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SAVANNAH RIVER SITE CAPABILITIES FOR CONDUCTING INGESTION PATHWAY CONSEQUENCE ASSESSMENTS FOR EMERGENCY REPSONSE

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Potential airborne releases of radioactivity from facilities operated for the U. S. Department of Energy at the Savannah River Site could pose significant consequences to the public through the ingestion pathway. The Savannah River National Laboratory has developed a suite of technologies needed to conduct assessments of ingestion dose during emergency response, enabling emergency manager at SRS to develop initial protective action recommendation for state agencies early in the response and to make informed decisions on activation of additional Federal assets that would be needed to support long-term monitoring and assessment activities.

I. INTRODUCTION

The Savannah River Site (SRS) is an 800 square kilometer (km) reservation in south central South Carolina, approximately 40 kilometers (km) east of Augusta Georgia. From the 1950s through the early 1990s, the mission of the SRS was the production of nuclear materials for national defense. This mission was fulfilled primarily through the operation of up to five nuclear reactors, two large chemical processing plants, and numerous support facilities.

Although production at most of these facilities has ceased, considerable quantities of high-level nuclear and mixed hazardous wastes that were generated by these production processes remain stored at SRS in large underground tanks. Current operations at SRS include management and disposition of these legacy wastes, as well as activities associated with the maintenance of the nation's tritium stockpiles.

Emergency Planning Hazards Assessments (EPHAs) conducted for SRS operational facilities and production processes have identified the potential for significant airborne releases of tritium (as tritium oxide) from ongoing stockpile management operations, and transuranics (mainly plutonium isotopes) and long-lived fission products (mainly cesium and ruthenium isotopes) from processed as part of ongoing long-term disposition and stabilization activities. Potential source terms are sufficiently large to require that SRS maintain radioactive inventories either stored in tanks or an ingestion exposure emergency planning zone (IPZ) for emergency response.

The IPZ, illustrated in Fig. 1, extends to a distance of approximately 80 km (50 miles) from the center of the SRS in all directions[1]. Furthermore, emergency preparedness plans for SRS establish requirements to assess potential consequences to the public through the ingestion pathway and issue protective action recommendations to appropriate state government agencies.

II. OVERVIEW OF CURRENT CAPABILITIES FOR CONSEQUENCE ASSESSMENT

The Weather INformation and Display (WIND) System consequence assessment capability at SRS is developed and operated by the Savannah River National Laboratory (SRNL) as a comprehensive resource for conducting quantitative assessments of environmental consequence during all phases of emergency response at SRS[2]. The backbone of the WIND System is a cluster of UNIX workstations that are used to gather and archive data from a regional network (mesonet) of meteorological monitoring stations. A suite of transport and dispersion models, either developed or adapted by SRNL and available on designated PCs, are run with the current observations from the mesonet and forecasts from the operational runs of a prognostic mesoscale model to generate real-time predictions of downwind consequences.

Local Meteorological Measurements. The observational mesonet consists of: (1) Towers adjacent to each of the eight major operations areas at SRS that are instrumented to measure winds, turbulence,

Fig. 1. Savannah River Site Ingestion Planning Zone (in Green)

temperature, and moisture at an elevation of 60 meters above ground level; (2) a TV transmission tower near the SRS that is instrumented to measure wind, temperature, and moisture at several levels through 360 meters above ground level; and (3) four monitoring stations in Augusta/Richmond Co. (GA) that were established under mutual aid agreements with local government agencies. Every 15 minutes, field observations are transmitted to the UNIX cluster and archived, as noted above.

Meteorological Forecasts. SRNL has adapted and configured a prognostic atmospheric mesoscale model, the Regional Atmospheric Modeling System (RAMS), to generate operational three-dimensional forecasts of meteorological conditions throughout the Central Savannah River area and much of the Southeast U.S.[3] Two real-time forecast data sets are generated: (1) A 6-hour high resolution (2 km grid) forecast of wind speed, direction, turbulence and other meteorological variables generated every 3 hours for a region encompassing the local Central Savannah River area; and (2) A 36-hour forecast produced every 12 hours for a regional area that includes much of Georgia and South Carolina (10 km grid). Both of the operational model runs use regional observations and upper air data, as well as gridded output from NWS operational numerical weather prediction models, for initial and boundary conditions.

