THE USE OF THREE DEDICATED NUCLEAR MEASUREMENT TOOLS FOR D & D OPERATIONS IN NUCLEAR FACILITIES

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Abstract

The operations of dismantling of nuclear installation are often difficult due to the lack of knowledge about the position, the identification and the radiological characteristics of the contamination.
In this sense the gamma contamination is particularly difficult to define in a significant global background when the activities are relatively high. Identification and estimation of the activity can become more complex in hot cells, for example, where space is limited and human intervention costly in cumulated dose.
The preparation of these human interventions leads, in addition to the standard procedures, to the need for mapping the dose-rate distribution in space from the knowledge of the contamination characteristics (position, identification, activities).
The introduction of three recent tools has improved the results obtained in terms of characterization for D & D operations : gamma camera, spectroscopy with efficiency calculated by computer and modeling of scene dose-rates.
For two years, three tools : the CARTOGAM gamma camera and the MERCURAD dose-rate modeling software developed in cooperation between the CEA, COGEMA and Canberra, and the ISOCS transportable gamma spectroscopy system developed by Canberra, have been in operation in industrial conditions in Europe, America and Asia.

This communication describes the present status of these three tools : main features, combined use of these tools, last improvements and first return of experience on site, in D&D operations or preparation of operations.

Résumé

Les opérations de démantèlement sont souvent rendues difficiles en raison de la méconnaissance a priori de la position, de la nature et des caractéristiques radiologiques des sources de rayonnements. Dans ce sens, la contamination gamma est particulièrement difficile à définir, dans un bruit de fond significatif, lorsque les activités en cause sont relativement importantes. Les identifications et les estimations des activités peuvent être compliquées en cellules chaudes, par exemple, où l'espace est limité et les risques de prise de dose aggravés.
Dans de tels cas, les interventions peuvent être préparées, entre autres procédures standard, à l'aide d'outils de modélisation des débits de dose ; une telle modélisation est basée sur la connaissance préalable des positions et activités des sources de contamination.
La mise en service de nouveaux outils de mesure et de modélisation a amélioré les résultats obtenus en termes de caractérisation, grâce à la combinaison de l'utilisation de gamma caméra, de spectrométrie gamma à efficacité modélisée et de logiciels de calculs de débit de dose.
Depuis deux ans, trois outils : la gamma caméra CARTOGAM et l'outil de modélisation de débits de dose MERCURAD, développés en coopération avec le CEA et COGEMA, ainsi que le système de spectrométrie gamma ISOCS développé par Canberra, ont été mis en service opérationnel, tant en Europe, en Amérique qu'en Asie.

La présente communication développe les principes de fonctionnement de ces trois outils, leur utilisation combinée, les dernières améliorations et les premiers retours d'expérience obtenus sur site, lors d'opérations de démantèlement ou de préparation de démantèlement d'installations nucléaires.

INTRODUCTION

Canberra, the Nuclear Measurement Business Unit of the AREVA Group, performs the design, manufacturing and selling of a complete range of instruments and systems for radioactivity measurement. A set of three main instruments is aimed at D&D (Decommissioning & Dismantling) activities : CARTOGAM, ISOCS and MERCURAD. Each of these tools can be used separately, but when combined, the effect is synergistic for the preparation of a dismantling project, for its carrying out and, after its completion, to prove that decontamination is complete.

At first, these three tools are briefly described and then examples of their use in dismantling operations are given, in order to give some concrete insight into their interest and the productivity gains they can offer in D&D activities.

CARTOGAM

CARTOGAM, a real-time portable gamma ray imaging system, is a complete portable tool for in-situ radiological mapping. It can automatically create radioactivity versus location maps and superimpose these gamma maps onto a video image of the item or area. Since the acquisition is done and controlled remotely, the personnel dose exposure is reduced and hot cell applications are allowed.

The video / gamma maps generated by CARTOGAM allow fast identification of hot spots, thanks to the fast generation (within a few tens of seconds or, at most, of minutes) of an image with sufficient resolution to reveal the most heavily irradiating zones and to allow assessment of their size, geometrical shape, homogeneity or heterogeneity.

