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# Lesson learned from the recovery of an orphan source inside a maritime cargo: analysis of the nuclear instrumentations used, and measures realized during the operations

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**Abstract** In this paper, the authors analyze the case study of the recovery of an orphan source of $^{60}$Co inside a maritime cargo full of metal wastes in the Italian Harbor of Genova carried out by the Italian Fire Fighters. Orphan radioactive sources or Radiological Dispersal Devices are a critical security issue in large geographical areas, and they result in a safety concern for people who may become accidentally exposed to ionizing radiation. The abandonment of orphan sources can usually be related to three factors: human errors, cost reasons (in order to avoid the payment of disposal procedures), or malevolent purposes (like the production of dirty bombs). The present data concern the nuclear safety measures implemented during the recovery event and the pool of procedures carried out in order to reduce the risks for the involved harbor operators. Following data collection and analysis, an important lesson about the management of such events and scenarios can be learned.

## 1 Introduction

The risks related to the illegal transportation and introduction of radioactive and nuclear (RN) materials is still an unsolved problem despite all the technical and political actions taken after September 11, 2001 [20]. The illegal introduction of RN materials can also provoke serious economic consequences which may involve a large fraction of the national emergency system [34]. While several actions have been taken into consideration at a political, managerial and technological level [16, 17, 25], a comprehensive cooperation between the relevant authorities is still missing; moreover, the existing reluctance of the shippers and harbor operators to

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implement effective inspection regimens (which may delay the shipments) could cause a RN emergency situation [20].

Orphan sources have damaged the health of people when abandoned in scrap yards or in foundries [5, 27, 38], resulting in a strong impact on the environment and the economy of the involved countries. The motivations behind these actions can be unpremeditated (an accident or a human error), intentional (in order to avoid the payment of disposal costs and relying on the shielding capability of the metals surrounding the source) or malevolent (a clandestine importation of orphan sources to create dirty bombs). Since the detection through radiation portal monitoring systems can be very difficult, it is not uncommon to come across a scenario [12, 13, 32] like the one occurred in the Italian Harbor of Genova, where an orphan source of Cobalt-60 ($^{60}$Co) was found in a maritime cargo full of metal wastes. In order to reduce the risk connected to such events, it is of primary importance to improve the effectiveness of the emergency response system. The scientific community is already studying innovative measuring systems to prevent the illegal introduction through harbors of RN materials hidden inside cargo containers [10, 11].

Among all the possible parameters, the nuclear instrumentation used to perform the measurements of the radioactive levels is a key aspect to be considered; a review of the main nuclear instruments that can be used for radioactive detection and identification can be found at [18]. The review describes the detection technologies which are commonly used in several application fields, like in nondestructive or passive methods and medical imaging [1, 2, 8, 9], and in the detection and identification systems for emergencies [7, 15, 19, 35, 37] moreover, instruments have been classified based on the different kinds of detectable ionizing radiation of interest, like neutrons [6, 21, 22, 24, 31, 39], charged particles and X or gamma photons [4, 26, 33, 36].

In this paper, the authors analyzed the nuclear instrumentation used to identify and, subsequently recover, an orphan source of $^{60}$Co hidden inside a maritime cargo located in the port of Genova: all the procedures carried out to safely recover the involved radioactive source were studied and summarized in order to design operative guidelines which could constitute an important lesson about the management of these particular emergency scenarios.

## 2 Identification of a $^{60}$CO source inside a maritime cargo

The maritime cargo container considered in this work came from the Middle East, and it contained copper material destined to an Italian foundry. Once arrived in Genova Harbor, the cargo was checked by the Italian Fire Fighters in accordance with the standard procedures which are usually carried out during the management of all the cargo containing metals. In particular, the cargo was carefully monitored because a cargo full of explosive was previously sequestered in the harbor of Gioia Tauro; therefore, the risk of finding triggering devices in other cargos was considered relatively high. Once the Fire Fighters detected the high level of the emitted radiation, an alarm was sent; then, the cargo was placed in an isolated area of the Genova harbor in order to be carefully monitored and to carry out the source recovery procedures described in the current paper.

### 2.1 Nuclear Instruments description and configuration

The purpose of the operations carried out during the recovery scenario in Genova harbor was to confirm both the position and the activity of the $^{60}$Co source hidden inside the cargo container, and to verify the possible presence of other RN sources.