Atmospheric Transport and Consequence Assessment Models. A suite of transport and dispersion models are available for assessing consequences of hazardous materials released to the environment. These models, developed or adapted by SRNL, are tailored to support a broad range of assessment needs during the early to intermediate phase of response. All of the consequence assessment models are run from a PC and are configured to automatically access meteorological observations and forecasts.

The two principal models used to assess plume and ingestion pathway exposure for the general public are summarized below:

(1) *Puff/Plume* is a segmented trajectory Gaussian dispersion model that provides a reasonably conservative initial estimate of potential downwind hazards from a chemical or radiological release. Puff or plume release trajectories are constructed for up to 12 hours of observed and RAMS forecast winds with results available in less than a minute. The model assumes uniform terrain. Output consists tabular and graphical displays of concentration, dose and deposition along the release centerline. Dose includes exposure from inhalation and shine, as applicable.

(2) The *Lagrangian Particle Dispersion Model (LPDM)* provides refined analyses of transport and dispersion on local to regional scales. LPDM utilizes the full three-dimensional winds forecast by RAMS to account for complex wind patterns due to the effects of terrain or other mesoscale atmospheric phenomena[3]. Output consists of static and animated graphical displays of concentration, dose, and deposition throughout the region surrounding the SRS. Dose estimates include exposure from inhalation and shine (plume and ground).

Both models determine surface layer contaminant deposition using deposition velocities calculated from particle settling, and a resistance analog simulation of particle interactions with surface vegetation.

III. SRS INGESTION PATHWAY CONSEQUENCE ASSESSMENTS

III.A. Development of Site-specific Derived Response Levels

Protective action guides (PAG) recommended by the U. S. Food and Drug Administration (FDA) for projected dose commitment to the public from consumption of contaminated food is 5 mSv (500 mrem) committed effective dose equivalent (CEDE) and 50 mSv (5000 mrem) CEDE to individual tissues and organs[4]. The FDA guidance also provides acceptable methodologies for determining isotopic-specific derived intervention levels (DILs). The DILs represent the “concentration in food present throughout the relevant period of time that, in absence of an intervention, could lead to an individual receiving a radiation dose equal to the PAG”.

The DIL values are derived using the following general relationship:

$$DIL(Bq/kg) = \frac{PAG}{f*FI*DCF} \quad (1)$$

where,

f is the fraction of food or water consumed that is contaminated,
FI is the amount (kg) of food or water consumed over a given period of time, and
DCF is the isotope-specific dose conversion factor (mSv/Bq)

Furthermore, the DIL for each isotope (or isotope groups in some cases) can be used to determine thresholds of atmospheric deposition that, through various transfer mechanisms, results in a concentration in the food product equal to the DIL. Derived response levels (DRLs) of surface deposition provide a practical means for identifying areas that potentially exceed ingestion PAGs based on field monitoring data or standard output of an atmospheric dispersion model.

Site-specific DILs and DRLs developed by SRNL for use in ingestion pathway consequence assessments at SRS are summarized in Table 1[5]. These values were calculated using methodologies and assumptions described in the guidance from FDA; site-specific values were used in the calculations when available along with values taken from the Nuclear Regulatory Commission (NRC)[6], as appropriate. All values for the DRLs in Table 1 are expressed in terms of deposition (activity per unit area) except tritium oxide. Since HTO in the atmosphere is readily absorbed by vegetation and quickly reaches equilibrium with moisture in the plant, the DRL is more appropriately expressed as an airborne concentration.

The SRS DILs for all isotopes and age groups except I-131 were calculated using standard assumptions regarding the fraction of food contaminated. For infants and children 3 months old, it is assumed that 100 percent of food consumed over a period of one year was contaminated. For all other age groups, 30 percent of food consumed over the period of one year was assumed contaminated[4]. Because the infant DIL is the most limiting of the age specific DILs that were calculated for ingestion of I-131, it assumes a contamination factor of 100 percent. No credit is taken for weathering or radioactive decay.

For isotopes with a short half-life (i.e. I-131), the consumption period is assumed to be the period of time it would take for the activity to decay to 1 percent of the original amount. Age-specific dose conversion factors used for DIL calculations were based in International Commission for Radiation Protection Publication 56.

