Improving Radiation Transport Simulation Capabilities for Nuclear Threat Detection Using SWORD

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***Abstract*—The SoftWare for Optimization of Radiation Detectors (SWORD), developed for the U.S. Department of Homeland Security, allows ionizing radiation transport simulation models of complex scenarios to be created and run with minimal training in the actual radiation transport codes. SWORD consists of a vertically integrated set of modules including a CAD-like model builder, an extensive set of prebuilt models and emission spectra, and a variety of visualization and analysis tools.**

Keywords—radiation,modeling,simulation

I. Introduction

Detection of ionizing radiation is one of the primary sensor-based channels for the detection of potential nuclear threat objects. The nature of the threat is such that a great variety of search and detection scenarios must be considered. Threat object sources are potentially rather weak compared to noise imposed by natural and man-made background radiation sources. Consequently, detection systems and concepts of operations must be carefully designed and planned to meet requirements. Radiation transport simulation is an important tool for design and evaluation of detection instruments, instrument testing, and evaluation of operational concepts. Under the sponsorship of the Domestic Nuclear Detection Office, now reorganized as the Countering Weapons of Mass Destruction Office, at the Department of Homeland Security, the U.S. Naval Research Laboratory has developed a software application know as SoftWare for Optimization of Radiation Detectors (SWORD) for use in radiation transport simulation.

A number of ionizing radiation transport codes are in common use, including well-known tools such as Monte Carlo codes Geant4 from Conseil Européen pour la Recherche Nucléaire (CERN) [1] and Monte Carlo N-Particle (MCNP) from Los Alamos National Laboratory [2] and discrete ordinates codes such as Denovo from Oak Ridge National Laboratory [3]. These tools are comprehensive, validated and widely used. However, they are neither easy nor intuitive and require a substantial learning curve and, perhaps, substantial training in order be used successfully.

SWORD attempts to address the effort required to perform meaningful radiation transport simulations. By creating a vertically integrated simulation package that allows the design of simulation scenarios in a computer aided design (CAD)-like environment, SWORD allows rapid simulation execution within realistic simulated environments with a minimum of training. Of course, as with all simulations, expert evaluation of results is required to assess validity, but that expertise does not need to extend to the complex setup syntaxes of the radiation codes.

SWORD has been instrumental in several projects that would have required considerably more resources otherwise to complete. In addition, SWORD is in use at U.S. Naval Research Laboratory (NRL), Defense Threat Reduction Agency (DTRA), Department of Homeland Security/Countering Weapons of Mass Destruction Office (DHS/CWMD) and Los Alamos National Laboratory on a regular basis, and has been distributed to almost 300 users worldwide.

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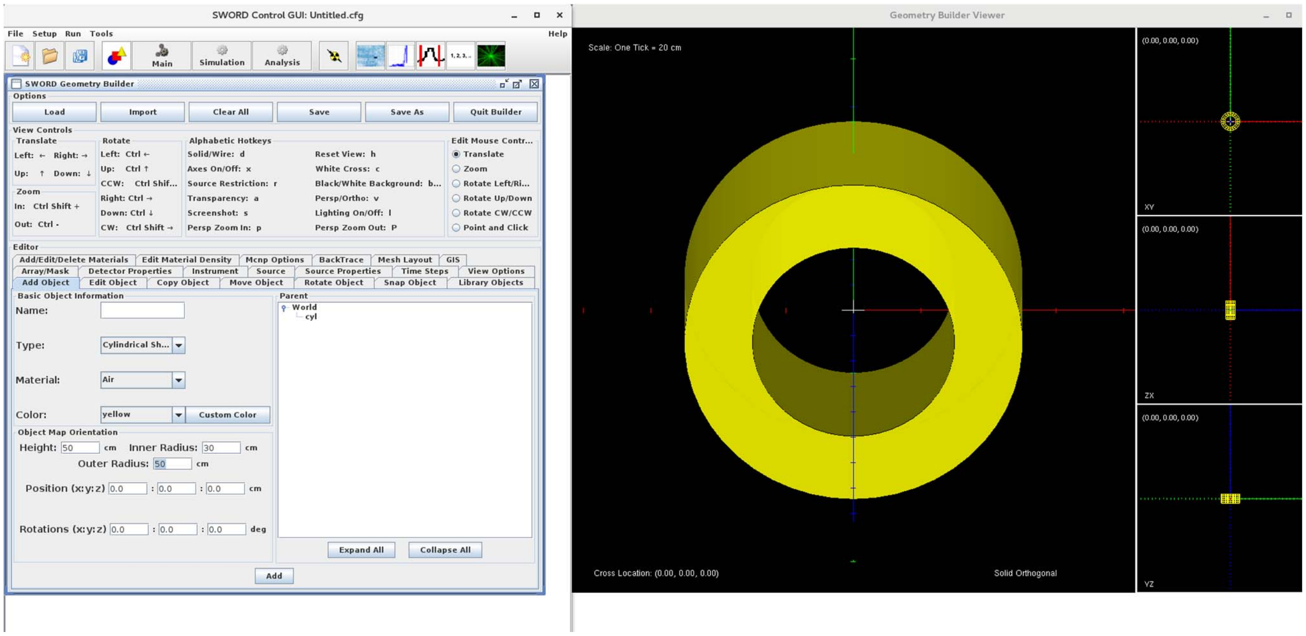

