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APPLICATION OF THE ORIGEN FALLOUT ANALYSIS TOOL AND THE DELFIC FALLOUT PLANNING TOOL TO NATIONAL TECHNICAL NUCLEAR FORENSICS

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ABSTRACT

The objective of this project was to provide a robust fallout analysis and planning tool for the National Technical Nuclear Forensics interagency ground sample collection team. Their application called for a fast-running, portable mission-planning tool for use in response to emerging improvised nuclear device (IND) post-detonation situations. The project met those goals by research and development of models to predict the physical, chemical, and radiological properties of fallout debris. ORNL has developed new graphical user interfaces for two existing codes, the Oak Ridge Isotope Generation (ORIGEN) code and the Defense Land Fallout Interpretive Code (DELFIC). ORIGEN is a validated, radionuclide production and decay code that has been implemented into the Fallout Analysis Tool to predict the fallout source term nuclide inventory after the detonation of an IND. DELFIC is a validated, physics-based, research reference fallout prediction software package. It has been implemented into the Fallout Planning Tool and is used to predict the fractionated isotope concentrations in fallout, particle sizes, fractionation ratios, dose rate, and integrated dose over the planned collection routes—information vital to ensure quality samples for nuclear forensic analysis while predicting dose to the sample collectors. DELFIC contains a particle activity module, which models the radiochemical fractionation of the elements in a cooling fireball as they condense into and onto particles to predict the fractionated activity size distribution for a given scenario. This provides the most detailed physics-based characterization of the fallout source term phenomenology available in an operational fallout model.

Key Words: DELFIC, ORIGEN, fallout models, radionuclide fractionation, nuclear forensics

1 INTRODUCTION

Nuclear forensics includes the analysis of radioactive debris following a nuclear explosion. This requires the collection of fallout samples from potentially dangerous radiation areas. The tools described in this paper are used by researchers and mission planners to direct the ground sample collection team, which is comprised of personnel from the Federal Bureau of Investigation, the U.S. Department of Defense, and the U.S. Department of Energy (the FBI/DOD/DOE National Technical Nuclear Forensics [NTNF] Integrated Collections Task Force). In particular, the tools are used for predicting the best sample locations while calculating dose to the collectors. The tools help describe the physical, chemical, and radiological properties of fallout. Oak Ridge National Laboratory (ORNL) has developed two user-friendly software tools: the Oak Ridge Isotope Generation (ORIGEN) Fallout Analysis Tool and the Defense Land Fallout Interpretive Code (DELFIC) Fallout Planning Tool.

2 THE ORIGEN FALLOUT ANALYSIS TOOL

The ORIGEN Fallout Analysis Tool is used to define the radiological source term following a nuclear explosion. It provides a new software interface for doing detailed analysis of the fallout radiological source term produced by ORIGEN.

2.1 ORIGEN

The ORIGEN code is a widely used irradiation and decay code that has been used for more than three decades [1]. It is the standard for nuclear weapon fallout radionuclide inventories [2, 3]. It tracks the generation and decay of fission products, actinides, and activation products. It tracks all nuclides over all time, instead of reverting to subsets of nuclides or decay approximations. ORNL has created an advanced neutron cross-section processing capability for use with ORIGEN to predict these radioactive products. It has been used by ORNL to create generic fission product inventories for use in the Defense Threat Reduction Agency's (DTRA's) Hazard Prediction and Assessment Capability (HPAC) as well as by DOE's National Atmospheric Release Advisory Center. As implemented in the ORIGEN Fallout Analysis Tool, it can be used to create problem-specific inventories of fission products, actinides, and activation products that provide more detail than the generic inventories.

2.1.1 Recent advancements to ORIGEN

Many improvements to ORIGEN over the past several years have advanced its ability to predict nuclide inventories, including fallout inventories [1]. Some of these advancements were done specifically for the fallout problem. New ORIGEN libraries were developed under a previous DTRA-sponsored project for activation analysis, actinide transmutation (e.g. ^{237}U, ^{239}U, ^{239}Np, and ^{240}Np), and fission product production and decay. Procedures were developed to enable users to create a problem-dependent ORIGEN cross-section library, given a known or calculated neutron spectrum.

The nuclear data used within ORIGEN have been updated to use modern Evaluated Nuclear Data Files (ENDF/B) evaluations. In particular, ENDF/B-VII decay data, energy-dependent fission yields for 30 actinides, and fine-group neutron cross-section data based on Joint Evaluated Fission and Fusion (JEFF) 3.0/A special-purpose activation files have been added to the version of ORIGEN being used with the Fallout Analysis Tool. Advanced methods and data for analysis of the photon source associated with the nuclide inventory were also added to the code. These advancements will be included in the Standardized Computer Analyses for Licensing Evaluation (SCALE) 6.1 version of ORIGEN soon to be released by ORNL [4].

