Estimating Public Exposure to Airborne Depleted Uranium Outside the U.S. Army Pohakuloa Training Area, Hawaii.

James Morrow, David Faucette, Helene Takemoto

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James. W. Morrow
J. W. Morrow, 1481 South King Street, Suite 548, Honolulu, HI 96814

David. T. Faucette
General Dynamics IT, Building T-184, 36 Mile Marker Saddle Road, Hilo, HI 96720

Helene Y. Takemoto
U. S. Army Engineer District, Honolulu, Fort Shafter, HI 96858-5440

ABSTRACT

During the 1960's the U.S. Army fielded a classified weapons system called the Davey Crockett. This recoilless gun system included a secondary co-axially mounted gun which fired a 20 millimeter spotting round to assist the shooter in accurately engaging a target. This M101 spotting round was composed of a uranium molybdenum alloy, 92% of which was depleted uranium. During 2007 and 2008 surveys, Army contractors found components and fragments of the M101 spotting rounds in range impact areas at the Pohakuloa Training Area (PTA) on the island of Hawaii. This disclosure generated public concern about the possible exposure of Hawaii residents to airborne depleted uranium in the event that these fragments were struck by high explosive munitions and aerosolized into inhalable particles. In this study the AERMOD model was used along with existing meteorological data from PTA and a nearby National Weather Service (NWS) station to assess the potential exposure to airborne depleted uranium of the public residing outside the PTA boundaries. A number of exposure scenarios were investigated, and the results indicated that under simulated worst case meteorological conditions, predicted airborne depleted uranium concentrations at the PTA boundaries were below both World Health Organization (WHO) and U. S. Agency for Toxic Substances and Disease Registry (ATSDR) public health protection guidelines for uranium exposure.

INTRODUCTION

The August 2005 discovery of munition components of a 1960's vintage and now obsolete weapon system (the Davey Crockett) containing depleted uranium at Schofield Barracks on the island of Oahu [1] caused the U. S. Army to conduct a thorough archives search in an effort to identify the number and location(s) of such munitions at military installations in the Hawaiian islands.[2] That discovery and its disclosure to the public also triggered concerns about release of radioactive material into the local environment and potential adverse health effects.

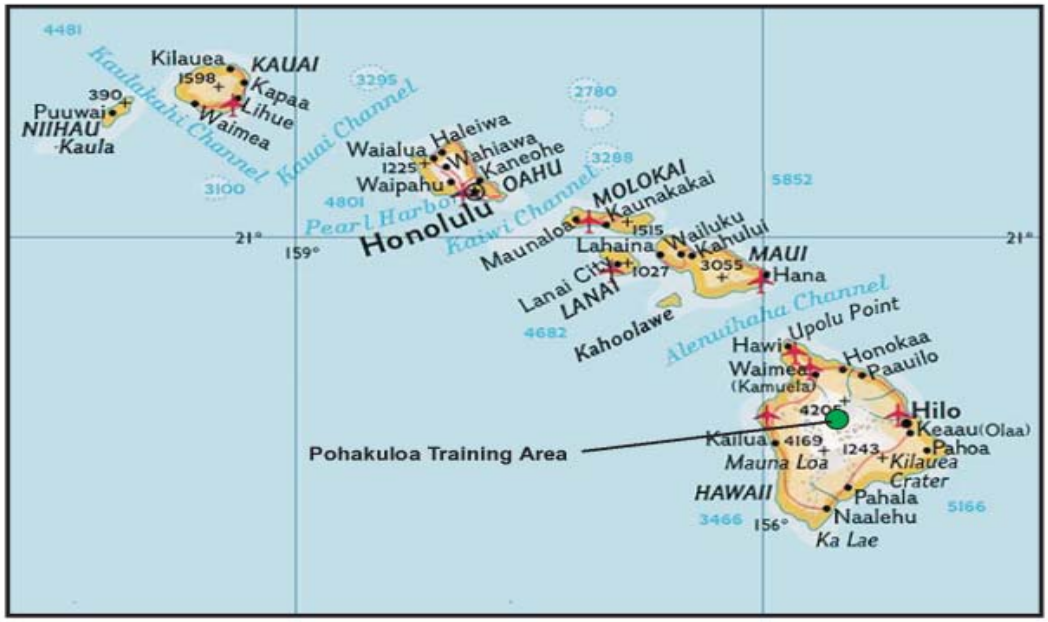
Depleted and natural uranium are composed of the same three isotopes, ^{238}U, ^{235}U, and ^{234}U, but differ in the percentages of each. ^{238}U comprises 99.27% of natural uranium but increases to 99.6 - 99.8% in depleted uranium (DU) due to the extraction of the latter two isotopes which due to

their much greater radioactivity are used to produce enriched uranium for nuclear power plants and weapons [3, 4]