The instruments which were used during the detection procedures were all commercial instruments with an uncertainty in a range of 10–15%. A HDS-100 G/GN detector [28, 29] and two PDR77 detectors equipped with an IM263 radiometer and two GM (Geiger–Müller) DT616 probes [14]. The HDS-100G/GN detector is specifically designed to search for and identify RN materials during radiological threats scenarios (such as illicit trafficking and Radiological Dispersal Devices or RDDs); it features both a CsI(Tl) scintillator and a plain silicon diode as sensitive elements: the scintillator allows to perform spectrometry and low gamma dose rate measurement, while the diode is commonly used during high gamma dose rate measurements. Moreover, the HDS-100G/GN detector is equipped with a LiI (Eu) scintillator, which allows it to carry out neutron measurements if needed. The nominal energy range of the response is between 30 keV and 3 MeV for gamma-rays and X-rays, and between 0.025 eV and 15 MeV for neutrons; the dose rate measuring range is between 0.01 μSv/h and 100 μSv/h.

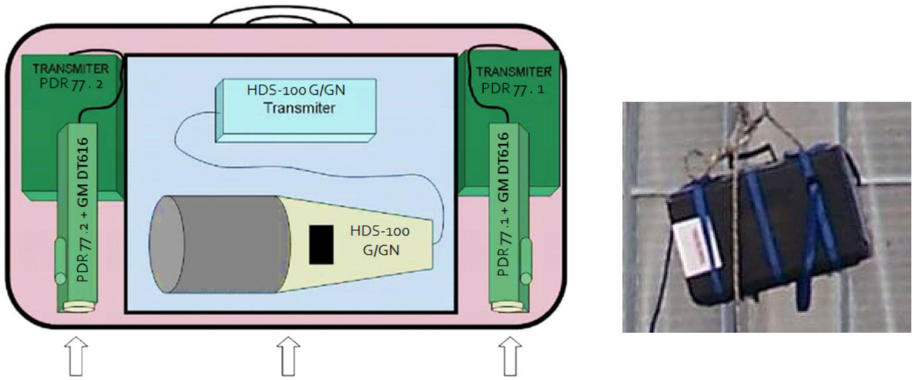
The PDR-77 detector does not have the ability to detect neutrons, but it is a more rugged detection system which hosts different probes for the measurement of alpha and beta particles, and of X-rays and gamma-rays. The alpha probe responds to alpha particles above 3 MeV, while the X-rays probe features channels for different energy ranges: The 17 keV channel has lower and upper thresholds of 12.5 keV and 21.5 keV, respectively; the 60 keV channel has limits between 50 and 70 keV; the "PEAK ALIGN" channel has, instead, thresholds of 70 keV and 95 keV.

During the intervention in Genova harbor, two beta/gamma probes of the PDR77 detector have been used (DT616). Beta/gamma probes are energy compensated in order to provide a tissue equivalent dose–response, which starts to drop at energies below 100 keV. The probe can be operated in two different configurations based on the status of the window covering the detection area: when the window is opened, the detector includes the contribution of beta particles to the measured dose rate, otherwise, the contribution from beta particles is neglected. In 2010 (at the time of the intervention in the port of Genova), the HDS-100 G/GN was the only instrument of the Italian Fire Fighters able to transmit data through wi-fi communication; during such event, it had to exclude the presence of other radionuclides rather than detecting a $^{60}$Co source. Regarding the DT616 probes, they are very flexible instruments and allow to assess the dose value in a very short time frame; each probe features two GM tubes, one specific for the detection of low dose rates and one for the detection of higher dose rates [14]. In order to recognize in nearly real-time the highest value of the dose rate detected on the field, the IM263 radiometer was configured with a throughput rate of 1 SPs (samples per second) in order to give a near-instantaneous readout of the dose rate magnitude.

All instruments were calibrated in response to a $^{137}$Cs radioactive source. Before their use in Genova, a preliminary evaluation of the overestimation errors caused by exposure to high energy gamma-rays emitted from $^{60}$Co was also performed. The instruments were then mounted in a custom tool case and assembled with a data transmission system and a power supply (Fig. 1a). The white label on the tool case indicates the position of the PDR77 probe number 1.