2.2 Fallout Analysis Tool

The Fallout Analysis Tool graphical user interface (GUI) is designed for specific studies concerning the time-dependent inventories within fallout. Fallout sources are modeled with SCALE using the activation/decay code ORIGEN. Some of the available analyses include plotting the time-dependent inventories, exporting the photon source associated with an inventory, activity-size distribution analysis, and some simple plotting of dose rate contributions over time.

The main Fallout Analysis Tool GUI consists of numbered panels down the left-hand side, indicating the typical order of use for a complete fallout analysis. There are generally four steps:

1. Edit Model Parameters—the user edits the required technical information and the calculation parameters required for an ORIGEN run. When the model parameters have all been entered, SCALE can be run.
2. Run Model Using SCALE—the user performs the ORIGEN calculation. ORIGEN will be executed to perform the irradiation and decay calculations for each time step during irradiation and through the maximum decay time. ORIGEN is quite fast, requiring less than one minute for typical fallout calculations. A successful SCALE run produces an ORIGEN binary concentration file (a *.F71 file).
3. View SCALE Files—the user can review the SCALE input file created by the GUI, messages normally sent to the DOS prompt by SCALE, error messages if SCALE did not finish properly, and the full text output file. The user can also see all of the irradiation and decay time step inventories listed in the binary file using the F71 File Explorer utility program.
4. Advanced Analysis—using the F71 File Analyzer on the generated *.F71 file, the Fallout Analysis Tool can model radionuclide fractionation, which is important to post-detonation forensics.

At the top of the main Fallout Analysis Tool display are menus that allow users to create new model input files, load previously created files, run one of the utility programs, or display the help file. Users can load a previously saved model input file and start with step 2. Users can load a previously generated output file and start with step 3 using the F71 File Explorer. Users can also start the advanced analysis on any *.F71 file using the F71 File Analyzer.

2.2.1 Edit model parameters

Three sets of information are required to simulate the irradiation/decay problem for fallout: the ORIGEN library file for cross sections that corresponds to the problem-dependent neutron spectrum, the parameters relating to the irradiation and decay of the fallout source, and the composition of the fuel and activation materials. The model-editing dialog is laid out in numbered panels for each of the above three types of information as well as for a problem description and the internal ORIGEN neutron/photon spectra group structures.

For the library of cross sections, SCALE comes with quite a few different libraries covering many of the more popular reactor fuel forms. For a fallout source, typically a library corresponding to a neutron spectrum faster than a reactor is used. The appropriate library needs to be selected.

Two parameters are not physical parameters but are calculation parameters—they control how many subdivisions to use within each simulated cycle. The more subdivisions there are, the more accurate the calculation but the longer the calculation time. The first of these parameters, the number of steps during irradiation, controls how often the nuclide inventories are updated during the irradiation to account for the buildup and depletion of isotopes as a function of time. A value of 10 is the default.

The second calculation parameter is the number of decay steps per decade of time. This value sets how many time steps per decade will be computed as the decay time runs from the end of the irradiation to the last decay time listed. Larger values of this parameter make ORIGEN run times longer and create larger binary concentration (*.F71) files for the final output. The benefit of large values (~10) for this parameter is smoother curves when plotting the activity of isotopes over time. The user should list at least one decay time desired. Other significant times can be listed so that there will be an evaluation at that specific time. Otherwise, the time steps will be logarithmically spaced between the end of the irradiation and the maximum of the listed decay times.

The fuel composition is divided into two tabs—one tab for U and Pu (all that is needed for most studies) and the other tab, where any isotope can be entered. For the U and Pu isotopes, the total amounts can be entered followed by the weight fractions of the common isotopes. The basis is a string description of what is being modeled. In a typical ORIGEN calculation, this is “reactor core,” “per metric ton,” “assembly,” or other unit.

For problems requiring the use of more isotopes, such as structural activation materials, the second tab can be used. In this tab, isotopes and their amounts can be entered or changed one at a time. The user can select a specific isotope by first selecting the element from a periodic table display, then selecting the isotope and metastable state from pull-down lists.

For a large list of isotopes, the “Import” button can be used. This button will open a small dialog box, where the user can paste data from Excel or a text editor. The data must consist of two columns: the isotope number and the amount in grams. Some elements list “natural” as a choice for isotope. This indicates that the element has been evaluated with its isotopes weighted according to their natural abundances.

2.2.2 F71 File Explorer

The F71 File Explorer allows users to plot the results of the calculation in a variety of ways (masses, atoms, or activities) for selected subsets of isotopes for selected subsets of time. Results can also be grouped by element or by mass number. Neutron and gamma ray spectra can be exported to a text file or formatted as source definitions for input to the Monte Carlo N-Particle Transport (MCNP) or Monaco Monte Carlo codes (part of SCALE 6) [5].