Fig. 1. SWORD graphical user interface (left) and geometry viewer (right). Note that the geometry viewer can display rendered (as shown) or wireframe views.

II. SWORD Components

SWORD is a Linux application that currently runs on both RedHat Enterprise and Ubuntu Linux distributions. SWORD is available via the Radiation Safety Information Computational Center (RSICC) at Oak Ridge National Laboratory [4]. It ships in the form of both Linux binary installers and preinstalled on a VMware virtual machine. SWORD source code is not generally available.

SWORD consists of the following integrated components:

- A CAD-like design environment using a variety of simple shapes to produce complex objects
- An extensive library of pre-built, modifiable objects including gamma-ray and neutron detectors, radiation sources, threat objects and various environment objects such as vehicles and buildings.
- A library of emission spectra that can be applied to any object in the simulation. In addition, user-defined emission spectra may be added.
- An interface to multiple radiation transport codes.
- Aggregation code that collects energy deposits in all objects designated as detectors and collects spectrum histograms from any subset of detectors the user designates.
- Analysis code that applies user-defined energy resolution smearing to spectra. In addition, simple image reconstruction for coded aperture or Compton imagers creates images over user-specified energy bands.
- Applications to visualize and perform simple analyses on both spectra and images.

A. *SWORD CAD System*

The SWORD CAD system, known as the geometry builder, consists of a graphical user interface (GUI) and a fully interactive model display. From the GUI, the SWORD user can add simple 3-D geometric volume components such as spheres, boxes, cylinders, etc. and size, translate, rotate and snap them together as desired (Fig. 1). Each of these volumes can be arranged in a parent-child hierarchy to allow complex objects with internal structure to be constructed (see examples below).

Volume materials are assigned from an included and/or user-defined list of materials built up from isotopes, elements and other materials. In addition to the isotopic and elemental constituents, density is also specified.

Any volume can be identified as a detector. During simulation runs, any detector volume has all energy deposits recorded. In addition, all particles crossing a detector volume boundary are recorded separately, whether or not they deposit energy in the volume. Energy resolution parameters are specified for each detector, with resolution smearing applied as a post-simulation process.

Both coded aperture and scatter-camera imaging detectors are supported for neutrons and gamma-rays. The GUI allows for automated random mask production as well as user-produced masks.

Emission sources can be defined as surface, volume or point sources. Emission spectra are chosen from a wide range of included options, or can be defined by the user.

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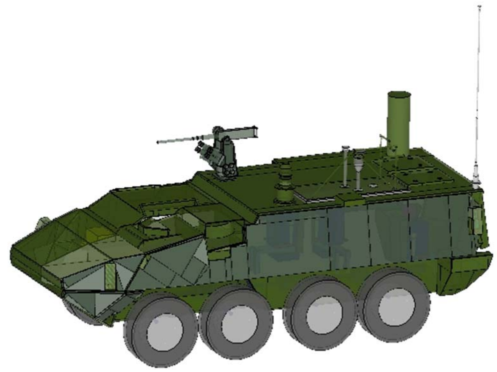

Fig. 2. SWORD model of NBCRV Stryker armored vehicle.