During the calibration measurements, the readout difference between the two GM DT616 probes was used to estimate the required sideward movement of the tool case. Once the readout from the 2 GM DT616 probes was not significantly different, the tool case was moved vertically (Fig. 1b) to find the point of maximum irradiation. Figure 2 shows the position of the tool case on the crane.

Specific instrumentation from Mirion to Canberra was selected in order to allow the operators to control the devices and receive data by a safe distance.




**(a)** **(b)**

**Fig. 1** **a** Scheme of Custom tool case final configuration. **b** Picture of the tool case final


**Fig. 2** Tool case placed on the crane for the measurements

Besides the HDS-100 G/GN and PDR77 detectors, several FH40 Digital Survey Meters [40] (Thermofisher) were distributed to the operators working in the radioactive area in order to constantly monitor the dose level and to trigger an alarm in response to an exceeded dose threshold. The FH40 is a wide range digital Geiger counter suitable for nearly all measurement tasks arising in radiation protection: through the optional plug and play probes, it allows us to perform an alpha, beta, neutron and gamma measurements. The dose rate measuring range of the FH40 is between 10 nSv/h and 1 Sv/h within an energy range of 30 keV to 4.4 MeV, while the dose measuring range goes from 100 nSv to 10 Sv. The operators, located in the control room of the operational area, were able to monitor the measured values from all the instruments involved in the recovery procedures, and at the same time, they were able to communicate directly with the CBRNe first responders deployed on the field.

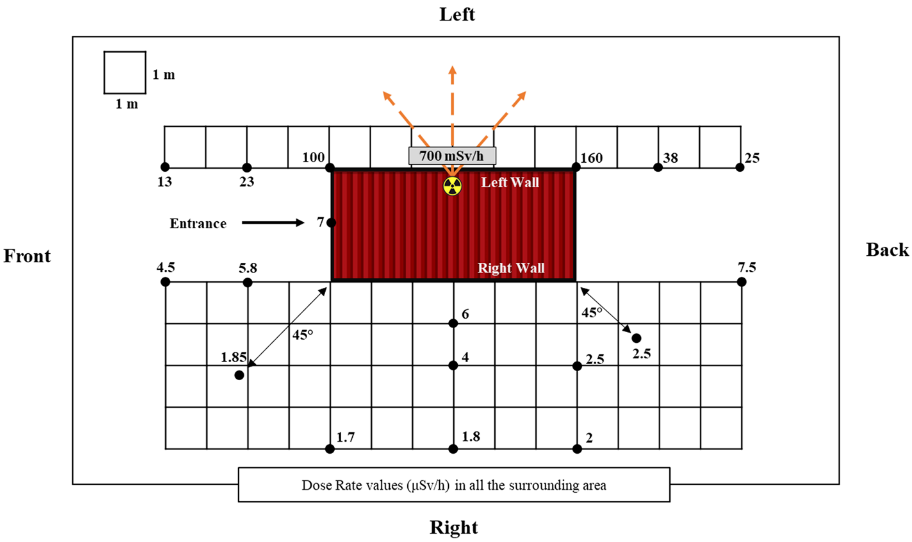



**Fig. 3** Dose rate values measured around the maritime cargo

Some of the operators were positioned on a fire ladder, and they were equipped with a Rados TLD dosimeter RDS-30 (Mirion), a Dose Rate Meter 6150AD—AD60 (Automess) [3] and a FH40 featuring a wireless data transmission system to check in real-time the dose rate. The RDS-30 Radiation Survey Meter is a gamma radiation detector that has been designed for applications involving abnormal radiation levels. The detectable radiations are gamma and X-rays from 48 keV to 1.3 MeV, and the dose rate measuring range goes from 0.01 μSv/h to 100 mSv/h. The AD60 consists of a GM counting tube to measure photon radiation (gamma and X-radiation), and it provides both analog (0.1 μSv/h—10 mSv/h) and digital (0.01 μSv/h—9.99 mSv/h) display modes. The RDS-30 was used to let the operators to directly visualize the cumulated dose and, thanks to its "Time to Dose" function, to estimate the time that could be spent in the area within certain exposition values before reaching the alarm dose threshold value. The AD60 was mounted on a telescopic stick and used to monitor the dose rate values during the phase of the maritime cargo approach.