The F71 File Explorer is an excellent tool for analyzing the inventories of any irradiation and decay solution, including fallout sources. It tracks all the isotopes created over all the times of interest. It allows you to see the top contributors for the time window selected using the units of interest for the problem being investigated. The contributions from approximately 2000 isotopes over times of interest from less than a second to more than a century can be explored using the tool. Data used to produce the plots can also be exported as a text list for use in other programs.

2.2.3 Export photon source

The photon source can be displayed and/or exported for any or all of the subsets of isotopes (fission products, actinides, and activation products). The photon source data can be exported in Monaco, MCNP, or generic formats, ready for use by these and other external codes. The photon source can include contributions from gamma rays, X-rays, and continuum sources. The photon source can be represented by discrete lines or multiple energy group bins. Since there can be on the order of tens of thousands of discrete lines, different criteria can be used to determine which lines to keep and which ones to bin into groups. Photon spectra can be rebinned into any specific group structure provided or into any number of uniform bins. Once the above choices have been made, the photon source can be exported as a text file for use in a variety of applications. One such application would be to create the photon source for a code such as Gamma Detector Response and Analysis Software (GADRAS) to simulate the detector response to the fallout source term.

2.2.4 F71 File Analyzer

The F71 File Analyzer was designed to perform specific analyses for fallout studies. The plan is to add more capability over time to this tool. Available analyses include activity-size distribution analysis and some simple plotting of dose rates over time.

The main window of the F71 File Analyzer contains three tabbed panes: “Selection,” “Plot,” and “Data List.” The user can move among the three panes simply by clicking on the tabs. After performing certain calculations, a different pane will be automatically selected to show the results. Some calculations post results on both the “Plot” and “Data List” panes. The data shown in the “Data List” pane can be selected with the mouse and copied into a word processor or spreadsheet for further analysis.

The main tabbed pane, “Selection,” is divided into two panels. The left-hand panel allows the user to select one or more time steps from the ORIGEN binary concentration file (*.F71 file). The right-hand side lists the available analyses that the user can perform. These analyses include activity-size distributions (using the established DELFIC fractionation model based on the work of Freiling [6, 7]), special plots such as relative isotopic contributions to dose rate over time (e.g., Fig. 1), creating HPAC NWPN (nuclear weapon module) formatted source term files, and rank ordered lists of isotope contributors to the integrated dose for various times of interest for groups such as the Federal Radiological Modeling and Assessment Center.

2.2.5 Activity-size distributions

The first step in an activity-size distribution analysis using DELFIC’s fractionation model is to select the time step from the *.F71 file corresponding to the time of soil solidification. Only one time step can be chosen for this analysis. Then, one must specify two parameters needed to distribute the activity among the groups specified in the particle size distribution: the soil solidification temperature and the particle size cutoff diameter.

An element (more often the oxide of the element) is classified as refractory if its boiling point is higher than the soil solidification temperature. For each mass chain, the fraction of moles that are refractory can be calculated. Yields for each mass chain (totaling 2 over all mass chains) can be displayed using the “Yield” button, which produces the familiar double-humped curve for the case selected. The total number of fissions that occurred based on the sum of the fission product amounts can be displayed using the “Summary” button.

The activity-size distribution as a function of particle diameter and mass chain can then be calculated. This distribution can be shown by choosing which mass chains to calculate and plot. The distribution can be summed over all mass chains to create a single activity-size distribution of particular interest in fallout studies. Distributions can be plotted as either probability density functions or cumulative distribution functions.

