Design and Implementation of a Mobile Radiological Emergency Unit Integrated in a Radiation Monitoring Network

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Abstract—The first hours elapsed after a radiological incident are critical to take appropriate actions to protect the population and to assess its impact on the environment. The development of mobile laboratories equipped with different radiation detectors, with robust communication systems, and with a highly autonomous uninterruptible power supply constitute the spearhead of modern radiological warning networks. Their main function is to provide additional radiation information with acceptable accuracy in the shortest possible time. This paper describes our development of a mobile laboratory and the demonstration of its usefulness in various emergency drills conducted in the vicinity of a nuclear power plant.

Index Terms—Computerized monitoring, mobile laboratories, radiation monitoring, radioactive pollution, surveillance.

I. INTRODUCTION

MOBILE laboratories equipped with various types of radiation detection systems and using near real-time data transmission constitute one of the most useful tools for the in situ characterization and evaluation of radiological impacts. They take on particular relevance immediately after the occurrence of an uncontrolled release of ionizing radiation into the environment, such as may occur from an incident or accident at a nuclear fuel cycle facility, hospital, research laboratory, or as the result of a terrorist act in which a “dirty” bomb has been used.

The basic elements of such mobile laboratories are the use of GPS positioning together with different ionizing radiation detection devices, all under the control of a computer system which, via an efficient communications network, remits in near real time the information obtained to the corresponding points where decisions will be made (“headquarters” or HQ).

One finds in the literature several papers on the use of such a basic mobile laboratory model [1], [2]. Some are designed to be carried on aircraft, mainly helicopters [3], [4]. Their main drawback is their expense—capital outlay, maintenance, and the highly skilled personnel required (pilots). To at least partially overcome this problem, recourse can be made to the alternative of unmanned aerial vehicles (UAVs) [5]. Their cost is significantly lower than manned aircraft. Their main drawback is in the maximum load that they can carry—only about 50 kg [6]—and their limited operating autonomy—usually in the range of 1 to 5 hours [5], [6].

The present communication describes the development of a mobile laboratory that can contribute efficiently to the assessment of an emergency situation regardless of where it occurs. To this end, it is necessary to take into account the minimal parameters required in the design of such a mobile laboratory.

II. MATERIAL AND METHODS

In an emergency situation, the decisionstaken at HQ will initially be based on the information received in near real time from radiological monitoring networks. Given the relatively high cost of each monitoring station, it is impossible to implement networks with a high density of monitoring stations that would allow a radiological alteration in any environment to be detected. It may be useful instead to complement the existing radiological network with a mobile laboratory that can contribute efficiently to the assessment of an emergency situation regardless of where it occurs. To this end, it is necessary to take into account the minimal parameters required in the design of such a mobile laboratory.

The minimum information to be transmitted in near real time from a mobile laboratory has to be the georeferenced dose rate from external gamma irradiation. However, by itself, this information is very limited because it does not allow HQ to identify the radionuclides causing this dose rate or their origin, or...
whether the dose rate is due to radionuclides deposited on the ground or present in the form of aerosols. It is therefore also necessary (i) to provide at least the inhalation dose rate due to the presence of radionuclides in air, (ii) if possible, to identify the principal radionuclides contributing to that rate, and (iii) to relate the detected radioactive levels with the prevailing meteorological parameters at the current location of the mobile laboratory. This makes it highly recommendable that the mobile unit should include a gamma spectrometry system and a basic meteorological station.

All the information generated in the mobile laboratory needs to be passed to HQ via reliable and robust communication systems. If there were only a single communication system, such as GSM, this would make coverage dependent on the current location of the mobile laboratory. There must therefore be some alternative means of communication, e.g., via satellite or by radio. Finally, during any radiological emergency, it is of prime importance to have as much information available as possible and as soon as possible to allow HQ to make the most appropriate decisions to protect the population and limit the impact on the environment. Consequently, it may be interesting for the mobile laboratory to have as great an electrical autonomy as possible, so as to ensure the operation of all of its measurement devices.

