The Radiation Field Training Simulator (RaFTS): Reducing Dose by Simulating Sources

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ABSTRACT

To prepare for real-world emergencies involving high-radiation-dose hazards or unknown radiation hazards, first responders need to practice in those environments. However, training with actual hazardous high-radiation sources involves tremendous logistical difficulties, expense[3], and unnecessary radiation exposure. In general, current approaches to training avoid high-radiation sources. Frequently, such training uses event controllers who tell participants what their instruments should be reading or utilize simulated instruments with preprogrammed readings, but this is underpreparing emergency responders for the complexities of such hazards because instruments behave differently in such high-hazard environments. People in charge of the training recognize the inadequacies of these approaches and wish for something better. The Radiation Field Training Simulator is the solution they have wished for.[4]

Current training simulators are limited in a variety of ways. They do not adequately provide the operational realities of training with actual responder equipment. They also do not provide the most realistic and scientifically-sound scenarios to train against. To address this need, the Lawrence Livermore National Laboratory (LLNL) developed a next-generation training capability, the Radiation Field Training Simulator (RaFTS) for which we were awarded an R&D100 Award by R&D Magazine in 2017[5] and a TechConnect Defense Innovation Award in 2018.[6] Three US patents protect LLNL's intellectual property.[7] RaFTS has been granted a three-year[8] US Department of Energy (DOE) Technology Commercialization Fund award[9] for LLNL to work with the UK's Argon Electronics Limited and the Tennessee-based ORTEC, among other detector manufacturers, to commercialize RaFTS. Our project was selected for a 2021 FLC National Excellence in Technology Transfer award[10]. This paper will describe our past work and then discuss the next generation of RaFTS which will meet and hopefully exceed the expectations of the emergency responder community.

BACKGROUND

RaFTS provides the capability to inject simulated data into suitably adapted radiation detection instruments that responders use in real events. The data injection occurs using the physics operators encounter with the hazard and is impacted by how they are using the instrument which significantly increases the realism of training exercises. RaFTS accomplishes this mimicking of the source by generating signals that accurately mimic those of an actual radioactive source or sources. These generated signals are injected into detector systems in place of, or in addition to, signals that would be generated from natural background or radiation sources. This requires working with manufacturers of radioactive measurement devices to provide the required access to their signal chain. Several manufacturers have shown interest already. Lawrence Livermore National Laboratory (LLNL) has demonstrated the capability with both a high purity germanium-based gamma-radiation detector and a sodium-iodide-based gamma-radiation detector. See Figure 1 below for the development versions of RaFTS.

Figure 1: RaFTS operates on different spectrometer systems: (Left) on a commercial semiconductor-based system, the Ortec Detective; and (Right) a commercial sodium-iodide-based detector. The flexibility of RaFTS for different types of detector instruments makes this innovation an attractive commercial product for the rad-nuc safety sector.

EXISTING METHODS OF TRAINING

Civilian and military responders around the world expend enormous effort and resources to maintain their readiness to respond to real-world emergencies. Their efforts include preparing for emergencies involving high-level radiation sources or contamination scenes such as occur in transportation accidents with medical or other highly radioactive sources, nuclear power plant accidents (e.g., Fukushima), interdiction of criminal smuggling of radioactive sources, and even radiological and nuclear terrorism. Unfortunately, current training does not adequately prepare teams for the realities of emergencies in which a radiation source, or sources, are present (Figure 2). The potential health effects of using hazard-level radiation sources as well as the security, procurement costs and impracticality of using them or spreading contamination around an area to represent realistic condition are not acceptable. Ideally, emergency responders should train in their home locations, using their actual operating equipment, against a full range of realistic scenarios, with particular emphasis of incidents that reflect the reality of the hazards they could face.

Figure 2: Field exercises can look high fidelity, but they're generally limited to small radiation sources, which lose the physics reality (detectors don't respond realistically or consistently across the multiple device types used), and source handlers and licensing can be required.