## 2.2 Measurements

In order to recover the radioactive source hidden inside the cargo container, a campaign of measurement was specifically designed. First of all, measurements were taken at different spots in order to study the variation of the intensity exposition rate generated by the $^{60}$Co source. To perform such measurements, a FH40 detector, positioned at 120 cm from the ground level, was used. The second set of measurements was carried out using the AD60 mounted on the telescopic rod to place the probe in contact with the left wall of the maritime cargo. By moving along the walls of the cargo, the maximum dose rate value measured was 700 mSv/h at the center of the wall, at 60 cm from the ground (Fig. 3). This value decreased by ten orders of magnitude by moving the probe 2 meters away from the wall itself.

Since the fluence rate was non-homogeneously attenuated by the material inside the cargo (and by the cargo itself, the values of the dose rate measured on the three sides of the maritime cargo were affected as well. Variations related to the distance from the cargo and the ground

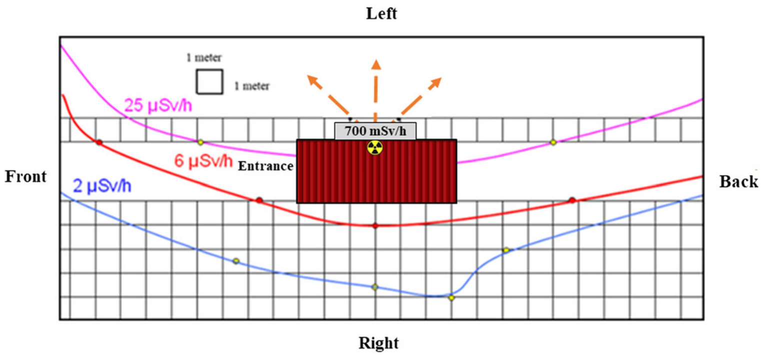



**Fig. 4** Iso-dose rate graphs

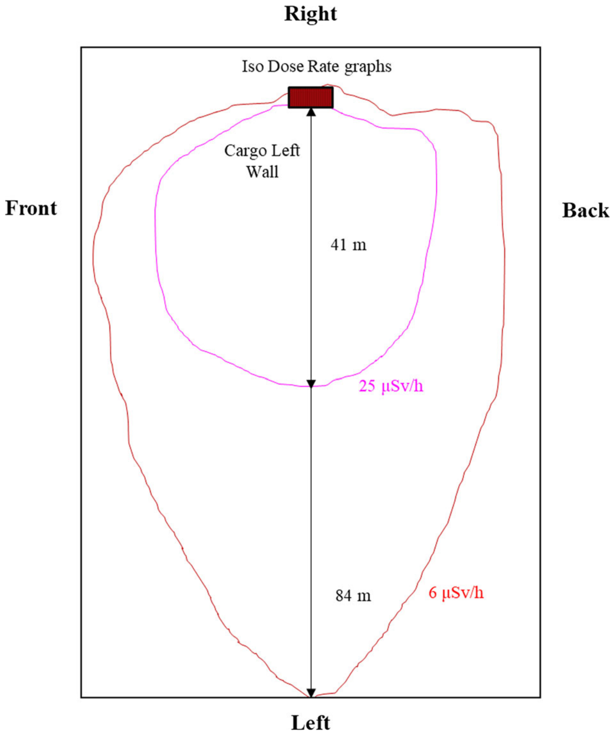



**Fig. 5** Iso-dose rate graph on the cargo side of the left wall

level were also found. Nevertheless, iso-dose rate graphs of 2, 6 and 25 µSv/h were drawn to identify and design an approach plan and operations aimed to manage the cargo and, at the same time, to reduce the risks for the operators involved in the procedures (Fig. 4). The measured values increased when the instruments were placed close to the left corners of the cargo; however, the situation was different when the dose rate measurement was carried out on the left side of the cargo container (Fig. 5 and Table 1), showing a dose rate of 6 µSv/h.

