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Live Identification: An Emerging Detection and Identification Technology for Radiation Detection in Complex Environments

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ABSTRACT

New initiatives underway within the Office of Nuclear Smuggling Detection and Deterrence (NSDD) focus on equipping partner countries with detection systems that support law enforcement missions. These initiatives happen in environments with complex, and often time-sensitive, pedestrian traffic flows. The high probability of encountering medical isotopes in these environments, and the difficulty in detecting, localizing, and identifying radiation sources, make dual detection and identification systems attractive options for pedestrian scanning missions. This work summarizes the radiation detection performance findings from an emerging class of radiation detection technology: systems that offer Live Identification, commonly referred to as Live-ID. Live-ID is the ability to simultaneously detect and identify radioactive material in a manner that combines primary screening and secondary adjudication. Radiation detectors with effective Live-ID methods reduce the burden on law enforcement by adjudicating nuisance alarms in complex pedestrian environments such as airports, stadiums, and large public gatherings. This work will detail the different categories of Live-ID technology and showcase the performance findings from a rigorous evaluation against special nuclear material and medical isotopes. We also present the unique missions and concepts of operations (CONOPs) that can emerge through Live-ID, and the operational considerations on systems with this capability.

INTRODUCTION

The prompt and accurate resolution of radiation detection events, by using instruments that can identify radiation sources, is critical across many types of missions. Many new detection and identification systems are also advertised as providing real-time ID functions, particularly against medical isotopes. This NSDD-led effort evaluated performance, operability, and how live identification (Live-ID) fits into nonproliferation missions.

The Science and Engineering Team (SET) at Pacific Northwest National Laboratory (PNNL) evaluated radiation detection systems with live identification capabilities between May and July of 2020. Equipment was selected from a market survey of Live-ID-capable radiation detectors, down-selecting to systems that showed the most promise to successfully provide simultaneous alarms and identifications of radioactive material. Additionally, some detection systems without

Live-ID were assessed to provide information on the response of “baseline” equipment in comparison to those with live identification. This work summarizes a subset of the findings from the NSDD study on live identification.

METHODS

The evaluated instruments included only those that were considered to be “human portable”. These classes included:

- Wearable systems such as personal radiation detectors (PRDs) and backpack radiation detectors (BRD).
- Handheld radioisotope identification devices (RIDs) used traditionally for secondary inspection.
- Person-portable monitoring systems such as area spectrometers (AS).

Evaluation took place on 11 systems under test (SUTs). Details on the instruments that were assessed are provided in Table 1.

Table 1. The SUTs tested during this campaign and their detection characteristics

System under test[1]	Live identification mode	Sensor
AS 1	Transient	Four 6.3 cm Ø x 16 cm NaI(Tl)
AS 2	Functional	5.1 cm x 10.2 xm x 40.6 cm NaI(Tl)
AS 3	Functional	7.6 cm Ø x 7.6 cm NaI(Tl)
AS 4	Functional	5.1 cm x 10.2 cm x 40.6 cm NaI(Tl)
BRD 1	Transient	5.1 cm Ø x 10.2 cm NaI(Tl)
BRD 2	Functional	7.6 cm Ø x 7.6 cm NaI(Tl)
BRD 3	Functional	7.6 cm Ø x 7.6 cm NaI(Tl)
BRD 4	Retrospective	6.3 cm Ø x 6.3 cm NaI(Tl)
RID 1	Transient	19 cm^3 CdZnTe
SPRD 1	Functional	5.1 cm x 2.5 cm x 1.3 cm CsI(Tl)
SPRD 2	Retrospective	1.0 cm x 1.0 cm x 4.0 cm Cs_2LiYCl_6(Ce)

The characterization of Live-ID-capable systems had the following objectives:

1. Characterize the primary detection performance of systems under test (SUTs) for both special nuclear material (SNM) and medical isotope signals.
2. Characterize the Live-ID performance of the different radiation detectors.
3. Evaluate the effectiveness of the instruments at promptly alerting and localizing radiation sources.

[1] Names of instruments are not provided to preserve instrument and vendor anonymity.

These objectives were addressed through instrument assessments in multiple testing scenarios, described in Table 2. These evaluations assessed instrument performance in both primary scanning and secondary inspection missions. “Primary” refers to the detection mission of an instrument, where radiation sources cause the system to produce an alarm or indication when the radiation field is above the average background. “Secondary” refers to the traditional identification mission for a radiation detector, where a spectroscopic system performs a measurement of the person or conveyance that caused a primary alarm, which is then analyzed by an on-board algorithm and an identification result is displayed to the operator. Comparatively, Live-ID provides both an alarm and isotope identification simultaneously for a detection event.

