Development of a Fleet of Intervention Mobile Unit for Radiological Accident Monitoring of Internal Contamination

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Abstract

In the event of an accident involving radioactive material, there could potentially be a large number of people who require monitoring for internal contamination. If the release contains radionuclides which emit high-energy gamma rays then the most suitable means of providing this monitoring is whole body counting. The advantage of a mobile system over fixed *in vivo* monitoring facilities is that the latter may be to a considerable distance from the accident. Besides, the mobile system will allow members of the public who may have been exposed because of their proximity to the accident to be monitored with the minimum of delay and inconvenience. As already explained for medical surveillance, rapid monitoring is also important because many radionuclides which may be present are short-lived and the seriousness of the accident will need to be quickly assessed.

To answer this challenge, the IRSN, the French institute for radiological protection and nuclear safety, has developed a fleet of mobile unit, unique in Europe, able to monitoring on-site up to 2500 people per day. This paper describes the development of these i*n vivo* mobile laboratories. The specificities, calibration procedures and performances of these systems will be presented.

Key words: Mobile units, *in vivo* monitoring, internal contamination, emergency, radiological accident

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I Introduction

The medical surveillance of workers exposed to a risk of internal contamination by radionuclides by in vivo monitoring will be generally preferred for X and gamma emitters of relatively short period while the analysis of 24 hour urines or the 72 hour faeces will often represent the examination of choice for alpha and beta emitters. Nevertheless, because the *in vivo* measurements require the patient to be physically present during the measurement, the analysis of urines is often preferred by the professionals of nuclear medicine, although it is not always adapted to exposures by short-lived emitters (Franck *et al.* 2012). On the other hand, in the event of an accident involving radioactive material, there could potentially be a large number of people who require monitoring for internal contamination. If the release contains radionuclides which emit high-energy gamma rays then the most suitable means of providing this monitoring is whole body counting. The advantage of a mobile system over fixed *in vivo* monitoring facilities is that the latter may be to a considerable distance from the accident. Besides, the mobile system will allow members of the public who may have been exposed because of their proximity to the accident to be monitored with the minimum of delay and inconvenience. As already explained for medical surveillance, rapid monitoring is also important because many radionuclides which may be present are short-lived and the seriousness of the accident will need to be quickly assessed.

To answer this last challenge, the IRSN, the French institute for radiological protection and nuclear safety, has developed since 2007 a fleet of mobile unit, unique in Europe, able to monitoring on-site up to 3500 people per day and capable to answer to any radiological emergencies involving internal contamination of gamma emitters:

- 4 light emergency body counting mobile units: to carry out a fast trial of contaminated / non contaminated people
- 4 heavy emergency body counting mobile units: for a better management of the psychosocial phase of the crisis
- 2 expertise body counting mobile units: to carry out trial of contaminated individuals in case of complex contamination and expertises for nuclear workers.

The presentation and performances of these systems are presented below in function of the urgency of the situation.

II General Presentation

A) The 4 light emergency mobile units

The goal of these mobile units is to carry out a fast trial (contaminated / non contaminated) of people. The unit has been built on standard Peugeot Boxer minivan (figure 1). The carossery is insulated and equipped with air conditioning, electric and diesel heaters making all year usage possible. The monitoring unit uses 230 V AC, which is usually taken from the nearest wall. This external mains is backed up by a light electric generator of 3,75 kVA (EU30IS from Honda) located in a trailer providing a self-contained standby power supply for up to 24 hours of continuous operation unattended.

This minivan is equipped with four seats type measurement geometry (figure 2), as it requires much less space than a bed geometry and is easier for the subjects to access. Each *in vivo* monitor consists of two NaI(Tl) detectors and digital electronics (Unispec ®]) from Canberra. Both NaI(Tl) detectors are independently adjustable to allow movement up and down and at various distances from the subject, and may be used concurrently for most subjects. The whole body detector (3”x 3”) is positioned so that the detector centre is on the subject’s thorax. This position can be used for all adults and for children who are older than about 4 y (i.e. taller than 100 cm). For smaller children, a special baby seat can be used. The thyroid detector (2”x 1”) is positioned over the lower neck and can be accurately placed for all adults up to 200 cm tall and for children greater than 100 cm in height. An example of whole body and thyroid measurement of a subject is shown in figure 3. As the system is designed to be readily transported, it was not possible to use the massive shielding often used for fixed whole body counters. Instead, a shadow shield arrangement has been used, which places the shielding where it is most effective, i.e. around both detectors and in the back of the seat. The counting time is fixed at 10 minutes but can be adjusted in function of the urgency and the number of people to be controlled.

Besides, the minivans are equipped with a video conference system and satellite antenna in order to communicate independently within any phone network in case of interventions during crisis.