Having defined the basic generic features which a mobile laboratory must have, in the rest of this section we shall describe the mobile laboratory designed and implemented by the Environmental Radioactivity Laboratory at the University of Extremadura (LARUEX) as an integral part of the Radiation Alert Network of Extremadura (RARE) for near real-time radiological surveillance. The vehicle used is a commercial van of 4.96 m length and 22.9 m$^3$ capacity.

A. Radiation Detection Systems

A dose rate monitor (Fig. 1 left), previously calibrated for measurements of ambient dose rates is installed over the vehicle’s right front wheel. The monitor comprises a 54.2 cm$^3$ pressurized proportional counter, designed to measure dose rates in the range 0.005 $\mu$Sv$\cdot$h$^{-1} - 1$ mSv$\cdot$h$^{-1}$ [7].

The monitor was calibrated using the “free field” technique, with a $^{60}$Co and $^{137}$Cs sources of certified activities [8], [9]. To calibrate the monitor’s readings of the cosmic component, a series of dose rate measurements were made at several locations over the territory of Spain, corresponding to different altitudes in the range 300–2500 m above sea level [10]. To make an accurate measurement of the gamma dose rate $H_{10}$, the measurement device should be set at 1 m above the ground in an obstacle-free area. Since our device is coupled to a van, it is necessary evaluate the corresponding attenuation of the gamma radiation coming from the ground. A series of measurements were made within the range of 0.1–0.4 $\mu$Sv$\cdot$h$^{-1}$ environmental dose equivalent rates. To this end, two types of measurements were made: the first with the monitor mounted on the mobile unit, and the second with it mounted on a tripod at 1 m above the ground and free of any obstacle within a radius of 20 m.

Fig. 2 shows the correlation between the two sets of measurements. One observes that the attenuation due to the monitor’s being attached to the mobile unit is, for this range of dose rates, about 40%.

The dose rate monitor takes the count, $x$, of the pulses that are generated when photons interact with the gas contained in its ionization chamber to calculate the count rate, i.e., the number of pulses registered per unit time,

$$ r = \frac{x}{t} $$

where $t$ is the counting time. This rate is used to determine the environmental dose equivalent rate $H_{10}$. The uncertainty associated with the measurement of $t$ is negligible compared to the uncertainty associated with the counts. With the application of error propagation, the uncertainty associated with the count rate is given by

$$ \sigma_r^2 = \left( \frac{1}{t} \right)^2 \sigma_x^2 $$

(2)

As one deduces from (2), it is important to determine the optimal time of measurement, since the uncertainty associated with the count rate is inversely proportional to the square of the counting time. For this reason, the monitor was placed on a tripod at 1 m above the ground in an open area, and 15 series of dose rate measurements were made, with different counting times. The mean values and corresponding standard deviations of these series are listed in Table I.

Obviously, any increase in the counting time will be matched by a decrease in the associated uncertainty, but it will also mean a reduction in the number of points at which measurements are...
TABLE I
MEAN VALUES OF THE DOSE RATE FOR DIFFERENT MEASUREMENT TIMES

<table>
<thead>
<tr>
<th>Time (s)</th>
<th>Average ± SD (µSv/h)</th>
<th>Relatively uncertainty (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>0.174 ± 0.009</td>
<td>5.8</td>
</tr>
<tr>
<td>40</td>
<td>0.172 ± 0.006</td>
<td>4.1</td>
</tr>
<tr>
<td>60</td>
<td>0.169 ± 0.006</td>
<td>3.4</td>
</tr>
<tr>
<td>90</td>
<td>0.171 ± 0.003</td>
<td>2.8</td>
</tr>
<tr>
<td>120</td>
<td>0.171 ± 0.003</td>
<td>2.4</td>
</tr>
<tr>
<td>150</td>
<td>0.172 ± 0.003</td>
<td>2.1</td>
</tr>
<tr>
<td>180</td>
<td>0.171 ± 0.003</td>
<td>1.9</td>
</tr>
<tr>
<td>210</td>
<td>0.170 ± 0.003</td>
<td>1.8</td>
</tr>
<tr>
<td>240</td>
<td>0.170 ± 0.003</td>
<td>1.7</td>
</tr>
<tr>
<td>270</td>
<td>0.171 ± 0.003</td>
<td>1.6</td>
</tr>
<tr>
<td>300</td>
<td>0.171 ± 0.002</td>
<td>1.5</td>
</tr>
<tr>
<td>600</td>
<td>0.171 ± 0.002</td>
<td>1.1</td>
</tr>
</tbody>
</table>