Table I. SRS-Specific DILs and DRLs for Ingestion Pathway[4]

Radionuclide	DIL (Bq/kg)	DRL (Bq/m^2)		
		Produce	Beef	Milk
HTO*	1.00E+07	2.70E+05	8.25E+05	9.26E+05
Sr-89	1.44E+03	1.44E+04	3.22E+05	2.22E+05
Sr-90	1.59E+02	1.59E+03	3.56E+04	2.44E+04
Nb-95	1.22E+04	1.22E+05	5.93E+03	5.93E+05
I-129	5.56E+01	1.11E+02	2.56E+03	1.15E+03
I-131	1.67E+02	3.33E+02	7.78E+03	3.44E+03
I-133	7.04E+03	1.41E+04	3.22E+05	1.44E+05
Cs-134	9.26E+02	9.26E+03	3.07E+04	9.63E+03
Cs-137	1.37E+03	1.37E+04	4.44E+04	1.41E+04
Ru-103	7.41E+03	7.41E+04	2.48E+03	9.26E+08
Ru-106	4.44E+02	4.44E+03	1.48E+02	5.56E+07
Ce-144	4.81E+02	4.81E+03	5.19E+04	5.93E+05
Np-237	4.07E+00	4.07E+01	4.44E+02	1.00E+05
Np-239	3.19E+04	3.19E+05	2.11E+07	7.78E+08
Pu-238	2.48E+00	2.48E+01	2.37E+04	1.56E+05
Pu-239	2.22E+00	2.22E+01	2.11E+04	1.37E+05
Pu-241	1.22E+02	1.22E+03	1.15E+06	7.41E+06
Am-241	2.00E+00	2.00E+01	1.07E+03	4.81E+04
Cm-244	1.59E+00	1.59E+01	8.52E+01	4.07E+04
Cs Group	1.15E+03	1.15E+04	3.70E+04	1.19E+04
Pu-Am Group	2.22E+00	2.22E+01	2.11E+04	1.37E+05

*DRL values for HTO are air concentration in Bq/m^3

Differences in the SRS values listed in Table I and those published by the FDA are due to rounding with exception of HTO. Since the environmental half-life, λ_e, of tritium in the food pathway (days) is much shorter than its radioactive half life (12 years), strict adherence to the FDA methodology would lead to unreasonably conservative values. The alternative approach developed by SRNL, which was subsequently adopted by DOE and reviewed by and deemed consistent with FDA methods, partitions the tritium absorbed by the plant into an aqueous component (λ_e = 1 day) and an organically bound component (λ_e = 27 days) and bases the period of ingestion to the 1 percent threshold of the original concentration on these environmental half-lives[7].

The site-specific DRLs were calculated from unique equations defined for produce, grain, dairy, eggs, meat, fish, and beverage. The exposure pathway for consumption of eggs is not considered significant since chickens in the region are housed in covered shelters and generally given only commercial feeds. Similarly, exposure through consumption of fish and beverage (drinking water) is not significant for airborne releases due to the relatively small available surface area of nearby streams and ponds and the dilution of any material that would be deposited. For each food product category, site specific or regulatory accepted default values for critical agricultural or physiological factors related to transfer of deposited contamination into the food were applied.

SRNL also developed more realistic models of ingestion pathway dose to use for more thorough, long-term ingestion dose assessment[8]. Models developed for each of the food product categories allow for weathering and decay of the contamination, time-dependent agricultural cycles (e.g., growing season), and food processing characteristics prior to ingestion. These models were implemented into a spreadsheet and require only entry of deposition (based on either model estimates or field monitoring data) to perform an explicit calculation of estimated ingestion dose during emergency response.

III.B. Implementation for Emergency Response

Initial, real-time assessments of ingestion pathway consequences during emergency response are based on simulations performed with the RAMS-LPDM model. Custom scripts used to control the graphical displays of model output include instructions to generate and display isopleths of model-estimated deposition equal to the SRS DRL values for produce, beef, and dairy products. This output is displayed on standard regional maps.

Figs. 2a and 2b show example output for a hypothetical instantaneous release of 300 Curies of Cs-137. Fig. 2a depicts DRL values as lines on a map that includes displays of color-contoured values of calculated surface deposition. The script that generates this plot also calculates and displays the total area bounded by the DRL isopleth. The second display, shown in Fig. 2b, depicts areas exceeding the DRL deposition values as color contours. These example plots are presented in the units (English) that are preferred by local emergency managers.