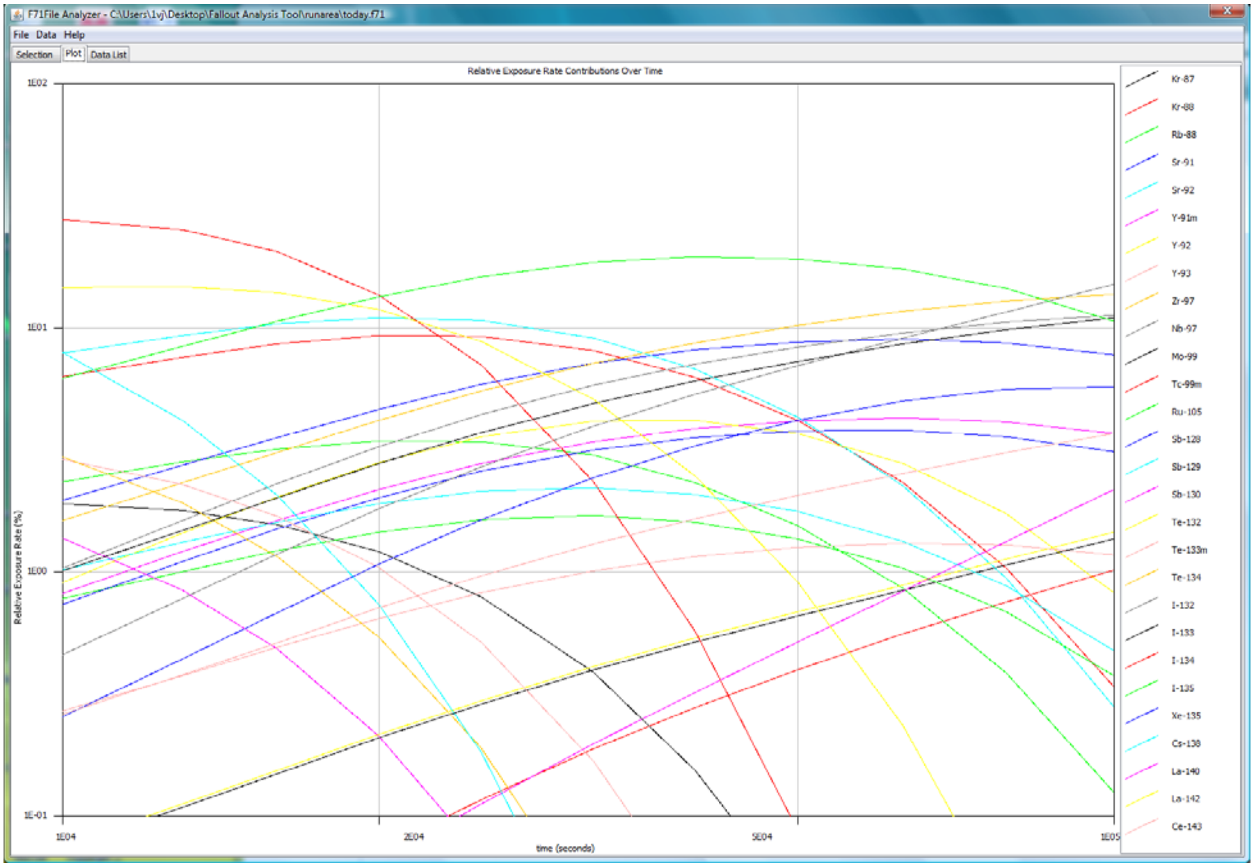

Figure 1. Fallout Analysis Tool Relative Exposure Rate Contributions Over Time

Amounts of refractory isotopes, volatile isotopes, and other isotopes (that have yet to be classified when no boiling point is listed, such as for light elements and actinides) can all be exported as separate *.F71 files for further independent analysis.

The above analysis uses two static data sets: (1) the elemental (oxide) boiling point temperatures used to classify elements as either refractory or volatile when compared with the soil solidification temperature and (2) a default particle-size distribution (both taken from DELFIC). Both of these data sets can be plotted and listed as tables in the other tabbed panes using the Data menu of the F71 File Analyzer window.

2.2.6 Special plots

Special plots can be created for activity or dose rates over time, either as totals or by fraction for each isotope. Typically, a group of cases from the *.F71 file are selected for those plots. Dose rates can be calculated using two different sets of activity-to-dose-rate conversion factors:

- Point Source—using the factors by Unger and Trubey [8], compute dose rate (mSv/hr) for a given activity (MBq) of an isotope at a point one meter away from a person (they are not for exposures from ingestion, inhalation, or ground deposition).
- Ground Shine—using the dose conversion factors by Eckerman and Leggett [9], determine each nuclide’s contribution to external exposure rate (R/hr) or dose rate (rem/day). The activity due to these radionuclides is concentrated on the ground (Ci/m^2), for an infinite

extent. This option requires the user to specify the contamination area that the nuclides from the *.F71 file should be spread over to determine the isotope's concentration.

3 THE DELFIC FALLOUT PLANNING TOOL

ORNL has developed the Fallout Planning Tool interface to DELFIC tailored to the interagency ground sample collection mission. It uses Google Maps and Google Earth interfaces for route planning and four-dimensional (4D) visualization of results. Operationally it is used by the FBI/DOD/DOE NTNF Integrated Collections Task Force. It provides the physical, chemical, and radiological properties of the fallout field to guide quality sample collection.

3.1 DELFIC

DELFIC tracks dose rates, integrated doses, times of arrival, particle sizes, and activity concentrations as a function of location and time. It is the DOD's research reference fallout code originally developed by DTRA's predecessors: the Defense Atomic Support Agency and the Defense Nuclear Agency [10]. It is composed of four main modules: cloud rise, diffusive transport, particle activity, and output processor. ORNL has made substantial improvements to DELFIC as a part of this NTNF project.