Existing methods to train with radiation-detection equipment for rad/nuc emergencies typically use small non-hazardous radiation point sources or virtual simulators or a combination of both approaches. Problematically, and unlike RaFTS, these current methods that employ small sources or use virtual simulations cannot approximate with sufficient realism an actual large-scale emergency event. Using small radiation sources in training is common because at least some radiation-detection equipment will provide a response to the user, if placed physically on top of or sufficiently close to the detector. However, in most cases, they cannot observe those sources quickly, once beyond a foot or two, meaning these sources cannot represent an actual hazard, which would become detectable at much larger distances. Radiation detection physics is far more complicated in cases of large-scale contamination or hazard-level sources. For example, large-scale events might appear to a detector operating in the contamination area to be originating from all directions, which can be very confusing to the operator, but is quite realistic. Small radiation sources cannot replicate such physics. Additionally, in search exercises, trainees often key-off the yellow-vested safety technician required to accompany the small source when their instruments are not reading anything. For contamination exercises, small, contained radiation sources cannot replicate a distributed contamination zone, nor are we allowed to spread radioactivity around a city to practice emergency responses.

Virtual reality can be used to approximate how an instrument might “read” radioactivity. However, virtual reality cannot adequately reflect the challenges of field operations: Operators cannot experience their equipment becoming too heavy; their screen being unreadable in the sunlight; or the equipment is too large to crawl through an exercise feature; or their instrument batteries fail too soon. In short, virtual simulators can result in “virtual consequences” and oversimplify the operational realities of emergency response and do not adequately train the users in all aspects of the needed response.

Probably the most comparable approach to RaFTS, instrument simulators can duplicate the instrument look and feel but must be customized for each individual instrument manufacturer and additionally require duplicate purchases of simulation hardware. For instruments that have physically separate radiation-sensing probe modules that convert the invisible radiation into electrical pulses, there have been attempts to create replacement detection-probe components. However, these only work with that one instrument. Responders often do not have the financial resources to buy nonoperational training-only simulators, and some have expressed that they do not like the idea of removing the operational detector for a training-only simulator and then mistakenly deploying with a non-operational system in a real emergency.

A NEW METHOD FOR TRAINING

RaFTS draws upon detailed scenarios created using U.S. national emergency response assets and capabilities such as the National Atmospheric Release Advisory Center (NARAC).[11] The data generated for these sophisticated scenarios are prepared as inject signals into the operating detectors used by the trainee. It fully enables trainees to practice their response and reachback protocols (e.g., RadResponder).[12] The RaFTS capability, now demonstrated on two different types of detectors, is intended to be inexpensive, work on a variety of instrument types, will ultimately yield a giant leap forward in the ability to train against sources and scenarios that matter to emergency responders. We believe this technology can be adapted beyond radiation detectors to include chemical, biological, explosive, and other detector technologies. This report will describe the current capability of RaFTS on radiation detectors.

Figure 3 shows the capability of the RaFTS system to generate realistic input data that works with the most sophisticated radiation detection response instrumentation, namely a detector system that not only detects the presence of radioactivity but is also used to identify the radioactive isotope(s) present through characteristic gamma radiation energies (a gamma ray spectrometer). The fidelity of the information contained in the “energy spectrum” is dependent on the type of detector, and the source of the radiation as well as the physics of how the user encounters the source. The system will allow any radioactive material or materials to be used to mimic (in) the scenario. The strength of the signal depends on the size of the source, the operating characteristics of the detector, distance to the detector, and how the operator uses their instrument and can be modified to include intervening shielding materials as needed, just as would occur in reality in urban search or similar conditions.

