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A CASE STUDY OF THE NCRP 156 WOUND MODELING OF EMBEDDED DU FRAGMENTS USING DATA FROM URINE URANIUM CONCENTRATIONS OF WOUNDED VETERANS

by

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To the Graduate Faculty:

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LIST OF ACRONYMS AND ABBREVIATIONS

AIPH	Army Institute of Public Health
BQ	Bequerel
BVAMC	Baltimore Veteran's Administration Medical Center
CIS	colloid and intermediate state
DoD	Department of Defense
DU	Depleted Uranium
IMBA	Integrated Modules for Bioassay Analysis
IRF	intake retention factors
HPRT	hypoxanthine-guanine phosphoribosyl transferase
ICRP	International Committee on Radiation Protection
NCRP	National Council on Radiation Protection & Measurements
NRC	Nuclear Regulatory Commission
ODS	Operation Desert Storm
PABS	particles, aggregates, and bound state
PDHA	post-deployment health assessment
TPA	trapped particles and aggregates

ABSTRACT

Depleted Uranium (DU) munitions were initially used by the United States (U.S.) military during the first Persian Gulf War in 1991 in order to penetrate heavily armored vehicles. However, as a result of friendly fire, several U.S. military personnel received wounds from DU fragments and munitions. One of the ongoing concerns for these wounded veterans is the potential long term exposure received from DU embedded fragments. The United States Army Institute of Public Health (AIPH) is the first laboratory that analyzes the urine bioassays from Soldiers that are injured with DU fragments. Many DU wounded personnel have been continuously monitored for urine uranium excretion for the past 24 years. Urine uranium excretion data was evaluated in order to determine the efficacy of the NCRP 156 wound model and its default parameters. The predicted urine uranium activity from NCRP 156 wound model parameters was compared to AIPH measured bioassay urine uranium activity. The predicted urine uranium activity levels were within an average of 0.90 ± 0.95% of the actual measured urine uranium activity levels for the first four post-uptake sample days of 97, 162, 333, and 475; however, the predicted urine uranium activity levels were within an average of -38.09 ± 6.17% of the actual measured urine uranium activity levels for the last two post-uptake sample days of 499 and 518. NCRP 156 predicted the measured levels of urine uranium activity within approximately 20% and was successful in predicting urine uranium activity from actual bioassay date from AIPH. To date, there have been no clinical observations of deleterious consequences from embedded DU fragments and based on the NCRP 156 model predictions, there is a low probability of long-term effects associated with radiation exposure.

CHAPTER 1. INTRODUCTION

1.1 OVERVIEW

Depleted Uranium (DU) munitions were first utilized by the United States (U.S.) military during the first Persian Gulf War in 1991 in order to penetrate heavily armored vehicles. DU is a byproduct of the uranium enrichment process when ^{235}U and ^{234}U radionuclides are removed from naturally occurring uranium leaving ^{238}U. The end byproduct of enrichment is the creation of uranium metal having a content of radioactive material that is reduced to about 60% of natural uranium. Natural uranium contains about 0.720% ^{235}U (Parrington 1996). DU contains 0.711% ^{235}U by weight as defined by the Nuclear Regulatory Commission (NRC). The Department of Defense (DoD) specifications state that DU used by the military will be 0.3% ^{235}U by weight and claim the actual DU used in armaments is typically 0.2% ^{235}U by weight. Uranium mostly decays through alpha particle emission (ANL 2001). The primary radiological hazard is associated with internal deposition of uranium. This potentially arises through inhalation or wounds. (Szrom 2004). This thesis will focus on the contamination of wounds by DU metal, which is most frequently encountered when small DU fragments come in contact with the surrounding tissues at the wound site.

DU is utilized as a kinetic energy munition in the form of a high-density rod, or penetrator, to pierce armored vehicles. DU plays a vital component in military operations as it is twice the density of lead and relatively cheap to manufacture compared to other shielding and munition materials (Fetter 1999). The DU munition is manufactured of solid DU and some alloyed materials within the body of the penetrator. The tip of the

DU round is constructed from a non-DU plastic in order to improve the stability in flight. DU munitions undergo adiabatic shear and self-sharpen as they breach the armored targets. In comparison, tungsten munitions become blunt, or "mushroom", as they strike a target. After impact, the extreme friction encountered during penetration causes very high temperatures and small particle fragmentation. The particles in this extreme environment often ignite. DU penetrators produce DU shrapnel and also target armor fragments as they penetrate a vehicle, thus disabling the vehicle and harming the crew (NCRP 2006).

Several U.S. military personnel received wounds from DU fragments as a result of friendly fire. Friendly fired DU munitions struck 6-Abrams tanks and 15-Bradley fighting vehicles during Operation Desert Storm (ODS) from the first Persian Gulf War. These DU accidents resulted in 11 deaths and approximately 50-severely wounded personnel in the form of burns, lacerations, fractured bones, and various internal injuries, many of which contained DU fragments. One of the ongoing concerns for these wounded veterans is the potential long-term radiation exposure and biological effects received from DU embedded fragments (Fetter 1999). The United States Army Institute of Public Health (AIPH) functions as the first laboratory that analyzes the urine bioassays from soldiers that are injured with DU fragments. DU enters the body as fragments via shrapnel wounds as a DU round penetrates the target and causes shards of DU to injure the personnel inside. DU may also enter the body as metal fume if the shield is ignited during combat. Metal fumes present themselves as aerosols to be re-suspended if enough energy is added to a system, providing an inhalational hazard (NCRP 2006).