The Davey Crockett included a sub-system that fired a 20 mm spotting round to assist the gunner in striking the desired target with the main munition. The spotting round projectile weighed approximately 3,180 grains (207.8 g) and was composed of a uranium molybdenum alloy, 92% of which was depleted uranium (DU); [2, 5] thus each round contained approximately 191 g of DU. It was fragments of this DU and other components of the Davey Crockett system that were found at Schofield Barracks.

The Army's largest installation in Hawaii is the 108,890-acre Pohakuloa Training Areas (PTA) situated on the plateau lying between the Mauna Kea and Mauna Loa volcanoes on the island of Hawaii (Figure 1). Elevations on the installation range from approximately 1,300 to 2,700 meters above sea level. The Army's archives search report (ASR) [2] indicated that training on the Davey Crockett weapon system was likely conducted at PTA during the 1962 - 1968 period. Ground and aerial surveys of PTA ranges conducted in 2008 identified numerous Davey Crockett pistons and a few projectiles and fragments of the M101 spotting rounds (Figure 2) on several ranges (Ranges 10, 11T, 14, and 17) (see Figure 3) [1, 6] which had been previously identified as ranges meeting the security and safety requirements necessary for Davey Crockett training.[2] Because the rounds are in impact zone where the primary hazard is unexploded ordnance, helicopter mounted radiation sensors were the primary means of survey. These sensors had a minimum detection limit of 3 - 5 M101 rounds on or near the surface.[6]

Figure 1. Location of Pohakuloa Training Area



The ASR [2] also confirmed that 714 M101 spotting rounds had been shipped to Oahu from the Lake City Army Ammunition Plant in Missouri on 27 April 1962. However, the report also stated that due to the number of Davey Crockett weapons in Hawaii, it was "highly probable" that additional M101 rounds were shipped in from other munitions plants, but records could not be found. An Army spokesman at a Hawaii County Council meeting estimated that least 2,050 rounds would have been required to meet training requirements during the six years that the Davey Crockett was fielded.[7]

It was the purpose of the study reported herein to determine whether there was any potential for adverse public health effects due to the inhalation of DU particles released when the aforementioned M101 spotting rounds were struck with high explosive munitions and aerosolized.

Figure 2. M101 Spotting Round at PTA

METHODOLOGY

The general approach of this study was to assume that M101 spotting rounds or fragments thereof lying within the range impact areas were struck by high explosive rounds, i.e., bombs, artillery rounds, rockets, etc. and completely aerosolized. The AERMOD [8] model was employed with worst case emission rates and meteorology to estimate maximum DU concentrations at the PTA boundaries. Annual and maximum monthly concentrations were selected for output based on existing uranium health guidelines discussed in the Results and Discussion section below.

Source

The sources were located in the center of each of the four ranges where evidence of Davey Crockett use had been found, and each range site was modeled separately. For modeling purposes, the source was defined as a volume source with initial 3.05 m dimensions and release height.

Emissions were based on the verified 714 (Scenario A) and estimated 2,050 (Scenario B) M101 spotting rounds shipped to Hawaii. The assumption was made that they were all fired at the PTA installation. For both primary scenarios A and B, two subordinate scenarios were evaluated. In sub-scenario 1 (A1 and B1), it was assumed that the stated number of M101 rounds (rd) were equally distributed over the 8,760 hours in a year resulting in the following emission rates:

Scenario A1: 714 rd/ 8760 hr = 0.0815 rd/hr
0.0815 rd/hr x 191g/rd / 3600 sec/hr = 0.0043 g/sec

Scenario B1: 2050 rd/ 8760 hr = 0.234 rd/hr x 191g/rd
0.234 rd/hr x 191g/rd / 3600 sec/hr = 0.0124 g/sec

In sub-scenario 2 (A2 and B2), it was assumed that the stated number of M101 rounds were equally distributed over the 365 days in a year and aerosolized during a single hour each day. Each hour of the day was individually modeled to identify the worst hours. This resulted in the following emission rates:

Scenario A2: 714 rd/ 365 hr = 1.956 rd/hr
1.956 rd/hr x 191g/rd / 3600 sec/hr = 0.104 g/sec

Scenario B2: 2050 rd/ 365 hr = 5.616 rd/hr
5.616 rd/hr x 191g/rd / 3600 sec/hr = 0.298 g/sec

Meteorological Data

Two years of surface meteorological data (2006 and 2007) collected at the PTA base camp as part of an earlier air monitoring project [9] were obtained for this study. The data set included temperature and wind direction and speed. Upper air soundings data were obtained from the National Weather Service station (WBAN 21504) at the Hilo International Airport some 30 miles east of PTA.