B. Object and Emission Libraries

SWORD comes with libraries of pre-built gamma-ray and neutron detectors, emission spectra and environmental objects such as vehicles, buildings, containers, etc. The detectors and other objects are built in SWORD from primitive volumes. They can be user-modified as required and saved in a user library. As with all SWORD objects, any object can be defined as a detector or an emission source. Library objects can be dropped in to existing scenarios as required.

Included emission spectra are stored as XML text files and can be modified as required. Emission spectra, both lines and continua, can be user-created as well either from scratch of as modifications to existing spectra. Instructions are included in the SWORD documentation. User-created spectra appear in the GUI as emission source options.

C. Radiation Transport Code Integration

Once a SWORD model is created, simulations using that model can be run directly from SWORD. SWORD supports integration with the Geant4 and MCNP Monte Carlo codes and with the Denovo discreet ordinates code. The same SWORD model can be run on all three codes, albeit with a few limitations on source definitions. SWORD ships with Geant4 installed and ready to use out of the box. The user must acquire MCNP or Denovo separately, but integration with SWORD is straightforward.

D. Result Aggregation and Analysis

Once the radiation transport simulation has been run within SWORD using Geant4, data in the form of energy deposits are aggregated. Runs using MCNP or Denovo do not aggregate individual energy deposits. SWORD supports automatic aggregation across multiple cores on a single computer or across multiple computers. In the case of runs on supercomputer systems, data can be aggregated manually after download from the supercomputer. SWORD produces text files containing records of the integrated energy deposit for each emitted particle for each detector volume. Manual aggregation is as simple as concatenating these text files. In addition, the model can specify an “instrument” consisting of one or more

detectors. The SWORD analysis process applies energy resolution smearing for the instrument-aggregated data then creates a histogram spectrum in an ANSI/IEEE N42.42 compliant XML format [5]. The analysis process can be run as often as desired without necessarily rerunning the radiation transport code, saving time if the user desires to investigate different energy resolution parameters or different combinations of detectors.

The analysis process will also produce images from models set up with imaging detectors. Simple algorithms are used for both coded aperture and scatter camera image production. Images are stored in the NASA Flexible Image Transport System (FITS) format [6].

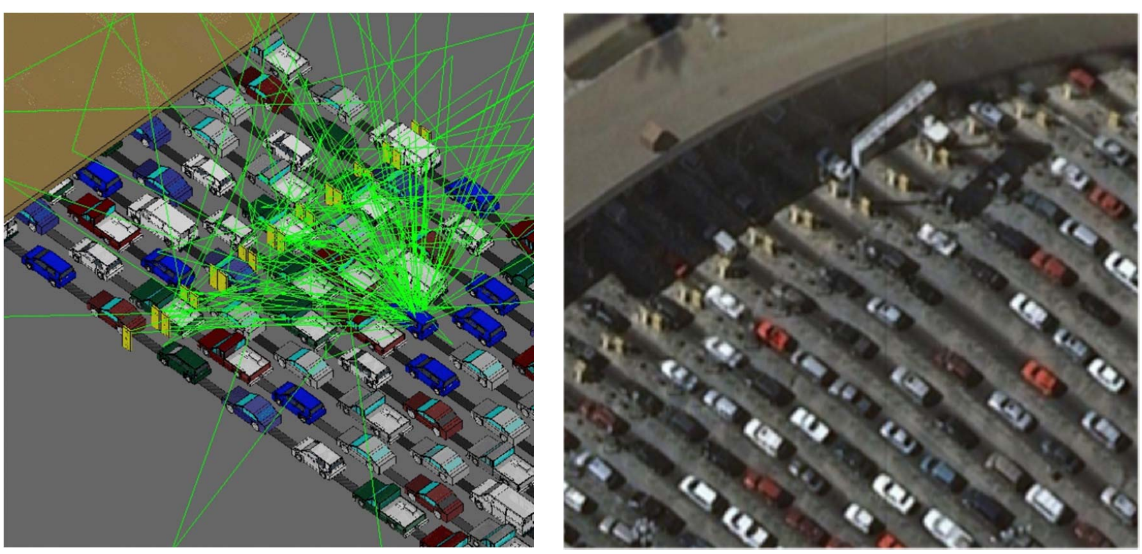

Fig. 3. SWORD simulation of Tijuana border crossing (left) and photo of actual crossing (right).