1332.5 keV emission. It has a 7-litre capacity Dewar of $L_N\text{H}_2$ which provides 4 days autonomy. For the in situ gamma spectrometry of soils, the detector is placed facing downwards on its tripod at 1 m above the ground. For these measurements, the detector was calibrated using a semi-empirical technique originally developed by Beck [12], and widely used in the field of in situ gamma spectrometry [13]–[15], and that we have further optimized in our laboratory [16]. To determine the Minimum Detection Activities (MDA) of the in situ soil measurements, we followed the method proposed by Nir & Haquin [17]. For a 3600 s measurement, an MDA in the range of 60–200 Bq - m$^{-2}$ for the typical fission products $^{137}$Cs, $^{60}$Co, and $^{131}$I can be obtained.

For the gamma analyses of aerosol filters and other samples within the low background iron shielding, the Ge detector efficiency was calibrated for the 60 to 2000 keV energy range, using a standard QCY-48 cocktail from Amersham International. Under these working conditions, capturing aerosols for 40 min on 0.8 μm nitrocellulose filters of 4.7 cm in diameter, and measuring the filters for 60 min, the MDA values were less than 0.2 Bq · m$^{-3}$ for the typical fission products $^{137}$Cs and $^{131}$I.

B. Additional Equipment for Radiation Characterization

The aerosol filters mentioned in the previous section are obtained by an aerosol collecting system installed in the vehicle. The system has an inflow rate of 3341 · min$^{-1}$, using a 4.7 cm diameter glass fibre filter. The inflow rate falls significantly to about 201 · min$^{-1}$ with 0.8 μm pore size, 4.7 cm diameter, nitrocellulose filters. However, this pore size is small enough to retain such radionuclides as $^7$Be.

The information on the radionuclide activity levels measured from the aerosol filters is supplemented with data provided by the mobile laboratory’s meteorological station. This is installed on a telescopic mast that can be raised to a height of 1.7 m above the vehicle’s roof. This station measures wind speed using ultrasonic. For speeds in the range 0–60 m · s$^{-1}$, the precision is 3%, and the response time is 0.25 s. It also measures wind direction with a precision of 3° and a resolution of 1° [18]. Other parameters measured with precisions better than 5% are barometric pressure, temperature, relative humidity, and rainfall.

C. Basic Equipment for Operation

Fig. 3 presents a diagram of the distribution of the different power sources available in the mobile laboratory. The philosophy of this system is, on the one hand, to achieve the greatest possible electrical autonomy, and, on the other, to ensure that the power supply to all the devices and detectors will be uninterruptible. Given these premises, the mobile laboratory’s main power supply is a 4 kVA gasoline generator with an autonomy of between 8 and 10 h. The secondary supply is a 12 V, 72 Ah battery, with a minimum autonomy of 3 to 4 h. This battery can be charged from the vehicle’s engine whenever the vehicle’s battery is fully charged. An electrical isolation system is implemented to prevent the vehicle’s battery draining. Which of the two power supplies is used is selected by a manual switch. After this switch, the mobile laboratory has a UPS system to protect the detectors and other electronic devices from unexpected power disruptions. This is a UPS battery which, in case

Taken or a greater distance traveled by the vehicle that will have to be associated with the dosimetry value. In both cases, the results will be a loss of temporal or spatial resolution. One must therefore seek a trade-off between these two opposing effects. We considered that, for emergency situations, the optimal measuring time should be no more than 30 s, with which the uncertainty in the count rate would be less than 6%. In emergency situations it is necessary to give priority to the availability of a high density of radiological data even at the cost of less accuracy. However, for the mapping of a geographic area in non-emergency situations we took the optimal measurement time to be 180 s, yielding dose rate counting uncertainties of less than 2%. In these situations, measurement accuracy should have the priority.