In order to generate a worst case data set suitable for use with AERMOD, the onsite surface data were augmented with artificial total sky cover and temperature and wind data at a 10m height. When processed in accordance with Turner's key to stability categories,[10, 11] the measured and augmented data generated Pasquill stabilities of "D" during the day and "D", "E" and "F" during the night, depending on actual wind speed. This resulted in the annual frequencies presented in Table 1.

In generating the AERMET [12] output files for modeling, albedo, Bowen ratio, and surface roughness were based on average summer time conditions in grasslands.

Table 1. Annual Frequency of Stability Categories

Year	Stability "D"	Stability "E"	Stability "F"
2006	71.4%	11.6%	17.0%
2007	68.1%	11.5%	20.4%

Receptors and Terrain

Groundlevel receptors were spaced 50 meters apart along the PTA boundary. Elevation data were extracted from the U. S. Geological Survey's National Elevation Data (NED) database,[13] and AERMAP [14] was used to obtain the elevation at each receptor.

RESULTS AND DISCUSSION

The modeling results are summarized in Tables 2 , 3, 4, and 5, and the locations of maximum DU impacts are depicted in Figure 3 along with the locations of the ranges and meteorological station.

The tables include public health protection guidelines for uranium exposure from the World Health Organization (WHO) [2] and the U.S. Agency for Toxic Substances and Disease Registry (ATSDR).[15] Those guidelines are applicable to both natural and depleted uranium since all uranium behaves the same chemically and differs only in its radioactivity.[2, 16] Because of their low radioactivity, both natural and depleted uranium are more likely to be primarily chemical hazards than radiation hazards.[14, 16] Their carcinogenic potential is very low as the ATSDR reports that "no human cancer of any type has ever been seen as a result of exposure to natural or depleted uranium".[16]

Because uranium is not considered an acute toxic hazard but rather as a chronic exposure hazard, the WHO and ATSDR guidelines tend to be long term. ATSDR defines its "chronic exposure" as 365 days or longer and "intermediate exposure" as >14 - 364 days.[17]

The highest predicted annual and monthly DU concentrations, 0.0101 and .0299 $\mu g/m^3$, were approximately 3.36% and 7.47%, respectively, of the ATSDR guidelines. The annual maximum occurred in a scenario in which 5.6 M101 rounds were aerosolized every day at 21:00 hours Hawaiian Standard Time (HST) at the Range 17 site. The monthly maximum occurred under the same conditions except at 22:00 HST. The areas of maximum predicted impacts for 2006 and 2007 were on the PTA boundary northwest of the ranges in the vicinity of UTM grids 216,000E - 2,185,000 N and 221,000E and 2,189,000N (WGS-84) which is consistent with the annual predominance of southeasterly winds at the PTA base camp (Figure 4).

The majority of annual and maximum monthly concentrations listed in Tables 2 - 5 are one to two orders of magnitude below the aforementioned health guidelines despite the following conservative analysis assumptions regarding source activity and meteorology:

- all the M101 spotting rounds were expended at PTA when in fact some were used at Schofield Barracks on Oahu;
- all the M101 rounds were struck and aerosolized within a 1-year period;
- the M101 rounds would be struck and aerosolized at the same hour each day in a 1-year period;
- the M101 rounds aerosolized in the single hour scenarios were assumed to be present in groups of 2 - 6 rounds when groupings of that size were not detected during the aerial surveys;
- the M101 rounds and their fragments would all still be present on the ranges after over 40 years of bombardment by explosive munitions; and
- neutral ("D") and stable ("E" and "F") atmospheric conditions would prevail at all times throughout the year with no occurrences of unstable conditions.