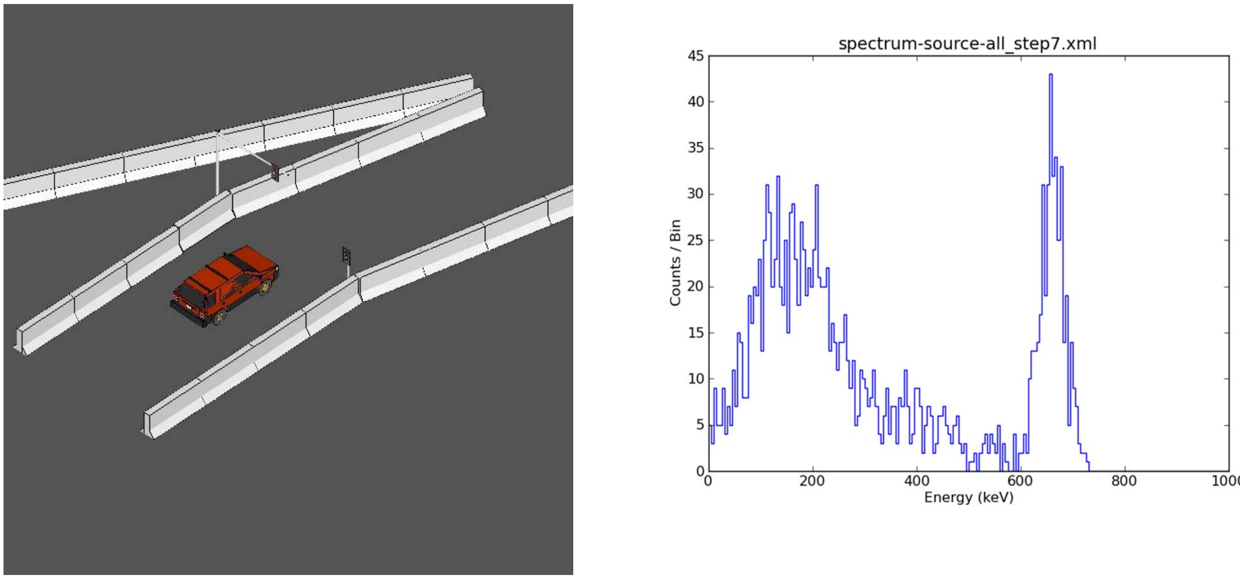

Fig. 4. SWORD simulation of car containing radioactive source passing roadside detector (left) and resulting detected spectrum (right).

E. *Result Visualization*

SWORD ships with several visualization tools that can also perform limited data analysis. A spectrum viewer displays spectra both with and without energy resolution smearing applied.

The Spectrum Analyzer application allows fitting of gaussian spectrum lines with a simple polynomial continuum model. Spectra in both N42.42 XML and International Atomic Energy Agency (IAEA) ASCII SPE formats are supported. Fit parameters can be constrained as required to allow controlled analysis of partially resolved line features. Fit results are stored in both single, detailed files and in summary form with multiple fits in a single file. The latter allows easy analysis of variation between spectra, for example, as a function of time. Spectrum Analyzer also includes a library of common gamma-ray line features.

An Image Viewer application supporting FITS format images will display the image and allow simple analyses.

The use of standardized output formats allows the use of the many third party tools developed for these formats.

III. SWORD EXAMPLES

By way of examples of SWORD homeland security use cases, we will discuss land, maritime and aviation projects for which SWORD has been used at NRL:

