CANBERRA solutions for source location and activity determination for investigations of ORCADE dismantling project at AREVA NC La Hague site

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Abstract

The operations of dismantling of nuclear installations are often difficult owing to the lack of knowledge about the position, identification and radiological characteristics of residual radioactivity.

As part of the investigation team for the ORCADE dismantling project at AREVA NC La Hague UP2-400 reprocessing plant, CANBERRA had the opportunity to use new nuclear measurement systems and modeling tools to develop a methodology to locate and characterise radioactive hold up.

The methodology uses different types of dose rate meters, gamma spectrometers and modelling tools, depending on the type of problem.

In this paper, the methodology and tools are described, followed by typical case studies, including hot cell activity evaluations and drum categorization methodologies. For each case, the detector and modelling tool choices are explained and justified.

This methodology helps to prepare and execute post-operational clean out and dismantling activities. These examples give concrete insights into their significance and the productivity gains they offer.

\textbf{Keywords:} D&D, Gamma spectrometry, radioactivity modeling, source location, source identification, MERCURAD, PASCALYS, ISOCS, CARTOGAM
1. CONTEXT OF D&D MEASUREMENT ACTIVITIES

Dismantling a nuclear installation is often difficult due to the lack of knowledge about the position, the identification and the radiological characteristics of the contamination. In that way, the contamination is particularly difficult to define in a significant global background when the activities are relatively high. For example, identification and estimation of the activity become more complex in hot cells, where space is limited and human intervention is costly in terms of accumulated dose.

CANBERRA, the Nuclear Measurement Business Unit of AREVA, not only designs, manufactures and sells a complete range of instruments, but provides solutions and services to take care of the global problem depending on customer needs. In that way, the following items have to be specified:

- definition of the needed investigations,
- detector choice,
- dose rate modeling,
- coupling dose rate measurement and model,
- coupling gamma spectrometry measurement and model,
- coupling neutron measurement and model.

To be able to propose the best solution, CANBERRA has developed knowledge and intervention strategies based on its feedback experiences in many countries.

Each part of the scene characterization is described in the following chapters. Thanks to this methodology, CANBERRA is able to give the customer not only measurement results, but also activities, localization and eventually to guaranty safety or process threshold corresponding to the customer’s needs.

2. ORCADE INVESTIGATION PROJECT STAKES

2.1. Generalities

The ORCADE UP2-400 dismantling project at AREVA-NC La Hague began in late 2002 when all new facilities in UP2-800 had started. The project concerns all the facilities of the first reprocessing plant: from dissolution to U, Pu and fission products (FP) extraction and storage in tanks. To support all dismantling sub-projects, a transversal investigation project was created in 2005.

2.2. Stakes of the Investigation ORCADE’s project

The Investigation project support the different missions of the global ORCADE project which are :

1. Definition of dismantling scenario,
2. Design of waste packaging installation,
3. Good waste categorization,
4. Radioactive discharges optimization,
5. Safety analysis (dose rate, criticality…)
To be successful, the investigation project needs many skills and means as:
- video investigation capabilities,
- documentary research,
- laboratory analysis,
- nuclear measurements and modeling.

Inside the investigation project CANBERRA is in charge of this last item.

3. NUCLEAR INVESTIGATIONS IN A DISMANTLING PROJECT

3.1. Necessary data retrieval

The first phase of nuclear measurement investigation is crucial. A facility prepared to dismantling has usually a long history of operations with numerous events which have occurred its lifetime. The knowledge of these events is very important in the definition of measurement strategy. These first assumptions usually come from interviews with the facility previous operators, allowing definition of a first model. A good expectation in an activity evaluation is already to take in account right information (detector choice for example).

3.2. Scene modelling

For a high activity cell, a first model evaluation can save a lot of money for the investigation phase. From large activities panel assumptions and geometry descriptions of the scene, sources would be able to be placed in the model and dose rate evaluation would be determined as a range of magnitude, which will define the type of investigation:

- Is the staff able to enter the cell?
- Possibility to introduce nuclear measurement?
- Logistics required for nuclear measurements?