Figure 3. Location of Maximum DU Impacts

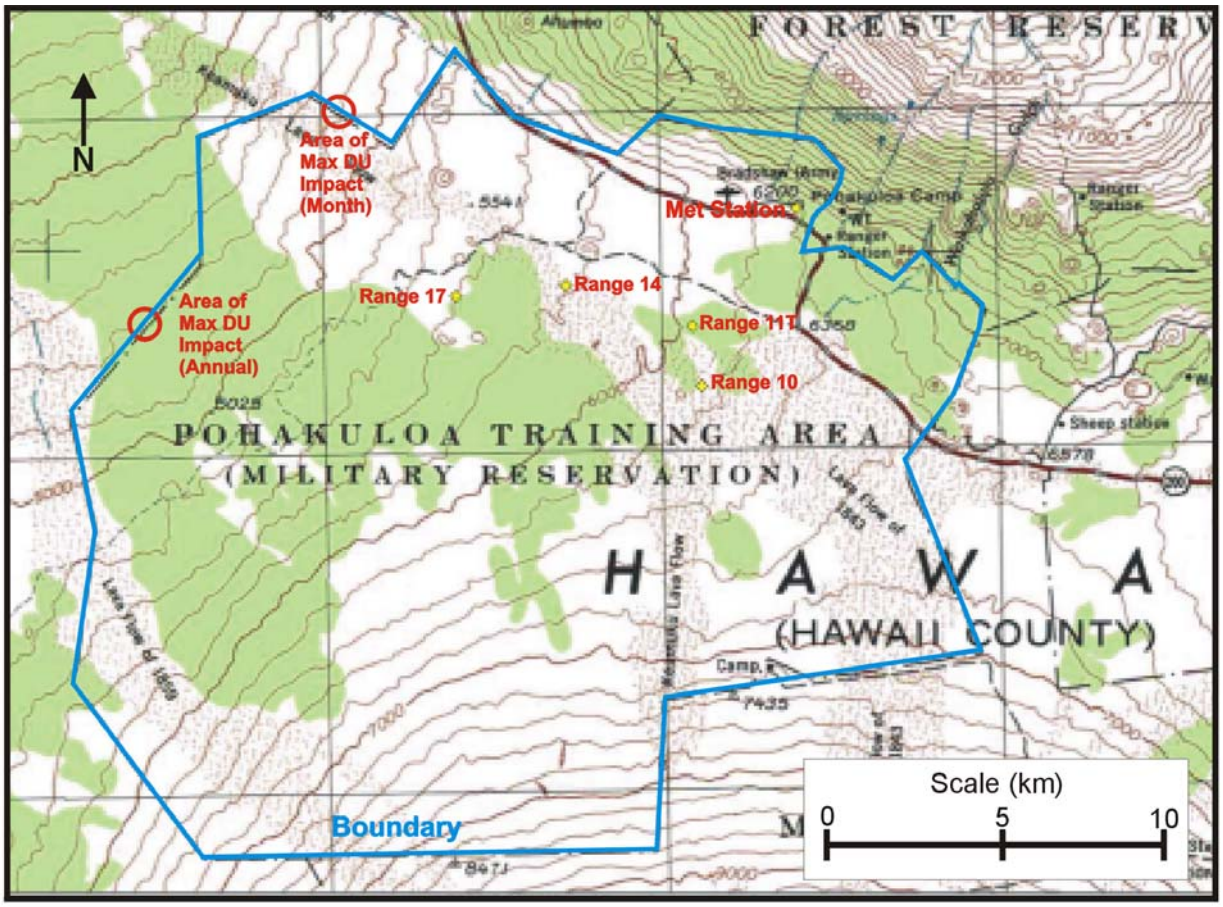


Table 2. 2006 Estimated Worst Case Annual and Maximum Monthly DU Concentrations (µg/m^3) Based on 714 M101 Spotting Rounds