DU wound fragments may be surgically removed or left in place at the site of injury depending on the fragment size and location in respect to other anatomical structures. Smaller DU particles and fragments are frequently left in place due to the potential of surgical morbidity (McDiarmid 2004). The committed internal dose from DU fragments is a function of contact time, particle solubility, and excretion rate (Army Environmental Policy Institute 1995). The ongoing health concerns for DU wounded veterans is derived from the small radiological effects of DU, but primarily from the greater risk of chemical and heavy metal toxicity from uranium (Bakhmutskya 2011). DU is radioactive as demonstrated in the decay scheme seen in Figure 1.1, but is not considered highly carcinogenic. This lack of carcinogenicity is evident in occupational cohort studies involving individuals with higher exposures than Gulf War veterans (ATSDR 1999). The highest radiation dose estimates for DU exposed veterans based on ICRP 30 calculations are estimated to be in the range of 0.001 Sieverts (Sv) per year and 0.053 Sv for 50 years (McDiarmid 2000). Because committed dose equivalents and dose equivalent rates are so small, the chemical toxicity of DU is the primary concern due to nephrotoxicity, neurotoxicity, and reproductive toxicity (McDiarmid 2004).

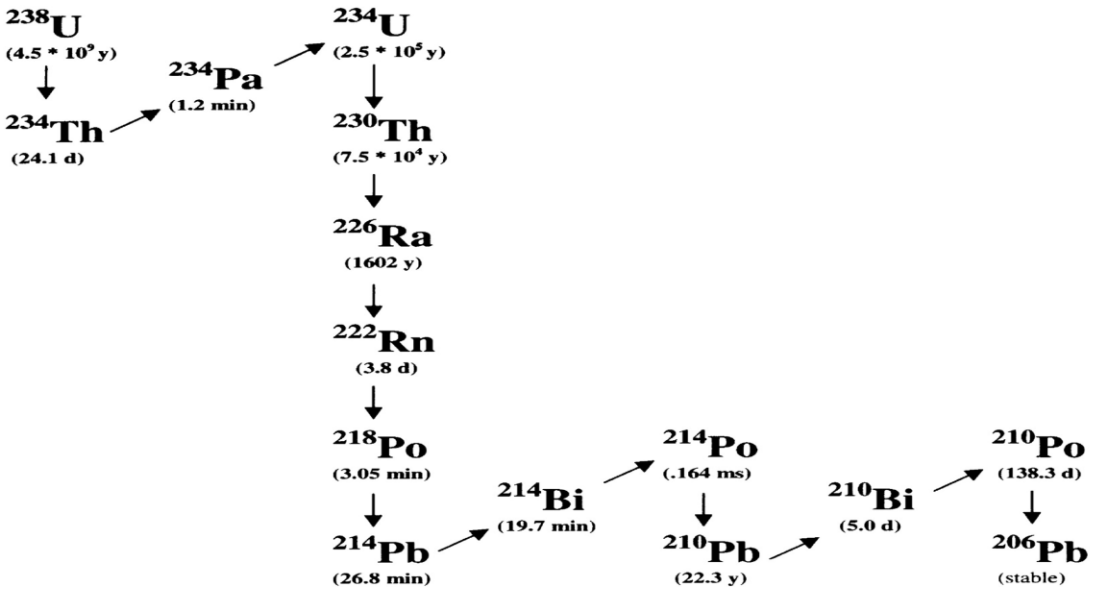

Figure 1.1 DU decay scheme

1.2 NCRP 156 BIOKINETIC WOUND MODEL

The National Council on Radiation Protection and Measurements (NCRP) report No. 156 biokinetic wound model (Figure 1.2) consists of seven compartments, five for the wound site and two for the radioactive material leaving the wound site. The five wound site compartments are comprised of:

1) fragment;

2) particles, aggregates, and bound state (PAB);

3) trapped particles and aggregates (TPA);

4) soluble;

5) colloid and intermediate state (CIS).

The NCRP 156 model wound compartments are considered independent of the anatomical location of a wound. NCRP assumes that the nature of the majority of injuries is that they occur in the shallow skin tissue or muscle. The NCRP 156 model does not distinguish between wounds resulting from punctures, abrasions, cuts, or burns; however, the model does note that the level of injury severity will affect the biokinetics of the radionuclide at the wound site. The physical and chemical properties of the radionuclides in the wounds are the basis for each compartmental representation. Radioactive material in the wound site is described as a fragment, particulate, solution form, or in a colloidal state. Transfer solubility compartments is described as being first-order kinetics. The default retention categories for the NCRP 156 wound model were established as weak (W), moderate (M), strong (S), and avid (A) (NCRP 2006).