Figure 1: the light emergency mobile units

Figure 2: Inner view of the light emergency mobile unit.

Figure 3: whole body and thyroid measurement of a subject in the emergency minivan

B The 4 emergency heavy mobile units

In emergency situations it will be also necessary to perform direct measurements on people for reassurance of the public, even if such measurements would not be necessary from a strict radiation protection point of view. As a matter of fact, the additional emergency means based on shelters have been developed. A general view of the shelter placed on its truck for road transportation is shown in figure 4. Their goal, in addition to help the trial of people, will be to perform a better management of the psychosocial phase of the crisis.

As shown in figure 5, ten seats have been installed in a shelters, equipped with the same *in vivo* systems as the minivans as presented above, in order allowing operators to both means (light and heavy emergency systems) without any difference and then allowing a very fast stake in operation. They are also entirely self-contained and then very well adapted for interventions during a crisis. These shelters are also equipped with a same video conference system and satellite antenna in order to communicate independently within any phone network in case of interventions during crisis.

The major difference of these mobile units is their possibility in addition of be transported by truck or train is the possibility of aero-transportability allowing them a very fast travelling by military planes everywhere in France or in the world if required in case of important crisis (figure 6).

Figure 4: General view of the heavy emergency mobile unit (the shelter is placed on its truck for road transportation)

Figure 5: Inner view of the heavy emergency mobile unit (shelter)

Figure 6: Trial of aero-transportation of the shelter

C The 2 expertise mobile units

To complete this fleet, 2 expertise mobiles units have developed equipped with more sophisticated *in vivo* systems able to answer to crisis involving more complex contaminations (such as actinides or multi-gamma contaminations) (Franck *et al.*, 2012). A general view of this expertise truck is given in Figure 1. This vehicle is organized as a fixed *in vivo* laboratory with two main rooms: a first room with toilets serves as an office and is equipped with a bench for conditioning samples if urinary excreta if required and a second room for *in vivo* monitoring. The truck is also equipped with a dressing room with paper jackets to be used for *in vivo* measurements.

All equipment operates with 220 V power supplied from internal or external power sources. Primary power is provided from an externally connected 50 m flexible ground cable connected into a weatherproof receptacle located in the right side of the truck. The receptacle feeds a 100 A distribution panel serving the truck. An air-cooled gasoline engine generator of 8 kW- 10 kW (Voyager 9DM - 10DT from Mase) located in the receptacle provides a self-contained standby power supply for up to 48 hours of continuous operation unattended. This power system allows the laboratory to operate in any location regardless of available services.

Moreover the truck is equipped with a video conference system and satellite antenna in order to communicate independently within any phone network in case of interventions during crisis.

Figure 7: General view of the expertise mobile unit

To gain optimum sensitivity and obtain a large range of energy, two Broad Energy high purity Germanium (BEGe) detectors equipped with Electrically Refrigerated Cryostat (Cryo-Pulse®) from Canberra are used which can be independently adjusted in six degrees in all directions for the 3 geometries: whole body, thyroid and lung (Figure 8).

- whole body detectors are positioned so that the 2 detector centres are 25 cm above the subject's chest and thigh. This position can be used for all adults and for children over the age of four (i.e. taller than 100 cm). For smaller children this vertical position can not be maintained and the detectors are placed as low as possible ;
- only one detector is used for the thyroid measurement. It is positioned over the lower neck and can be accurately placed for all adults and children ;
- for lung monitoring the 2 detectors are placed over the subject's lungs and in uniform contact with the subject's upper chest ;

The counting time is fixed respectively at 20 minutes in case of expertise respectively for whole body and lung measurement and 15 minutes for thyroid measurement but can be adjusted in function of the urgency and the number of people to be controlled.

Figure 8: Inner view of the expertise mobile unit. Left: thyroid measurement, middle: whole body measurement, right: lung measurement

4 Calibration

The different systems were calibrated for efficiency using the phantoms shown in figure 9.

- For whole body activity in the 88 keV to 1460 keV energy range using a mixed radionuclide standard uniformly distributed in a block phantom (Kovtun *et al.*, 2000). The mixed radionuclide standard contains the following nuclides: ^{133}Ba, ^{54}Mn, ^{137}Cs, and ^{60}Co. Phantoms were constructed from phantom blocks to represent children and adults of average height and weight: 12 – 24 – 50 – 70 – 90 and 110 kg.
- Calibration factors for determining iodine radionuclides activities in the thyroid were obtained using two mock plastic thyroids loaded with ^{133}Ba and ^{129}I respectively placed in the neck phantom developed by Radiology Support Devices (ICRU, 1992), allowing us to derive calibration factors for the short-lived iodine nuclides ^{132}I, ^{133}I, ^{135}I as well as for the longer-lived ^{131}I.
- For lung monitoring, the expertise truck system was calibrated using the anthropomorphic Livermore torso phantom (Griffith *et al.* 1978). The phantom is loaded with 2 sets of lungs homogeneously distributed with ^{241}Am and ^{152}Eu throughout the tissue equivalent material providing photon emissions with energies between 13 keV and 1400 keV. A set of five plates over the torso phantom was used to cover a Chest Wall Thickness (CWT) range from 1.67 to 4.27 cm.

