Multi-phased Approach for Detection Systems and Measures for Nuclear and other Radioactive Material out of Regulatory Control

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Abstract. The U.S. Department of Energy/National Nuclear Security Administration (DOE/NNSA) works to reduce global nuclear dangers by engaging countries and advancing capabilities to prevent, counter, and respond to nuclear and radiological proliferation and terrorism threats and incidents worldwide. DOE/NNSA trains and equips countries around the world to deter, detect, interdict, characterize, adjudicate, and recover illicit radiation sources.

The acquisition of nuclear or radiological material by a terrorist organization would be catastrophic. It is imperative that this material does not secretly enter and exit ports on its way to the wrong hands. DOE/NNSA provides equipment and training to countries around the world to help countries build capacity to determine which of this material has a legitimate purpose for being there, which doesn't, and why.

Key Words: Radiological Proliferation, Out of Regulatory Control, Interdict, Adjudicate

1. Introduction

Radioactive material out of regulatory control is routinely detected at shipping ports and international borders in cargo containers in the form of orphan sources and contaminated materials. In cooperation with partner nations, DOE/NNSA has installed radiation portal monitors at shipping ports and international borders around the world to monitor cargo containers for illicit radioactive materials. Due to these detection systems and effective assessment tools, these containers are interdicted, and the radioactive materials are recovered and secured [1,2].

Most alarms from cargo containers can be attributed to Naturally Occurring Radioactive Material (NORM). In these cases, the cargo containers are checked and released. However, some alarms from cargo containers prove more difficult to investigate, resulting in containers being detained indefinitely. DOE/NNSA provides advanced training for customs, port security, and radiation experts to characterize the cargo container's radiation signature, provide a health and safety risk assessment, establish a recovery plan, and recover the radiation source.

2. Deterrence, Detection, and Interdiction

DOE/NNSA assists partner nations in establishing detection systems and measures to monitor cargo containers at shipping ports and international borders for illicit radioactive material. As a result, radioactive material out of regulatory control is being detected and interdicted, and in many cases, the presence of detection systems may have even deter illicit trafficking. As more cargo containers are interdicted using Radiation Portal Monitors (RPM), many are determined to contain NORM, but cargo with orphan radiation sources and contaminated materials also have been interdicted.

2.1 Interdiction at Shipping Ports and International Borders

The primary tool for detecting radiation sources out of regulator control being transported through shipping ports and international borders is the Radiation Portal Monitor. An RPM is a high sensitivity gamma and neutron detection system which is positioned on both sides of the entry/exits lanes. A vehicle entering an RPM will be subject to a passive scan for radiation emissions as it passes the detectors. The primary concern at shipping ports is illicit materials in cargo containers. At international land borders, all vehicles are of concern. If radiation emissions are detected, an alarm will sound in the Central Alarm Station (CAS). The alarm trigger results in the acquisition of digital photographs of the vehicle and container number as well as initiates the investigation and adjudication process.

A vehicle which triggers an alarm will initially be directed through a second RBM for confirmation. Once confirmed, the vehicle will be sent to a secondary inspection area for further investigation.

FIG 1. Radiation portal monitor system to scan cargo containers at a shipping port.

2.2 Secondary Inspection for Investigation and Adjudication

Customs, border, and port security officials employ establish procedures and best practices to investigate and adjudicate radiation alarms in the secondary inspection phase. The secondary inspection area is typically a secure located near the CAS where more detailed radiation measurements with handheld radiation detection equipment can be conducted. Often these areas have raised walkways to facilitate the process as shown in Figure 2. The manifest is reviewed to determine the container contents and whether it contains radioactive materials or NORM. The primary trigger of radiation alarms at an RPM is NORM. NORM includes materials such as clay tiles and bricks, kitty litter, cement, porcelain and granite which contain slightly elevated concentrations of naturally occurring potassium, uranium, thorium, and their associated decay products. Although these materials may contain only minute quantities of naturally occurring radioisotopes, when transported in bulk quantities, they are readily detectable by an RPM.