Table 2. Summary of test scenarios carried out in the Live-ID evaluation

Scenario	Summary
Modeling Measurements	Collect high-statistic characterization measurements to support future modeling and simulation activities.
Ambient Background Characterization	Determine the false alarm and identification rate when detectors are operated in an ambient background environment.
Nuisance Alarm Characteristics	Characterize P_D/P_{ID} and P_{FA}/P_{FID} in the presence of NORM and high activity medical isotopes.
Primary Detection Settings	Develop ROC curve to inform instrument settings in primary detection missions.
Source Localization	Compare the effectiveness of each instrument in localization (survey) missions.
Static Performance	Compare the performance of each instrument in the secondary inspection (identification) mission.
Dynamic Performance	Compare the performance of each instrument in the primary inspection mission.

RESULTS

Live Identification Capabilities

Live ID is the capability for a detection system to simultaneously alert an operator to the presence of a radiation source, and identify the isotope generating the detection event. Live-ID is a nuanced feature and is implemented in many ways. There were found to be roughly three categories in which Live-ID capabilities are implemented in detection systems.

1. **Functional Live Identification**: radiation detection events and isotope identifications are instantly displayed to an operator, and persist after the detection event ends, in a manner that allows adjudication or reachback.
2. **Retrospective Live Identification**: an identification is provided after the conclusion of a detection event, usually a significant period after the initial alarm. These systems usually prompt an operator action to display the ID.
3. **Transient Live Identification**: a system will provide a brief isotope identification, but the information is not associated to detection events.

Figure 1 shows the three types of Live-ID from the perspective of a device screen during a detection event. As a target with a radiation source passes through the detection zone of an instrument, the response of the system differs depending on whether the live identification is functional, retrospective, or transient. Functional and retrospective live identification systems can enable a CONOPS where operators do not need to pay constant attention to the detection system. Conversely, transient Live-ID CONOPS would require an operator to be focused on the response of a detector during the mission to interdict the identified isotopes.