Main specifications :

Imaging :

Energy range : from 50 keV to 1.5 MeV

Acquisition modes :

- High Count rate mode
- Low Count rate mode (allows real time signal processing for improved spatial resolution)

Display modes :

- Counts vs. position
- Dose rate according to user-defined nuclide or energy

Figure 1 : CARTOGAM detector head, with portable stand and controlling PC

Detector type : CsI(Tl)

Detector sensitivity* : can detect in 30 minutes a point source of ^{137}Cs that generates a dose-rate of 100 nGy/h (10 µR/h) at the detector, when used in low count rate mode.

Exposure time : from 40 ms to 100 hours.

Field of view : typically 43° x 33° (HxV) for a collimator of 50° (30° collimator available on request).

Spatial resolution* :

Collimator	662 keV	1332 keV
50° (standard)	2.5°	4.5°
30° (optional)	1°	2°

* : typical performances values are given for a standard unit at 25°C (77°F).

Physical :

Detection head :

- Weight : 17.7 kg (39 lbs)
- Length : 414 mm (16.3 in.)
- Diameter : 80 mm (3.2 in.)

Detection head to PC cable :

- 30 m (90 ft) long (standard, supplied with system)
- additional cables up to 200 m (600 ft) on request.

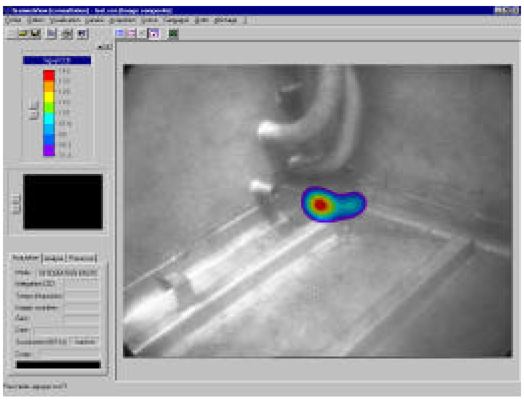


Figure 2 : CARTOGAM view with gamma and video images superimposed showing contamination near the discharge opening of a tank

ISOCS

ISOCS is a complete In Situ Object Counting system developed by Canberra for use in a wide variety of measurement applications. The standard ISOCS system includes a germanium detector with a multi-attitude cryostat, an Inspector MCA, a laptop computer, Genie 2000 gamma spectroscopy software, ISOCS mathematical efficiency calibration software, a set of adjustable shield/ collimator components and a special equipment cart to facilitate aiming of the detector and movement of all system components.

In situ gamma spectroscopy is commonly used to quantify radionuclide content of near-surface soil or structure contamination (floors, walls, ceilings, ducts, pipes, valves). The ISOCS mathematical efficiency calibration software overcomes the limitations of traditional (tiresome and expensive) efficiency calibration techniques using reference radioactive sources. It allows practical modeling and accurate assay for a wide variety of sample shapes, sizes, densities and distances between the sample and the detector. Efficiency values can be calculated for photon energies in the range of 50 keV to 7000 keV. Photon attenuation effects due to collimators and shielding components (if present) can be included in the efficiency calibration process. Attenuation effects due to the sample material itself, the container wall, and the air between the sample and the detector, are also included in the calculations. For typical objects and energy ranges of interest, an experienced user can complete the entire efficiency calibration process in several minutes. The resulting ISOCS efficiency calibration functions can then be used to analyze acquired spectral data files with the standard Genie 2000 analysis software.

Extensive validation testing of the ISOCS calibration software has been completed by Canberra. Some comparative tests have been performed with NIST- traceable radioactive sources for direct determination of the reference efficiencies. But most of the comparative tests have been performed using the standard MCNP mathematical calibration methodology to determine the "reference" efficiency values, which has been shown to be accurate to within 5 - 10% or better, when properly used. The accuracy of the ISOCS software appears to be nearly as good as the standard MCNP method for common and simple sample geometry. For normal measurement conditions, the expected accuracy of ISOCS efficiency values is within 5 - 10% for energies > 150 keV and within 10 – 20% for energies < 150 keV. Comparative tests involving heavily shielded sources (with <0.01% photon transmission) or heavily collimated detectors have shown deviations from reference efficiency values of 50 – 100%. The accuracy of the ISOCS software seems then more than adequate when used primarily for in situ measurement applications.