Commercial products that contain radioisotopes are also routinely transported through shipping ports and international borders. Often, these cargo containers are not required to be placarded as a radioactive shipment. Examples include smoke detectors and lantern mantles which contain radioactive americium-241 (Am-241) and thorium-232 (Th-232), respectively.

FIG 2. Secondary inspection area for cargo containers with raised walkway.

In the secondary inspection process, a detailed scan of the vehicle or cargo container is conducted using handheld radiation survey meters. The RPM scan data will show the approximate location of the radiation hotspot. Once the radiation hotspot is located and pinpointed, its position is marked. Often, the radiation source can be detected on multiple sides of the vehicle or cargo container. During the scanning process, the dose rate is continuously monitored for safety. Once the hotspot has been identified, the next step is to identify the radioisotope. Radioisotope identification is typically conducted with either a Radioisotope Identifier (RIID) or a High Purity Germanium (HPGe) detection system. Both instruments contain a gamma spectrometer to measure the energy spectrum of the radiation. A RIID contains a low resolution detector and a HPGe contains a high resolution detector. If the HPGe is available, it is the preferred instrument to acquire the highest quality data. Most

CAS stations are equipment with one or both systems. The spectrometer is placed next to the hotspot and a gamma spectrum acquired. Each instrument provides a preliminary identification of the radioisotope. By knowing the radioisotope and reviewing the manifest, an assessment can be made whether to release the container or detain it for further investigation.

2.3 Competent Authority and International Assistance

In cases where the alarm cannot be readily adjudicated or there are health and safety concerns, competent authority experts can assist port and border authorities with the technical assessment and adjudication process. Competent authorities may also request international assistance through the International Atomic Energy Agency (IAEA) or the DOE/NNSA to include technical consultation, specialized training, assistance with spectral data analysis, and source recovery.

3. Assessment and Adjudication

DOE/NNSA provides advanced training to customs and port security officials, as well as radiation experts, on assessment, adjudication, and recovery of radiation sources. The training focuses on characterizing the radiation signature of the vehicle or cargo container, assessing the health and safety risks, mission planning, and source recovery operations. A variety of handheld detection systems are provided to determine the location of gamma and neutron sources, identify radioactive material using gamma spectroscopy, measure dose rates, and survey for contamination. The technical data is used develop a source recovery plan and mitigate safety risks to responder personnel through administrative and engineering controls.

The source recovery plan contains the concept of operations which is a step by step approach to the source recovery operations. Included in the plan are the administrative and engineering controls to mitigate safety risks due to exposure and contamination. Non-radiological hazards are also assessed and mitigated. When the source is located and secured, additional measurements are conducted to characterize the radiation source, survey for contamination, and packaged for storage.

3.1 Radiation Signatures of Cargo

A vehicle or cargo container containing radioactive materials has a characteristic radiation signature which is dependent on its physical size and shape. A point source will appear as a localized hotspot and may be detectable on multiple sides of the container. For example, if it is near the rear of the container, it could be detected not only at the rear of the container but also both sides. This signature is characteristic of a legitimate radiation source, but also that of a radiation source out of regulatory control. The left image in Figure 3 shows an example of a radiation signature from a point source.

If the radioactive material is distributed in commercial products such as metal, wood, etc., the radiation signature could have a three dimensional shape extending over a section of the vehicle or cargo container. This radiation signature might appear to be originating from a particular area of the cargo with a nearly uniform count or dose rate. The center image in Figure 3 shows an example of a distributed radiation signature from an extended source. This type of signature has been observed from metal products containing low levels of cobalt-60 (Co-60). The Co-60 was accidently introduced in the smelting process of recycled scrap metal which was then made into commercial hardware. Wood products from the Chornobyl region have also been shown to contain low levels of cesium-137 from the reactor accident.