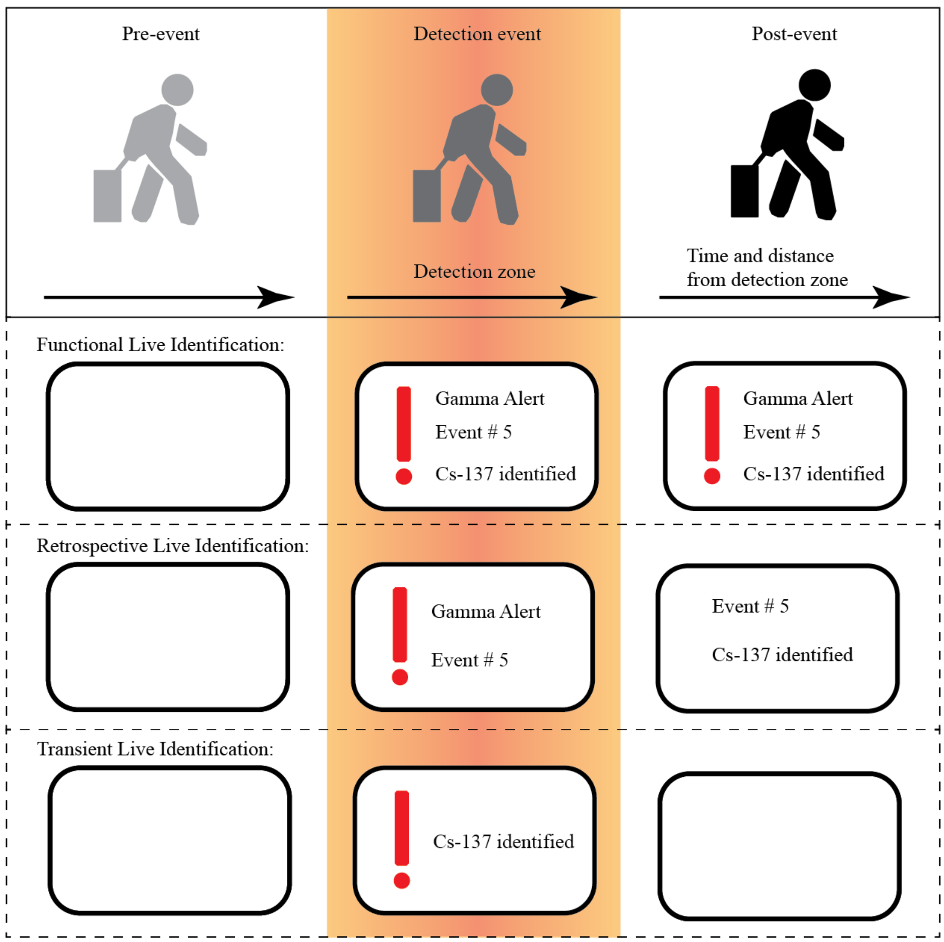

Figure 1: Illustration of the different types of Live-ID

Comparing Detection and Live Identification Fluence Rates

The detection and identification of SNM is the key function of a detection system in NSDD missions. In this evaluation, SUTs were assessed in scenarios representing how the detectors are used in primary scanning detection and secondary identification missions. In the primary scanning scenario, SUTs were positioned 50 cm from a linear motion system that conveyed SNM sources 30 times past the detectors at a speed of 1.2 m/s. Shielding was then added incrementally to determine the conditions where SUTs were no longer able to detect the SNM isotope. For SUTs with live identification capabilities, focus was placed on collecting and analyzing the identifications that were provided during primary scanning measurements.

A key focus in this study was assessing whether systems could successfully implement Live-ID at, or near, the same signature they could simply detect a radioactive source. Likewise, analysis focused on comparing how much mass of SNM could be detected versus identified in live time. The approach followed in this work analyzed the probability of detection and identification at multiple gamma fluence rates to generate sigmoidal curves illustrating the comparative performance of each SUT. For each detector and source, a highly enriched uranium (HEU), weapons grade plutonium (WGPu), or depleted uranium (DU) source was passed in front of the detectors for 30 trials under a shielding condition that provided a specific fluence rate. By assessing several test configurations along the lower edge of detection performance, the fluence rate where the lower confidence bound on probability of detection (P_D) at 80% was determined. This fluence rate for detection was then compared to the fluence rate where the lower bound on probability of identification (P_{ID}) was 80% for all SUTs.

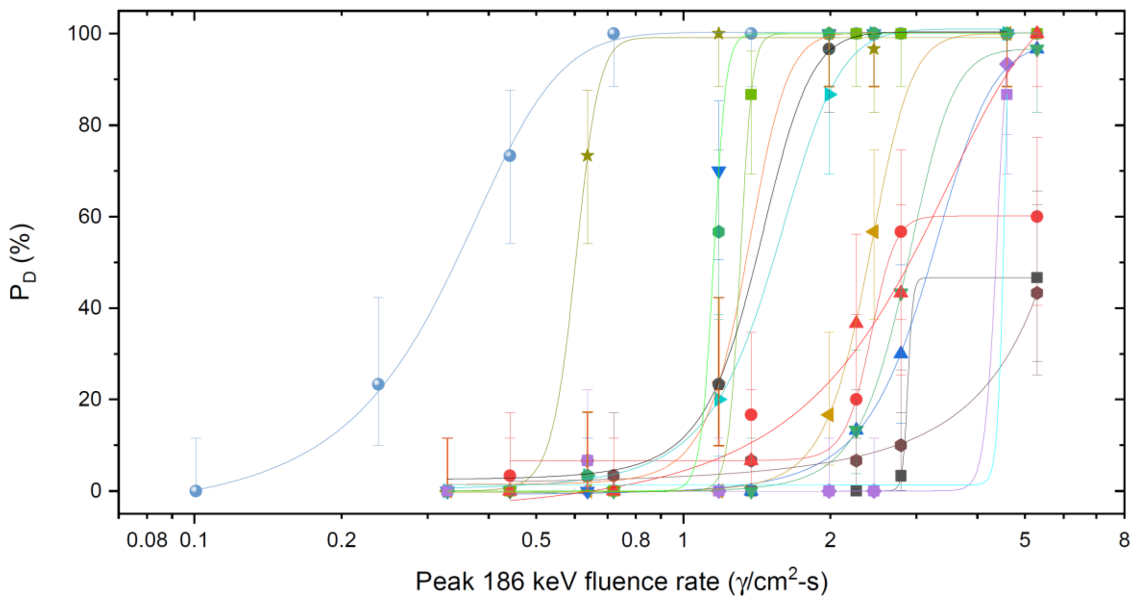

Figure 2: Example sigmoidal curves on the detection of HEU under different shielding conditions. Each curve represents the drop-off in detection performance for a (anonymized) radiation detector as shielding is added to the source, and the incident fluence rate is decreased.