For gamma emitters, CANBERRA uses MERCURAD application based on MERCURE V6 (reference [1]) gamma attenuation code developed by the French Atomic Commission at Saclay (CEA/SERMA). This code is used but also sold by CANBERRA. It has a very convenient interface which can be used by a technician for modelling a complex scene within about 30 minutes. Figure 1 summarizes this first part of the methodology.

![Diagram showing the process of using MERCURAD for dose rate evaluation](image)

For neutron emitters, only MCNP is used because no simplified code for 3D geometries exists yet.
3.3. First measurements to confirm hypothesis

The first evaluation of dose rate will allow selecting detectors, electronics and associated shielding and/or collimators. For very complex problems (which concerns mainly high activity cells), several iterations are needed. Simple measurements have to be done first, before complex measurement on model and first hypothesis refining.

4. MEASUREMENT POSSIBILITIES

4.1. Main solutions

The measurement solutions are very numerous. Usually only gamma and neutron detectors are used. Alpha and beta emitters are detected by their gamma emission, which explains why the ratio between gamma and alpha has to be known in the case of total gamma counting (without spectrometry). This ratio can have a deep impact in waste categorisation. Gamma spectrometry measurement will be preferred when this ratio cannot be easily identified or when the gamma emitters are numerous.

4.2. Total counting measurement

4.2.1. Gamma measurement

Ionization chambers are usually chosen because of their sensitivity and their ability to be used in very hot cells. In that case, the electronics will be placed away from the detector and current amplification electronics will be preferred.

Geiger-Müller dose meters can also be used. Such detectors can be very small and are very useful when there is little space to introduce the detector in the hot cell.

4.2.2. Neutron measurement

Because of their sensitivity, $^3$He tubes are preferred. But they are also sensitive to gamma. In the case of high gamma emission, BF$_3$ detectors will be chosen. For very high neutron emission, fission chambers can also be used. All these detectors can only detect thermalised neutrons. If the neutron spectrum in the cell is not a thermal spectrum, the neutrons will have to be thermalised, usually with polyethylene blocks which increase the space needed around the detector.

4.3. Source location: CARTOGAM possible use

The CARTOGAM (gamma camera) will be used (see reference [2]) when the location is not known and when it is very important to know the radioactivity’s location in order to define the dismantling scenario. This tool can drastically decrease the number of needed measurements.

The main advantage of the CARTOGAM system compared to others is that it superimposes visible and gamma images using the same optics (see figure 2).
The use of CARTOGAM will also simplify the need for sampling. The localization of the needed sample is made easier as the sample contains radionuclides. Laboratory analysis on these samples will determine all radionuclides and specific ratios. To avoid expensive laboratory analyses, gamma spectrometry measurements can also be done in the field.

### 4.4. Source identification: use of NaI, CZT, or Ge detectors

While gamma spectrometers are useful for source identification, NaI detectors are a cheaper solution, with a poorer resolution (<10% at $^{137}$Cs) but a good efficiency for very low activity determination. They will be preferred for simple gamma spectra with known radionuclides only the proportion of which has to be determined.

CZT (Cd-Zn-Te) detectors (figure 3) are small and will be preferred in high activity cells. Their resolution is better than NaI detectors (usually 1.5% to 3%). CANBERRA frequently uses this type of detector coupled with CARTOGAM or adapted to the InSpector 1000 Hand-Held MCA (figure 4), which easily distinguishes $^{60}$Co from $^{137}$Cs.
The last and best solution is to use germanium detectors with a resolution usually around 0.2%. This is the solution for very complex spectra. This type of detector can determine the isotopic composition of U and Pu. CANBERRA developed BEGe (Broad Energy Germanium) detectors for 15 years. Such a detector coupled with an ISOCS modelling code (see reference [4]) is a very versatile solution. CANBERRA also proposes a wide range of Ge detectors for specific problems.

