CZT Gamma Spectrometry
Applied to the In-situ Characterisation of Radioactive Contaminations

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Abstract
Tests conducted by EDF have shown that gamma spectrometry using a CZT probe can quickly determine the dominant isotopes present in out-of-core radioactive contaminations. The contaminations examined todate result from corrosion processes and are situated inside circuits and components.

EDF believes that NPP radioprotection services should be equiped with portable CZT gamma spectrometers and is currently taking steps to achieve this. In addition, the information supplied by such an instrument has important ALARA applications.

Introduction
Recent advances in CdZnTe[1] semi-conductor technology now allow NPP operators to perform gamma spectrometry of a quality that is quite satisfactory for a variety of radioprotection applications. The main outcome is that NPP radioprotection personnel can easily identify the dominant radioactive isotopes present within different circuits.

One of EDF's main applications for CZT gamma spectrometry is the isotopic identification of out-of-core contaminations. Such contaminations result largely from corrosion processes and are situated inside circuits and components.

An awareness of the different isotopes present within radioactive contaminations not only improves NPP surveillance - it also has important ALARA implications. One can efficiently determine both preventive measures and remedies for reducing operator doses.

The quality of today's CZT spectrometric probes combined with their ease of use have encouraged EDF to examine this technology more closely. In particular, EDF was interested in knowing if CZT gamma spectrometry can be considered as a new "tool" for its NPP radioprotection services which would be complementary to radio-chemical analyses.

CZT spectrometric probes
CZT gamma spectrometry is not as accurate as that performed by a Ge detector. Nonetheless, CZT detectors do have a number of other advantages.

CZT probes operate at ambiant temperatures and hence do not require bulky cooling systems. They can also be operated by classical MCA electronics and give spectra with a (spectral) resolution of about 2 % at 662 keV. Being very compact, CZT probes can easily be deployed remotely over distances of several tens of meters. This makes them particularly suitable for hostile areas where access is difficult.

On the other hand, CZT probes loose their efficiency at the higher energies (the limit is approximately 2 MeV). They are also less sensitive and more expensive than NaI detectors. (It should be reminded however that their spectral resolution is significantly better than that of NaI detectors.)

The most important advantages of CZT probes for EDF applications are their compact size (easy to deploy) and good spectral resolution (ability to distinguish and identify the photon peaks in multi-isotope spectra).

EDF applications
The technical performances that EDF requires from a CZT spectrometric sensor are as follows :

1) Measure gamma spectra over the energy range 100 keV – 1.8 MeV and under various exposure levels (the most common being from approximately 10 μGy/h to 300 mGy/h).

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[1]) often called "CZT" in the technical literature.

2) Identify the isotopes 60Co, 58Co, 110mAg, 124Sb, 122Sb, 51Cr, 59Fe, 54Mn, 131I and 137Cs.
3) Estimate the relative activity of each isotope (as a percentage of the total activity of the radioactive source).
4) Estimate the relative contribution of each isotope to the total exposure (direct photon flux only; without scatter).

It is important to note that in a large number of situations EDF is only interested in identifying isotopes whose activity is greater than about 5 % of the total activity of the source (i.e. the dominant isotopes). This is consistent with the idea of CZT gamma spectrometry being a diagnostic tool for the radioprotection services within the NPP.

It is also important to note that points (3) and (4) above are estimates expressed as percentages. Absolute activities of the isotopes are not computed because no assumptions are made concerning the geometrical shape of the radioactive contamination.

The CZT spectrometer built by EDF

The sensor (acquisitions)

EDF R&D, in collaboration with CEA Marcoule, built a portable CZT gamma spectrometer from commercially-available components. The sensor is capable of performing both spectral acquisitions and analyses of the measured spectra.

The EDF spectrometer is composed of three interchangable CZT probes from Ritec that are connected (via a 30 m cable) to an Inspector 2000 MCA from Canberra. The complete system is operated from a portable PC computer.

The three Ritec probes are the 500, 60 and 20 mm^3 detectors. The long cable allows the command post to be placed outside the intervention area thus minimising operator exposure.

EDF has tried different ways of deploying the CZT probes : uncollimated and on-contact with the contaminated structure, uncollimated measurements of the ambiant exposure and collimated measurements from a distance of 1-2 m.

The typical acquisition time for an uncollimated, on-contact measurement is 5-7 minutes.

Example of an uncollimated, on-contact measurement.

Analysis

The spectral analysis is performed in two steps.

Preliminary processing is done using the standard routines supplied with Inspector 2000 (the Genie 2000 software). This allows the operator to calibrate the spectrum, identify the dominant isotopes and compute certain intermediate activities.