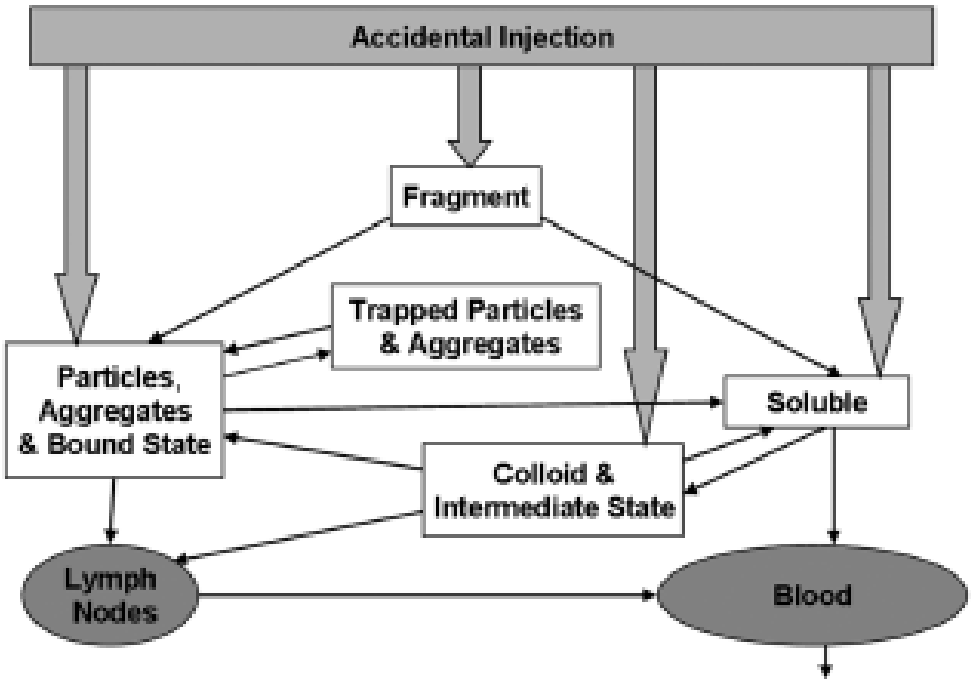

Figure 1.2. NCRP 156 biokinetic wound model

Fragments and particles are considered solids in the NCRP 156 model. Particles are deemed smaller than fragments with an upper limit of 20-μm diameter. Particles may come from fragments that are composed from corrosion products ultimately experienced as contaminated material in the body. The soluble compartment of the wound model represents radionuclides that are introduced in soluble form or originate from the fragment or PABS compartments. Wound data from animal studies suggests that radionuclides in solution form have a wide range of biokinetic behaviors; thus, three compartments (CIS, PABS, and soluble) are used to describe their interactions in the wound model. The three soluble-based compartments allow the model more mathematical flexibility for various wounds and differing radionuclides. Interactions between the CIS and soluble compartments are highly dependent on the radionuclides aqueous chemistry and the potential for radionuclides hydrolyzing within the wound site. A radionuclide's propensity for hydrolyzing in the wound determines its persistence in the wound site as an example. Highly charged ions would be expected to bind with fixed tissue constituents. Radionuclides that are soluble in saline have a higher tendency to move to the CIS compartment. The PABS compartment involves particles, and those compounds in the CIS compartment that have aggregated. Radioactive compounds in the PABS compartment are highly retained at the wound site or they may be transported into the lymph nodes via tissue macrophages (NCRP 2006).

The Trapped Particles and Aggregates (TPA) compartment represents the alternating and dissolution biokinetic nature of particles, or foreign-body reaction, leading to fibrous tissue encapsulation of radioactive materials at the wound site. This foreign-body reaction is dependent on the amount and size of the particles in question at

the wound site. The effects of irradiation on the surrounding tissue from the encapsulated radioactive particle have not been fully studied to date. Radioactive material transport from a fragment in the wound is not likely to be a factor due to the slow rate of corrosion for fragments compared to particles. Hence, a separate "trapped fragment" compartment was not included in the wound model (NCRP 2006).

1.3 ANIMAL STUDIES: RATS IMPLANTED WITH DU FRAGMENTS

Urinary uranium excretion from DU metal fragments was researched in rats extensively in 2002 by Hahn *et al*. Six rats were implanted with four 2.6 ± 0.1g DU metal wafers, two in each thigh muscle. Urinary uranium excretion was measured periodically over the animal's lifespan, which happed to be 530 ± 166 days. Urine samples were collected daily from 2-days pre-implantation to 7-days post implantation, then twice weekly up to 28 days, weekly up to 88 days, then bimonthly up to 564 days, followed by monthly up to 664 days. The daily urinary uranium excretion increased steeply during the first 30 days from zero to a peak value of 0.003 to 0.01% of the implanted DU per day. The daily urinary uranium excretion was observed to be greatest at approximately 90-days post DU implantation. The average daily urinary uranium excretion rate was 2.4×10^{-5} (24 ppm) per day for the first five months, then decreased to a level of 1×10^{-6} (10 ppm) per day for the remaining days of the study. Overall, urinary uranium represented approximately 90% of soluble uranium that was cleared from the wound sites. The other 10% of the DU metal fragments was retained in the kidneys or bones. The total DU absorbed was estimated to be equal to 1.1 times the cumulative uranium excretion. The DU implanted wafer fragments became corroded and encapsulated within dense mineralizing fibrous tissue up to 0.5-mm thick within one year

of implantation. This encapsulation of DU fragments hindered uranium solubility and particle movement to the lymph nodes. The total uranium absorption for rats surviving longer than one year was calculated to be 72 ± 4% of the total uranium absorbed during the first year from the DU wafer implants. By day 662-post implantation, or near the time of death, uranium absorption was estimated to be 0.96 ± 0.55% of the total amount of DU deposited in the tissue. The uranium retention in the wound was calculated to be 99.0 ± 0.55% of the total amount implanted. Wound retention was measured as 100% minus that fraction systemically removed (i.e. via dissolved uranium absorbed by the blood) or translocated to the lymph nodes. The research concluded that essentially all the solubilized uranium makes it to the blood or the lymph nodes with only a very small amount going from fragment to the PABS compartment. The published transfer rates for the retention of DU at the wound site is shown in Figure 1.3 (Hahn 2002).

Transfer rates for wound-site retention of DU i.m. implanted as wafers into rat legs.[a]

Pathway	Transfer Rate (d^{-1})[b]
Fragment to soluble	0.0
Fragment to PABS	0.0079
Soluble to systemic	3.1
PABS to TPA	0.72
TPA to PABS	0.0005
PABS to soluble	0.0
PABS to lymph nodes	0.0039
Lymph nodes to blood	0.029

[a]Material injected into fragment compartment.
[b]Parameter value fixed.

Figure 1.3. DU transfer rates at the wound sites from Hahn wafer study (2002).