The ISOCS system can be a valuable tool for guiding site decontamination activities and confirming that site cleanup criteria have been achieved. In situ measurement of surface soil, subsurface soil and building structure components can be performed during all phases of D&D process.

Figure 3 :
The ISOCS shield systems and all available components installed on an RDC Ge detector with a Big Mac dewar

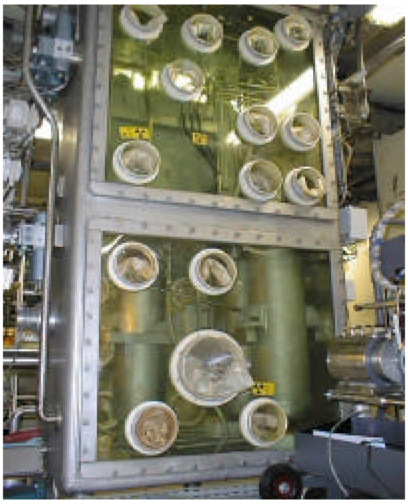


Figure 4 :
ISOCS used for in situ spectroscopy in a glove box in a COGEMA facility at Marcoule site

MERCURAD

MERCURAD is a 3D simulation software for dose-rate calculation, enabling 3D dynamic simulation of structures (sources, shielding, collimators, etc.). MERCURAD is based on the new powerful 6.0 version of the MERCURE code developed and validated by the CEA (French Atomic Energy Commission). It allows multi-source, multi-volume and multi-point calculations, much faster than a Monte-Carlo based method like MCNP for a given accuracy.
MERCURAD is a CEA and COGEMA licensed software.

The new MERCURAD software makes extensive use of a powerful graphical user interface, thus allowing very complex items to be easily defined and presented.

Main specifications of computing methods :

Gamma ray transport :
Straight line attenuation mode, with integration of point kernels in 3D geometry.

Build-up algorithms :
New CEA method ; new multi-layer formula developed using neural networks, up to 50 mfp (mean free path)

Calculated values :
Dose equivalent rate : µSv/h in H*(10) ICRP74
Effective (anterior posterior) dose rate : µSv/h
KERMA rate in Air : µGy/h or mrad/h
Exposure : mR/h
Energy flux rate : flux in MeV/s
Uncollided flux : photons/cm^2/s.

Numerical integration of sources :
by using Monte Carlo method.

Quantitative values :
Energy range from 15 keV to 10 MeV
Maximum group number : 195

Involved interactions :
Photoelectric absorption
Incoherent interactions
Coherent interactions
Pair Production
Bremsstrahlung
Fluorescence

Display :
Volume drawings : Opaque, Semi-transparent, Mesh, Thread, Normal
Image View : Normal view, perspective
3D rotation : On X, Y and Z axis, with virtual rotation knobs
Special Effects : Zoom (direct, reverse),Travelling with virtual rotation knobs

System minimum requirements :
Pentium II with 128Mbyte of memory
Minimum 60 Mbyte free disk space
Windows NT SP6, Windows-2000 SR2 or Windows-XP PRO
LPT port.