Advanced processing is achieved by software that was specially developed by CEA for EDF. The main functions are :

a) An estimation of the relative activities of each identified isotope inside the component. In this case, the analysis compensates for the spectral attenuation created by the component's structure. Todate, the operator can choose from one or two attenuations by steel, water or concrete.
b) An estimation of the relative contribution of each isotope to the total exposure outside the component and at the point where the spectrum is measured. This calculation only applies to the direct photon flux.

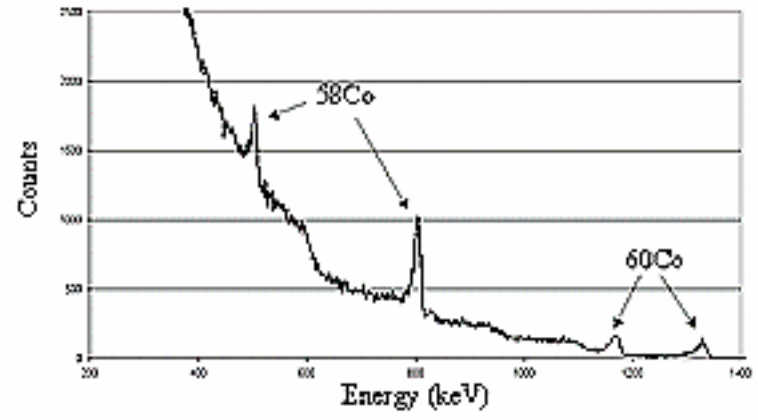
The analysis is easy and rapid and can be performed in the controlled area of the NPP, immediately after the acquisition of the spectrum.

EDF examples

The following examples illustrate different measured spectra and the results of their analyses.

Example 1 : Uncollimated & on-contact measurement of a valve of the Residual Heat Removal System (12 mm steel wall thickness (approx.)).

Two isotopes are clearly identified (^{58}Co and ^{60}Co).



The spectral analysis computed the following values :

i) The ^{58}Co activity (inside the pipe) is approximately 63% of the contamination's total activity. The incertitude is $2\sigma = 9\%$.

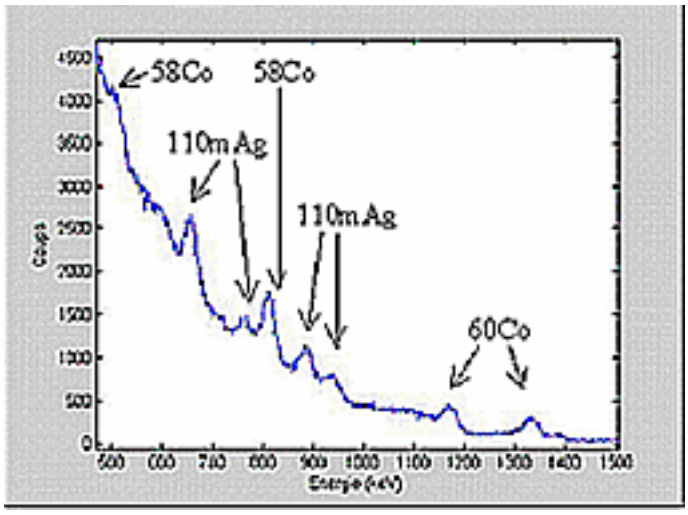
ii) The ^{58}Co produces about 38% of the total exposure outside the pipe ($2\sigma = 13\%$).

iii) ^{60}Co has an activity of about 37% inside the pipe ($2\sigma = 9\%$).

iv) ^{60}Co creates approximately 62% of the exposure outside the pipe ($2\sigma = 13\%$).

Example 2 : Uncollimated & on-contact measurement close to an exchanger of the Chemical & Volume Control System (3 mm steel wall thickness (approx.)).

^{58}Co, ^{60}Co and ^{110m}Ag are identified from the measured spectrum.



The relative activities of the isotopes (inside the component) are :

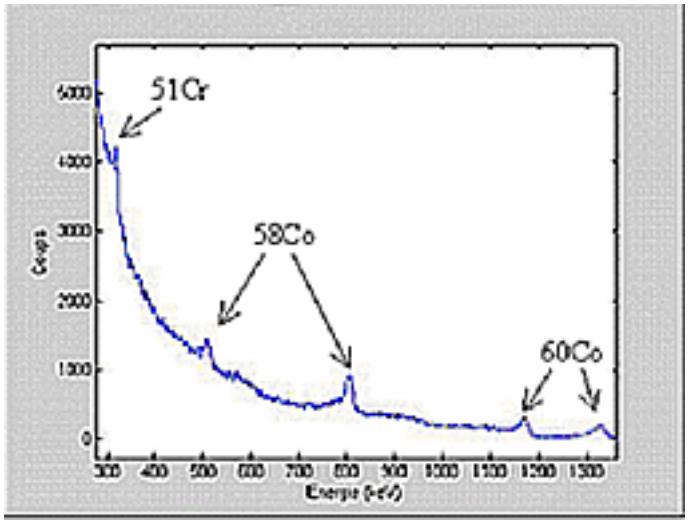
^{58}Co : 28 % ($2\sigma = 7\%$).
^{60}Co : 40 % ($2\sigma = 8\%$).
^{110m}Ag : 32 % ($2\sigma = 7\%$).