Pellmar *et al* (1999) implanted rats with small cylindrical DU pellets (2x1 mm diameter) varying in number as either 4, 10, or 20 DU pellets with inert tantalum pellet fragments for a total of 20 metal pellets per rat. The DU implant surface area for 20 pellets was approximately 31.4 mm^2. The DU implanted rats were sacrificed serially at 1

day, and 1, 6, 12, and 18 months after implantation and urinary uranium samples were collected at each sampling time. The maximum daily urinary uranium excretion rate was seen at 150 days post implantation compared to 90 days in the Hahn study; however, the Pellmar study did not take additional urine samples during the 1 to 6 month period post implantation. The Pellmar data was similar to that of Hahn's in regards to the maximum kidney uranium concentrations being observed at six months post implantation with a decrease between 60 and 70% of the maximum concentration at 18 months (Pellmar 1999). NCRP 156 noted that the variations in urinary uranium excretion data were possibly due to the initial DU surface area of the implants, i.e. pellets versus wafer sizes. The DU surface area from the Hahn DU wafer fragment study was estimated to be 320 mm^2 compared to 31.4 mm^2 in the Pellmar DU pellet study. Discrepancies in the rate and degrees of corrosion and encapsulation rates of the DU fragments could have also contributed to the urinary uranium excretion rate differences. Both studies demonstrated that the biokinetics of uranium in the kidneys paralleled the kinetics of soluble uranium released from the wound site to the blood.

The Hahn DU metal wafer study data calculated the pattern of DU wound retention based on the urinary uranium excretion rates (Figure 1.4). This data set demonstrated that urinary uranium levels were exceeded by twice the background level within 3 to 5 days post implantation. Linear interpolation was used for intervals between collection dates. The wound retention urine data showed a slow, continual release to the blood compartment from a small fraction of the implanted DU wafer fragments of 0.96 ± 0.55%. The Hahn study further demonstrated that there was not a long-sustained release of solubilized uranium from the DU wafers into the blood, especially after one-year post

implantation (Figure 1.5). As mentioned earlier, the urinary uranium excretion rate increased for the first 90 days, then stabilized and slowly decreased over the life span of the rats.

TABLE B.9—*Cumulative absorption of uranium from DU metal wafers implanted in thigh muscle of rats.*[a,b]

Time After Implant (d)[b]	Cumulative Uranium Absorption (percent of implant)						Systemic[c]	SD[c]
	Rat 86	Rat 90	Rat 96	Rat 97	Rat 100	Rat 102		
5	0.00036	0.00029	0.00016	0.0012	0.00039	0.00086	0.00011	0.0014
10	0.0062	0.0040	0.0047	0.009	0.0061	0.0097	0.0066	0.0023
20	0.016	0.033	0.017	0.035	0.024	0.029	0.026	0.0080
32	0.022	0.067	0.028	0.11	0.052	0.058	0.056	0.032
60	0.029	0.17	0.082	0.22	0.11	0.11	0.12	0.067
88	0.054	0.23	0.24	0.40	0.24	0.19	0.226	0.11
116	0.081	0.29	0.31	0.47	0.32	0.23	0.28	0.13
158	0.12	0.51	0.43	0.68	0.54	0.30	0.43	0.20
200	0.14	0.58	0.49	0.76	0.64	0.35	0.49	0.22
256	0.16	0.66	0.55	0.83	0.86	0.39	0.58	0.27
298	0.18	0.69	0.57	0.89	0.99	0.41	0.62	0.30
354	0.19	0.75		0.93	1.15	0.42	0.69	0.38
396	0.21	0.81			1.29	0.46	0.69	0.47
452	0.23	0.89			1.40	0.50	0.76	0.51
508	0.24	0.93			1.53	0.52	0.80	0.56
550	0.26	0.97			1.63	0.52	0.84	0.60
592	0.27	1.01				0.53	—	—
662	0.28	1.05	(0.86)[d]	(1.17)[d]	(1.87)[d]	0.54	0.96	0.55

[a]Summary of data for systemic absorption of solubilized DU calculated from the data of Hahn. *et al.* (Hahn, 2000; Hahn *et al.*, 2002) from daily urinary uranium excretion rates of individual rats and the average terminal uranium content of kidneys and eviscerated carcass (see text).

[b]Only about one-half of the full data sets for the six individual rats is shown here.

[c]Composite fit to the systemic absorption, with its standard deviation.

[d]Values obtained from linear extrapolation of cumulative uranium absorption data for the last 12 weeks (Rat 96, Rat 97) or 28 weeks (Rat 100) before death.

Figure 1.4. Wound retention data from Hahn DU wafer study (2002).

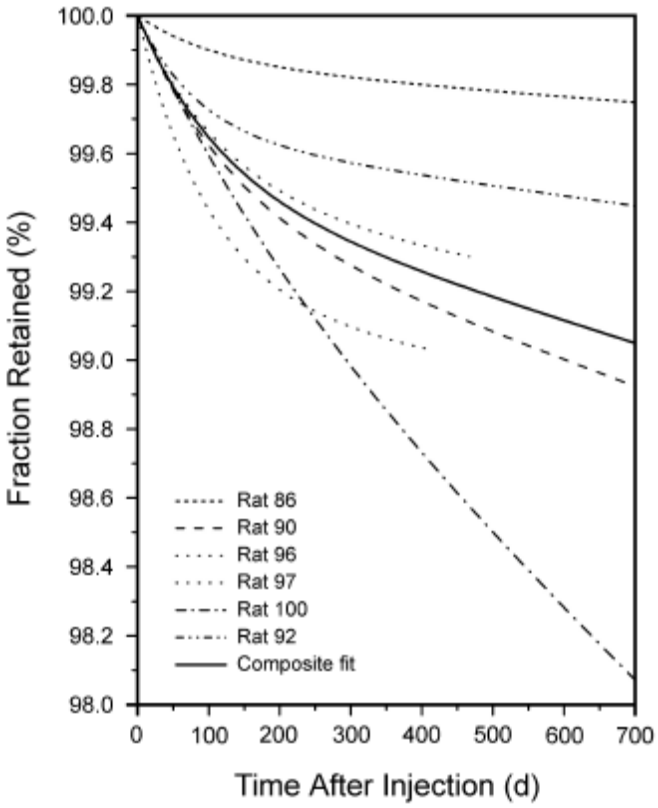

Fig. B.7. Retention of uranium at the wound site in rats i.m. implanted with DU metal wafers. Individual curves for six rats (identified by number) were obtained using the wound model (Section 4) to analyze their systemic uranium data (Table B.10).