Taking into account the uncertainties associated with the calibration, the correction factors applied, and the measurement itself, the total uncertainty associated with the dose rate measurements when the vehicle is stationary was estimated to be around 15%, reaching 30% when the vehicle is in motion. These uncertainties are the actual resolution of the measured dose rate levels, and need to be taken into account when constructing the isodose lines in the corresponding maps.

For the detection of local anomalies, it is necessary to work with very short measurement time intervals—between 1 and 10 seconds [6], [11]. For this purpose, a stabilized NaI(Tl) detector (see Fig. 1 left) is also installed over the vehicle’s right front wheel. This detector has dimensions of $2'' \times 2''$ with which it is possible to obtain gamma spectra at a resolution of 6.6% for the 661.7 keV $^{137}$Cs peak. It is designed to measure dose equivalent rates $H_{10}$ in the range 0.010 μSv · h$^{-1}$ – 100 mSv · h$^{-1}$, and to identify gamma emitting radionuclides contributing to the counts using a 1024-channel multichannel analyser calibrated in the energy range of 50 keV to 3 MeV. The nuclide identification tolerance energy window is greater than 4%.

The high resolution gamma spectrometry system consists of a portable coaxial p-type intrinsic hyperpure Ge detector. When mounted on its tripod, it allows the in situ radioactive measurement and characterization of soils. Housed within the low background iron shielding available inside the mobile laboratory (see Fig. 1 right), it also allows the radioactive characterization of the aerosols collected by the filters in the suction pump. This detector has a relative efficiency of 43.1%, an energy resolution of 2.0 keV, and a peak-to-Compton ratio of 56-to-1 for the $^{60}$Co

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of failure of the other power systems, can provide at least 30 min of power. In sum, the mobile laboratory has a minimum of 12 hours of uninterruptible power autonomy apart from that which the vehicle engine itself can provide.

Finally, the mobile laboratory has a flap covering a connector yo plug in an external power supply. This system is designed to supply power to the sensors and devices for long periods of time, thereby allowing the mobile laboratory to be used as a fixed automatic radiation monitoring station.

D. Positioning and Communication Devices

A conventional GPS device is installed to register the mobile laboratory’s geographical position, altitude above sea level, and speed.

The primary communication system is GSM, using a conventional cellular telephone. The mobile unit has a secondary backup communication system to take over automatically when there is no GSM coverage or the quality of that service is insufficient. This secondary system is based on satellite communication. The two systems are controlled by the mobile laboratory control software, which switches automatically from one to the other depending on the availability of coverage and the service quality.

E. Management and Delivery of Information

The GPS, cellular telephone for GSM communications, the modem for satellite communications, as well as the dose rate monitor, the multi-channel analyzer, and the electronics associated with the HPGe gamma spectrometer are connected via RS232 or USB to a conventional laptop computer.

Communication with these devices, and the storage and management of the information they provide, is handled by the computer program MobileLab, developed in our laboratory. This software was specifically written to manage the capture, display, and transmission in near real time of the data obtained by the mobile laboratory’s instrumentation, and its reception and display at HQ. Its main features are:

Acquisition and Storage of Data: The MobileLab software is designed to interpret character strings from all the devices connected to the computer via RS232 or USB ports, adapting to their respective communication protocols (ASCII, NMEA, etc.). All data generated by the different devices are stored locally as they are acquired as well as being transmitted to HQ in near real-time. This allows their further analysis and processing in the on-board computer. To transmit the recorded data, the software organizes them into frames. The basic frame consists of: dose rate data ($\mu$Sv·h$^{-1}$), date/time, position (Lat;Long), elevation above sea level (m), vehicle travel speed (km·h$^{-1}$), air temperature ($^\circ$C), barometric pressure (bar), rainfall (1·m$^{-2}$), and wind speed and direction (m·s$^{-1}$ and $^\circ$, respectively). The meteorological data are only included when the vehicle is stopped at the time of making the measurements. As well as these standard frames, the MobileLab software is able to send any type of digital file to HQ, with options for images, gamma spectra, and reports.