The relative contributions of the isotopes to the exposure (outside the component) are :

^{58}Co : 13 % ($2\sigma = 6\%$).
^{60}Co : 48 % ($2\sigma = 13\%$).
^{110m}Ag : 39 % ($2\sigma = 13\%$).

Example 3 : Uncollimated & on-contact measurement of a valve of the Safety Injection System (12 mm steel wall thickness (approx.)).

In this case, ^{58}Co, ^{60}Co and ^{51}Cr are identified.



Relative activities of the isotopes :

^{58}Co : 22 % ($2\sigma = 7\%$).
^{60}Co : 29 % ($2\sigma = 8\%$).
^{51}Cr : 49 % ($2\sigma = 10\%$).

Relative contributions of the isotopes to the exposure :

^{58}Co : 24 % ($2\sigma = 10\%$).
^{60}Co : 75 % ($2\sigma = 10\%$).
^{51}Cr : 1 % ($2\sigma = 1\%$).

Conclusions

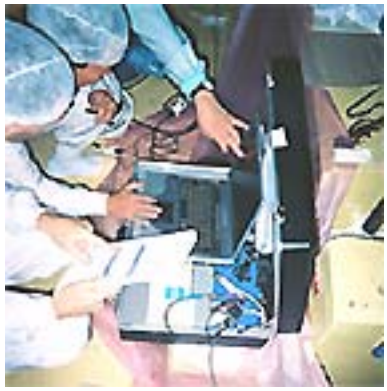
1) Tests conducted by EDF have shown that gamma spectrometry using a CdZnTe probe is an important aid in quickly determining the dominant isotopes present in out-of-core radioactive contaminations. The contaminations examined todate result largely from corrosion processes and are situated inside circuits and components. This type of spectral measurement which is performed by radioprotection personnel is complementary to the analyses of the volumic activity of water samples performed by chemists and thus leads to better overall diagnoses.

2) EDF is currently investigating equiping its radioprotection services with portable CZT gamma spectrometers.

3) The information supplied by CZT gamma spectrometry can be applied to a variety of applications such as checking the efficiency of a decontamination operation, placing of protections, estimating doses for future interventions (i.e. input data for dose prediction software) and determining the origin of contaminations.

Acknowledgement

The authors acknowledge the technical assistance of Nicolas Boursier and Christophe Le Goaller (CEA) in building the CZT gamma spectrometer described in this paper.



The command post of EDF's CZT gamma spectrometer.

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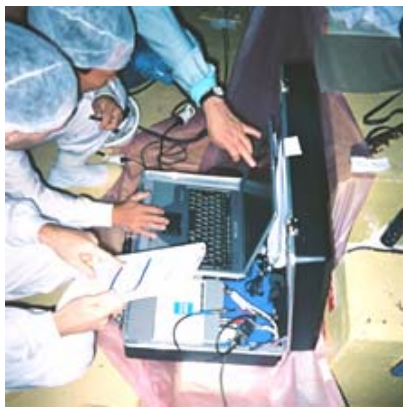
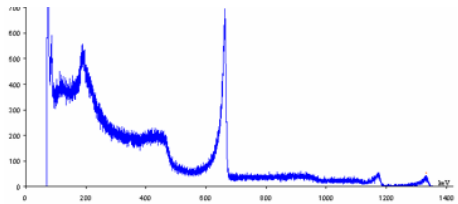


- EDF has built a portable CdZnTe gamma spectrometer for identifying the dominant isotopes in radioactive contaminations.

- Spectrometer performances :
  - Spectra over 100 keV – 1.8 MeV,
  - Detection of 60Co, 58Co, 110mAg, 124Sb, 122Sb, 51Cr, 59Fe, 54Mn, 131I, 137Cs.



- Examples show spectra of contaminations resulting from **corrosion processes within circuits**.

- EDF plans to equip its NPP **radioprotection services** with CZT gamma spectrometers.

- Has important **ALARA** applications (checking decontaminations, placing protections, predicting doses, etc.).