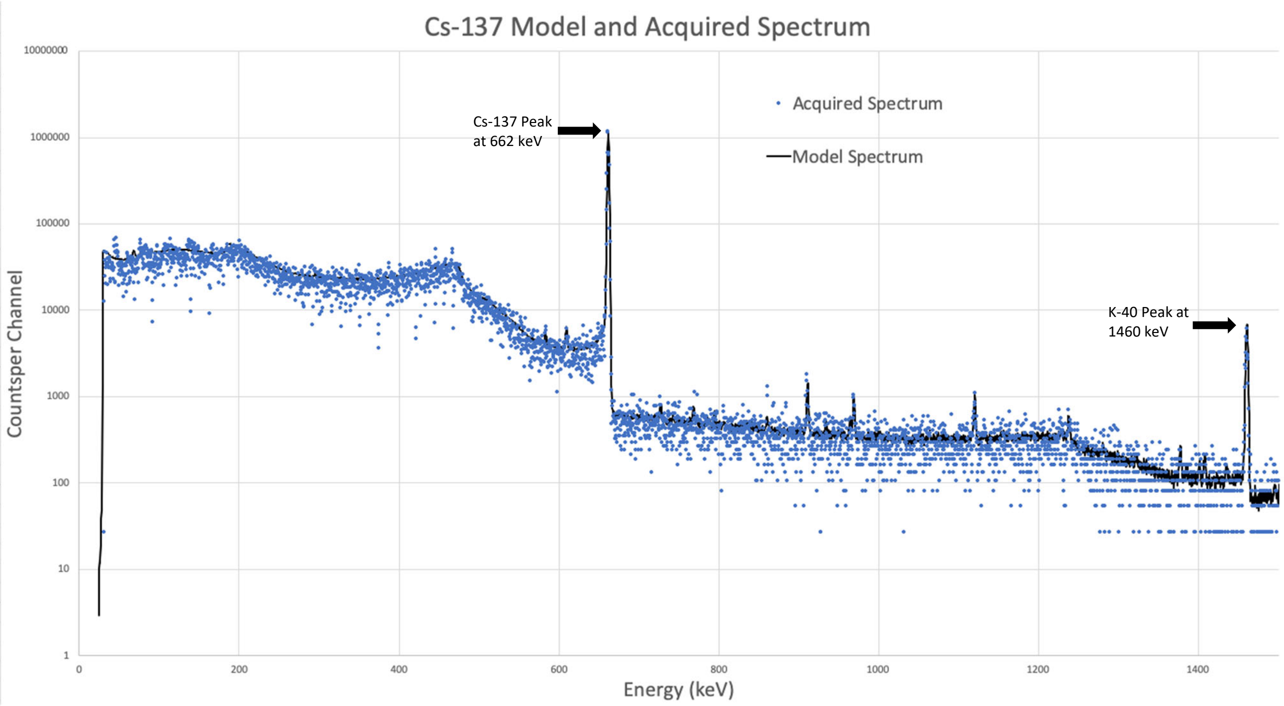

Figure 3: Comparison of an actual Cs-137 spectrum used as the model spectrum (black line), and the RaFTS generated spectrum (blue dots). The RaFTS spectrum started as simulated preamplifier pulses which went through a shaping amplifier and into an MCA. The energies of the detected peaks are used to identify the radioactive isotopes that are present. Note that background features are present in both spectra, such as the K-40 peak at 1460 keV. The FHWM of the peaks are the same. The RaFTS spectrum was scaled to match the model spectrum counts.

To achieve the goal of making a universally adaptable simulation tool, the current project will merge the unique capabilities of RaFTS and LLNL's scenario-development expertise with the hardware and software simulator systems developed by Argon Electronics. Argon's instrument simulators—the PlumeSIM scenario software—and the company's established relationships with both commercial instrument manufacturers and the end-user community make this partnership particularly powerful. It provides the opportunity for technology transfer as Argon already has a ready tool and market to pair with LLNL's RaFTS. Once combined, the merged technologies promise to eliminate the need and costs[13] of using even weak real radiation sources in training. It will also enable trainees to build operational familiarity with their own equipment in their own environments in a manner that represents the actual conditions they could face. A fact that, we predict, will make our product highly appealing to many users (Figure 4).

