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Demonstrating Safeguards Applications of DRiFT Gas Detector Capabilities

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Background and Work Proposed

- DRiFT, a Detector Response Function Toolkit, post-processes MCNP output to model detector response
- Three primary components: scintillator (focus of FY 21 TED work), gas detectors (focus of this FY), and semiconductor detectors
- Capability to model scintillator detectors has previously been demonstrated
- Ability to model realistic nuclear instrumentation response for He-3 and other gas-filled neutron detectors has been developed and benchmarked
- Gas-filled neutron detectors are heavily used in nuclear safeguards, and a focus of this release has been to expand software usability by practitioner end-users

The MCNP Code

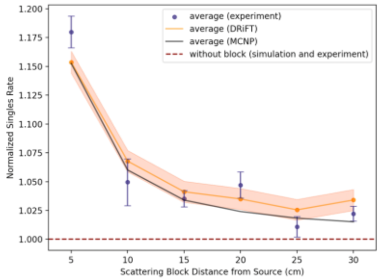
World-class radiation transport

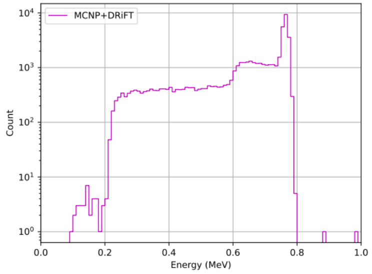
