an optimized approach to the control of the source in the plants (chemistry, purification, procedure and intervention instructions) must involve effective consultation between the chemistry, radiation protection and operational branches. Studies showed that if the CZT device is used in a goal of radiation protection, it is able to obtain satisfactory results for the main radionuclides compared to the EMECC reference technology that will always be more accurate.
The inSpector 1000-CZT gamma spectrometer provides key complementary information to improve knowledge at an operational level to manage EDF fleet contamination and therefore reduces dosimetry.

This tool allows to improve good practices and provide better process control (because of its good availability and ease of use) while EMECC system remains a strategic milestone to update precise snapshots of the unit health.

Therefore it is worth to extend use of CZT instrument and perpetuate both systems deployment.

References

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