In addition, output from LPDM can be imported into commercial geographical information system software. A custom software extension was developed that reads LPDM generated gridded output and creates shape files of deposition and DRL contours. For example, Fig. 3a shows DRL contours for the hypothetical Cs-137 release on a map of major roads and political boundaries. Fig. 3b shows deposition and DRL contours overlaid on digital orthogonal maps of infrared imagery.

During emergency response, a RAMS-LPDM simulation is performed immediately after engineering staff from the affected facility has developed reasonable estimates of expected isotopic source term. These data are generally available within 1 to 2 hours after activation of the Emergency Operations Center. The LPDM simulations are based on the most recent available winds generated from a blend of surface observations and the latest forecasts (6-hour) from RAMS running on the 3-hour operational cycle for the local region. Source term and other release parameters are supplied through a graphical user interface. Users can specify a simulation that includes up to five individual isotopes from a single release location or a simulation for up to five separate release locations. Results from a RAMS-LPDM simulation are available in 5 to 20 minutes, depending on the number of sources or isotopes that are simulated.

Model results indicate that DRL values are exceeded in areas beyond the SRS boundary trigger two significant actions by emergency managers: (1) development of protective action recommendations for state agencies in Georgia and South Carolina; and (2) a determination whether additional Federal assets should be requested for conducting long-term assessments. The GIS-based displays are particularly useful for developing a concise narrative of the area for which the protective action recommendations apply, including clear and specific identification of roads or geopolitical boundaries.

Model results are also used to direct the activities of local field monitoring teams. The DRL isopleths on the digital orthogonal imagery are useful for rapidly identifying areas that may be critical to the ingestion pathway, such as potential agricultural fields.

IV. CONCLUSIONS

Technologies developed and implemented for operational use at SRS during the response to an unplanned radiological release to the atmosphere have proved to be effective for conducting prompt, detailed early assessments of potential dose to the public from ingestion of contaminated foods. These assessments have enabled emergency managers at SRS to develop initial protective action recommendations for state agencies early in the response and to make informed decisions on the activation of additional Federal assets that would be needed to support long-term monitoring and assessment activities.