Outputs PTRAC files

DRiFT

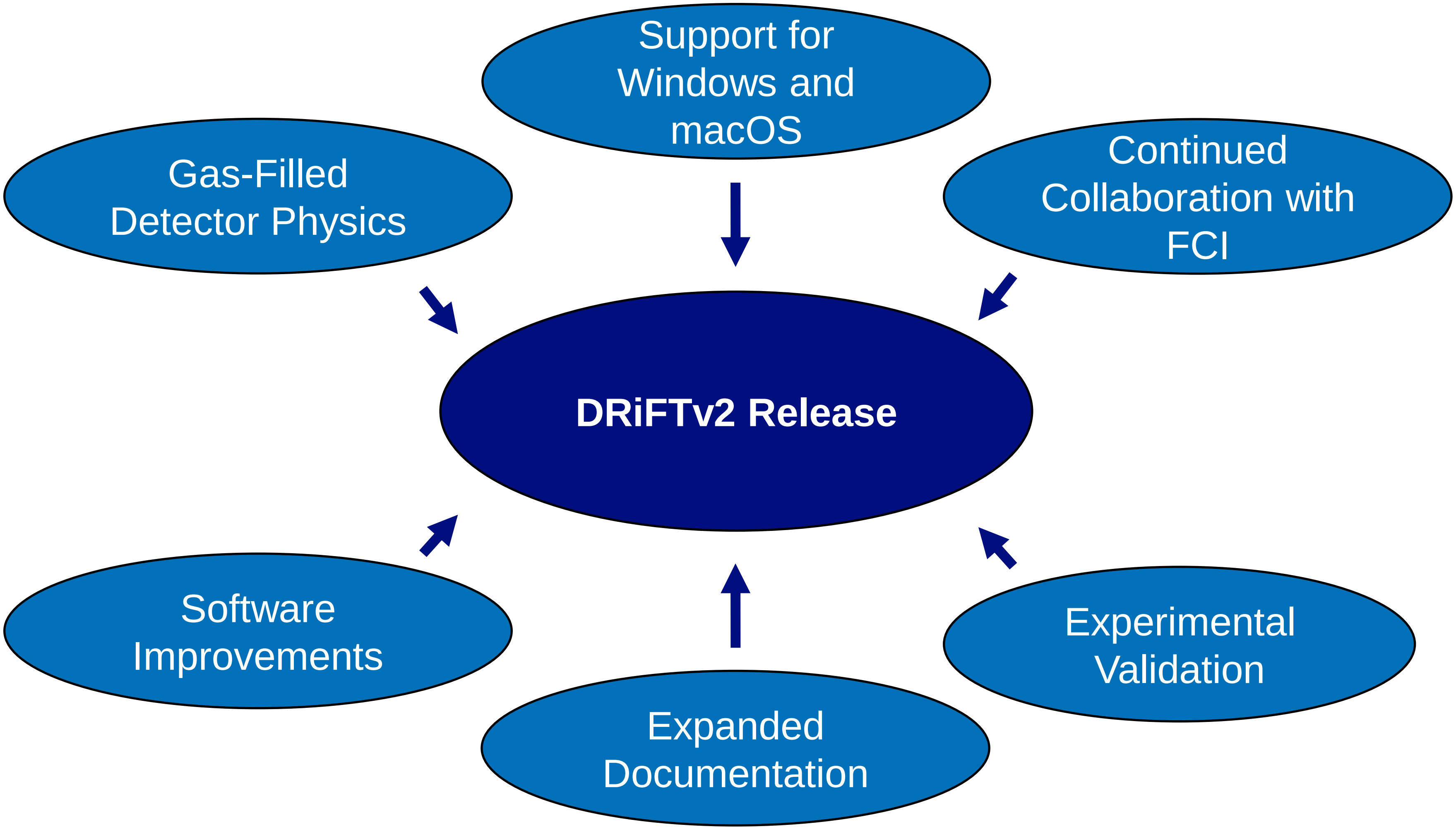
High-fidelity detector responses

Generates outputs in the same format as measurements



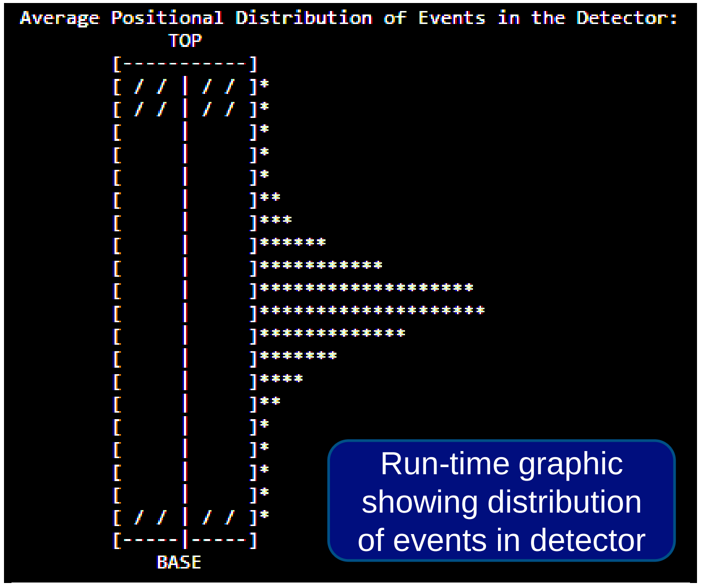


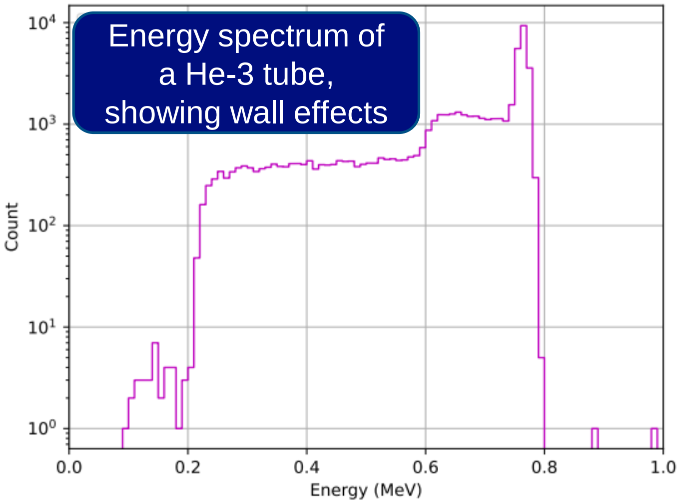
Summary of Key Results



Key Result: Gas-Filled Detector Physics

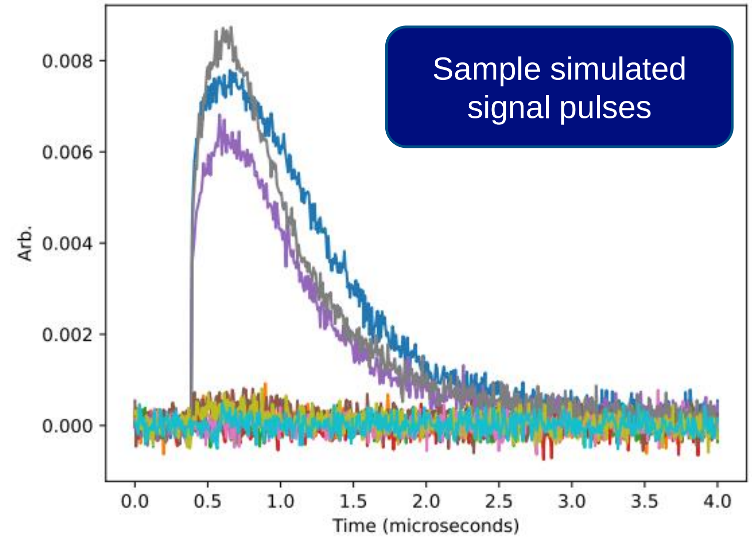
- Gas-filled detector responses and the response of a charge-integrating preamplifier are now modeled in DRiFT
- Uses data tables generated by SRIM and Garfield++ to calculate electric fields and ionization
- Two detector fill gases and two quench gases are available to mix and match at any concentration from 95% to 100% fill gas
- Continuous voltage support between 1000 and 1900 V, continuous temperature support between 253 and 293 K, and continuous pressure support between 1 and 10 atm
- Both cylindrical and spherical detector geometries are supported at any arbitrary size