Capacity for Plotting the Captured Data on Maps: The software includes a module that allows the information acquired to be plotted as georeferenced images, together with the tool needed to perform the georeferencing. This makes it possible to produce maps as needed at any given time, from cartographic, topographic, or satellite images, or from mapping images of any other nature, in which the geographic references of at least three points are known.

Comparison of Dose Rate Values Using Isodose Maps: The MobileLab software has a module that allows the incorporation in image format of a georeferenced isodose map. The new georeferenced dose rate values recorded in the mobile laboratory can then be compared with the dose rate value extracted from the stored isodose map. The criteria to use in the comparison are user configurable. Then, if the newly recorded georeferenced dose rate exceeds the value extracted from the isodose map by more than some pre-set threshold, an acoustic alert signal is generated, and the location of the anomaly is identified for subsequent new measurements to be made at the same location.

Transmission and Reception of Information: The MobileLab software includes various mechanisms to allow communication between the mobile laboratory and HQ. First, there are two profiles under which to run the program: (i) the Mobile Unit profile, which has an interface oriented to obtaining information from the mobile laboratory instrumentation, and which will be the default profile for the onboard PC; and (ii) the Central HQ profile which presents fewer options, focusing on the display of information from the mobile unit such as tables of the information received, or a window displaying the position and the radiological or complementary data on the corresponding maps, and which will be the profile used in the HQ PC.

The software includes mechanisms for communication between the onboard PC and the HQ PC: message exchange (chat), automated real-time transmission/reception of the georeferenced data recorded by the mobile laboratory, and file transfer. These connections are implemented on a TCP/IP stack with sockets.

Automated Management of the Communication System: Connections are established using the operating system’s communications system. The design supports communication outages, restoring the connection automatically on the basis of policy settings that are established beforehand. The MobileLab software has a communications control module based on the internal label of the data frames which are sent to HQ. When the data receiver software confirms the reception of a data frame, MobileLab tags this data frame as “sent” and removes it from the send queue. Packet losses therefore do not affect the final transmission. With respect to the communication
system, the default is to use two channels: GSM as primary, and satellite as secondary. If the primary connection is not available, or a number of re-connection attempts are made without success, the secondary system is switched in. Communication is maintained via this system for a period of time set in the configuration, before again attempting to re-establish the communication link via the primary system. The whole process is automatic, and does not require any action on the part of the user. Fig. 4 shows schematically the currently implemented communication scheme. The main data flow is between the mobile laboratory and HQ located in the logistics centre of the Radiation Alert Network of Extremadura (RARE) in Cáceres (Spain). Once HQ has received the data, it forwards the information to as many points as are desired to configure.