A cargo container which contains NORM can have a radiation signature which is uniformly distributed across the entire container. Examples would include clay tiles, porcelain, kitty litter, granite, cement, etc. as well as ores containing uranium and thorium. The right image in Figure 3 shows an example of a radiation signature from a uniformly distributed source. For lighter weight materials, such as kitty litter, the container may have a uniform count or dose rate extending from the bottom to the top. For heavier weight materials, such as clay tiles, granite and ores, the uniformly distributed count or dose rate may only extend up to half height due to container weight limit restrictions.

FIG 3. Radiation signatures of point (left), distributed (center) and uniformly distributed (right) sources in cargo containers.

3.2 Characterization Process for Radiation Signatures

The characterization of the radiation signature of a vehicle or cargo container can be conducted in less than 20 minutes using a handheld survey meter. The characterization survey requires acquiring readings at low (0.3 meters from container bottom), middle (1 meter from container bottom), and high (2 meters from container bottom) positions around the container. For a 20 foot container, five columns on the sides about one meter apart starting at a corner and three columns on the ends about one meter apart starting at a corner will provide high density measurement coverage of the entire container. The survey data can be recorded on a characterization map, of which an example is shown in Figure 4. The dose rates in Figure 4 are given in μSv/h. By reviewing the characterization map in Figure 4, the data shows elevated readings along the rear of the container and extending a quarter of the length on the sides. This radiation signature would indicate a distributed source in the middle to upper section of the rear quarter of the container.

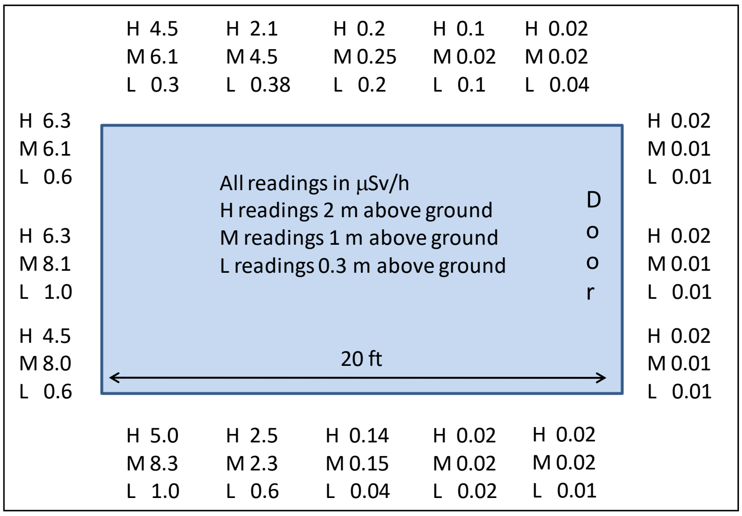

FIG 4. Radiation characterization map of a cargo container with a distributed source.

3.3 Point Source Localization

If the radiation signature is consistent with a point source, one can use the $1/r^2$ method to determine the approximate position inside the container. The simple approach is the measure the count or dose rate at the surface of the container and then move away perpendicular until the count or dose rate is ¼. The distance between the two measurements is the distance the source is located inside the container. An example of position estimates for a radiation point source derived from a series of measurements at the rear and sides of a cargo container is shown in Figure 5.

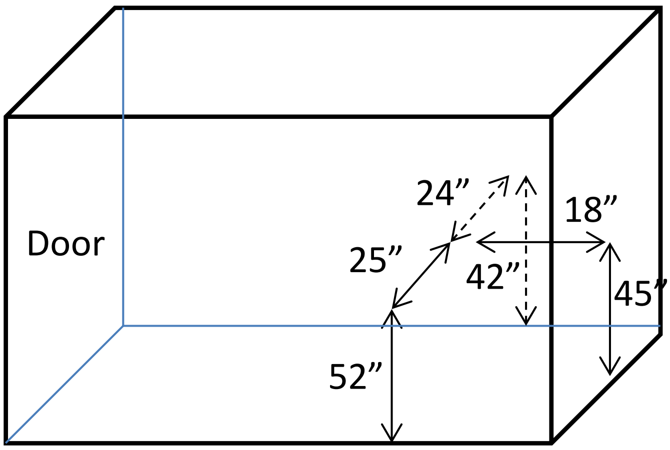

FIG 5. Position estimates for a radiation point source derived from measurements at the rear and sides of a container.