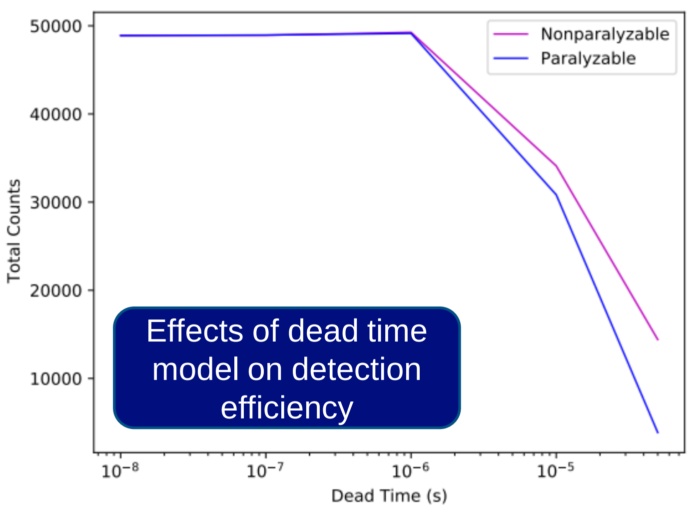


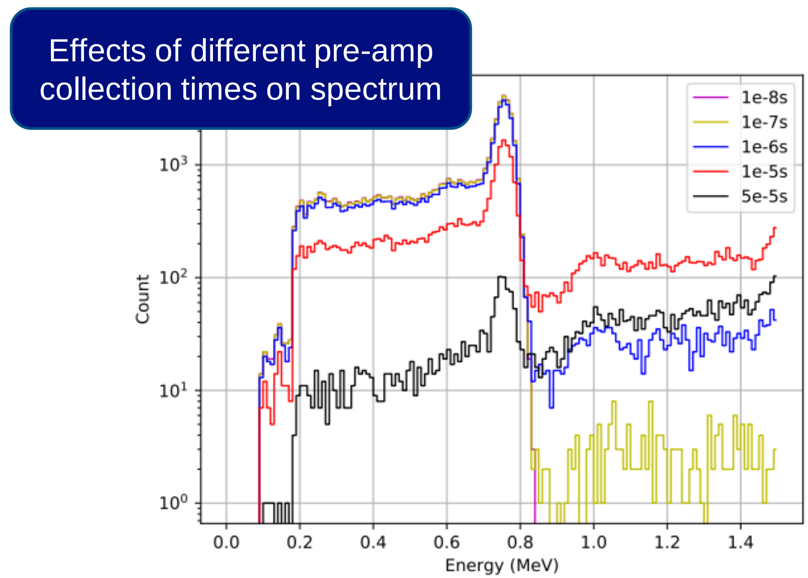


Key Result: Gas-Filled Detector Physics

- Ability to perform automatic Rossi-Alpha calculation is included
- Individual simulated signal pulses from detector events are generated and can be output by DRiFT
- Pulse pileup, dead time, inactive end-tube regions, and spurious after-pulsing are all modeled







Key Result: Software Improvements

- Improved DRiFT execution speed significantly in many cases
- Now handles HDF5 output to work with MCNP6.3 outputs
- Added compatibility with MCNP universes and lattices
- Unit test suite was expanded from 3 to 20 tests to better test code functionality
- Additional diagnostic capabilities, like the ability to flag room return and reals/accidentals added

source_e (MeV)	NPS	det_pulse (MeVee)	det_cell	corr_count
2.46561	2	0.760884	1 [-1,0,0]	no
2.30261	3	0.308517	1 [-1,1,0]	no
0.443801	9	0.0429783	1 [-1,0,0]	no
1.71909	12	0.282561	1 [0,1,0]	double
1.44482	12	0.276578	1 [1,0,0]	double
3.87434	24	0.138036	1 [1,-1,0]	no
2.39633	39	0.724142	1 [-1,1,0]	double
0.847697	39	0.092614	1 [1,0,0]	double

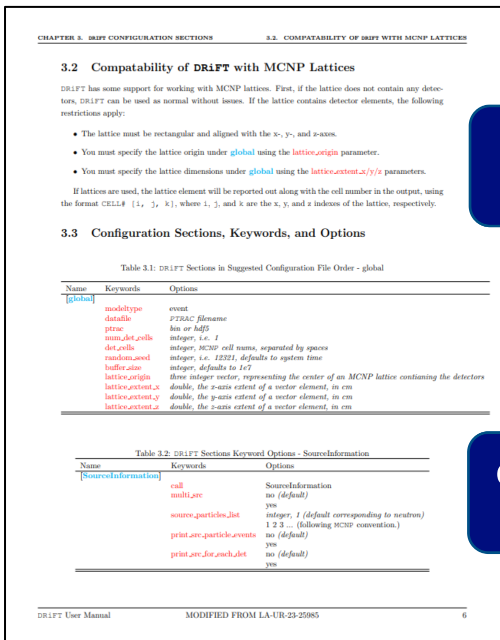
DRiFT now distinguishes between events in different lattice elements and calculates coincidences appropriately

```
Running test: testSetGetValue... Passed!
Running test: testValidateDouble... Passed!
Running test: testValidateString... Passed!
Running test: testValidateVector... Passed!
Running test: testCurrent... Passed!
Running test: testGetDigitizerRate... Passed!
Running test: testGetResolution... Passed!
Running test: testGetTerRes... Passed!
Running test: testGetVoltageRange... Passed!
Running test: testEENoise... Passed!
Running test: testConvertVector... Passed!
Running test: testGetFileKeys... Passed!
Running test: testNthDegreeInterpolator... Passed!
Running test: testMatDiv... Passed!
Running test: testMatMult... Passed!
Running test: testLight_Output... Passed!
Running test: testGet_Gain... Passed!
Running test: testQuantum_Efficiency... Passed!
Running test: testScintillation_Yield... Passed!
Running test: testScint_Noise... Passed!
```