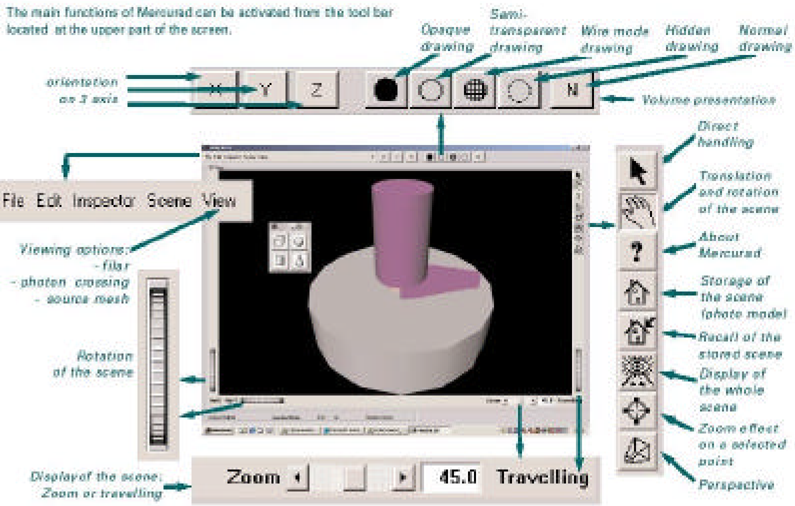
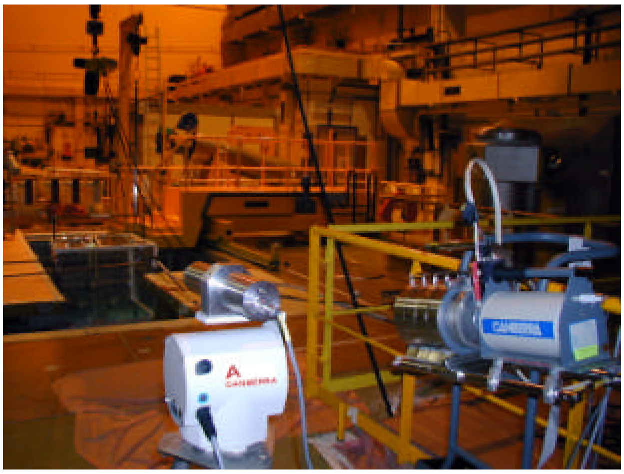


Figure 5 : Illustration of the scene manipulation tools in MERCURAD

PREPARATION OF DISMANTLING OPERATIONS

Thorough knowledge of both the structures to be dismantled and their environment is a prerequisite for optimizing dismantling operations. But in practice, the dismantling operations of nuclear installation are often difficult due to the lack of knowledge about the position, the identification and the radiological characteristics of the contamination. However, this knowledge appears essential for ensuing adaptation of working conditions.
Irradiation has usually specific sources : pipe plugging, vessel bottom, soiled portions of civil structures, etc. By identifying these sensitive areas, it is possible to eliminate them by using decontamination techniques and consequently to reduce background irradiation.

Activity inventories have traditionally been based on discrete reading obtained by hand-held instruments which cannot provide precise data on the location or size of "hot spots". Gamma imaging techniques have been recently developed to enable rapid location of gamma activity in a nuclear facility. They are combined with In situ gamma spectrometry and dose-rate calculation software to prepare the operations in the following way :



- Imaging surveys with CARTOGAM are firstly used to find out where hot spots are.

- Then, ISOCS is used to determine nuclides and activity : it enables accurate determination of the composition of gamma emitting sources located by gamma imaging and of their activity.

- Knowing the location, nuclide and quantity of radioactivity, MERCURAD can compute accurately the dose-rate to the workers. Different scenarios (various decontamination and shielding methods for example) can be evaluated to select the optimum one.

Figure 6 : CARTOGAM and ISOCS used in a COGEMA facility (UP1 / Marcoule)

DECONTAMINATION OF EQUIPMENT AND FACILITIES

As an example, the opposite picture (Figure 7) shows an image from CARTOGAM used on a COGEMA installation in La Hague before decommissioning. The gamma camera is used to determine the most irradiating items for decontamination purposes. The decontamination can then be performed only locally around hot spots, and not in the whole cell. This methodology offers potential savings for the decontamination process, from minimizing the work time and volumes of generated effluents. It also reduces the personnel exposures.
The dose-rate around the hot spot has been evaluated to be 0.39 Gy/h (39 rad/h) by using MERCURAD.

Note that to be sure of the location of hot spots, at least two images from different viewing angles are generally required. It has sometimes appeared that the idea given by a first view (showing for example a hot spot on an item in the foreground) was wrong ; a second view taken from a 30° to 40° viewing angle showed after that the contamination came in fact from another item in the middle distance, which was hidden on the first view.