Scenario	Range 10		Range 11-T		Range 14		Range 17	
	Annual	1-Month	Annual	1-Month	Annual	1-Month	Annual	1-Month
8760 hr/yr	0.0003	0.0005	0.0004	0.0008	0.0005	0.0010	0.0008	0.0016
01:00 HST	0.0004	0.0008	0.0004	0.0009	0.0004	0.0010	0.0003	0.0006
02:00 HST	0.0004	0.0008	0.0003	0.0007	0.0004	0.0009	0.0002	0.0011
03:00 HST	0.0004	0.0008	0.0003	0.0006	0.0004	0.0006	0.0002	0.0004
04:00 HST	0.0005	0.0009	0.0004	0.0015	0.0003	0.0010	0.0002	0.0004
05:00 HST	0.0005	0.0009	0.0004	0.0007	0.0004	0.0009	0.0002	0.0005
06:00 HST	0.0006	0.0011	0.0010	0.0010	0.0004	0.0007	0.0003	0.0009
07:00 HST	0.0008	0.0016	0.0005	0.0031	0.0004	0.0018	0.0004	0.0029
0800 HST	0.0010	0.0028	0.0006	0.0019	0.0005	0.0046	0.0003	0.0029
09:00 HST	0.0009	0.0020	0.0005	0.0014	0.0004	0.0019	0.0004	0.0014
10:00 HST	0.0009	0.0033	0.0005	0.0021	0.0007	0.0015	0.0006	0.0020
11:00 HST	0.0004	0.0018	0.0005	0.0021	0.0006	0.0024	0.0009	0.0017
12:00 HST	0.0004	0.0019	0.0005	0.0016	0.0006	0.0016	0.0008	0.0020
13:00 HST	0.0004	0.0028	0.0004	0.0038	0.0006	0.0027	0.0009	0.0024
14:00 HST	0.0004	0.0012	0.0004	0.0011	0.0006	0.0016	0.0009	0.0022
15:00 HST	0.0005	0.0017	0.0005	0.0018	0.0007	0.0024	0.0010	0.0034
16:00 HST	0.0004	0.0011	0.0005	0.0012	0.0007	0.0017	0.0010	0.0017
17:00 HST	0.0004	0.0012	0.0005	0.0013	0.0007	0.0018	0.0010	0.0027
18:00 HST	0.0005	0.0010	0.0005	0.0012	0.0008	0.0020	0.0013	0.0035
19:00 HST	0.0007	0.0026	0.0008	0.0029	0.0015	0.0052	0.0025	0.0085
20:00 HST	0.0008	0.0025	0.0010	0.0026	0.0016	0.0043	0.0029	0.0074
21:00 HST	0.0010	0.0027	0.0012	0.0033	0.0020	0.0057	**0.0035**	0.0094
22:00 HST	0.0009	0.0051	0.0019	0.0101	0.0017	0.0078	0.0018	**0.0104**
23:00 HST	0.0008	0.0039	0.0012	0.0061	0.0010	0.0030	0.0009	0.0033
24:00 HST	0.0004	0.0020	0.0010	0.0055	0.0006	0.0017	0.0004	0.0016

WHO exposure guideline: 1.0 µg/m^3 (annual)
ATSDR minimal risk level (MRL): 0.3 µg/m^3 (chronic exposure/highly soluble salts)
0.4 µg/m^3 (intermediate exposure/highly soluble salts)
8.0 µg/m^3 (intermediate exposure/insoluble compounds)

Table 3. 2006 Estimated Worst Case Annual and Maximum Monthly DU Concentrations (µg/m^3) Based on 2,050 M101 Spotting Rounds

Scenario	Range 10		Range 11-T		Range 14		Range 17	
	Annual	1-Month	Annual	1-Month	Annual	1-Month	Annual	1-Month
8760 hr/yr	0.0008	0.0016	0.0010	0.0022	0.0013	0.0028	0.0022	0.0047
01:00 HST	0.0011	0.0023	0.0010	0.0001	0.0011	0.0001	0.0008	0.0001
02:00 HST	0.0013	0.0023	0.0010	0.0021	0.0010	0.0026	0.0006	0.0033
03:00 HST	0.0013	0.0023	0.0009	0.0017	0.0011	0.0017	0.0006	0.0011
04:00 HST	0.0013	0.0026	0.0012	0.0043	0.0009	0.0028	0.0005	0.0011
05:00 HST	0.0015	0.0026	0.0010	0.0019	0.0012	0.0025	0.0007	0.0014
06:00 HST	0.0018	0.0031	0.0030	0.0030	0.0012	0.0020	0.0007	0.0025
07:00 HST	0.0024	0.0047	0.0014	0.0090	0.0011	0.0052	0.0012	0.0082
0800 HST	0.0028	0.0080	0.0017	0.0054	0.0014	0.0131	0.0009	0.0084
09:00 HST	0.0025	0.0056	0.0015	0.0041	0.0012	0.0055	0.0010	0.0040
10:00 HST	0.0026	0.0094	0.0015	0.0061	0.0020	0.0044	0.0018	0.0057
11:00 HST	0.0013	0.0052	0.0014	0.0059	0.0018	0.0069	0.0026	0.0048
12:00 HST	0.0011	0.0054	0.0014	0.0046	0.0016	0.0047	0.0022	0.0056
13:00 HST	0.0013	0.0080	0.0013	0.0108	0.0018	0.0076	0.0027	0.0068
14:00 HST	0.0012	0.0035	0.0012	0.0033	0.0017	0.0046	0.0025	0.0063
15:00 HST	0.0013	0.0048	0.0014	0.0050	0.0021	0.0069	0.0029	0.0099
16:00 HST	0.0012	0.0033	0.0014	0.0035	0.0020	0.0049	0.0028	0.0049
17:00 HST	0.0012	0.0035	0.0014	0.0039	0.0021	0.0053	0.0029	0.0077
18:00 HST	0.0013	0.0029	0.0015	0.0034	0.0023	0.0058	0.0038	0.01:00
19:00 HST	0.0021	0.0075	0.0024	0.0083	0.0043	0.0149	0.0071	0.0245
20:00 HST	0.0024	0.0073	0.0028	0.0076	0.0046	0.0123	0.0083	0.0212
21:00 HST	0.0030	0.0078	0.0034	0.0093	0.0056	0.0163	**0.0101**	0.0269
22:00 HST	0.0027	0.0147	0.0056	0.0289	0.0050	0.0224	0.0053	**0.0299**
23:00 HST	0.0024	0.0112	0.0035	0.0175	0.0029	0.0085	0.0024	0.0096
24:00 HST	0.0012	0.0058	0.0028	0.0159	0.0016	0.0049	0.0012	0.0046