Unit tests cover many areas of code functionality

Key Result: Expanded Documentation

- Additional developer-focused documentation was written
- A new section was added to the manual covering new features, and the entire manual was revised to improve navigability



CHAPTER 3. DRiFT CONFIGURATION SECTIONS 3.2. COMPATABILITY OF DRiFT WITH MCNP LATTICES

3.2 Compatability of DRiFT with MCNP Lattices

DRiFT has some support for working with MCNP lattices. First, if the lattice does not contain any detectors, DRiFT can be used as normal without issues. If the lattice contains detector elements, the following restrictions apply:

- The lattice must be rectangular and aligned with the x-, y-, and z-axes.
- You must specify the lattice origin under global using the lattice_origin parameter.
- You must specify the lattice dimensions under global using the lattice_extent_x/y/z parameters.

If lattices are used, the lattice element will be reported out along with the cell number in the output, using the format CELL# [i, j, k], where i, j, and k are the x, y, and z indexes of the lattice, respectively.

3.3 Configuration Sections, Keywords, and Options

Table 3.1: DRiFT Sections in Suggested Configuration File Order - global

Name	Keywords	Options
[global]		
	modeltype	event
	datafile	*PTRAC filename*
	ptrac	*bin or hdf5*
	num_det_cells	*integer, i.e. 1*
	det_cells	*integer, MCNP cell nums, separated by spaces*
	random_seed	*integer, i.e. 12321, defaults to system time*
	buffer_size	*integer, defaults to 1e7*
	lattice_origin	*three integer vector, representing the center of an MCNP lattice contianing the detectors*
	lattice_extent_x	*double, the x-axis extent of a vector element, in cm*
	lattice_extent_y	*double, the y-axis extent of a vector element, in cm*
	lattice_extent_z	*double, the z-axis extent of a vector element, in cm*

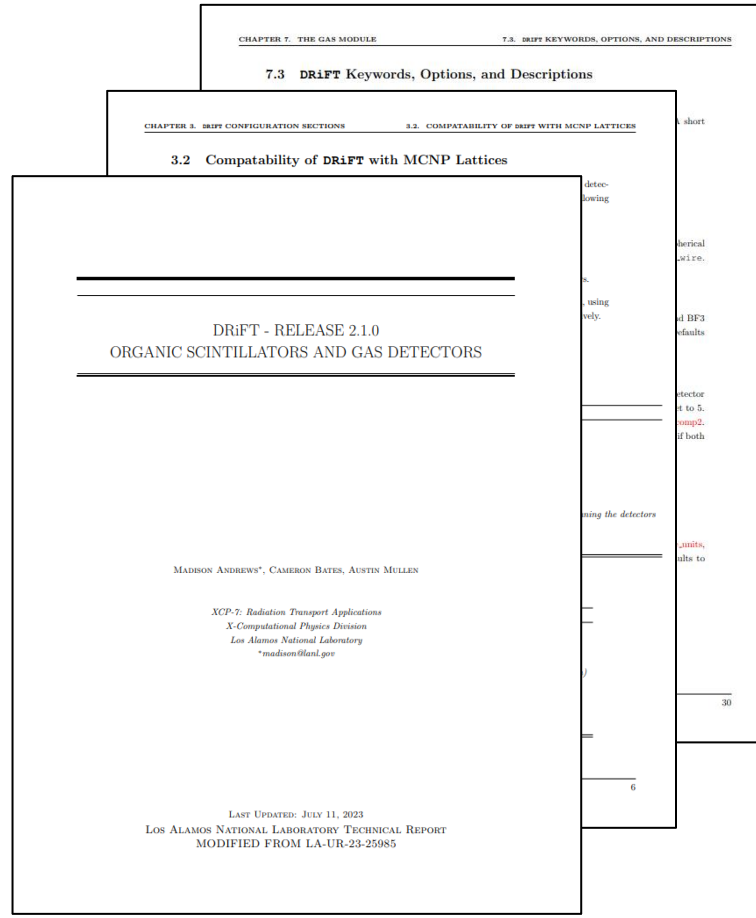
Table 3.2: DRiFT Sections Keyword Options - SourceInformation

Name	Keywords	Options
[SourceInformation]		
	call	SourceInformation
	multi_src	no *(default)*
		yes
	source_particles_list	*integer, 1 (default corresponding to neutron)*
		1 2 3 ... (following MCNP convention.)
	print_src_particle_events	no *(default)*
		yes
	print_src_for_each_det	no *(default)*
		yes