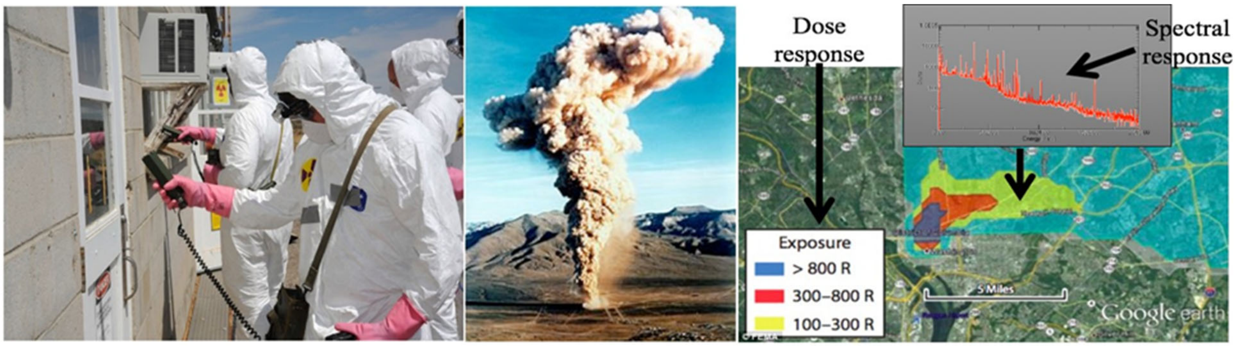

Figure 4: A broad range of exercises are possible (left image) a simple scanning of a building to find a source or sources, (middle and right images) exploring the spread of a plum of radioactivity, its deposition on the ground (extent of contamination) as well as the composition of the radiation source released.

DEMONSTRATIONS

In 2016 and 2017, LLNL demonstrated RaFTS with the operational High Purity Germanium (HPGe) detector in Washington, D.C., to multiple agencies. The agencies included the U.S. Department of Energy (DOE) Emergency Response Programs, the Department of Homeland Security (DHS) Domestic Nuclear Detection Office, the DHS Federal Emergency Management Agency, the U.S. State Department Office of Treaty Verification, and others. LLNL also demonstrated RaFTS to members of the DOE Radiological Assistance Program, to the Global Materials Security Programs, and to the International Atomic Energy Agency Emergency Response Programs. The only equipment needed for such exercises or demonstrations is a radiation detector and the RaFTS hardware with a pre-calculated scenario programmed into RaFTS, which can be easily generated to include several radiation sources (at fixed locations or dispersed radioactivity) and a field of play (a parking lot, a park, or any other open space).

COMMERCIALIZATION

The key issues for the success of the RaFTS equipment and training will be to obtain the support from two key groups: the organizations responsible for training; and the user community. Each of these groups will need to see the benefits of the RaFTS system in improving the capabilities of the first responder groups. Thus, our principal thrust will focus on the organizations responsible for training as they will view switching to RaFTS as a tradeoff between the status quo and improved exercises, and they will have to incur the cost of modifying their existing detectors to function with RaFTS or at replacement time through recapitalization. Our second effort will be to introduce the RaFTS equipment to the user communities through demonstrations that will familiarize these customers with the ease of use and the improved level of training possible.

The RaFTS system was developed to readily address these groups' concerns. We feel that the decrease in costs of an exercise using RaFTS versus current exercises will be of significant interest to those who sponsor training. Additionally, the realistic nature and user-friendly experience of RaFTS-based training will be of interest to the user community. We will need to expend an effort to inform both groups of the benefits to them, so outreach is a key part of our commercialization plan. LLNL has already provided several demonstrations for federal emergency responders, who expressed significant interest.

We are currently working to broaden the range of detector types and manufacturers that RaFTS works with, while miniaturizing the hardware for the system to work with a variety of detector systems. To accomplish this, we have teamed with Argon Electronics (UK) Limited who already has experience working with many different detector manufacturers to develop simulation hardware and software. We are also working to broaden the scenarios available, including realistic radioactive plumes that evolve over time, just as they would in a real-world incident.

Argon's established relationships and established routes to market promise to greatly speed broad adoption of RaFTS, could establish a completely new ecosystem of training device peripherals. Argon's instrument- and manufacturing-interface experience is a unique combination. Argon will be serving as the primary point of contact to the rest of the detector manufacturing community, and they are uniquely suited to this role. Some detector manufacturers have already provided hardware and work with our team on the engineering required to work with RaFTS.