3.1.1 Cloud rise module

The DELFIC Cloud Rise Module (CRM) is a dynamic, one-dimensional, entraining parcel model of buoyant cloud rise. It solves a set of coupled ordinary differential equations that represent the conservation equations for momentum, mass, and turbulent kinetic energy. It provides the solution for the state variables of the parcel (e.g., temperature) as a function of time. As a physics-based model, it is responsive to the current atmospheric properties, which include temperature inversions, relative humidity, and wind shear. The lapse rate affects the buoyancy and rate of rise of the cloud. The relative humidity affects the amount of latent heat released when the moisture condenses and freezes. The wind shear affects the rate of entrainment of ambient air into the rising cloud.

The solution from the dynamic parcel model is then used to solve the stabilized cloud particle size height distribution. This is done by tracing the particle's rise due to the parcel rise and superimposing the particle-settling velocity as a function of the different particle sizes in the distribution (i.e., it discretizes the stabilized particle cloud into a number of vertical layers based on the yield of the detonation). Each layer is replicated at the start of the particle rise for each particle size group. Since each size group has the same parcel rise velocity but different settling rates, layers that are co-located at the start of the particle rise end up stabilizing at different altitudes, thereby simulating particle fallout during cloud rise. The parcels in DELFIC's CRM are then transported in the horizontal due to advection during cloud rise. A simplified version of the DELFIC CRM without this advection during cloud rise is used in HPAC's nuclear weapon source term model.

3.1.2 Diffusive transport module

The DELFIC Diffusive Transport Module is a disk-tosser transport and dispersion code. That is, it discretizes the cloud into disks instead of Gaussian puffs or Lagrangian tracer particles. It takes the solution from the particle rise calculation as the initial conditions for each disk that is to be transported. Each layer for each particle size is represented by a disk of finite thickness with a top, base, and radius. These disks are then subjected to spatially and time-varying winds along with gravitational settling to determine their landing positions. The disks grow due to turbulent diffusion during their transport.

3.1.3 Particle activity module

The DELFIC Particle Activity Module (PAM) calculates the distribution of activity with particle size. DELFIC is the only existing operational fallout code that predicts fractionation into and onto particle surfaces. DELFIC and its PAM have been around since the late 1960s. According to Freiling, fractionation is any alteration of radionuclide composition occurring between the time of detonation and the time of radiochemical analysis, which causes the debris sample to be nonrepresentative of the detonation products as a whole [6]. There are both chemical fractionation and physical fractionation. Chemical fractionation distributes refractory species throughout the volume of the particles and volatile species on the surface of the particles. Refractory species are those elements (or oxides) that are in the liquid soil droplets when they solidify. Volatile species are those elements (or oxides) that are still in the gaseous phase when the liquid soil droplets solidify. Physical fractionation is caused by the separation of the larger particles from the smaller particles. Larger particles fall out early and close-in, where refractories dominate, due to their smaller surface-to-volume ratio. Smaller particles fall out later and further downwind, where volatiles dominate.

The DELFIC PAM is based on Freiling's Radial Distribution Model, which was modified by Tompkins [10]. It predicts the activity size distribution for each mass chain and for the total fallout based on the refractory fraction of each mass chain at the time of particle solidification. It has been added to the ORIGEN Fallout Analysis Tool (described earlier) for detailed studies of chemical fractionation. Combined with the physical fractionation due to particle settling during cloud rise, DELFIC gives the most complete activity-size and activity-height definition of the fallout source term available for use in fallout codes.

3.1.4 Output processor module

The DELFIC Output Processor Module allows the user to request one of 18 different map types to display the physical, chemical, or radiological properties of the fallout footprint. The variety of quantities that can be displayed help in the interpretation of the fallout conditions. The map types available from DELFIC are listed in Table I.

3.1.5 Recent advancements to DELFIC

ORNL has made several key advancements to DELFIC, primarily within the PAM [11]. ORNL started with the 1992 version of DELFIC, maintained by SAIC. ORNL updated the fission yields, improved the way that nuclear data are stored, and corrected changes made by SAIC that introduced errors into the way DELFIC handled branch merging among the decay chains. Upgrades included replacement of the nuclear data with information from ENDF/B-VII, expansion of the robustness of the decay engine, and further expansion of the exposure rate multipliers.

3.2 Fallout Planning Tool

ORNL tailored the DELFIC Fallout Planning Tool interface to the interagency ground sample collection mission. It uses Google Maps and Google Earth interfaces for route planning and 4D visualization of results. Operationally, it is used by the FBI/DOD/DOE NTNF Integrated

Collections Task Force. It provides the physical, chemical, and radiological properties of the fallout field to guide quality sample collection while calculating dose to the collector.