DRiFT User Manual MODIFIED FROM LA-UR-23-25985 6

Key words are hyperlinked to improve manual navigability

Color coding implemented to improve readability



CHAPTER 7. THE GAS MODULE 7.3. DRiFT KEYWORDS, OPTIONS, AND DESCRIPTIONS

7.3 DRiFT Keywords, Options, and Descriptions

CHAPTER 3. DRiFT CONFIGURATION SECTIONS 3.2. COMPATABILITY OF DRiFT WITH MCNP LATTICES

3.2 Compatability of DRiFT with MCNP Lattices

DRiFT - RELEASE 2.1.0
ORGANIC SCINTILLATORS AND GAS DETECTORS

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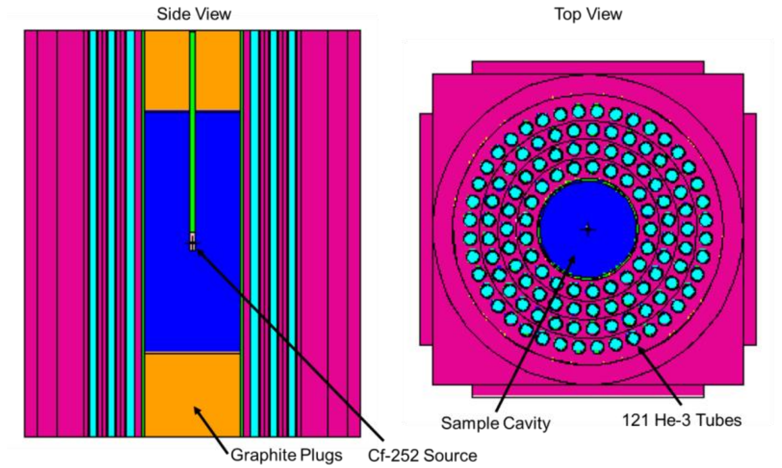
Los Alamos National Laboratory Technical Report
MODIFIED FROM LA-UR-23-25985

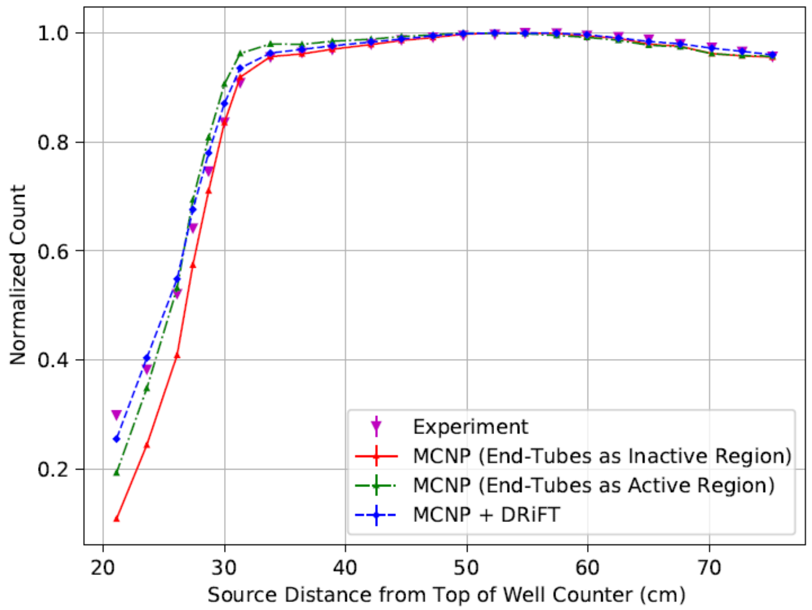
Key Result: Experimental Validation

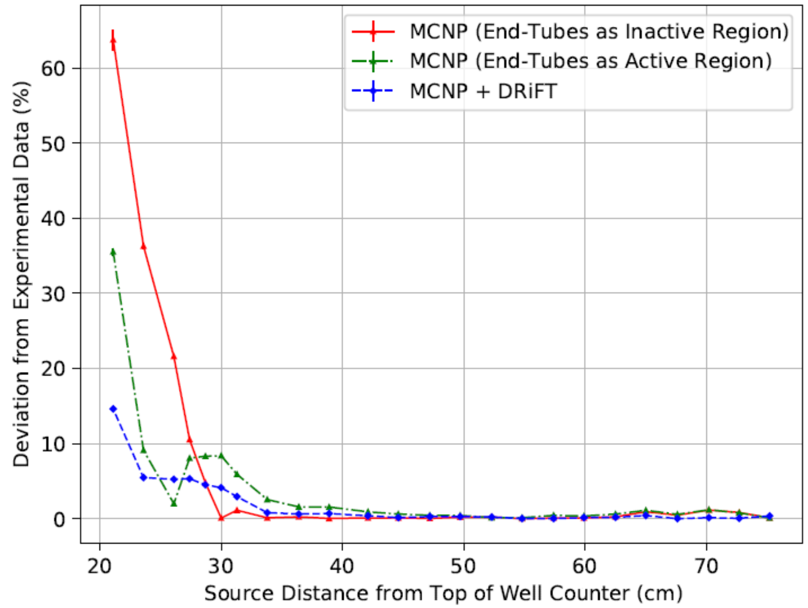
- Two experimental campaigns were designed and carried out as part of this project to evaluate and demonstrate DRiFT features
- An experiment on the Epithermal Neutron Multiplicity Counter (ENMC) was designed to validate DRiFT's ability to model He-3 tube response, particularly its handling of inactive regions at the ends of the He-3 tubes
- A set of experiments on a two-tube He-3 detector system were designed to demonstrate DRiFT's ability to model pulse pileup in He-3 tubes and flag events that occur due to room return