The analysis of detection and identification as a function of fluence rate showed that 27% of the systems evaluated were able to detect and Live-ID at the same fluence rate. Another 27% of systems evaluated required a greater signature (fluence rates within an order of magnitude) to Live-ID a source compared to just alarming on detection. The remaining 46% of detection systems required a significantly greater signature (fluence rates greater than two orders of magnitude) to provide live identification results beyond just simply alarming on the source.

A key takeaway from this study is how varied Live-ID capabilities are, and how this feature is best capitalized on when systems are able to live identify at fluence rates close to the signatures that provide detection alarms. Where necessary, CONOPS can be tailored depending on how close Live-ID performance is to detection performance.

Medial Isotope False Positives

Medical isotopes are a potential source of nuisance alarms in pedestrian scanning missions. Three medical isotopes were characterized in this work:

1. ^{67}Ga - common in diagnostic procedures to screen for tumors. As shown in Figure 3, ^{67}Ga can be mistaken for HEU due to its similar emissions to ^{235}U. Peak finding algorithms can be particularly susceptible to misidentifying ^{67}Ga.
2. ^{131}I - common in the treatment of thyroid cancer. As shown in Figure 3, ^{131}I can be mistaken for WGPu due to its similar emissions to ^{239}Pu. Region-of-interest (ROI) or energy window-based algorithms can be susceptible to misidentifying ^{131}I, which also has similar gamma-ray emissions to the industrial isotope ^{133}Ba.
3. ^{99m}Tc - common in computed tomography diagnostic and imaging procedures. ^{99m}Tc represents > 80% of all nuclear medicine procedures and is among the most likely medical isotopes to be seen in the field.