Figure 1.5. Wound retention fractions from Hahn DU wafer study (2002).

1.4 HEALTH EFFECT STUDIES OF DU EXPOSED GULF WAR VETERANS

Veterans from the first Persian Gulf War and the ensuing conflicts in Iraq and Afghanistan that suffered injuries or wounds containing DU as a result of friendly fire have been monitored for health effects on a periodic basis. The Baltimore Veteran's Administration Medical Center (BVAMC) has been conducting medical surveillance and monitoring since 1994 with biennial assessments. Medical surveillance includes a clinical assessment consisting of a detailed medical history, exposure history, physical examination, laboratory tests, and radiographic procedures to confirm existing DU

fragments. Laboratory procedures tested hematologic and blood chemistry, neuroendocrine, immunologic, and genotoxicologic parameters including semen quality. Twenty-four urine samples were collected to evaluate the total urinary uranium levels and kidney function (McDiarmid 2004).

The clinical results in 2001 from the ten year follow-up study conducted at the BVAMC showed that veterans with confirmed DU fragments demonstrated higher mean urine uranium excretions compared to those veterans only exposed to DU without fragments and those with no DU exposures, either externally or internally. Elevated urine uranium concentrations were more likely a result of very slow movement of DU particles from fragments in situ. The other laboratory examinations revealed only a few abnormalities. Kidney function tests were normal with only negligible perturbations in some of the proximal tubules of the kidneys. It was noted in the ten-year follow up group that genotoxic tests showed a small association with hypoxanthine-guanine phosphoribosyl transferase (HPRT) mutations and higher urine uranium levels (McDiarmid 2004).

Another study involving seventy-four 1991 Gulf War veterans with known DU exposures was conducted in 2005 at the BVAMC. Urinary uranium concentration levels were still elevated for those with DU fragments when compared to non-DU exposure populations. Genotoxic tests in this cohort exhibited a weak association between HPRT mutations and elevated urinary uranium levels. Overall, the clinical and medical examinations revealed no evidence of adverse health effects from DU retained fragments (McDiarmid 2007). Thirty-five veterans from a cohort group of 77 Gulf War veterans were re-evaluated in 2007. This group of DU exposed veterans demonstrated similar

results as the previously mentioned groups from 2001 and 2005. However, this group demonstrated no statistically significant association between HPRT mutations and elevated urinary uranium levels (McDiarmid 2009). The 20-year follow-up study group continued to demonstrate similar findings as the previous studies with sub-clinical observations and no clinical significant DU health effects (McDiarmid 2013).

Depleted uranium's effects on the reproduction and development of a fetus have been studied as well. The primary toxicity from DU comes from the chemical carcinogenic component only. One study reported a correlation between increasing maternal DU levels in rats and elevated uranium levels in the maternal kidneys, placenta, and fetus, suggesting DU does cross the mammalian placental barrier. However, DU dose levels were not reported during this study (Domingo 2001). Another study on the effects of DU on mice fetuses was conducted in 2013. This study concluded that DU concentrations greater than 5 mg/kg/day could cause toxicity in the form of decreasing the skull ossification of the mouse fetus (Mirderikvand 2014). However, the DU doses administered daily to the mice is high when compared to the minimal DU fragment exposure a veteran may receive. To date, no significant reproductive effects have been reported in veterans with embedded DU fragments.

1.5 OBJECTIVES

The primary objective of this research is to evaluate the efficacy of the intake retention factors (IRFs) in modeling embedded DU fragments as listed in Appendix D Table D.4 in NCRP Report No. 156. The IRFs in NCRP 156 are based on rat data collected from urine uranium concentrations. Data from six urine bioassay samples, from an injured soldier with DU shrapnel fragments located in the leg and foot areas

bilaterally, obtained over a fourteen month period was received from AIPH in order to evaluate NCRP No. 156 IRFs. This research study compared the injured soldier's human urine uranium concentrations during this fourteen month span to predicted values obtained from the NCRP 156 wound model to determine if the published IRFs based on rat studies are consistent with the measured human urine bioassay data.

The secondary objective of this research was to determine if any adjustments to the NCRP 156 wound model would be necessary to better fit the actual human bioassay results. Since human studies are difficult to conduct due to ethical concerns, the chance to compare human data from an actual wound case to the published wound model animal-study-values is considered valuable and appropriate for future military operations and long-term healthcare of wounded veterans.

1.6 HYPOTHESIS TESTING

NCRP Report No. 156 wound intake retention factor values are expected to accurately predict the residual urine DU bioassay levels from a wounded soldier with DU fragments, using the methods employed within the IMBA Dosimetric software and corresponding models.

Null hypothesis (H_0): The NCRP Report No. 156 intake retention factors do accurately predict the urine uranium concentration levels of wounded veterans with embedded DU fragments.

Alternate hypothesis (H_1): The NCRP Report No. 156 intake retention factors do not accurately predict the urine uranium concentration levels of wounded veterans with embedded DU fragments.

The null hypothesis will be supported if the NCRP Report No. 156 intake retention factors predict the urine uranium concentration levels of wounded veterans with embedded DU fragments within 10% relative error. A relative error of 5% would be considered a great fit to the model, while a 20% relative error would indicate a very poor fit. A relative error of 10% or a large p-value would be consistent with the model, and a p-value of 1% would be strong evidence that the model is not valid with the data. The alternate hypothesis will be supported if the NCRP Report No. 156 intake retention factors do not predict the urine uranium concentration levels of wounded veterans with embedded DU fragments outside a relative error greater than the 10% parameter.