Key Result: Experimental Validation

- DRiFT results validated against experimental measurements using the Epithermal Neutron Multiplicity Counter (ENMC)
- DRiFT outputs compare favorably to experimental results when compared to outputs generated using the MCNP code alone

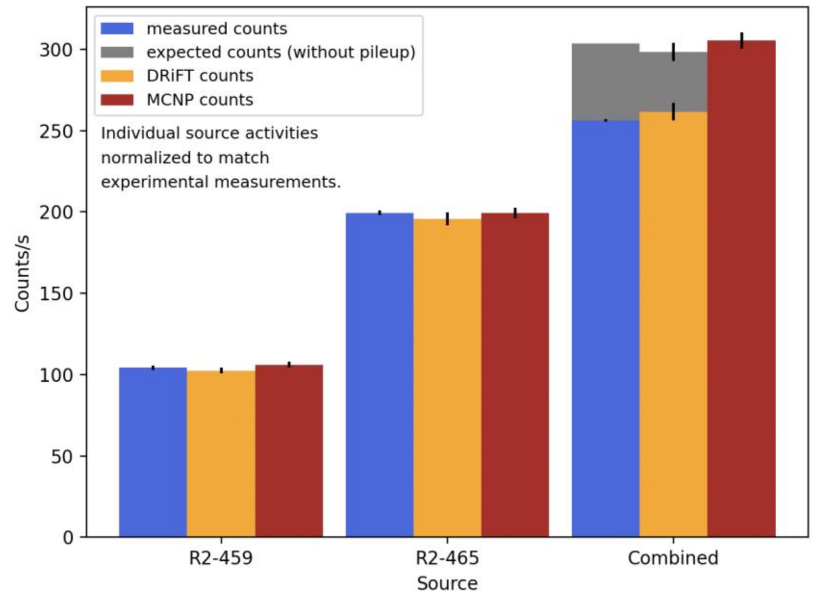


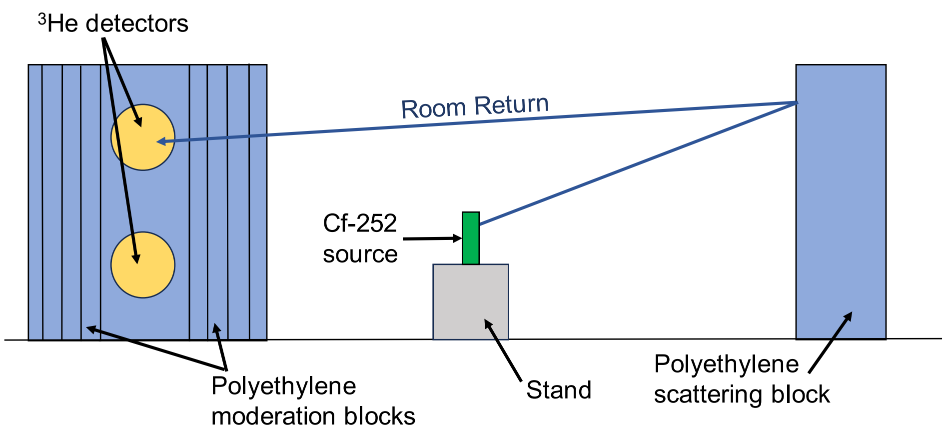


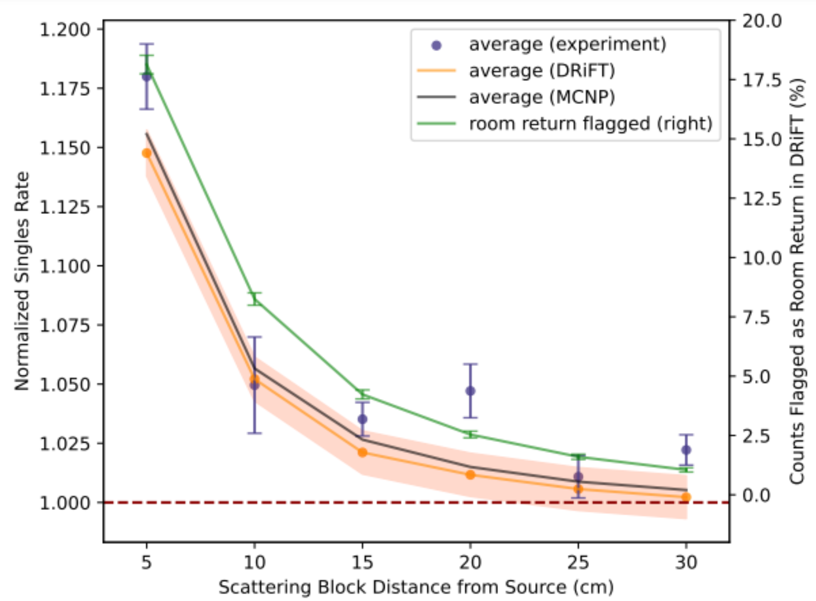


Key Result: Experimental Validation

- DRiFT demonstrated using experimental measurements with a standalone two-tube He-3 detector setup
- DRiFT's ability to model pulse pileup and accurately flag room-return events was shown