The Fallout Planning Tool GUI allows the mission planner to manage individual projects that typically represent unique scenarios. Within a specific project or scenario, the mission planner has to accomplish a series of tasks: (1) define event, (2) define meteorology, (3) calculate fallout, (4) define routes, and (5) calculate dose. After accomplishing these tasks, the mission planner can produce 4D visualizations of the fallout characteristics as well as the collection routes.

Table I. DELFIC map request options

Type	Description
1	Count of fallout deposit increments that contribute to each map ordinate
2	Exposure rate normalized to H+1 hr (Note: H hr is the time of detonation)
3	Exposure rate at time H+T1 hrs, accounting for time of arrival of fallout
4	H+1 hr normalized exposure rate due to particles of size d1 to d2
5	Integrated exposure from H+T1 hrs to infinity, accounting for time of arrival of fallout by the approximate method
6	Integrated exposure from H+T1 to H+T2 hrs, accounting for time of arrival of fallout by the approximate method
7	Integrated exposure from H+T1 to H+T2 hrs, assuming all fallout has arrived by H+T1
8	Integrated exposure from H+T1 hrs to infinity, assuming all fallout has arrived by H+T1
9	Integrated exposure from H+T1 hrs to infinity, accounting for time of arrival of fallout by the exact method
10	Integrated exposure from H+T1 to H+T2 hrs, accounting for time of arrival of fallout by the exact method
11	Mass of fallout per unit area
12	Mass of fallout per unit area deposited from H+T1 to H+T2 hrs
13	Mass of fallout per unit area deposited by particles of size d1 to d2
14	Activity per unit area from an individual mass chain at H+T1 hrs in units of curies m^{-2}, or in equivalent fissions m^{-2} if T1=0.
15	Time of onset of fallout
16	Time of cession of fallout
17	Diameter of smallest particle deposited
18	Diameter of largest particle deposited

3.2.1 Define event

The first task for the mission planner is to define the event. The mission planner needs to provide some basic information such as yield, height of burst, location, and time of the event. Additional information can be entered, such as the fission yield (if different than the total yield), fission type, and soil type (which affects the radiochemical fractionation). Also within this task, the mission planner must select which map types are to be calculated, the domain and resolution desired for the maps, and the times of interest for the maps. Any of the 18 map types provided by the historical DELFIC can be requested in addition to two new map types added by ORNL: the specific activity of the fallout in equivalent fissions per gram and the fractionation ratio of two different mass chains. Both of these new map types are key inputs to mission planning.

3.2.2 Define meteorology

The meteorological data needed by DELFIC includes both an atmospheric profile for temperature, pressure, and relative humidity as a function of altitude as well as time and/or spatially varying winds. Both the atmospheric profile and the initial wind profile are used for the cloud rise calculation whereas the time and/or spatially varying winds are used by the diffusive transport module.

Different options are available to the mission planner. A single effective wind can be input that will not vary with altitude, in which case the Fallout Planning Tool will use U.S. Standard Atmosphere for the atmospheric profile. The more common options, however, include the use of the National Oceanic and Atmospheric Administration weather servers for downloading either forecast data or observation data. Another option currently provided includes the use of HPAC's historical upper air climatology data. The option of importing the weather data by file upload is provided if an alternative meteorology source is available.

3.2.3 Calculate fallout

Mission planners have to complete three subtasks within the Calculate Fallout task. (1) create the DELFIC input deck based on the entries in the "Define Event" and "Define Meteorology" tasks; (the user can also import a previously created or edited DELFIC input deck for this first subtask); (2) run DELFIC to create the DELFIC output file; and (3) generate the visualization of the results. An optional fourth step is to create a PDF report that contains the information entered into the GUI in the tasks above plus a single-page map over the domain requested for each map type requested.

3.2.4 Define routes

Now that visualizations of the physical, chemical, and radiological properties of the fallout have been created, they can be overlayed onto maps of the area to plan collection missions. Mission planners can use Google Maps (Fig. 2), OpenStreetMap, or their own map images as background for the fallout maps to be overlayed onto. The individual fallout map for any quantity can be displayed with the contours requested. In addition, display boxes showing the map value at the mouse position allow the planner to see the exact value of the mapped characteristic at the grid point resolution used. Multiple mouse-over boxes for different characteristics can be displayed together so that the planner can see the correlation between two different characteristics as a function of location. This helps the planner see instantaneously which locations will satisfy multiple criteria that may be desired, such as concentration of activity and dose rate. After the map has been explored for desired locations for sampling, the mission planner can plot a route by selecting a starting location, selecting one or more way points along the desired sampling route, and continuing until the last point of the route is entered, typically back at the base of operations where the route started. The planner can enter the speed of travel as well as the time spent at any way point to perform a sample collection. Multiple routes may be created for any given scenario.