5. SCENE MODELLING SOLUTIONS

5.1. Why do we model the scene?

Detectors give counts per second. The modelling of the scene with sources location assumptions, allows determining not only counts, but also proportions, radionuclides and activities.

The use of CARTOGAM before modelling can help to make better assumptions in source location and drastically decrease the uncertainties. The following figure illustrates this methodology.

![Diagram of methodology for activities determining](Image)

**Figure 5:** Cart for Ge detector and associated collimator

**Figure 6:** Methodology for activities determining
The determination of geometrical efficiency and detector efficiency allow determination of activities from a spectrum in counts per second via the following formula:

\[
A(Bq) = \frac{M(cps)}{\varepsilon_{\text{geom}}(\gamma / \text{Bq}) \times \varepsilon_{\text{det}}(\text{cps} / \gamma)}
\]

Where:  
A is the activity in Bq  
M the measurement of the peak net area in counts per second (cps)  
\(\varepsilon_{\text{geom}}\) the geometrical efficiency in gamma rays per Bq or \(\gamma \cdot \text{cm}^2 \cdot \text{s}^{-1} / \text{Bq}\)  
\(\varepsilon_{\text{det}}\) the detector efficiency in cps per gamma ray or cps / (\(\gamma \cdot \text{cm}^2 \cdot \text{s}^{-1}\))

Different codes can be used as gamma ray attenuation calculation. The use of the code is discussed below.

5.2. Which model and calculation to be used?

A very precise model is not often needed. The model has only to take into account the objects and layers between the assumed sources and the detector. Often the main uncertainties come from not knowing the layers thickness between the source and the detector. In that case a very precise code is really not needed.

Nevertheless, a more precise code can be useful when the scene is known more precisely, when the geometry is complex, or when there is a need to reuse the geometry model for other applications. This case often occurs for hot cells modeling. Where high activities are concerned, the facility’s personnel issues are quite important and the time for modeling is significant.

5.3. ISOCS use for easy modelling

ISOCS gamma code attenuation is the best compromise for simple scene. The user interface uses templates which cover the most common geometries. With this approach, simple geometries can be modelled by technicians in less than 15 minutes. It allows the model to be done in the field during the measurement.

5.4. MERCURAD-PASCALYS advantage

We have seen that MERCURAD is a complete 3D code for dose rate evaluation from any kind of gamma spectrum and activities. It can also be used to calculate activities from a measurement spectrum. This way to use MERCURAD is called PASCALYS.

The main advantage of PASCALYS compared to ISOCS is its modeling capabilities. An other advantage concerns the detector efficiency. As PASCALYS considers the detector as a point, any kind of detector can be used easily with this modeling approach.

The third advantage concerns the possibility of reusing the modeling scene. In a hot cell complete study, the geometry model can be used for other applications as health physics studies or dismantling scenarios.
With the MERCURAD-PASCALYS tool, a complex geometry can be generated and stored in a database. A complex geometry can be used by PASCALYS to determine activities from one field measurement, and then reused with MERCURAD to determine the activities dose rate. Objects can be easily removed from the scene (simulating dismantling activities) and dose rates recalculated.

5.5. General synthesis
During repairing and dismantling activities, multiple types of detectors can be used. As the source activities determination is very complex, CANBERRA proposes different approaches depending on customer environment. CANBERRA is able to propose a large range of solutions.

Therefore the model used in the activity determination can be reused when dose rates have to be determined. It provides a consistent tool for engineering studies and dismantling scenarios.
6. ORCADE PROJECT EXAMPLES

6.1. Calibration and quality insurance

Inside the AREVA-NC investigation project, CANBERRA has deployed the previous described tools and methodology to characterized different hot cells in the following facilities:

- HAO: High Activity Oxide facility where fuels are previously sheared and dissolved,
- HADE: High Activity facility where Decanting, fission product and actinides Extraction are performed,
- HAPF: High Activity facility where Products issued from Fission are stored.