III. ANALYSIS AND RESULTS

A. Dosimetric Characterization of the Environment Around the Almaraz Nuclear Power Plant

Two sampling campaigns were conducted in 2009 in the vicinity of the ANPP. The objectives were: first, to evaluate specifically the external irradiation dose rate received by the population residing in that area due to gamma emissions from radionuclides in the soil; and second, to gather radiological information about the Plant’s environment, in particular, within a radius of 25 km around the Plant. The ANPP is located in the Autonomous Community of Extremadura (Spain) at a distance of 200 km from Madrid and 100 km from Cáceres. The total duration of the two campaigns was 21 days, during which 940 moving dose rate measurements were made of 180 s each, with the resulting relative uncertainty of each measurement being less than 2% (see Table I). Table II summarizes the statistics of the dose rate measurements, vehicle speed, and altitude above sea level. One observes that there was a wide range of variation in these values. First, during moving measurements, the type of road along which the vehicle is being driven may make it impossible to maintain a constant speed, and the standard deviation of the vehicle’s speed may be significantly greater than the mean value. Second, with respect to the dose rate values, the wide range of variation is a reflection of the relatively broad variety of the lithological composition of the soils in the study area, as was found in a previous study [19]. And third, the mean value of the dose rate as recorded in the moving vehicle is greater than the mean value reported for soils of Spain [20]. This is because most of the soils around ANPP have substrates of acidic rocks, limestones, quartzites, sandstones, and shales. Some of these rocks have constituent minerals, such as uraninite and monazite, with naturally high radioactivity concentrations (up to 240 Bq kg\(^{-1}\) of \(^{226}\)Ra, 260 Bq kg\(^{-1}\) of \(^{232}\)Th, and 1840 Bq kg\(^{-1}\) of \(^{40}\)K) [21]. Indeed, the \(^{226}\)Ra, \(^{232}\)Th, and \(^{40}\)K activity levels measured in soils around the ANPP [21] are higher than the global average as estimated in the UNSCEAR report [22].

The data from these measurements were used to construct an isodose map of the surroundings the ANPP. In this process, it was taken into account that the resolution of the map is determined by the total uncertainty associated with the dose rate measurements in motion which, as indicated above, is 30%. Interpolation was by means of kriging—a linear least squares estimation algorithm that computes a weighted estimate of a parameter at an unobserved point from the measured values at nearby points. The method produces a far more realistic result than if only distance from nearby points is taken into account, as it is in the inverse distance method [23]. Fig. 5 shows the isodose map of the proximities of the ANPP generated using kriging interpolation.

To validate the data generated in the isodose map, we compared its values with other published dose rate levels for the same study area and generated by means of well-established techniques. In particular, we considered for comparison the values of the effective terrestrial dose rate determined by airborne radiometry during the uraniferous prospection campaigns which served as the basis for the creation of the Natural Radiation Map of Spain (MARNA) [20], [21], [24]–[26]. Ground to air comparisons were made considering at least one dose
Fig. 5. Map of the terrestrial equivalent dose rate in the proximity of the Almaraz NPP.

Fig. 6. Comparison of the dose rates obtained by aerial radiometry in the MARNA project [24] with the dose rates recorded in the mobile laboratory developed by the LARUEX research group for RARE.

Fig. 7. Dose rate measurements made with the vehicle in motion, recorded during the 2009 emergency simulation exercise. The map also shows the sites at which in situ gamma spectrometry measurements were made of the activity levels in soils.

rate datum pair per 5 km × 5 km of the land area analyzed, one measurement made with the mobile laboratory and the other by aerial radiometry. Thus, for the total area analyzed (ca 2500 km²), we used 100 pairs of dose rate values and quantified the ratios between them (see Fig. 6). In Fig. 6, the horizontal continuous lines identify the margin of error of the mobile laboratory dose rate measurements which, as was noted above, is 30%. This comparison shows that 89% of the ratios between the two sets of dose rate values lie within the margins of error applied to the mobile dosimetry. This is further confirmed by the value of the correlation coefficient between the two series of data which was 0.8.

B. Emergency Simulation Exercises in the Area Surrounding the Almaraz Nuclear Power Plant

The present mobile laboratory has participated in various emergency simulation exercises. Those described below have been held annually since 2009 in the vicinity of the ANPP. The participation of the present mobile laboratory in sampling drills was to establish and report, as soon as possible, the radiological impact on a geographic area of an hypothetical accidental radioactive discharge from the ANPP.

At all times during these exercises, the mobile laboratory was operated by two analysts: one was responsible for driving the vehicle, and the other for monitoring the communications and measurement systems, which were operating in automatic mode.

Fig. 7 shows schematically the route taken by the mobile laboratory in the 2009 exercise. Table III presents the summary statistics of the volume of data captured and the analyses performed in those exercises, and, as a result of the targets set in each simulation exercise, the total number of kilometres characterized dosimetrically and the average speeds reached by the vehicle.