3.2.5 Calculate dose

After the routes are created, the dose along them can be calculated. To accomplish this, the mission planner must select the route and the start time for the route. The Fallout Planning Tool then calculates the dose accumulated along each route segment and at each way point where a collection time was entered. The Fallout Planning Tool also calculates the distance and time for each segment and collection point to produce a table for the selected route and mission start time. The distance, time, and (most importantly) dose are displayed for each segment and collection point along with the route totals. This total predicted dose for the route can be compared to operational exposure guidance. Of course, the collection team will only use this for planning and will rely on actual measured dose rates and doses for managing the team during the collection mission. A visualization of the selected route(s) can be generated at the end of this task.

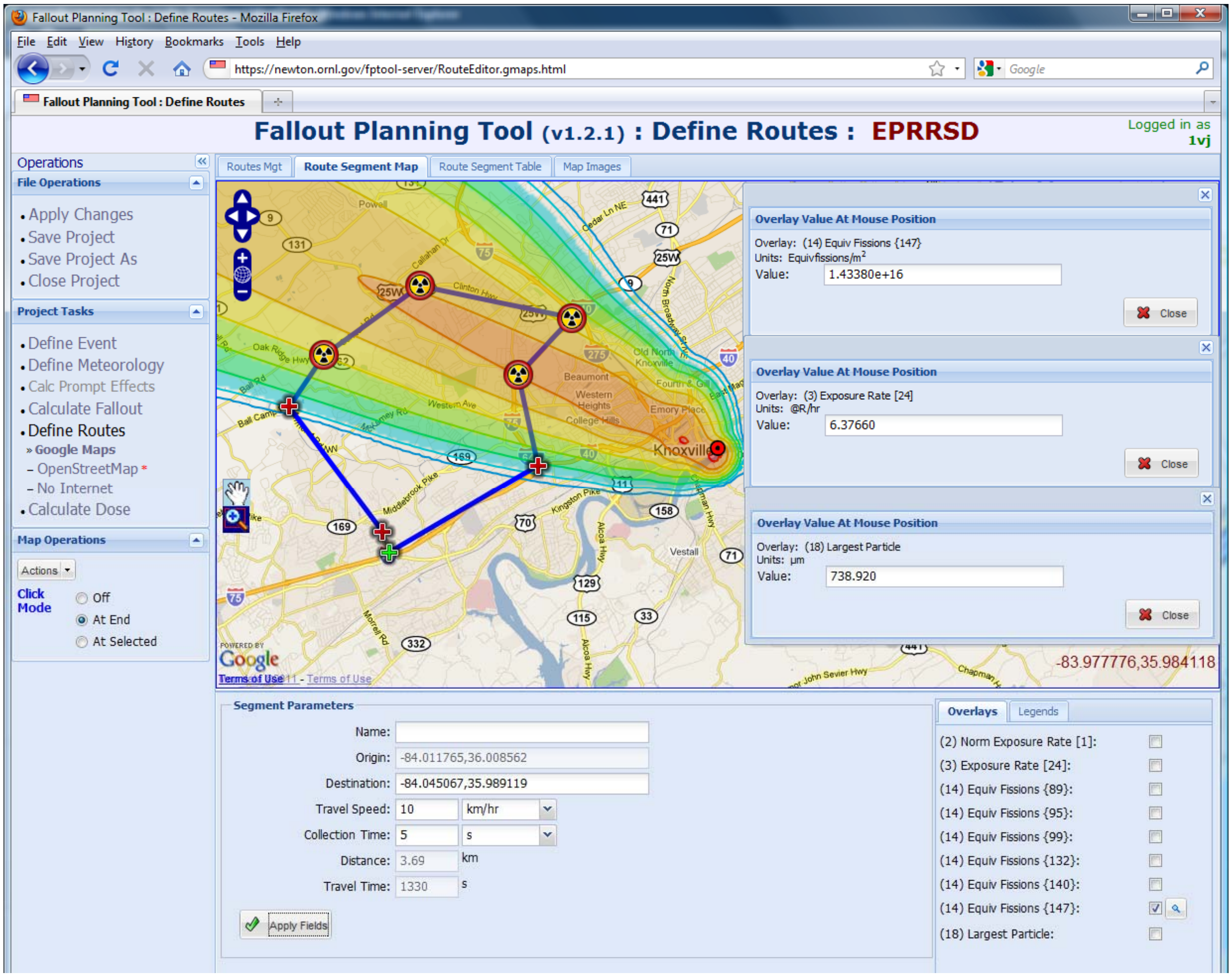

Figure 2. Fallout Planning Tool Define Routes task

3.2.6 Visualizations

The results of the Calculate Fallout task and the Calculate Dose task can both be converted into Keyhole Markup Language (KML) visualizations for display with Google Earth. This provides a robust spatial *and temporal* visualization of the fallout properties and the collection sorties. This provides a convenient capability to transfer the results of the mission planning process to others with a KML viewer. Some examples of the power of the 4D KML format are showing the rapid decay of the dose rate field with time and providing fly-through-track visualization along the route that may be unfamiliar to those going into the fallout field.