To achieve these goals, this effort will scale the size and complexity of RaFTS to produce a marketable product. Specifically, in their current state, the RaFTS prototype systems are too bulky and heavy for widespread field demonstration and user evaluation. Consequently, the commercialization activities will parallel and steer the technical development undertaken in this project.

CURRENT PROGRESS

LLNL held a commercialization kickoff meeting with Argon Electronics in November 2019 and signed a cooperative research and development agreement in March 2020.[14] Since teaming with LLNL to develop and commercialize RaFTS, Argon has reviewed and replaced all electronic hardware with latest generation currently available technology and implemented a faster more flexible central processor. Additionally, the original Python code has been completely rewritten in C and optimized for modularity, flexibility, performance, and memory efficiency. The initial interface to facilitate support of response simulated radiological hazard generated by Argon PlumeSIM and point simulation Gamma sources has also been implemented. Figure 5 shows a spectra of Ho-166m (without background) as would be collected using a NaI-type detector, generated by Argon's RaFTS hardware / software implementation and compared with the input spectra:

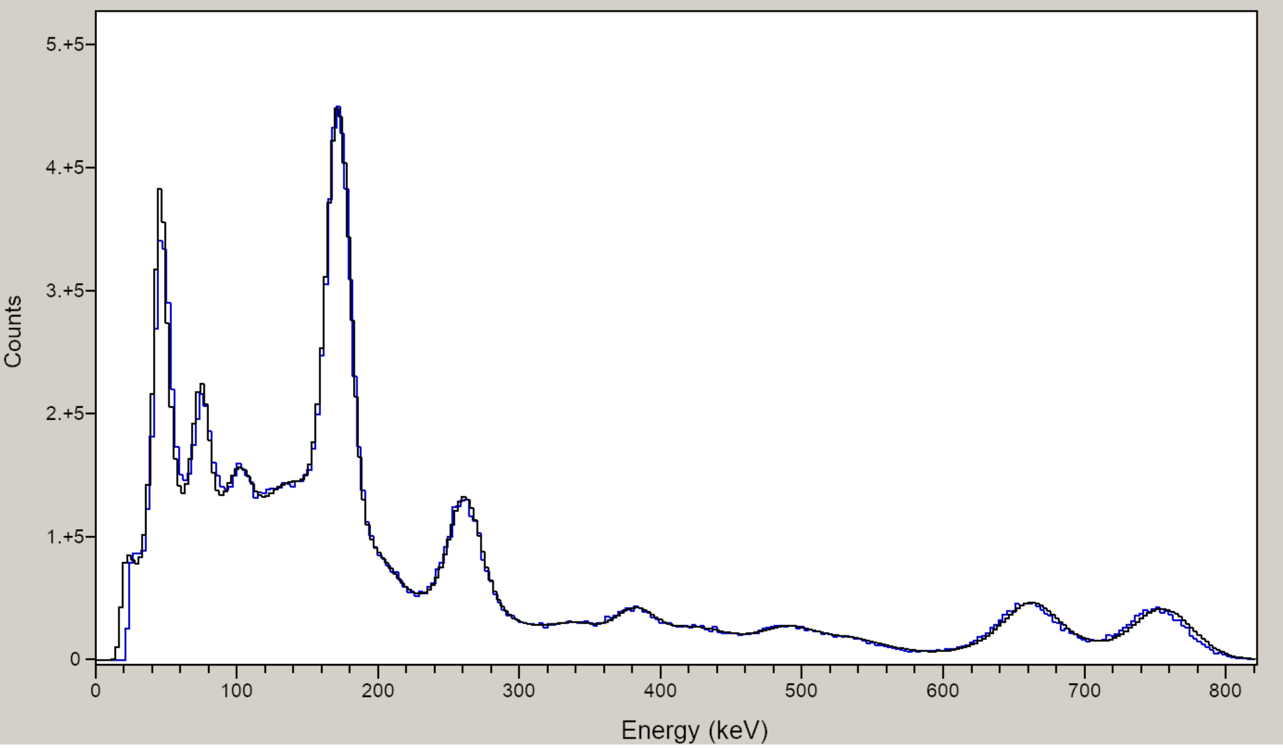

Fig 5

In addition, our commercialization effort and progress was recently a featured article in the July 2021 issue of ANS Nuclear News[15].