The measurement time selected for recording the dose rate was set at 30 s, seeking a compromise that would minimize the radiation monitor error of measurement at the same time as maximizing the spatial resolution of each of the measurements. The results showed that over 97% of the information generated in the mobile laboratory was successfully transmitted to the network’s logistics centre in Cáceres and from there to the different HQs. During the exercise conducted in 2009, there was a temporary GPS system failure that resulted in the generation of 87 erroneous data frames in which the measured parameters were not
correctly georeferenced. These frames were subsequently eliminated after their reception at HQ. To avoid this problem, a control of the devices connected to the onboard computer was implemented in the MobileLAB software. Thus, if the application does not receive data from a device (GPS, dosimeter, gamma spectrometer) then it does not generate a complete data frame to send to HQ. There were 7 communications disruptions due to lack of GSM coverage in the first year, 10 in the second, and 9 in the third. They were all handled automatically by the MobileLAB program in accordance with the design criteria described above. Specifically, at least 3 attempts were made to automatically reconnect with HQ via GSM. Since these failed, the system was automatically switched to the satellite communication channel. Communication was thus maintained for a time defined in the configuration settings, after which a further three attempts were made to connect via GSM. The data frames generated in the mobile laboratory were stored on a stack until communication was restored, when they were sent to HQ.

In each of the three simulation exercises, either 1 or 2 in situ gamma spectrometric determinations were made for the radiological characterization of the soil at different locations. During these spectrometric measurements, the dose rate readings and the meteorological parameters were simultaneously recorded and transmitted. Likewise, aerosols were collected using a 4.7 cm diameter nitrocellulose filter in the collector. Table IV lists the activity levels of the natural and artificial radionuclides analyzed by the in situ gamma spectrometry, together with the values of the dose rate $H_{10}$ calculated from these activity levels using the expression given in the ICRU 53 Report [27]. The value obtained directly from the measurement with the dose rate monitor for one of the spectrometric determinations in each simulation exercise is also given in the table. One observes that the values given by the dose rate monitor coupled to the mobile laboratory are fully analogous with the levels calculated from the activity levels of radionuclides contained in the soil measured by in situ gamma spectrometry. This confirms the consistency in performance of the different detection systems installed in the mobile laboratory.

In sum, the overall results of the three simulation exercises in which the LARUEX’s mobile laboratory participated show it to have met its design goals.

**IV. CONCLUSIONS**

This communication has described the development of a land vehicle designed as an autonomous mobile laboratory for the radiological evaluation and characterization of geographical zones in normal situations or in situations altered by radioactive releases into the environment. The vehicle was successfully tested in the radiological and dosimetric characterization of the surroundings of the ANPP, demonstrating its capacity to perform radiological characterizations with the use of fewer resources and less time than other techniques. The results were compared with the dose rate values measured by means of already validated methods, obtaining a high degree of coincidence between the two. Finally, the usefulness of this mobile laboratory was demonstrated with its participation in three emergency simulation exercises in the environment of the aforementioned Nuclear Power Plant. Only 2 analysts were needed for the mobile laboratory’s handling and supervision.

Communication from the mobile laboratory to HQ was handled automatically by the software that had been developed for
the system, with more than 97% of the data recorded by the mobile laboratory being successfully transmitted in real time for at least 90% of the time. At least one in situ gamma spectrum per exercise of a soil of the surroundings of the ANPP, and one gamma spectrum of an aerosol sample captured during the exercise were successfully transmitted to HQ. The vehicle’s autonomy was fundamental in the three exercises, demonstrating the system’s significant capacity to provide data during the first hours following an emergency situation, assisting its HQ to acquire the information needed to make correct and timely decisions. It was also verified that the mobile laboratory’s different detection devices were capable of making radiological measurements in different environmental media (soil, air) with MDA values that are adequate for the system’s purpose (i.e., to detect and identify artificial radionuclides potentially released in an accident at a nuclear fuel cycle facility). There was also found to be a strong correlation between the dose rate levels calculated and identified by the dose rate monitor.

REFERENCES