CHAPTER 2. METHODS AND MATERIALS

2.1 DU BIOASSAY COLLECTION PROTOCOL

DU urine bioassays are collected from wounded veterans based on criteria of injury or suspected exposure to DU while conducting military operations while in garrison or deployed situations. The U.S. military has established guidelines for DU exposures which involves organizing soldiers into three categories based on their potential of being internally exposed. Level I DU exposures involve military personnel being directly injured while inside or near combat vehicles during the time of DU munition impact and also includes personnel entering a vehicle immediately after being hit by DU munitions. Personnel in Level 1 may have been exposed to DU fragments through direct impact, inhalation of DU aerosols, ingestion, or settling of DU particles on open wounds, burns, or breaks in skin. The Level 1 category also includes individuals being injured while inside a DU armored vehicle being attacked by non-DU munitions (Szrom 2004).

Level II DU exposures are comprised of military personnel or DoD civilian employees whose job requirements involve them working in and around military vehicles that contain DU particles or fragments. This exposure group was not in the vehicle when struck by DU munitions and did not immediately enter the damaged vehicle after the incident. Personnel entering DU damaged vehicles in the Level II category performed repairs, battle damage assessments, intelligence gathering, and explosive ordinance disposal; thus, the exposure times were kept to a minimum. Suspended DU particles within the damaged vehicles had nearly already dissipated or settled before entering. The

likely route of DU exposure for Level II was inhalation of DU re-suspension, ingestion via hand to mouth, or contamination from uniforms (Szrom 2004).

Level III DU exposures are essentially everyone else whose DU exposure was brief or incidental. The Level III DU group includes those individual entering DU-contaminated vehicles or equipment, or those who were downwind from burning vehicles and equipment struck by DU munitions, or downwind from burning DU munitions. The Level III DU category route of exposure basically consists of inhalation of airborne DU particles. Personnel in the Level III category may have received an exposure via inhalation; however, adverse health effects from this type of exposure are highly unlikely (Szrom 2004).

Soldiers returning from deployments must undergo several medical screenings after coming home. One of the medical screenings involves a post-deployment health assessment (PDHA), DD Form 2796 found in Appendix A, which entails enquiring about the soldier's exposure to a number of potential hazards while deployed downrange. One of the questions asks if the soldier was exposed to DU directly and if they were involved in inspecting destroyed military vehicles. If they answer yes to either question, the soldier will complete a DU questionnaire, which will determine their level of DU exposure as mentioned above. If they are in the Level I category, then a 24-hour urinalysis is conducted. The U.S. AIPH conducts the 24-hour urine collection and urinalysis. If the soldier tests positive for uranium in the urine, they are referred to BVAMC for ongoing follow-up assessments (Szrom 2004).

I received DU urine bioassays results for Army personnel with suspected DU fragments from the U.S. AIPH and Mr. Gerald Falo of the Health Physics Department.

An estimated 2,500 individuals were sampled; only 8 people had positive results for DU in urine. The data for those 8 positive results is listed in Table 2.1. Note, the exposure date and summary exposure information were taken from reviews of the DU questionnaire and miscellaneous paperwork accompanying the specimens. Some of the information provided was based on the recollections of the soldiers; therefore, some information was not available for proper review and research analysis.

Table 2.1 DU Urine Bioassay Positive Result Data from AIPH

Individual	Collection Date	U238 Concentration w/ uncertainty (ng/L)	Urine Volume (L)	U235/U238 ratio	Exposure Date	Summary exposure info	Fragment
1	7/13/2003	1380 +/- 83	1.89	0.0020 +/- 0.000018	4/6/2003	States VA form that he was wounded but no fragments	N
	Not recorded	713 +/- 46	2.25	0.0022 +/- 0.00029	5-4-03 (out of theater)	Believe intake was inhalation due to vehicle smoke/fire	N
	9/5/2003	NA	NA	NA			Y
	6/23/2004	463 +/- 23	1.8	0.0021 +/- 0.00044	?	Assuming inhalation & chronic exposure from fragment	Y
2	6/21/2014	4740 +/- 260	0.21	0.0019 +/- 0.00014	?	Assuming inhalation, DU Questionaire not sent	?
	6/21/2014 CDC ICP-MS performed	NA	NA	0.00206 +/- 0.00001	?		?
3	9/2/2003	11.8 +/- 0.2	0.055	0.0056 +/- 0.0005	?		N
	CDC Ratio performed	NA	NA	0.00415 +/- 0.00006	?	Natural Uranium Ratio	N
4	Not recorded	28 +/- 1.8	1.62	< Reporting Level	Apr-03	Bradley fire & security detail @ nuclear power plant	N
	CDC Ratio performed	NA	NA	0.00278 +/- 0.00003	Apr-03		N
	AFIP Ratio	NA	NA	0.0031 +/- 0.003	Apr-03		N
5	7/14/2003	83,400 +/- 6,300	0.99	0.0021 +/- 0.00010	4/8/2003	M1 Abrams tank hit by friendly fire, exposed to smoke from DU Rounds	Y leg/foot
	AFIP Ratio	63,000	NA		4/8/2003		
	9/17/2003	76,300 +/- 3,600	0.91	0.0021 +/- 0.000075	4/8/2003	HMMWV hit by friendly fire	Y leg/foot
	3/6/2004	22,000 +/- 1000	1	0.0021 +/- 0.000067	4/8/2003		
	7/26/2004	13,600+/- 653.4	1.26	.0020629 +/- 0.00011	4/8/2003		
	8/19/2004	20,100 +/- 930	1.1	0.0021 +/- 0.00010	4/8/2003		
	9/7/2004	14,100 +/- 580	1.6	0.0022 +/- 0.00010	4/8/2003		
6	10/6/2004 to 10/7/2004	3,500 +/- 150	0.84	0.0022 +/- 0.00015	12/18/2003	Bradley vehicle hit by friendly fire, near HMMV when it was hit	Y body
	Not provided	1,253 +/- 83	1.6	0.0021 +/- 0.00026	12/18/2003		Y Arm, hand, face, head
	Not provided	2280 +/- 110	2.065	0.0020 +/- 0.00018	12/18/2003		
	Not provided	490+/- 39	1.3	0.0019+/- 0.00065	12/18/2003	HMMV hit by friendly fire	Y
7	7/23/2003	25 +/- 2.6	0.54	0.0061 +/- 0.0042	3/25/2003	Inhalation of smoke and DU dust	N
	CDC Ratio performed	NA	NA	0.00570 +/- 0.00004	3/25/2003		
	AFIP Ratio	NA	NA	0.0055 +/- 0.0006	3/25/2003		
8	Not provided	160+/- 13	1.98	0.0043 +/- 0.0014	?	Humvee hit by friendly fire	N
	AFIP Ratio	NA	NA	0.0023 +/- 0.0003	?		