WHO exposure guideline: 1.0 µg/m^3 (annual)
ATSDR minimal risk level (MRL): 0.3 µg/m^3 (chronic exposure/highly soluble salts)
0.4 µg/m^3 (intermediate exposure/highly soluble salts)
8.0 µg/m^3 (intermediate exposure/insoluble compounds)

Table 4. 2007 Estimated Worst Case Annual and Maximum Monthly DU Concentrations (µg/m^3) Based on 714 M101 Spotting Rounds

Scenario	Range 10		Range 11-T		Range 14		Range 17	
	Annual	1-Month	Annual	1-Month	Annual	1-Month	Annual	1-Month
8760 hr/yr	0.0002	0.0006	0.0003	0.0005	0.0004	0.0008	0.0006	0.0013
01:00 HST	0.0003	0.0006	0.0003	0.0010	0.0003	0.0008	0.0003	0.0004
02:00 HST	0.0003	0.0005	0.0003	0.0008	0.0003	0.0007	0.0002	0.0004
03:00 HST	0.0003	0.0008	0.0002	0.0006	0.0002	0.0005	0.0002	0.0004
04:00 HST	0.0004	0.0009	0.0003	0.0006	0.0003	0.0006	0.0002	0.0004
05:00 HST	0.0004	0.0007	0.0003	0.0011	0.0003	0.0007	0.0002	0.0005
06:00 HST	0.0004	0.0008	0.0003	0.0012	0.0003	0.0006	0.0002	0.0006
07:00 HST	0.0004	0.0019	0.0004	0.0019	0.0005	0.0021	0.0004	0.0019
0800 HST	0.0006	0.0023	0.0004	0.0012	0.0002	0.0008	0.0002	0.0007
09:00 HST	0.0008	0.0026	0.0005	0.0021	0.0004	0.0019	0.0003	0.0014
10:00 HST	0.0006	0.0019	0.0004	0.0013	0.0005	0.0016	0.0006	0.0022
11:00 HST	0.0003	0.0012	0.0004	0.0013	0.0005	0.0013	0.0006	0.0014
12:00 HST	0.0005	0.0023	0.0005	0.0021	0.0007	0.0015	0.0010	0.0018
13:00 HST	0.0004	0.0022	0.0004	0.0026	0.0005	0.0020	0.0008	0.0021
14:00 HST	0.0004	0.0015	0.0004	0.0013	0.0005	0.0012	0.0007	0.0016
15:00 HST	0.0004	0.0016	0.0004	0.0017	0.0006	0.0010	0.0008	0.0015
16:00 HST	0.0004	0.0009	0.0004	0.0010	0.0006	0.0014	0.0008	0.0019
17:00 HST	0.0004	0.0014	0.0004	0.0012	0.0006	0.0013	0.0008	0.0018
18:00 HST	0.0004	0.0010	0.0005	0.0011	0.0007	0.0020	0.0011	0.0031
19:00 HST	0.0006	0.0019	0.0007	0.0022	0.0011	0.0036	0.0020	0.0062
20:00 HST	0.0007	0.0017	0.0008	0.0020	0.0014	0.0033	0.0024	0.0055
21:00 HST	0.0007	0.0025	0.0009	0.0030	0.0015	0.0049	**0.0027**	**0.0085**
22:00 HST	0.0006	0.0024	0.0009	0.0031	0.0015	0.0054	0.0012	0.0046
23:00 HST	0.0005	0.0027	0.0008	0.0043	0.0012	0.0068	0.0009	0.0050
24:00 HST	0.0004	0.0016	0.0004	0.0016	0.0003	0.0010	0.0004	0.0010