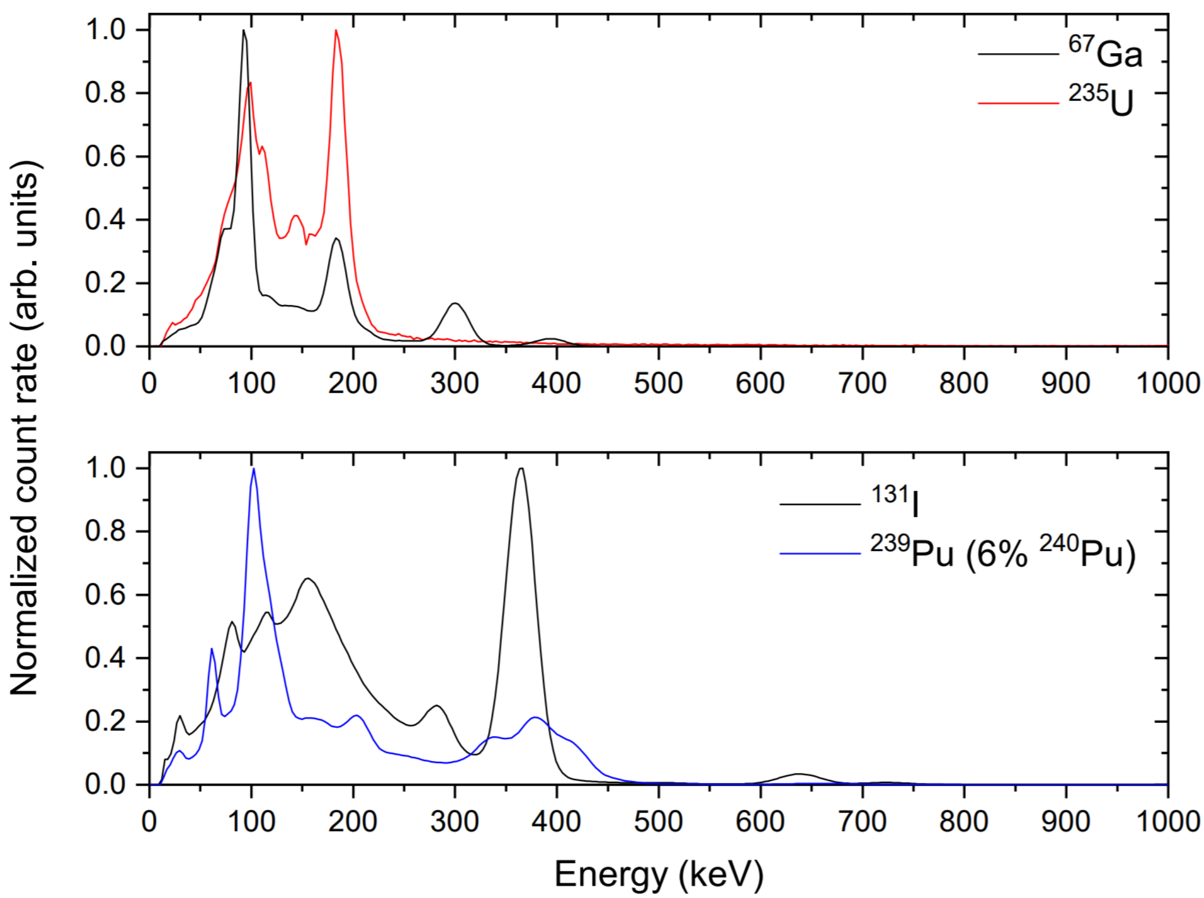

Figure 3: Medical isotopes with signatures similar to special nuclear material. The top spectrum overlays ^{235}U and ^{67}Ga measured from a NaI(Tl) detector, and the bottom compares ^{131}I and ^{239}Pu.

Medical isotopes were evaluated separately under “high dose” and “low dose” conditions. High doses, where source fluence rates were > 1000 γ/cm^2-s, were chosen to represent conditions where a freshly treated nuclear medicine patient would be encountered by the detectors. In these conditions, systems often presented “high dose” or personnel health warnings in addition to their isotope identifications. Low-dose conditions were chosen to represent conditions where a patient would have lingering radiation from a nuclear medicine procedure, in a fluence rate that falls along the lower edge of detection performance for a system. Similar to the analysis of SNM isotopes, the high or low dose medical isotope sources were conveyed past the detectors at a speed of 1.2 m/s, and at a standoff distance of 50 cm. To limit worker dose, high dose rate generating medical isotopes were assessed in 10 trials, while lower doses were assessed in several sets of 30 trials as the sources decayed past where SUTs were able to detect or live identify them. Table 3 provides a summary of the results from the high dose rate generating medical isotope trials.

Table 3: Category of isotope identification following 30 trials (10 per isotope) of high dose rate generating ^{67}Ga, ^{131}I, and ^{99m}Tc sources. Note that many systems produced combinations of different isotope categories (e.g. SNM + Medical).

	Primary Scanning Identification Tallies– out of 30 trials				
SUT	**SNM**	**Medical**	**Industrial**	**NORM**	**Unknown**
A	**0**	**28**	**0**	**20**	**0**
B	**4**	**17**	**6**	**1**	**0**
C	**1**	**25**	**8**	**0**	**0**
D	**10**	**29**	**0**	**8**	**0**
E	**0**	**23**	**16**	**0**	**4**
F	**3**	**17**	**10**	**0**	**30**
G	**19**	**30**	**24**	**0**	**0**
H	**29**	**30**	**29**	**0**	**0**
I	**5**	**30**	**1**	**0**	**4**
J	**2**	**8**	**0**	**0**	**0**
K	**10**	**20**	**6**	**0**	**0**

In conditions where either low or high dose rate generating medical isotopes were present, 81% of detectors produced some amount of SNM false positives. Only 18% of systems evaluated showed no false positive SNM Live-IDs in the presence of medical isotopes. Another 45% of systems showed tendency to produce SNM false positives only in the presence of high dose rate generating medical isotopes. A key finding from this work is that medical isotopes are an operational concern due to high rates of SNM false positives in Live-ID operation and secondary inspection missions. Manufacturers have the unenviable task of optimizing their algorithms such that nuisance alarms generated by medical isotopes are reduced while maintaining sensitivity to SNM detection.

Localization

Localization capability was evaluated to determine the temporal characteristics of how quickly systems alarm when a source passes by the detector. This was characterized by passing HEU sources in front of SUTs at a 50 cm distance of closest approach and timing when alarms occurred. Figure 4 shows the time-to-alarm for the different SUTs assessed in this work. SUTs are separated by color, and the intensity of the HEU source is distinguished by different shades. The width of each bar shows the variation in alarm-on position among multiple trials.