2.2 DATA ANALYSIS

Considering the eight positive DU bioassay results from AIPH with suspected DU fragments, individual #5 provided the most complete data and information to test the NCRP 156 wound model IRFs. The six DU urine bioassay values from the wounded soldier were modeled over a fourteen month period using published IRFs from NCRP Report No. 156 in order to test the predictive capacity of the IRFs listed in Appendix D, Table D.4. The predicted (or calculated) urine DU bioassay values from the modeled period was compared to actual DU urine bioassay values collected during the fourteen month period from the data received from the AIPH regarding the wounded soldier with DU fragments. The residuals between the modeled urine DU bioassay levels and actual urine DU bioassay levels were calculated for each specimen collected during the fourteen month collection period using the following equation:

$$\text{Percent Deviation} = \frac{(NCRP\ 156\ Model\ Predicted\ DU\ urine\ bioassay\ data) - (Actual\ DU\ urine\ bioassay\ data)}{NCRP\ 156\ Model\ Predicted\ DU\ urine\ bioassay\ data} \text{ x } 100\% \quad (1)$$

The initial uptake activity for DU was calculated using the published IRFs from NCRP 156 and the ^{238}U urine concentration data obtained from AIPH. The least squares fit method was utilized to estimate the amount of initial activity uptake for the DU wounded individual.

$$R^2 = \frac{\sum_{i=1}^{n} IRF\ x\ DU\ activity\ in\ Urine\ (Bq)}{\sum_{i=1}^{n} IRF^2} \quad (2)$$

The DU activity in the urine was calculated by multiplying the concentration of ^{238}U by the American standard value for the specific activity of DU, which is 12.4 kBq/g according to Argonne National Laboratory (ANL 2001).

$$\text{DU Activity (Bq)} = {}^{238}\text{U conc.(mg/L)} \times \text{DU SA(12.4 Bq/mg)} \quad (3)$$

The estimate of the initial uptake of radioactivity obtained from Equation 2 was used along with the NCRP 156 wound model to determine the predicted rate of DU excretion and the estimated exposure of each soldier up to 10,000 days post intake. A plot of the urine uranium activity (Bq) as a function of time post uptake was created using the NCRP 156 wound model along with Integrated Modules for Bioassay Analysis (IMBA) software. Plotted against the predicted values were individual measured excretion values over the same time period. Hence, the published IRFs listed in Appendix D, Table D.4, of NCRP 156 were used to predict the urinary uranium activity for up to 10,000 days post intake using the following equation:

$$\text{Urine Act.}_{(d)} = A_{(\text{intake})} \times \text{IRF}_{(d)}\ (\text{Bq}) \quad (4)$$

The DU activity in urine obtained from Equation 3 using human urine bioassay data from Army Institute of Public Health (AIPH) was plotted along with the predicted urine activity values from Equation 4.

2.3 AIPH DU CASE SELECTION

Considering the approximately 2,500 AIPH individuals who were sampled for suspected DU exposures, only 8-cases provided positive results for DU in the urine along with associated DU fragments suspected in the wounds. The most suitable case for testing the NCRP 156 IRFs from the information in Table 2.2 provided by AIPH was

individual #5. This individual case had the most complete data set that included six data points over a 14 month period, a known exposure date, and confirmed DU fragment in the leg and foot. The other seven cases from AIPH listed in Table 2.2 were provided with incomplete collection dates, an unknown exposure date, conflicting DU fragment confirmation, or incomplete urine data.

2.4 AIPH DU CASE ANALYSIS

Case analysis was conducted using the Integrated Modules for Bioassay Analysis (IMBA) Professional Plus bioassay analysis software, version 4.1.49. The IMBA software was created by the United Kingdom's (U.K.) Health Protection Agency in association with ACJ & Associates, Inc. IMBA[1] software uses the current ICRP biokinetic and dosimetric models for estimating internal doses and initial uptakes. The IMBA software program has undergone extensive quality assurance tests and is considered routine in evaluating internal dose exposures by the Approved Dosimetry Services in the U.K. and is also supported by several organizations in the U.S. and Canada including the United States Department of Energy and the National Institutes of Occupational Safety and Health Administration (Birchall 2007).