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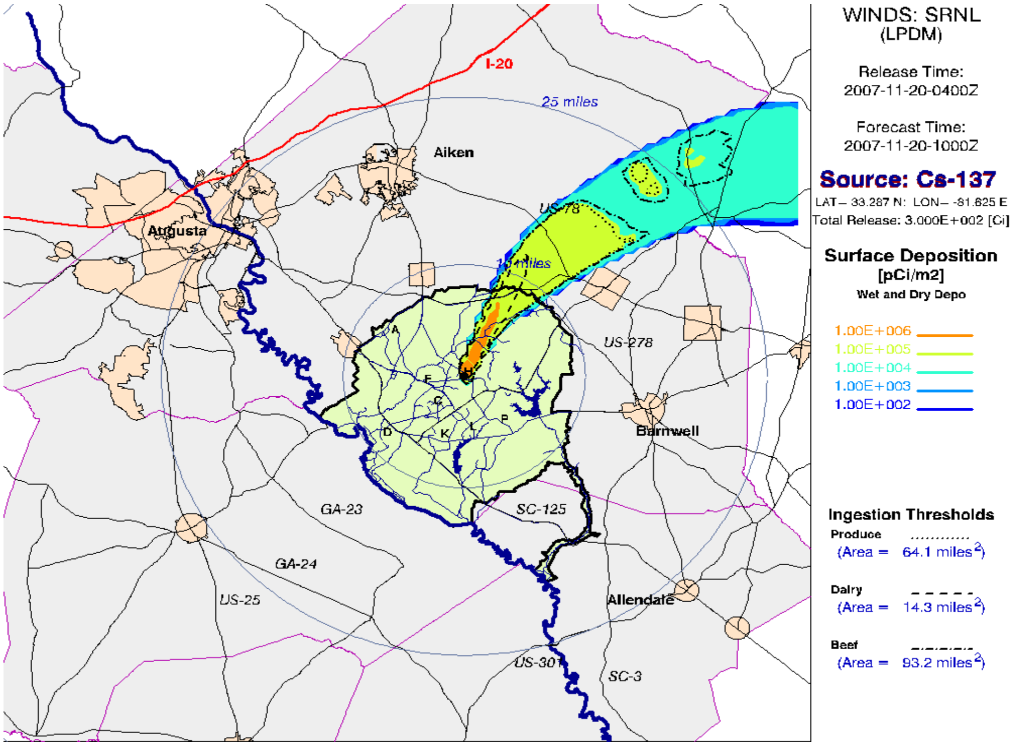
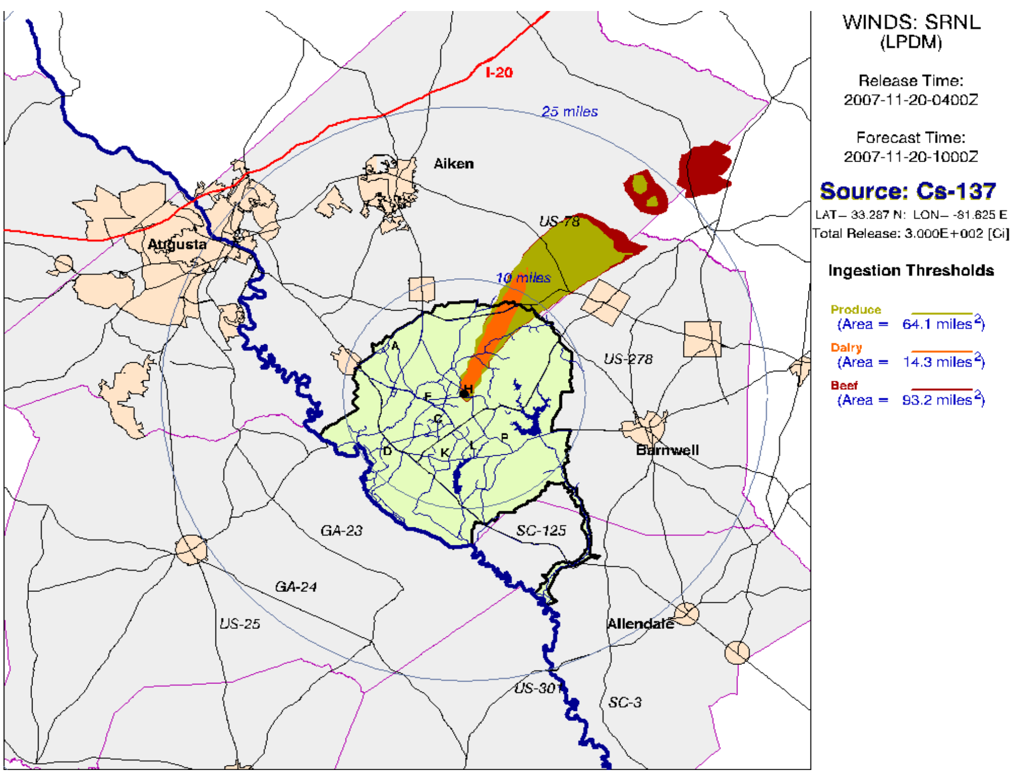
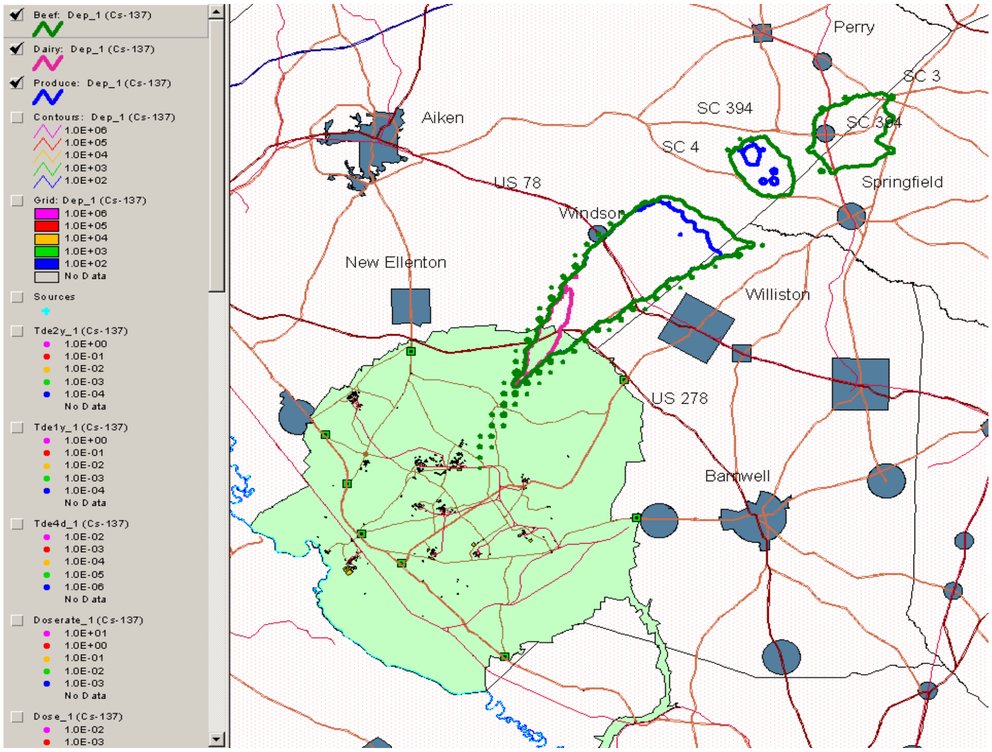