Key Result: Support for Windows and macOS

- Installers for Windows and macOS were developed
- Linux installer also updated
- All installers require no prerequisites and only require two steps to install, meaning that the software can be installed and run with practically no system requirements in a short amount of time
- This is very useful for expanding our reach into the Safeguards practitioner end-user community, which primarily uses Windows computers

Key Result: Continued Collaboration with FCI

- Worked with the FCI to approve the DRiFTv2 release, in conjunction with sponsor approvals
- External dependencies and licenses were reviewed and approved
- Process for external interested users to request and receive DRiFT is unchanged from version 1.0
- DRiFT 1.0 has currently been released to 29 external users in government, academia, and industry

Publications and Presentations

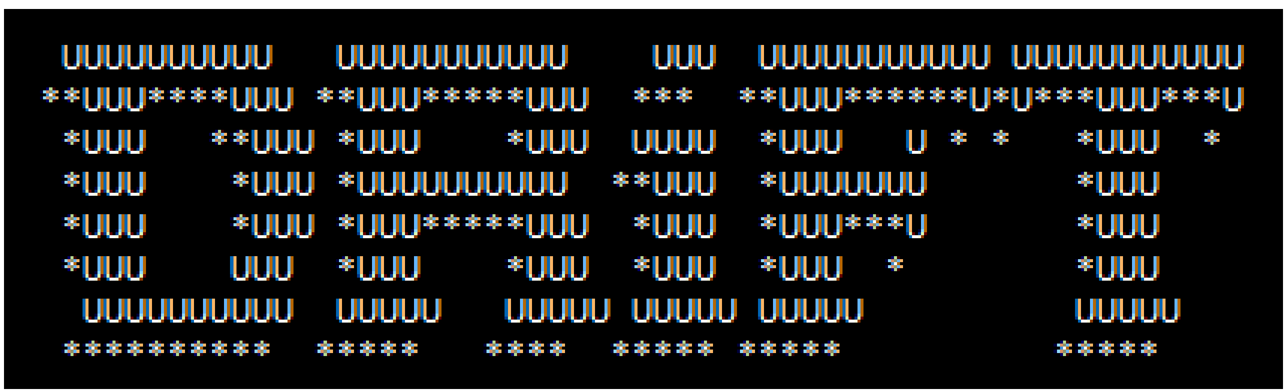
- Mullen, A.D., Andrews, M.T., Rondini, L.I., Thompson, C.J. 2023. “Simulating Gas-Filled Neutron Detector Responses with DRiFT.” *Nuclear Instruments and Methods A*. *Submitted*.
- Mullen, A.D., Andrews, M.T., Thompson, C.J. 2023. "Simulation of He-3 Neutron Detectors with DRiFT, a Detector Response Function Toolkit." Abstract for *IEEE Nuclear Science Symposium and Medical Imaging Conference*. Vancouver: IEEE.
- Mullen, A.D., Andrews, M.T. 2023. “DRiFT – Scintillator and He-3 Capability Overview.” Presented at the *Prompt Radiation Detection and Imaging Workshop*. Virtual: Nevada National Security Site.
- Mullen, A.D., Andrews, M.T., Rondini, L.I. 2023. “DRiFT: An MCNP Post-Processing Tool for High-Fidelity Modeling of Gas-Filled Detectors.” Presented at the *2023 MCNP® User Symposium*. Los Alamos: LANL.
- Rondini, L.I. 2023. “Demonstrating and Expanding DRiFT’s Helium-3 Detector Response Capabilities.” Presented as an end-of-internship deliverable to the XCP-7 Group. Los Alamos: LANL.

Related DRiFT Publications and Presentations

- Building off FY21 TED funds work focused on scintillators:
  - Andrews, Madison T., and Austin D. Mullen. "Drift Current Mode, Trigger Settings and Flexible Detector Specifications Applied to Scintillator Arrays." *Radiation Physics and Chemistry*. *Submitted*.
  - Mullen, A.D. 2023. “DRiFT – A Detector Response Function Toolkit.” Presented at the *MCNP6 for Nuclear Safeguards Practitioners Course*. Los Alamos: LANL.

Conclusions

- DRiFTv2 release now available externally
- Gas-tube detector response has been successfully implemented and validated against experimental results, providing measurable improvement over the capabilities of the MCNP code alone
- Overall user-friendliness of code has been improved to increase uptake in practitioner communities



Acknowledgements

Special thanks to Cole Thompson, Simon Bolding, Marc Ruch, Cameron Bates, and Joel Kulesza for their help with troubleshooting, providing datasets, and testing DRiFT!