3.4 Radioactive Material Identification

Radioactive material identification is a critical part of the radiation signature characterization process for determining if a radiation source in a vehicle or cargo container is out of regulatory control, illegal, or a potential threat. Most CAS stations are equipment with HPGe systems to conduct high resolution gamma spectroscopy. A five minute (minimum data acquisition time) gamma spectrum at the hotspot can provide competent authority experts the data required for analysis, identification, and assessment. The spectral data can be used to identify the radioisotopes, estimate source shielding, and quantify the source activity. The information obtained from the spectral data will aid experts in the overall assessment of the radiation source and safety planning in the event of a source recovery operation. An example of a high resolution HPGe gamma spectrum from a Radium-226 (Ra-226) source is shown in Figure 6.

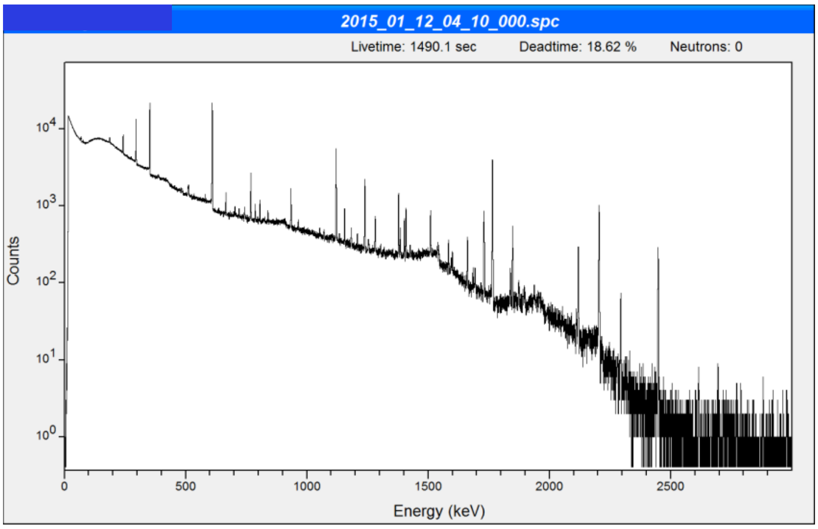

FIG 6. Example of a high resolution HPGe gamma spectrum from a Radium-226 source.

4. Source Recovery Operations

If the alarm cannot be adjudicated using the practices described in the previous sections, it may be necessary to recover the radiation source. Source recovery is a deliberate process based on a concept of operations plan with reassessment points. With the information provided by the characterization assessment, the concept of operations plan will address the controls required to mitigate potential risks and ensure the health and safety of the recovery team.

4.1 Source Recovery Operations Area

The source recovery operations area must ensure for administrative and engineering controls to limit exposure and contamination. The area selected should be secure with limited access by workers and the public. The typical source recovery operation will require the removal of non-source related material from the container until the radiation source is located. As such, a second empty container is typically used for removed material.

The schematic diagram in Figure 7 shows a typical source recovery operations area. A hotline is established to control and monitor personnel and equipment for entry and exit. A counting station is located nearby for the survey swipes obtained as the team progresses into the container. Material removed should be swiped as well as the cargo container floor as it is cleared.