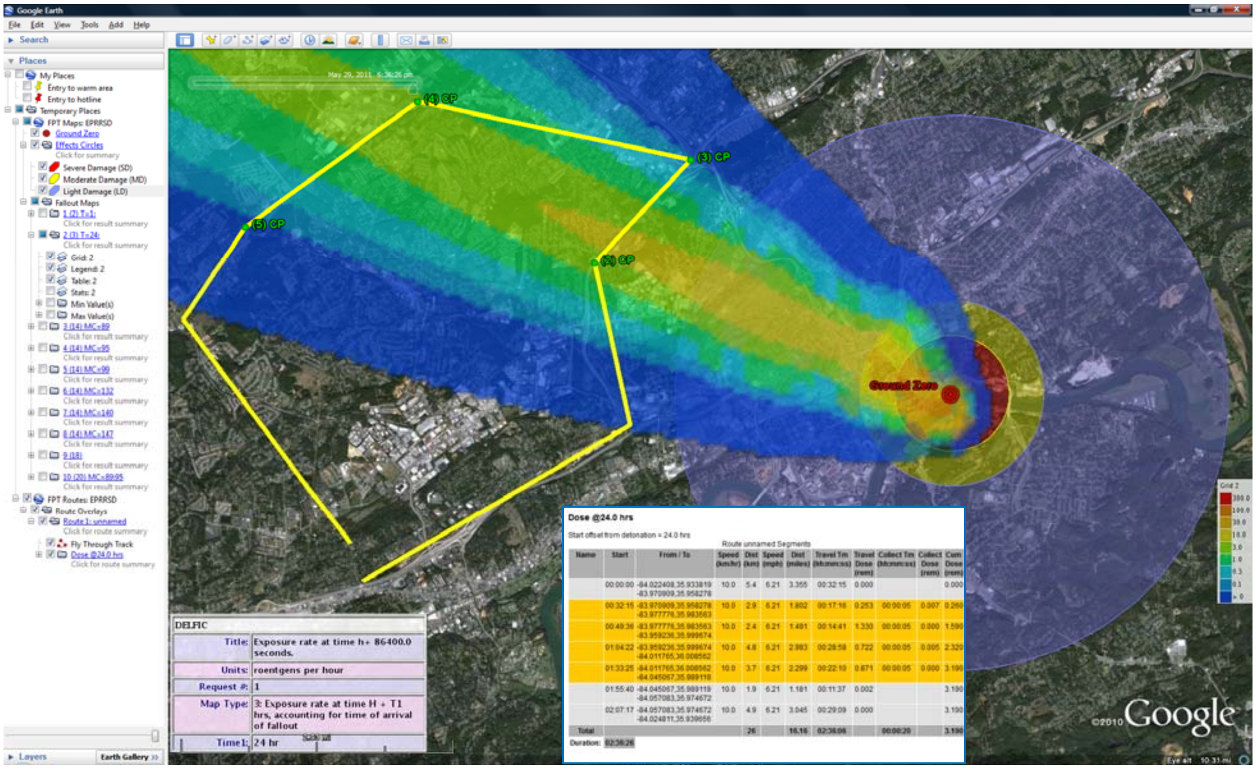

Figure 3. Fallout Planning Tool Calculate Dose task

4 CONCLUSIONS

The ORIGEN Fallout Analysis Tool and the DELFIC Fallout Planning Tool are being used by ORNL to support nuclear forensics as well as consequence management and response and recovery research efforts. ORNL's DELFIC Fallout Planning Tool Version 1.0 was released in October 2009 to the FBI/DOD/DOE NTNF Integrated Collections Task Force. It has been used in every NTNF post-detonation exercise since November 2009, including the National Level Exercise 2010, conducted at the Nevada Test Site. ORNL has also created the ability to take the DELFIC-predicted fractionated radionuclide inventory at any point in the fallout field and export it into the *.F71 file format for use with the ORIGEN Fallout Analysis Tool. This provides the ability to predict the photon source for any fallout sample or location. Future upgrades to the DELFIC Fallout Planning Tool include the ability to use vehicle protection factors that would reduce the dose during transit and improvement of the cloud rise module.

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