WHO exposure guideline: 1.0 µg/m^3 (annual)
ATSDR minimal risk level (MRL): 0.3 µg/m^3 (chronic exposure/highly soluble salts)
0.4 µg/m^3 (intermediate exposure/highly soluble salts)
8.0 µg/m^3 (intermediate exposure/insoluble compounds)

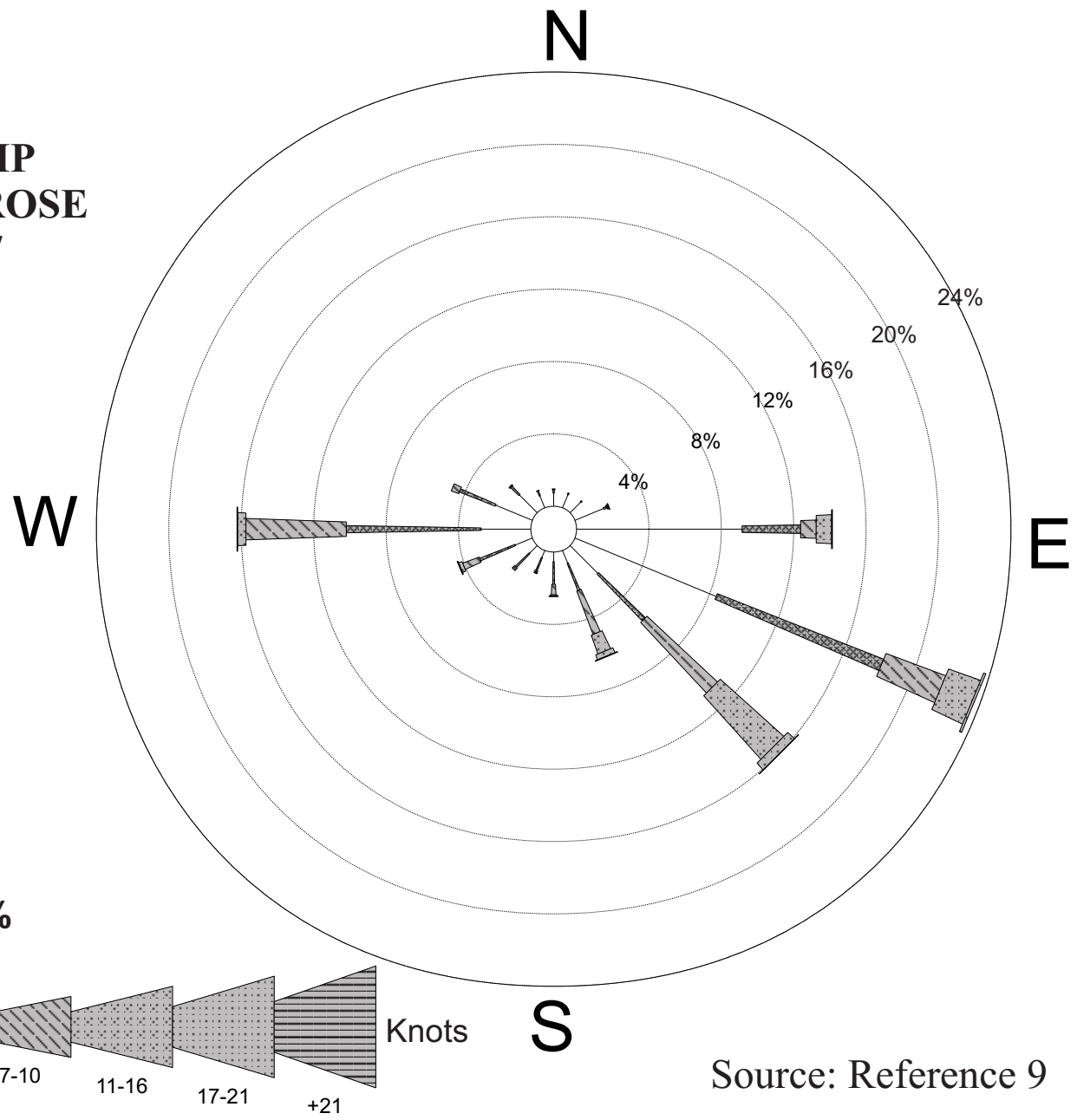
Table 5. 2007 Estimated Worst Case Annual and Maximum Monthly DU Concentrations (µg/m^3) Based on 2,050 M101 Spotting Rounds