A spectrometric analysis was performed with an ORTEC Detective-EX®-100T [30], and it confirmed the presence of $^{60}Co$ (Fig. 6a–d). A EX®-100T detection system allowed also

**Table 1** Dose rate values measured at different distances

| Distance from the left wall of the cargo (m) | Measured values (μSv/h) |
|---|---|
| 70 | 8.7 |
| 60 | 11.9 |
| 50 | 17.1 |
| 40 | 26.7 |
| 30 | 47.5 |
| 20 | 107 |
| 15 | 190 |
| 10 | 428 |
| 8 | 668 |
| 6 | 1188 |
| 5 | 1711 |
| 4 | 2674 |
| 3 | 4755 |
| 2 | 10,698 |
| 1 | 42,794 |

to perform high-resolution gamma spectroscopy with confirmatory neutron detection. Such operation was executed on three sidewalls of the maritime cargo, which had a higher level of shielding (front, back, and right sides), in order to avoid saturation of the instruments. The purpose of these measurements was to exclude the presence of other radionuclides rather than $^{60}$Co.

## 3 The network of nuclear instrumentation for constant monitoring during the recovery of a $^{60}$CO source inside a maritime cargo: design and fundamental measurements

The maritime cargo was placed inside a "C shaped" structure created with 9 shielding cargos (Fig. 7a). The "C shaped" construction was necessary to guarantee an additional shielding layer for radio-protection purposes. Since a large fraction of the radiation was attenuated by the copper in the cargo, it was not possible to completely characterize the source; therefore, an extra safety layer was required. During the construction of the "C shaped" structure, the operators were protected by water-filled cargos used to shield the contaminated cargo. The first two cargo levels formed a unique welded structure fixed with concrete material, which guaranteed a shielding height of up to 5 meters from ground level. The third level of cargos was, instead, placed on the previous block: a housing of 10 cm height was created in order to insert the probes of the instruments inside of it (Fig. 7b). The instruments had to work correctly inside the "C shaped" structure, and they had to check constantly if the dose rate exceeded 700 mSv/h. Therefore, it was of primary importance that the instrumentation used did not reach signal saturation; in order for the instruments to not become blind, only gamma measurements were performed during the recovery operation.

The measurements near the "C shaped" structure were performed using 3 PDR77 detectors equipped with IM263 radiometers and GM DT616 probes, as shown in Fig. 7c. In order to limit the attenuation of the transmitted data caused by the concrete and to directly operate the IM263 radiometers (for the operations of re-set, change of battery or eventual substitutions) with no

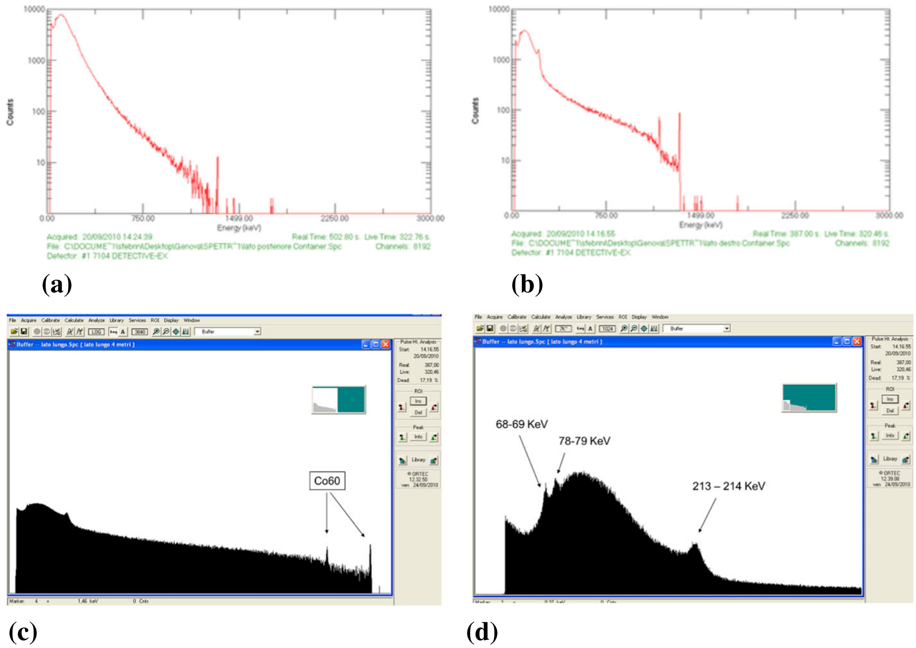



**Fig. 6** **a** Back part of the maritime cargo. **b** Right wall of the maritime cargo. **c** The left wall of the maritime cargo. **d** The left wall of the maritime cargo (Spectra detail)