(a)

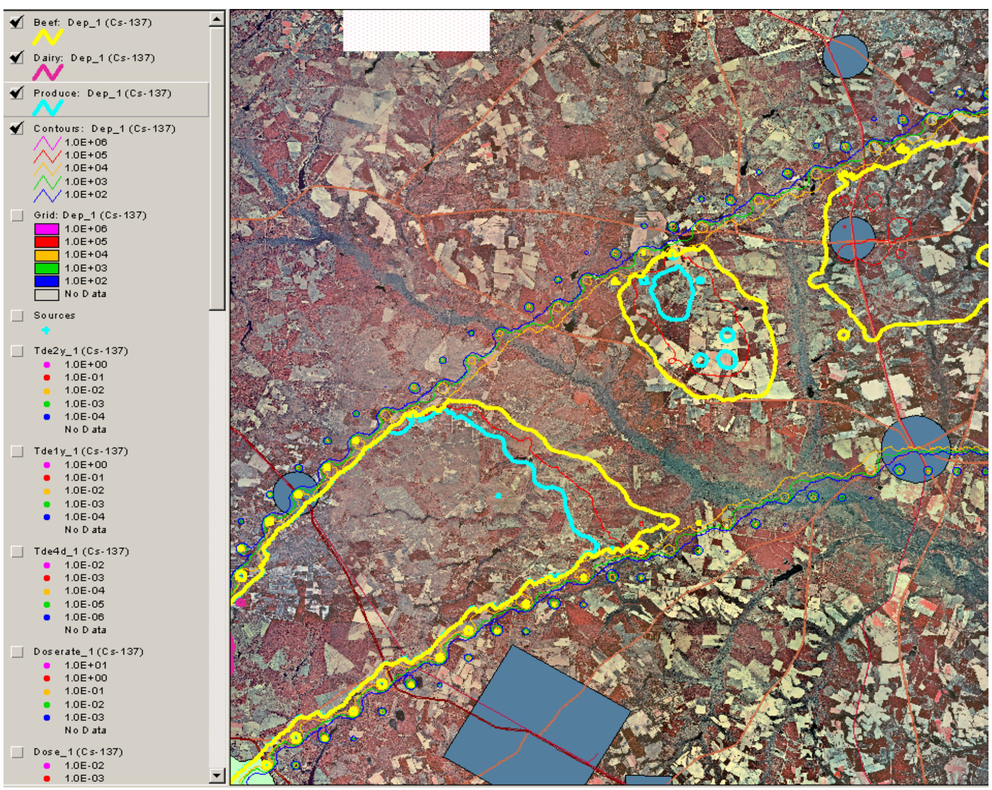


(b)

Fig. 2. LPDM results for a release of Cs-137. Example displays depict (a) color contours of surface deposition and applicable DRLs and (b) color contours of areas exceeding applicable DRLs



(a)



(b)

Fig. 3. LPDM results for a release of Cs-137. DRL deposition isopleths are displayed as GIS shape files on (a) stae and local highways and geopolitical boundaries and (b) digital orthogonal infrared imagery.