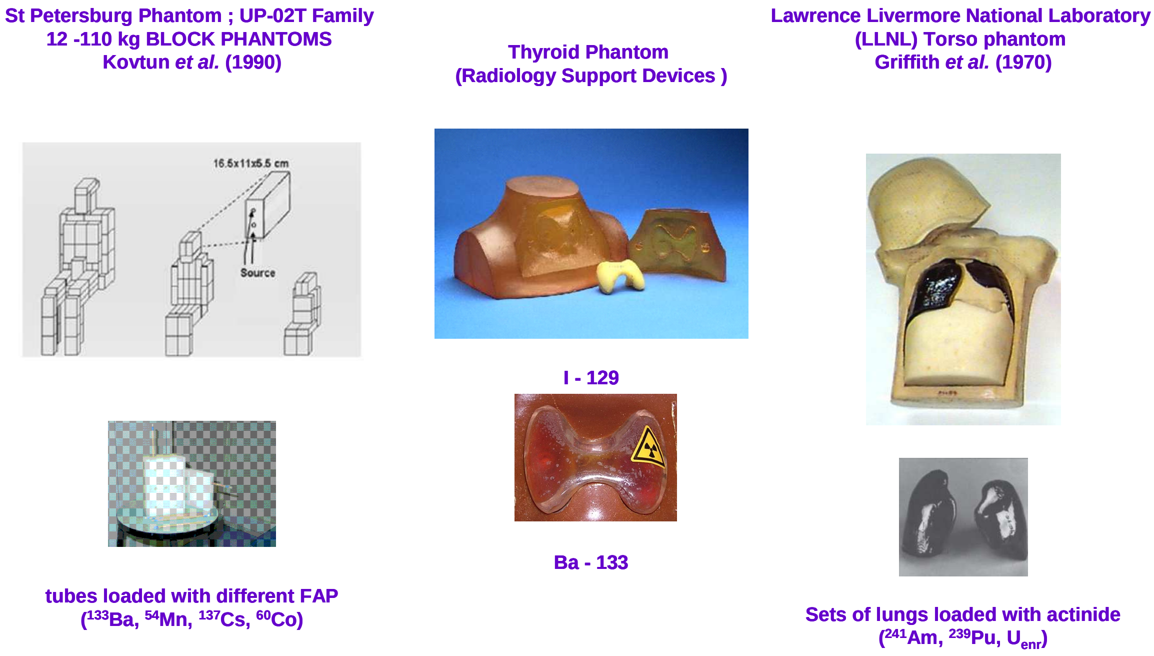

Figure 9: Different types of phantoms used for the efficiency calibration

5 Performances

One of the design criteria to check the performance of the different systems was that it should be able to detect intakes of individual nuclides which correspond to committed effective doses of 1 mSv.
Thus, for typical radionuclides found in case of radiological accident, corresponding to different counting geometries, the approximate Detection Limits (DLs) of the emergency and the expertise systems have been compared for a reference man as defined to ICRP 89 (2003) to (i) those obtained with our fixed *in vivo* system and to (ii) the activities remaining 24 hours and 7 days after acute inhalation at a level corresponding to a 1 mSv committed effective dose (ICRP 56, 1986 ; ICRP 67, 1993).
On the basis of the calibrations obtained for each geometry and standard counting time as define in the former chapters for both emergency and expertise vehicles as well as backgrounds with no contamination, DLs values were estimated using the following equation (ISO, 2010).

$$DL = (K_{1-\alpha} + K_{1-\beta}) \times \sqrt{R_0\left(\frac{1}{t_0} + \frac{1}{t_s}\right)}$$