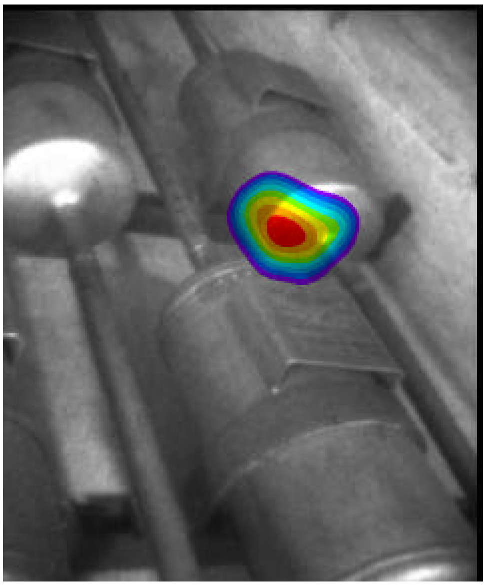


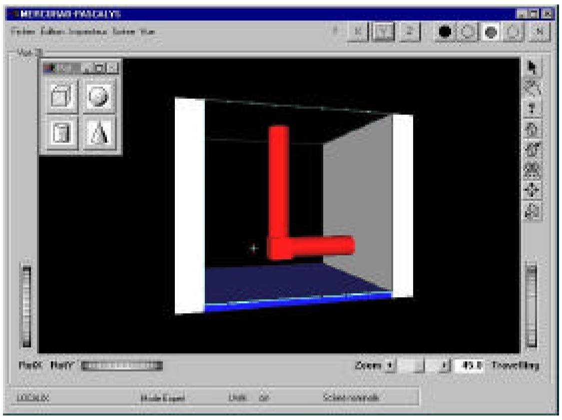
Figure 7 : CARTOGAM view showing a hot spot

Some other precautions have to be taken in using CARTOGAM to get interpretable and valuable imaging information. The distance from the hot spots must be sufficient to have enough contrast between the activity issued from these hot spots and the background activity. If there is a source of strong activity, relatively to the dose-rate to be measured, outside the field of vision, lateral shielding on the sides of the detector head is necessary.

OPTIMISATION OF DECOMMISSIONING OPERATIONS

Gamma imaging and in-situ gamma spectroscopy are commonly performed during decommissioning of the COGEMA UP1 reprocessing facility in Marcoule, in order to control the effectiveness and optimization of decontamination operations and to check the different criteria assigned to this project. The large size of installations, their complexity and difficulties of access (glove boxes for example), make it essential to use in-situ measurements. Mathematical calibration is also necessary, because no reference calibration items are available.

The CARTOGAM gamma camera is used to obtain radioactivity maps and identify hot spots. Then, the ISOCS system is used, firstly without collimator to get a global spectrometry measurement of the glove box, and for each hot spot, a measurement with collimator is performed, to determine the isotopic composition and to calculate the efficiency calibration function, depending on the geometry and on shielding ; for each identified radionuclide, the activity is calculated. The measurements done before and after decontamination process can be compared throughout the project to monitor progress.



The calculated activity is used to create with MERCURAD a model of the item to be dismantled in order to calculate dose-rate during operation for job optimizing.

The necessary external shielding can be calculated more accurately.

Knowledge of the radionuclides present or not can also help to determine if respirators are necessary.

Figure 8 : MERCURAD model of pipes

This methodology enables in-situ characterization of wastes issued of dismantling operations ; they can be classified according to their activity and dispatched towards the adequate storage, thus minimizing the storage costs.

CONCLUSION

All nuclear facility decommissioning and dismantling operations are characterized by three important issues : dealing with the contamination or activation of equipment or installations, respecting the ALARA principles (dose to workers must be As Low As Reasonably Achievable) and the ongoing search for cost savings.

The combined use of the three tools presented in this paper, CARTOGAM gamma imaging system, ISOCS in situ spectroscopy system and MERCURAD 3D simulation software for dose-rate calculation, can greatly help to meet the challenges of D & D activities by :

- reducing personnel exposures in accordance with ALARA principles, both by using remotely operated tools and by minimizing work time on site,
- optimizing waste generation through suitable source segregation and choice of decontamination techniques producing low volumes of secondary waste or discharge,
- cost-effectiveness, thanks to reduced work time on site and to a better assessment of activity inventories which leads to the possibility of storage of "declassified" wastes at lower costs.