All the measurement instruments used for ORCADE project were previously calibrated at an irradiator facility (at AREVA-NC La Hague or at CANBERRA Loches irradiator). Both are COFRAC certified. Technical notes, procedure, and storage of scene modelling insure a complete traceability of the results.

6.2. Activities determination in high activity hot cells

The following methodology is performed by:

- Using laboratory sampling analysis to determine gamma & beta emitters and ratios,
- Using equipment geometrical data as model and associated assumptions concerning liquid or sludge volumes,
- Confirmation of sample analysis by dose rate measurements via very thin GM tubes and CZT gamma spectrometry measurement,
- Model via MERCURAD code and MCNP to confirm MERCURAD results when gamma scattering effects occur,
- Determination of transfer function at each measured point (Gy h⁻¹/Bq)
- Quadratic minimization of differences between dose rate measured values and model results.

For example, the modelling of a very complex cell in the HAO facility was performed (see figure 8). After fitting the 44 dose rate measuring points to MERCURAD dose rate results (from few mGy/h up to 8 Gy/h), the total beta activity was estimated at around 45 TBq.

Figure 8: Modelling of one complex HAO cell
A second example concerns the activity evaluation of tanks containing fission products. The only probe to be introduced in this cell was the very thin CANBERRA Geiger Müller detector (mounted inside an $\varnothing < 8$ mm thermowell). These GM tubes where previously calibrated in an irradiator to establish their response up to 200 Gy/h.

![Figure 9: GM dose rate measurements on 2 tanks of fission products](image)

MERCURAD modelling was performed to determine the total beta activity, established around 2 300 TBq and an uncertainty about 50 %.

### 6.3. Measurement in Uranium Middle Activity facility (MAU)

In the Middle Uranium Activity facility (called MAU), the stake of ORCADE project was to determine when the different tanks and equipments are considered as sufficiently rinsed. The aim is to make the equipments compatible with the very low activity wastes specification (called TFA). For Uranium, the TFA limit is about 100Bq/g of final waste. Consequently the ORCADE project asked CANBERRA to achieve a methodology to classify the equipments according to 3 different categories:

- TFA waste
- Not surely TFA waste: equipment to be investigated
- Surely not TFA: equipment to be rinsed

The equipments were differentiated according their geometry and weight:

- Light ($< 500$ kg),
- Intermediate (from 500 kg to 1 Ton),
- Heavy ($> 1$Ton).

The equipments were modelled with MERCURAD and the measure was performed inside the facility.

To types of spectrum were achieved:

- almost Uranium spectrum,
- almost Cs137 spectrum.
So, it was possible to categorize the waste:

**Figure 10:** Differentiation between TFA, undetermined and non TFA waste

For light equipment, it’s very difficult to distinguish TFA and non TFA equipment as the limit around 80nGy/h which is nearly the background. For large tank the limit value of 200nGy/h is easier to measure. These results which are preliminary, have to be correlated with more precise gamma spectrometry Ge detectors in situ and on final drums.

### 7. CONCLUSION AND PERSPECTIVES

CANBERRA proposes a complete set of solutions for radioactivity location and determination. According to the problem facing the nuclear facility, different measurements and modeling approaches can be used. Many tools have been used for ORCADE dismantling project in La Hague to help the investigation team and increase the knowledge of the radioactive contents of the different facilities.

Within the ORCADE project, CANBERRA contributes to the three main drivers in accordance with sustainable development goals :

- Environmental aspects : reduction of the toxicity of the waste
- Finance : optimization of the global project cost by contributing to the planning of dismantling scenarios
- Social aspect : optimization of individual radiation exposure by detailed preliminary measurements facilitating use of ALARA methodology

New waste categorization challenges await CANBERRA at AREVA-NC La Hague site. Such a categorization doesn’t consist only in measuring the final waste at the end of dismantling, but also to help project teams during the realization phase. The target is also to provide a good level of decontamination and to optimize the final cost of dismantling.
8. REFERENCES