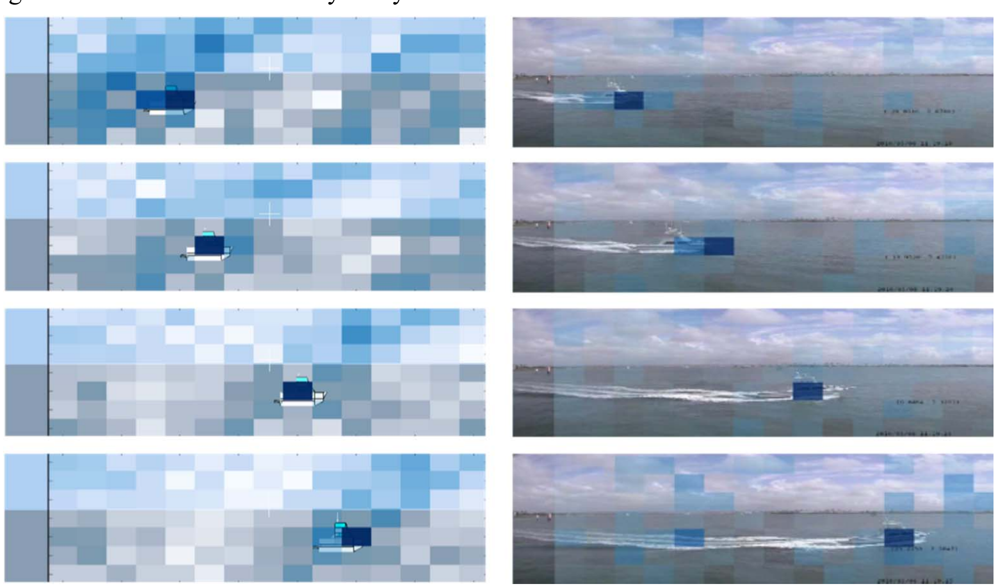

Fig. 5. Coded aperture images of gamma-ray source on a boat passing by the SuperMISTI detector. Simulation on the left, actual images on the right.

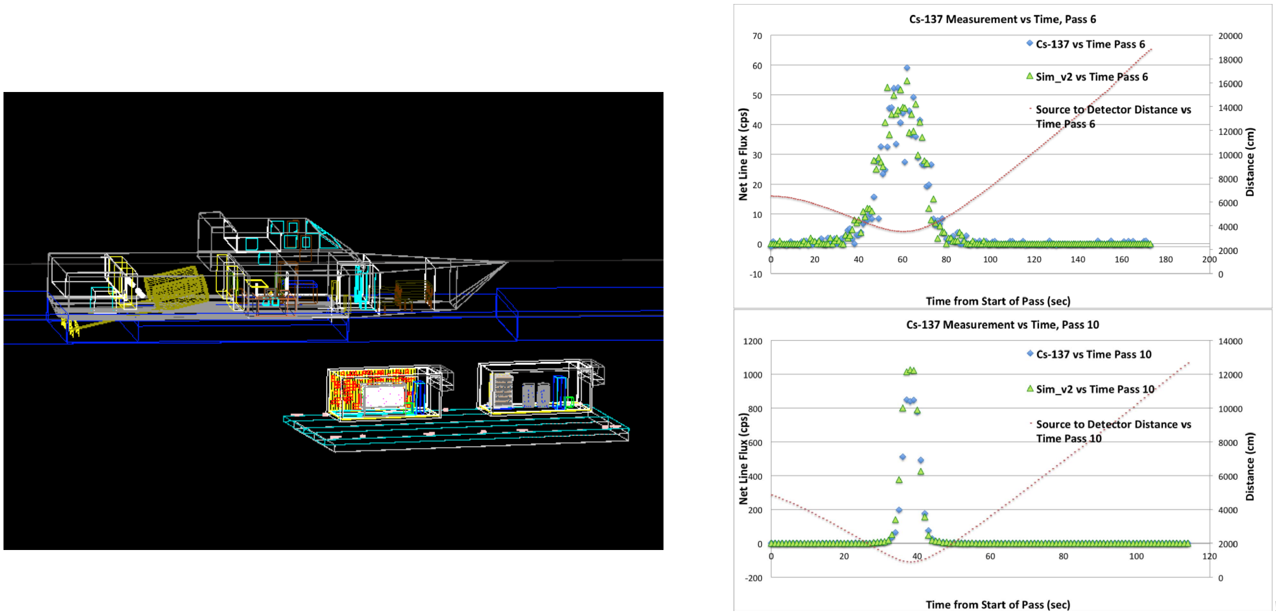

Fig. 6. SWORD model of MANTA test run with SuperMISTI on a barge in the foreground and the target boat behind (left). Comparison of Cs-137 line flux from vs time from two different test runs. Measurement in blue and simulation in green (right). Note reasonable agreement between simulation and data.

A. Land

SWORD has been used extensively to model radiation detectors being developed for the Nuclear, Biological, Chemical Reconnaissance Vehicle (NBCRV) version of the Stryker armored vehicle. This work was performed for Space and Naval Warfare Systems Command (SPAWAR), DTRA and the Joint Program Executive Office for Chemical, Biological, Radiological and Nuclear Defense (JPEO-CBRND).