This work was supported by Laboratory Technology Evaluation and Demonstration Funding

Program Impact

- Program targets include both NA-22 (Research and Development) and NA-24 (Nonproliferation and Arms Control) sponsors
- Potential funding opportunities exist with the upcoming NPAC/NA-24 proposal calls, including under NA-243 (Office of Nuclear Verification) and NA-241 (Office of International Nuclear Safeguards) calls.
- LANL NA-22 POCs interested in potential applications within NA-22 research and development work
- W-13 project managers for INRAD applications expressed interest in the technology
- 2 upcoming talks highlighting DRiFT capabilities scheduled for NEN Division experts
- LANL GEMS portfolio PM willing to set up additional project team meetings to highlight this effort with relevant LANL Program Office POCs that might have interest in this work

DRiFT Now Fills an Important Capability Gap in Simulating Gas-Filled Neutron Detector Responses

BACKGROUND & MOTIVATION

Current capabilities to accurately simulate gas-filled neutron detectors are limited

- Some capability exists in the MCNP code, but more nuanced effects of the detector and its associated electronics are neglected
- Accurate simulation of gas-filled neutron detectors is important for nuclear security, nuclear safeguards, and other applications

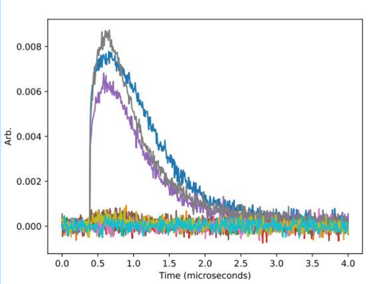
INNOVATION

DRiFT provides high-fidelity modeling of gas-filled neutron detector behavior

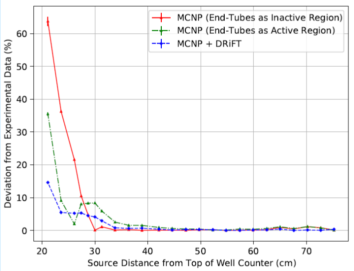
- Electron and ion transport in the detector are modeled to provide an accurate representation of the electronic signals produced
- The detector's associated electronics are also modelled, allowing downstream effects such as pulse pileup to be simulated
- These developments have been validated against experimental measurements

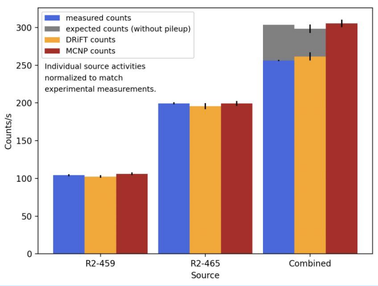
DESCRIPTION

DRiFT's gas-filled detector models have been validated by experimental measurements



- DRiFT models charge generation and collection in the detector, allowing it to produce realistic detector pulses; these simulated pulses are used to determine whether an even is registered by the detector, and if so, to reconstruct its energy (left)
- DRiFT's capabilities have been validated with an experiment carried out with the nuclear safeguards ENMC instrument, where using DRiFT with the MCNP code was able to more accurately represent the detector's behavior than the MCNP code alone (right)





- DRiFT's capability to model detector electronics was validated by another experiment, which demonstrated DRiFT's ability to accurately represent pulse pileup in a detector system (left)

ANTICIPATED IMPACT

This new capability is already being adopted by end users

- Since its release in August, the DRiFT executable with gas-filled detector capabilities have been released to **8** internal LANL users across the XCP, NEN, NPI, and RP divisions so far
- Release of DRiFT executable is currently pending for **6** potential external end-users across government, academia, and industry
- New capabilities allow practitioners to accurately model gas-filled detectors without prior coding or simulation experience

PATH FORWARD

Next Steps:

- Full implementation of semiconductor modeling capabilities into the DRiFT toolkit
- Further validation of DRiFT capabilities against more experimental datasets
- Expand dissemination of DRiFT information to increase uptake in end-user communities

Potential End Users:

- Nuclear security and safeguards practitioners

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Bibliography

1. Goorley, T., M. James, T. Booth, F. Brown, J. Bull, L. J. Cox, J. Durkee, et al. 2012. "Initial MCNP6 release overview." Nuclear Technology 180 (3): 298-315. doi:10.13182.
2. Andrews, M., Mullen, A., Woldegiorgis, S., & Rising, M. (2022). A DRiFT Organic Scintillator Executable for Nuclear Safeguards Applications. Journal of Nuclear Materials Management, 50(2), 20-27.
3. Andrews, M.T., C.R. Bates, E.A. McKigney, C.J. Solomon, and A. Sood. 2016. "Organic scintillator detector response simulations with DRiFT." NIM A 830: 466-472.
4. Andrews, Madison T., and Austin D. Mullen. "Drift Current Mode, Trigger Settings and Flexible Detector Specifications Applied to Scintillator Arrays." Radiation Physics and Chemistry. *Submitted*.
5. J.F. Ziegler, J. Biersack, U. Littmark. 1985. "The Stopping and Range of Ions in Matter." Pergamon Press.
6. Veenhof, Rob. 1998. "Garfield, recent developments." NIM A 419 (2-3): 726-730.
7. Andrews, M.T., et. al.. 2023. DRiFT - Release 2.1.1 Organic Scintillators and Gas Detectors. Los Alamos: Los Alamos National Laboratory, LA-UR-23-29836.
8. Mullen, A.D., Andrews, M.T., Thompson, C.J. 2023. "Simulation of He-3 Neutron Detectors with DRiFT, a Detector Response Function Toolkit." Abstract for IEEE Nuclear Science Symposium and Medical Imaging Conference. Vancouver: IEEE.
9. C. Ahl, M. Andrews, E. Lukosi. 2022. An HPGe semiconductor detector response function for use in DRiFT. Technical Report, Los Alamos: Los Alamos National Laboratory, LA-UR-22-30555.