FINAL THOUGHTS

While we have demonstrated the ability to retrofit existing equipment with a RaFTS port, one of the most important commercial impacts of RaFTS is its intended interoperability across the variety of instrument types. The RaFTS approach was designed to be applicable to nearly all radiation detection technologies — including those that produce the highest fidelity data — without requiring significant re-engineering on the part of manufacturers. This effort will focus on creating a new ecosystem of detection systems with signal–injection interfaces to enable rapid adoption of the RaFTS approach across multiple instrument types.

The numbers of detector sold varies significantly, depending on the purpose and type of the instruments. The most costly and capable detectors are used to identify and characterize sources using radiation-sensitive semiconducting materials such as high-purity germanium. For these, only a few hundred per year are sold, but the detail of the data collected is extraordinary. Far more common radiation dose- and source-discovery devices produce far lower fidelity data but are far more common. Sales of these are tens of thousands per year. A typical DOD acquisition is for many tens-of-thousands of instruments and the DHS grants program has funded purchases of hundreds of thousands of the lower-tech devices over the past few years. For each of these detectors to be effective, there must be a trained operator. The very large number of detectors purchased over the past decade provides a large market for the RaFTS system.

As with the adoption of any fundamentally new approach, it will take time for commercial instrumentation to come equipped with the needed RaFTS interface port. Thus, to expand our initial market, we plan both to offer an option to retrofit existing equipment to accept RaFTS inputs and to coordinate with manufacturers for their next generation instruments to come equipped with an ability to accept RaFTS injection. Future users could then obtain a RaFTS-compatible device by default when next recapitalizing their equipment.

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Argon Electronics (UK) Ltd. is a privately owned British corporation specializing in the design and manufacture of Chemical, Biological, Radiological, Nuclear and Hazardous Material training simulators and systems.

Notes

[1] https://www.llnl.gov/

[2] https://www.argonelectronics.com/

[3] As an example of these savings, the International Atomic Energy Agency presently spends about a million U.S. dollars a year for the shipment of sources for training - David Smith, International Atomic Energy Agency, private communication, 2017

[4] Realistic Radiation Detection Training Without Radiation Sources by Steven A. Kreek, https://www.youtube.com/watch?v=AvlNxI8tU2Y

[5] R&D 100 Archive of Winners – 2017, https://www.rdworldonline.com/rd-100-archive/2017/

[6] https://lasers.llnl.gov/news/science-technology/2018/september

[7] US 7,552,017 B1 (2009): Tailpulse Signal Generator
US 9,836,992 B2 (2017): Realistic Training Scenario Simulations and Simulation Techniques
US 10,650,700 B2 (2020): Incident Exercise in a Virtual Environment

[8] Graciously extended by DOE from a two-year term due to COVID delays.

[9] Lab wins six tech commercialization grants, https://www.llnl.gov/news/lab-wins-six-tech-commercialization-grants

[10] https://federallabs.org/news/flc-news/2021-flc-awards-%E2%80%93-winners-announced

[11] https://narac.llnl.gov/

[12] https://www.radresponder.net/

[13] As an example of these savings, the International Atomic Energy Agency presently spends about a million U.S. dollars a year for the shipment of sources for training - David Smith, International Atomic Energy Agency, private communication, 2017.

[14] https://www.llnl.gov/news/llnl-argon-electronics-sign-cooperative-research-agreement-bolster-realistic-radiation

[15] http://ans.org/pubs/magazines/nn/y_2021
https://www.ans.org/news/article-3052/rafts-the-radiation-field-training-simulator/