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Review

Review of current nuclear fallout codes

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ABSTRACT

The importance of developing a robust nuclear forensics program to combat the illicit use of nuclear material that may be used as an improvised nuclear device is widely accepted. In order to decrease the threat to public safety and improve governmental response, government agencies have developed fallout-analysis codes to predict the fallout particle size, dose, and dispersion and dispersion following a detonation. This paper will review the different codes that have been developed for predicting fallout from both chemical and nuclear weapons. This will decrease the response time required for the government to respond to the event.

Contents

1. Introduction

Since the development of nuclear weapons in the 1940's, the United States of America (US) along with other countries have detonated a number of atmospheric, surface, and underground nuclear devices. Table 1 shows the distribution of tests that have

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Table 1
Distribution of nuclear weapons tests worldwide.

Country	Number of events	Official listing
China	45	CT (partial)
France	198	CEA/DAM (partial)
India	3	
Pakistan	2	
Soviet Union	715	RFAE
United Kingdom	21-24 Joint USA-UK	BLACKNEST
	24 Joint USA - UK	NV209 (United States Nuclear Test, 2000)
United States	1032	NV209 (United States Nuclear Test, 2000)
Unknown/Disputed	1	
Total	2041	

been conducted worldwide. Nuclear weapons tests were banned in 1996 under the Comprehensive Nuclear Test-Ban Treaty (CTBT). However, with rumors of other countries either developing nuclear weapons technologies or conducting actual tests, it is crucial that the US update their nuclear forensic technologies to guarantee proper response in the case of nuclear attack (Bush, 2002).

These technologies include improvement of nuclear material characterization when interdicted material is found at border crossings, the analysis of nuclear facilities to ensure adherence with nonproliferation procedures, and the analysis of post-detonation debris. A segment of improving post-detonation debris includes response and analysis requirements; to improve response in these areas codes have been developed that map the potential path of fallout and predict placement of surrogate melt glass debris from a nuclear detonation (Eppich et al., 2014). By predicting both path and placement of the debris, the time required for collection and analysis of sample materials will decrease (Molgaard et al., 2015).

To help improve the US's nuclear forensics capabilities, Congress, in 2011, passed the Nuclear Forensics Attribution Act (NFAA). This act supplied funds to the Department of Homeland Security (DHS), the National Nuclear Security Agency (NNSA), and the Stewardship Science Academic Program (SSAP) to improve the nation's forensics capabilities. As stated, "…it is necessary to have a robust capability to acquire samples in a timely manner, analyze and characterize samples, and compare samples against known signatures of nuclear and radiological material (Act, 2002)."

One area in which the NFAA significantly increased funding was for improving forensic capabilities in the area of decreasing data-collection time of the glass surrogate created in the nuclear detonation. To shorten the analysis time required, the instrumentation used in evaluating the debris must be developed/improved and accurate fallout maps for the debris must be coded. By creating updated fallout maps, the probability that a collection team is able to find glass samples containing useful fragments of the detonated bomb material during the initial 24 h increases; therefore decreasing the overall analysis time for the event.

2. Code overview

Multiple codes have been developed by different government agencies to predict nuclear fallout. This section will outline the purpose that these codes were developed, and the calculation methodology used to accurately calculate the fallout.

2.1. DELFIC (FPT)

Oak Ridge National Laboratory in conjunction with the Defense Nuclear Agency participated in the development of the Defense Land Fallout Interpretative Code (DELFIC) and Fallout Planning Tool (FPT). DELFIC development began in the mid 1960's with a purpose to become the standard for fallout prediction especially when applied to population safety in the event of dispersion (Norment and Hillyer, 1979). DELFIC is a numerical fallout code that computes the cloud rise, growth, stabilization and transport of radioactive particles from a nuclear weapon detonation. The following codes listed later in the paper, start calculations post cloud stabilization period; however, DELFIC utilized the cloud rise module (CRM).

DELFIC mainly utilizes information that was gathered from the nuclear tests conducted in the 1940's thru the 1990's, however, to remain a competitive code, the CRM module was added to adjust the atmospheric parameters to better model the detonation scenario. After the user specifies the detonation conditions (i.e. barometric pressure, temperature in the area, and humidity levels) DELFIC begins calculations after the over-pressure wave reaches an equilibrium. By utilizing a fourth-order Runge-Kutta differential equation, the cloud rise from the IND can be accurately calculated. The code can output up to 18 maps relating to the specific blast. Recently, by the work done by Hopkins Et al. (Hopkins, 1994) the DELFIC code was updated from using a spatially constant wind field to using wind vectors. This capability was developed to work with wind data stored at the National Oceanic and Atmospheric Administration (NOAA). This expedites the computational time required by autonomously adding pressure, temperature, and wind vectors based upon data compiled at NOAA. Assuming the blast occurred previously to the date. With the addition of the various modules and by using data taken from nuclear tests conducted DELFIC is a competitive fallout code (Sugiyama et al., 2010).

2.2. HPAC

Hazard Prediction and Assessment Capability (HPAC) is a modeling software primarily developed by the Defense Threat Reduction Agency (DTRA) for military and civilian emergency response purposes to predict atmospheric dispersion from biological, chemical, or radiological attacks. The Nuclear Weapon Incident (NWI) and Radiological Weapon (RWPN) modules were added to HPAC to insure accurate fallout prediction of fallout during a WMD detonation. The NWI primarily focuses on predicting radiological dispersion from radioactive material attached to a chemical explosive. The NWI module allows the user to specify the chemical weapon system used to detonate the improvised nuclear device (IND) in which the modules will provide HPAC with an accurate source term. The RWPN module allows the user to specify the mass and type of explosive used to disperse the radioactive material. These parameters are used to calculate the source term. The HPAC uses the data entered by the user to develop a model of the formation of the smaller particles distributed during a nuclear detonation. To predict the distribution, HPAC uses the Second-order Closure Integrated Puff (SCIPUFF) model; which is based from the Gaussian plume model distribution. (O'Brien, 2004). The output of this program is a map that shows effects of the incident with respect to dose rate and particle size distribution (Moroz et al., 2009).

2.3. HYSPLIT

Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) Model was developed by the National Oceanic and Atmospheric Administration (NOAA) to calculate air particle trajectories and their dispersion and/or deposition. This code was originally created to aid in finding the fallout plumes from Soviet nuclear weapons tests. The original method for calculating path of fallout was by using wind data gathered from balloons and applying this to