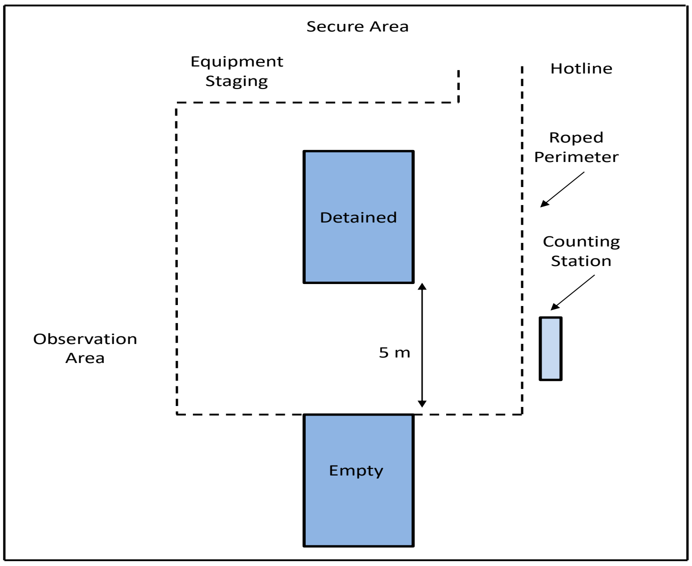

FIG 7. Secure area for source recovery operations with staging, hotline, and counting station.

4.2 Risk Assessment and Safety Planning

Two major concerns in any source recovery operation are exposure and contamination. To mitigate the exposure to the recovery team, administrative and engineering controls should be implemented. The controls will be outlined in the concept of operations plan to include the dose rate turnback limits, training requirements, dosimetry, survey meters, manipulating tools, shielding, and packaging.

Contamination is a concern as it will determine the personal protective equipment (PPE) requirements for the recovery team. Initial contamination surveys can be conducted on the outside of the cargo container. The most likely place for contamination to leak from the container is the door seams. Figure 8 shows a swipe pattern for a contamination survey of a cargo container door seams.

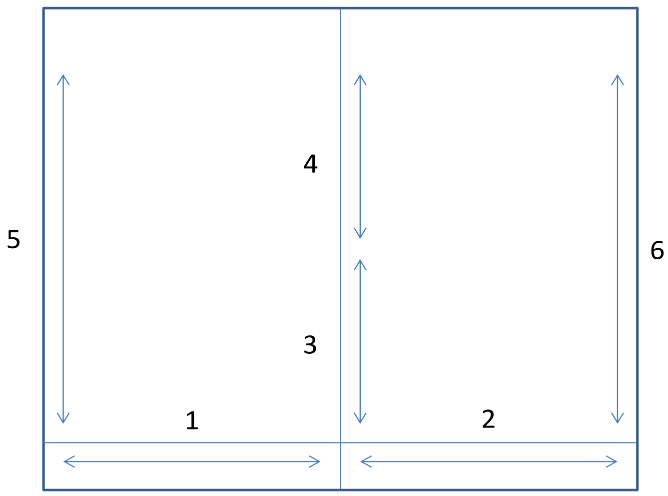

FIG 8. Swipe pattern for a contamination survey of a cargo container door seams.

If no contamination is detected and exposure risks are mitigated, the container can be opened to initiate the recovery operation. Upon opening the doors, the dose rate and contamination surveys will continue to be conducted as contents are removed to locate the source. If contamination is detected or the dose rate turnback limits reached, the recovery operations will be temporarily halted while the concept of operations is reassessed. Once the source is located and sequestered, additional dose rate and contamination surveys can be conducted, spectral data acquired, visual inspections conducted for markings and identification numbers, and photographs will complete the documentation process prior to packaging for storage.

5. Conclusion

Comprehensive detection systems and measures at shipping ports and international borders, in conjunction with effective interdiction, investigation, adjudication and recovery processes for nuclear and other radioactive material out of regulatory control in cargo enhances nuclear security worldwide. Best practice approaches can enhance the success of the adjudication and source recovery operations. DOE/NNSA offers training, detection equipment, and technical assistance to partner nations to deter, detect, interdict, characterize, adjudicate, and recover illicit radiation sources.

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