Scenario	Range 10		Range 11-T		Range 14		Range 17	
	Annual	1-Month	Annual	1-Month	Annual	1-Month	Annual	1-Month
8760 hr/yr	0.0006	0.0016	0.0007	0.0015	0.0011	0.0023	0.0018	0.0038
01:00 HST	0.0008	0.0016	0.0009	0.0001	0.0010	0.0001	0.0007	0.0000
02:00 HST	0.0010	0.0016	0.0008	0.0022	0.0008	0.0021	0.0007	0.0012
03:00 HST	0.0010	0.0022	0.0007	0.0018	0.0007	0.0015	0.0006	0.0011
04:00 HST	0.0011	0.0025	0.0007	0.0016	0.0008	0.0017	0.0005	0.0011
05:00 HST	0.0011	0.0020	0.0008	0.0030	0.0009	0.0019	0.0005	0.0015
06:00 HST	0.0012	0.0022	0.0009	0.0035	0.0008	0.0018	0.0006	0.0017
07:00 HST	0.0012	0.0055	0.0012	0.0054	0.0015	0.0061	0.0012	0.0055
0800 HST	0.0017	0.0065	0.0010	0.0035	0.0007	0.0023	0.0006	0.0019
09:00 HST	0.0023	0.0075	0.0015	0.0059	0.0012	0.0055	0.0008	0.0041
10:00 HST	0.0017	0.0055	0.0011	0.0038	0.0013	0.0045	0.0016	0.0062
11:00 HST	0.0009	0.0034	0.0012	0.0037	0.0014	0.0038	0.0018	0.0039
12:00 HST	0.0014	0.0067	0.0014	0.0061	0.0020	0.0043	0.0028	0.0052
13:00 HST	0.0011	0.0064	0.0011	0.0076	0.0015	0.0059	0.0022	0.0059
14:00 HST	0.0010	0.0044	0.0010	0.0038	0.0014	0.0035	0.0021	0.0047
15:00 HST	0.0011	0.0045	0.0011	0.0049	0.0016	0.0030	0.0023	0.0044
16:00 HST	0.0010	0.0027	0.0011	0.0029	0.0017	0.0041	0.0024	0.0053
17:00 HST	0.0011	0.0040	0.0012	0.0034	0.0016	0.0038	0.0024	0.0053
18:00 HST	0.0011	0.0028	0.0013	0.0032	0.0020	0.0056	0.0032	0.0089
19:00 HST	0.0017	0.0054	0.0020	0.0063	0.0033	0.0102	0.0058	0.0177
20:00 HST	0.0020	0.0049	0.0024	0.0058	0.0041	0.0096	0.0069	0.0157
21:00 HST	0.0022	0.0073	0.0026	0.0087	0.0043	0.0141	**0.0077**	**0.0245**
22:00 HST	0.0017	0.0068	0.0025	0.0089	0.0042	0.0154	0.0035	0.0133
23:00 HST	0.0015	0.0079	0.0022	0.0123	0.0035	0.0196	0.0025	0.0142
24:00 HST	0.0011	0.0046	0.0013	0.0047	0.0009	0.0027	0.0010	0.0030

WHO exposure guideline: 1.0 µg/m^3 (annual)
ATSDR minimal risk level (MRL): 0.3 µg/m^3 (chronic exposure/highly soluble salts)
0.4 µg/m^3 (intermediate exposure/highly soluble salts)
8.0 µg/m^3 (intermediate exposure/insoluble compounds)

FIGURE 4

PTA BASE CAMP
ANNUAL WIND ROSE
Feb 06 - Jan 07



Calm Winds: 0.02%

Source: Reference 9

CONCLUSION

The results of the foregoing analysis suggest that the presence of depleted uranium (DU) residue in range impact areas related to the historical use of M101 spotting rounds at Pohakuloa Training Area on the island of Hawaii has not previously and does not currently pose any inhalation hazard to the citizens residing outside the boundaries of that installation.

REFERENCES

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KEY WORDS

depleted uranium, Davey Crockett, health effect