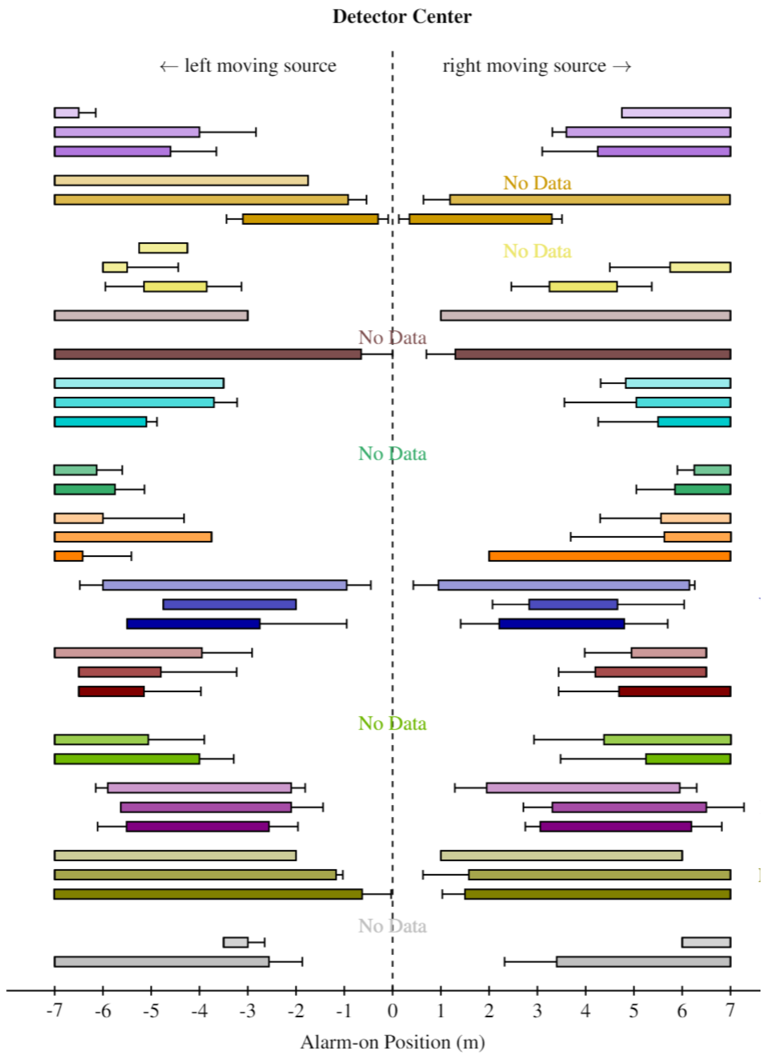

Figure 4. The distances between closest approach and when SUTs alarmed when HEU sources of varying intensity passed in front of the detectors.

Results from the localization study emphasized that a source can be significantly downstream from a detector by the time an alarm occurs. This latency between the radiation encountering the detector and the alarm occurred can challenge operators in situations with heavy and complex pedestrian traffic. Where traffic flows in a single direction, CONOPs should consider an interdiction zone 5 to 7 meters downstream from the detector when an alarm occurs. Likewise, when traffic is not restrained to one direction, an interdiction zone with a 5 to 7 meter radius from the center of the detector.

SUMMARY

The key findings from this work include the following:

1. Live-ID instruments are varied and add useful operational capabilities to the toolbox of a law enforcement agency's nonproliferation missions.
2. Several detection systems with "functional" Live-ID capabilities can be used to simultaneously detect and identify the NSDD pedestrian scanning target quantities of SNM, potentially enabling new missions or reducing the operational burden of radiation detection operations in complex pedestrian traffic environments.
3. Instruments with Live-ID were shown to have a high risk of producing false SNM identifications in the presence of medical isotopes common in pedestrian traffic environments. Further work with manufacturers to improve algorithms as well as careful design of the CONOPS for Live-ID systems, should be performed prior to large scale deployments of live identification systems.
4. Hysteresis was observed between the time the source passed by a detector and the time that the alarm notification was generated. CONOPS should consider positioning live identification detectors upstream from the responding operator position in order to allow effective interdiction of alarming traffic and/or consider pairing the system with ancillary equipment, such as a visual attribution system.

Ultimately, detection systems with Live-ID capabilities could add value to law enforcement missions that involve complex traffic flow and the time-sensitive adjudication of alarms.

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