Where $k_{1-\alpha}$ = 5% is the desired 1- α percentile of the Poisson distribution, $k_{1-\beta}$ = 5% is the risk of false negative assessment, R_0 the background effect counting rate, t_0 the duration of the background measurement and t_S is the duration of the patient measurement.
As shown in table 1, if we consider the activities remaining after 24h and 7 days, even with the light emergency system, they are generally much higher than the corresponding DLs with the exception of 241Am and 239Pu due to their low X and gamma emission abundance and high absorption in tissues. For the latter, using our mobile expertise facility, respectively, the intake would have to be approximately a factor 2 and a factor 200 higher to allow the detection of the activity corresponding to a dose of 1 mSv. This shows that in case of actinides contaminations in vivo monitoring is not the adequate method, excreta measurements should be preferred showing that a shorter time of measurement could be used and operation in a higher background as well. In the latter case, if in a contaminated area of 1 MBq activity of ^{137}Cs is considered, the estimated DLs is multiplied by a average factor 14.5 for a measurement carried out with the light emergency vehicle (Broggio *et al.*, 2012). As shown in table 2, the results still remain below the activities corresponding to 1 mSv for a measurement carried out 7 day after the contamination.
Anyway, if we can show that performances are still very good, even in a contaminated area, contamination both on clothing and on the subject could be our major problem. The common practice in

preparing for a measurement will be to have the subject shower and change into clean clothing which has had no contact with contamination. Moreover, if it is possible, in order to assure that clothing has no contamination subjects to be monitored will be dressed in special clothing such as new coveralls or other clothing used only for wear in the counter.

Table 1: Comparisons of Detection Limits for typical radionuclides after acute inhalation at a level corresponding to a committed effective dose of 1 mSv if the measurement is carried out 1 day and 7 days after contamination respectively for our mobile systems: expertise (DL_{ex}) and emergency (DL_{em}). Dose coefficients are issued by ICRP 68 (1994)

Radionuclides	Measurement geometry	Activities (Bq) measured 24 hours after intake corresponding to 1 mSv	Activities (Bq) measured 7 days after intake corresponding to 1 mSv	Eγ (keV)	$DLex_{(1)}$ (Bq)	$DLem_{(2)}$ (Bq)
^{132}Te $^{(3)}$	whole body	$1,5.10^5$	$1,6.10^4$	228,2	20	450
^{131}I $^{(4)}$	thyroid	$1,1.10^4$	$7.1.10^3$	364,5	2,4	190
^{137}Cs $^{(5)}$	whole body	$8,4 .10^4$	$6.4.10^4$	661,6	45	390
^{60}Co $^{(6)}$	whole body	$3,6. 10^4$	$1.2.10^4$	1332,5	40	320
^{241}Am $^{(7)}$	lung	8,2	7.7	59,54	15	/
^{239}*Pu* $^{(7)}$	lung	8,2	7.7	17,5	$4. 10^3$	/

(1) Measurement carried out with the expertise mobile system
(2) Measurement carried out with the emergency mobile system
(3) Absorption type F, AMAD (Activity Median Aerodynamic Diameter) 5µm. Biokinetic model described in ICRP 67, 1989
(4) Iodine vapour. Biokinetic model described in ICRP 68, 1994.
(5) Absorption type M, AMAD 1µm. Biokinetic model described in ICRP 67, 1993
(6) Absorption type F, AMAD 1µm. Biokinetic model described in ICRP 56, 1989
(7) Absorption type S, AMAD 1µm. Biokinetic model described in ICRP 67, 1993

Table 2: Detection Limits (DLem) for our emergency systems for typical radionuclides if the measurements are carried out 7 days after the contamination in a contaminated area with ^{137}Cs of 1 Mbq

Radionuclides	Activities (Bq) measured 7 days after intake corresponding to 1 mSv	$DLem_{(2)}$ (Bq)
^{132}Te $^{(3)}$	$1,6.10^4$	6530
^{131}I $^{(4)}$	$7.1.10^3$	2760
^{137}Cs $^{(5)}$	$6.4.10^4$	5660
^{60}*Co* $^{(6)}$	$1.2.10^4$	4640

6 Conclusion

There is an evident need to be prepared to measure rapidly large groups of internally contaminated people. Regardless of the type of the emergency situations —nuclear or malevolent use of radiation— casualties will most likely be members of the public and the number of affected people can vary from a few to mass casualties. Furthermore, it is necessary to be able to perform direct measurements on people for reassurance of the public even if such measurements would not be obligatory from a strict radiation protection point of view.

To answer to these issues, a fleet specially designed for radiological accident monitoring of internal contamination and able to assess the internal contamination for more than 2500 people a day have been developed at the IRSN since 2007 and is now in operation since 2010. With their communication network, they are immediately operational, entirely self-contained and then very well adapted for interventions during a crisis. Furthermore, they can be moved to the measurements sites anywhere in France within 24 hours and be operational in less than two hours.

They can carry out in vivo measurements for different types of contaminations and can be used in a wide range of subjects. Furthermore, thanks to the use of specific shielding it has been shown these systems are capable of detecting activities which are equivalent to a dose of less than 1 mSv up to 7 days after intake by inhalation for a wide range of radionuclides even in a contaminated area.

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