risk to the operators, a scaffolding was placed between the 2nd and 3rd level of the shielding cargos. The area outside of the "C shaped" structure was also monitored with dedicated instrumentation to check the value of background radiation (which was expected to be higher than the natural level during the recovery operation). The instrumentation used consisted in GF145 probes with RA141C radiometers (featuring an upper limit in the measurable dose rate of 10 mSv/h), which were placed on the edges of the "C shaped" structure (Fig. 7d); such instruments were only interrogated in case of need during the operations. In order to exclude other risks, a small hole was created in the contaminated maritime cargo, in order to insert a video-camera to transmit real-time images. In fact, it was necessary to verify that no potential triggering devices, which could provoke a potential explosion during the operation ("Dirty Bomb" scenario[1]), were hidden inside the cargo. The hole was used also to collect a sample of air inside the cargo to verify the possible contamination of the material kept inside the container and caused by the radionuclide present.

The dose-rate was measured before starting the recovery operation (Fig. 8a), then the material was removed from the contaminated cargo using an unmanned vehicle with a large nipper to open the roof wall and collect the contents (Fig. 8b). During the recovery, the nipper extracted all the copper skins; then, the material extracted was checked with a PDR77 detector equipped with an IM263 radiometer and a GM DT616 probe to find the source; during the operation, the radioactive contamination was also monitored by means of a FH40 radiometer equipped with a Thermo probe Fhz732 (Fig. 8c). During the recovery operation, measurements were performed with a TRP2 robot from Otomelara S.p.A. and dose rate values over 150 μGy/h were measured in the copper skin containing the $^{60}$Co source; the

[1] This action was planned and realized with the help of the Bomb Squad of the Italian Police State.

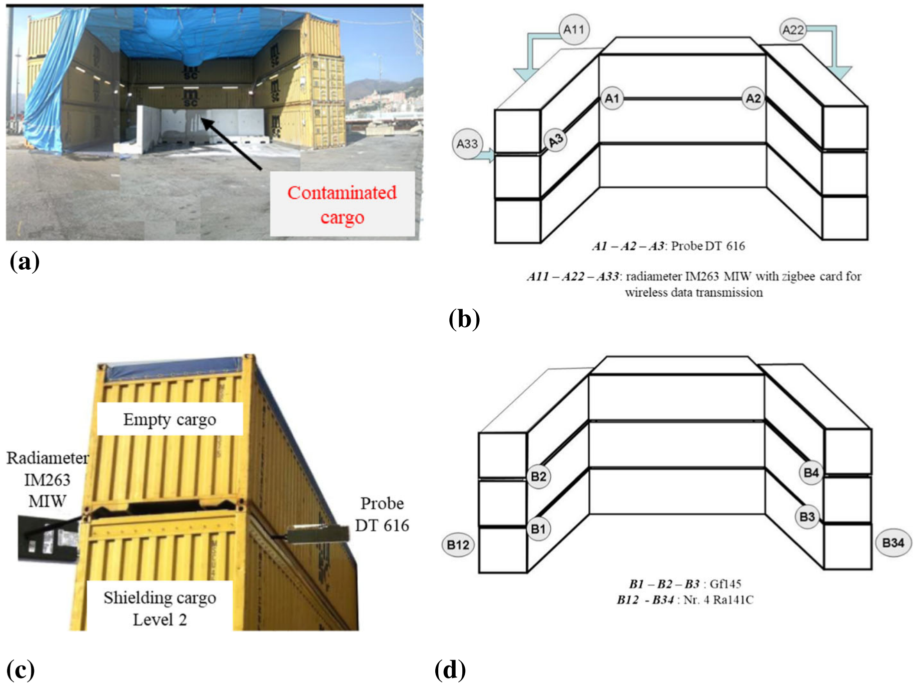



**Fig. 7** **a** Position of contaminated cargo. **b** Position of instruments for the "C shape" control area. **c** Position of the probe inside the "C shape" area. **d** Position of the instruments for the control out of "C shape" area

high dose rate values recorded triggered an immediate alert in the control room. However, the operations were safely conducted, and the recovery of the source was completed by sealing it inside a lead container and transported away. The measured dose-rate decreased to a safe level after the sealing. (Figure 8d).