Fig. 2 shows the SWORD model of the Stryker vehicle, based on CAD drawings and physical examination of the vehicle. The model was used to evaluate the response of new radiation detectors to a variety of situations that might be encountered during NBCRV operations including response to Radiological Dispersion Devices (RDD) and nuclear devices.

In addition to modeling complex vehicles like the NBCRV Stryker, SWORD has been used to model complex scenarios with a variety of moving objects. Fig. 3 is a single frame from an animation of a SWORD model of vehicles passing through the border crossing at Tijuana, Mexico. The green lines are tracks of gamma-rays from a source in the blue vehicle that interact with detectors in the yellow portal detection systems. The actual border crossing is shown in the accompanying photograph. Such simulation result displays can make preliminary evaluation of detector operations at a glance easy to perform.

SWORD has been used for extensive modeling of detection capabilities of potential roadside radiation monitor systems. A variety of simulations using SWORD have been performed to evaluate detectability of various radioactive objects in vehicles moving past detectors at a variety of speeds and distances. Fig. 4 shows an example of one of these simulation scenarios.

B. Maritime

NRL has been involved in two extensive maritime radiation detection campaigns that each had significant simulation components performed using SWORD. The Domestic Nuclear Detection Office (DNDO) Dolphin campaign (2010), in which one component included sources on boats passing by a large NRL gamma-ray detection system (SuperMISTI), was simulated after the fact and validated against measured results. Measured and SWORD-simulated gamma-ray coded aperture image results from SuperMISTI have been overlaid and are shown in Fig. 5. This test demonstrated the ability to detect relatively weak sources at relative long ranges (on the order of tens of meters) using a large imaging gamma-ray system and to be able to accurately simulate the detection process.

In the Office of Naval Research (ONR) MANTA campaign of 2012 various gamma-ray and neutron detectors on vessels were sailed passed a selection of stationary vessels, one of which contained a source. The detection systems had to make a blind identification of the source and vessel. SWORD was used extensively to predict results before the test in order for the experimenters to scale their efforts. After the test, simulations of the actual vessel tracks were performed to validate the SWORD models against the measured data. Results from this validation for the NRL SuperMISTI detector on a barge are shown in Fig. 6.

C. Aviation

SWORD comes equipped with detailed aviation models including a fully populated 737 airliner model. This model is

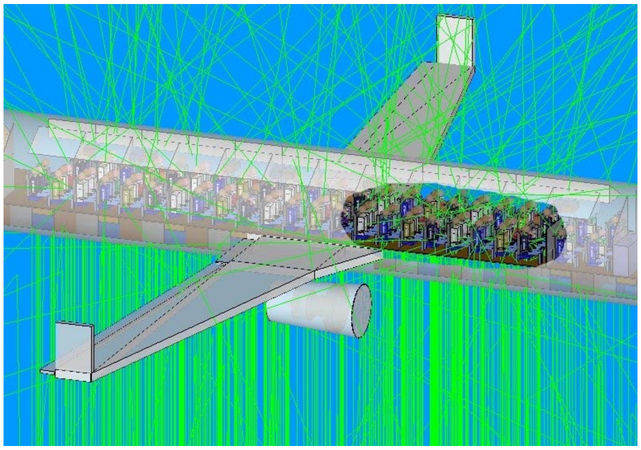

Fig. 7. Simulation of terrestrial gamma ray flash photons striking airliner.

usable for detection scenarios and has been used for modeling dose effects from terrestrial gamma-ray flashes (TGFs) and other natural high energy phenomena. Fig. 7 shows the SWORD 737 model with gamma-ray tracks from a simulated TGF.

In addition, SWORD modeling has been used as part of a George Mason University/NRL Surveying Pathways for Energetic Radiation Background (SUPERB) program for DHS/CWMD, tasked with establishing baseline gamma-ray and neutron background environments along potential aviation-related covert nuclear material smuggling pathways. Data are taken during both passenger and cargo flights. The program uses SWORD modeling and simulation to try to resolve unusual data features, such as transport of medical isotopes.

IV. Conclusion

SWORD has been used to implement simulations for a variety of radiation transport questions, many of which have been directly related to homeland security issues, particularly weapons of mass destruction detection. While many of these simulations can be performed without SWORD, the process almost inevitably takes much longer and requires personnel with more specialized experience. Using SWORD, virtually anyone with the required physics background can run complex radiation transport simulations with a minimal learning curve.

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