## 4 Conclusion

The recovery of a $^{60}$Co source from the harbor of Genova (Italy) was one of the most important radioactive emergencies handled by the Italian Fire Fighters during recent years. Such a scenario constitutes a fundamental case study to learn about the main operations which must be carried out in order to safely measure, identify and rescue an orphan source in an unconventional situation. The operation was divided into three critical phases. During phase 1, the maritime cargo and the surrounding area were monitored to evaluate the risks related to the recovery operation and to design a functional shielding to surround the contaminated cargo. During this phase, the calibration, use, and analysis of the measurements coming from the instrumentation have been fundamental to generate a background radiation map and understand the nature of the radioactive source. During phase 2, a shield with a "C shaped" geometry was built starting from 9 cargo containers to protect the operators during the recovery of the material in the cargo and set a network of instruments to control the level of radiation once the cargo was open. Finally, in phase 3, the source was identified and sealed safely in a lead container. The complexities of this operation have been several,

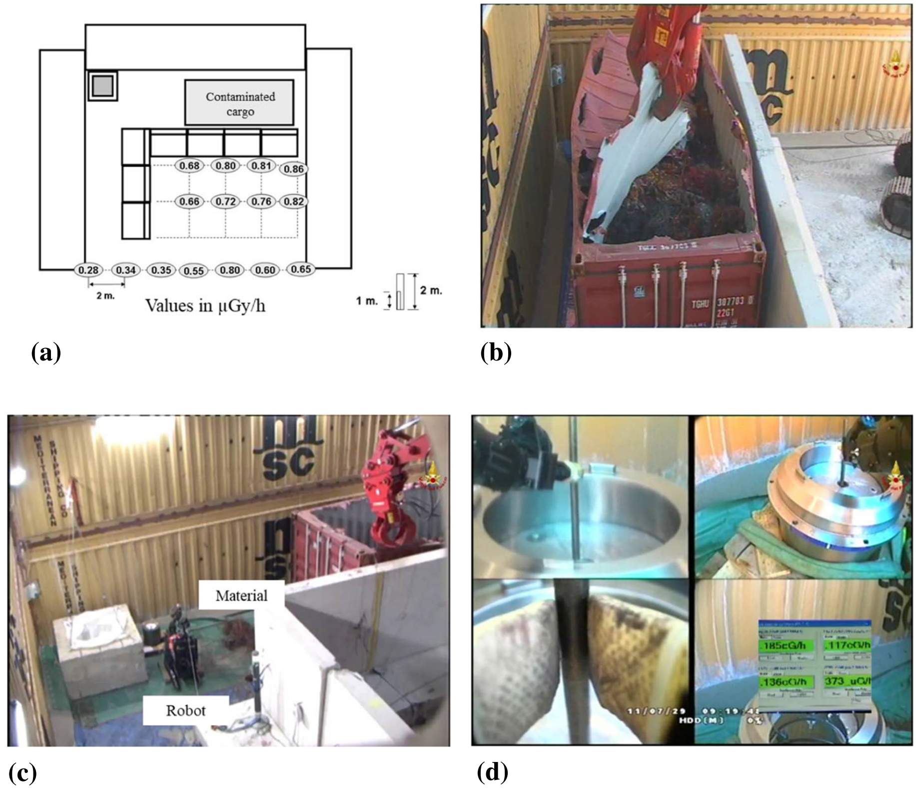



**Fig. 8** **a** Measures before the recovery operations. **b** Nipper to open the cargo roof and remove the material. **c** Robot during the operations on the cargo material. **d** Recovery and sealing of the $^{60}$Co source and sealing in a lead container

and they can mainly be summarized in the following way: handling the source in a confined environment with difficult access using unmanned vehicles; monitoring the level of radiation in the different phases using instrumentation and completing the intervention; minimizing the dose delivered to the operators. The operators that have worked close to the contaminated maritime cargo were Fire Fighters, professionally exposed to class A from the Italian Atomic Lab of the Italian Fire Brigades Emergency Direction. All goals were successfully achieved and the intervention was safely completed. Moreover, given the reference limits for exposed workers and the limits for general population [23], the firefighters and the staff present during the operations did not absorb a dangerous level radioactive dose.

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