The IMBA software, employed by Idaho State University IMBA Academic Edition package which allows the user to build and employ advanced dosimetry models within the IMBA suite, used NCRP 156's biokinetic wound model and ICRP intake retention functions for DU fragments to calculate approximate intakes from urine uranium concentration laboratory measurements in order to provide bioassay predictions

[1] Health Protection Agency; ACJ & Associates, IMBA Biomathematics Group, Chilton Didcot Oxon, OX11 0RQ, United Kingdom

from the DU fragment case. The IMBA Academic Edition also permits the user the ability to load the NCRP 156 wound model default parameters along with the bioassay data specific cases, in this instance case #5 from AIPH. Therefore, IMBA computed the systemic circulation of DU from the fragment site to the blood and the removal of DU via excretion using the NCRP 156 biokinetic wound model. IMBA also determined the total DU activity initially deposited in the wound site by taking into account the intake retention functions and uptake rates into the blood compartment based on the generic NCRP 156 wound model.

2.5 STATISTICS

A chi-square test (χ^2) is used to measure fit. If the p-value associated with the chi-square test statistic is large, greater than 10%, the data fits the NCRP model well. If the p-value is less than 1%, the model does not fit the data well at all. The chi-square statistic describes the goodness of fit to a data set by measuring the disparity between observed data point and the predicted data point on a curve (Derryberry 2015). The chi-square equation used in evaluating the DU data was:

$$\chi^2 = \frac{1}{\mu'}\sum_{i=1}^{N}(x_i - \mu')^2 \quad (5)$$

where μ' represents the experimental data mean and x_i represents a particular value in the set of data. A chi-square of zero occurs when the predicted function matches perfectly with the expected data points; however, a perfect match is highly improbable due to measurement errors, so a "good" agreement is thought to exist when the chi-square value is approximately equal to the number of degrees of freedom (Knoll 2010).

The chi-square test does not detect a non-random scatter bias around the fit of the curve to the data points; therefore, an autocorrelation coefficient value was applied to the data set. The autocorrelation coefficient (ρ) was calculated using the following equation:

$$\rho = \frac{\sum_{i=1}^{N} R_i R_{i+1}}{\sum_{i=1}^{N} R_i^2} \quad (6)$$

where N equals the number of residuals, R_i represents the ith residual in N residuals and ρ is a value between -1 and 1. The autocorrelation coefficient is expected to be close to zero in totally random circumstances and a ρ value of 1 or -1 represents a less random scatter of data points around the fitted function curve. The autocorrelation coefficient statistic can reveal a "poor" model fit to data resulting from non-randomness in bioassay data residuals and has been observed to be a useful statistical tool in bioassay analysis. The autocorrelation coefficient statistical test thereby offers a more rigorous evaluation to the fit of the case data than just the chi-square test by itself (Knoll 2010). In general, if there is little autocorrelation in the data, $\rho \approx 0$, then the interpretation of the p-value from the chi-square statistics is unproblematic. However, if ρ is significantly different from 0, the p-values from the chi-square statistics are almost always biased. If autocorrelation is a problem, the p-value from the chi-square statistic must be interpreted with caution (Derryberry 2015).

CHAPTER 3. RESULTS AND DISCUSSION

3.1 INITIAL DU UPTAKE CALCULATION ESTIMATE

The initial activity from the uptake of DU for the AIPH case #5 was calculated to be approximately $4.43 \times 10^4 \pm 3.12 \times 10^4$Bq (1.20 ± 0.84 μCi) based on the least squares fit method when inputted into an Excel spreadsheet using Equation 2. The initial activity of DU uptake followed a Poisson distribution within two standard deviations and a confidence interval of 95%.

Table 3.1 Calculation of Initial Activity Uptake from DU Shrapnel

Days between sample collection	IRF value	Initial uptake ^{238}U Conc. (Bq)	Initial Activity (μCi)
97	2.46×10^{-5}	4.16×10^4	1.12
162	1.81×10^{-5}	4.76×10^4	1.29
333	7.07×10^{-6}	3.86×10^4	1.04
475	4.27×10^{-6}	4.98×10^4	1.35
499	3.93×10^{-6}	6.97×10^4	1.88
518	3.80×10^{-6}	7.35×10^4	1.99
	Least squares fit	**4.43×10^4**	**1.20**

3.2 AIPH CASE #5: PREDICTED VS. MEASURED URINE ACTIVITY RESULTS

The initial uptake from the DU shrapnel as calculated using the least squares fit method was used to calculate the predicted urine uranium excretion over time. The predicted values were compared to the actual measured urine uranium activity excretion over time. The predicted urine uranium activity levels were within an average of 0.90 ±

0.95% of the actual measured urine uranium activity levels for the first four post-uptake days of 97, 162, 333, and 475. The predicted urine uranium activity levels in contrast were within an average of -38.09 ± 6.17% of the actual measured urine uranium activity levels for the last two post-uptake days of 499 and 518. The values of the predicted uranium activity levels and the measured values in urine are provided in Table 3.2. The corresponding percent differences associated with each measurement show the nature of predicted excretion compared to measured observations. Figure 3.1 is a plot of the predicted urine uranium activity levels versus the actual measured urine uranium activity levels. Figure 3.2 is a plot showing the percent difference between the measured urine activity versus the predicted urine activity. The uranium activity level in the urine increased in the AIPH case on days 499 and 518. This increase in uranium activity levels on days 499 and 518 may be due to differences in diets and metabolic rates between humans and animals. Chelating acting drugs or agents could also contribute to the larger percent difference seen in the predicted and measured values in the latter days. Medication and nutritional information was not available for review and therefore was not considered in determining or adjusting urine activity values.

Table 3.2 Predicted vs. Measured Urine Uranium Activity Levels

Days post uptake	IRFs	Predicted Urine Act. (Bq)	Measured Urine Act. (Bq)	% Difference
97	2.46×10^{-5}	1.0916	1.0238	6.62
162	1.81×10^{-5}	0.8018	0.8610	-6.87
333	7.07×10^{-6}	0.3134	0.2728	14.87
475	4.27×10^{-6}	0.1891	0.2125	-11.03
499	3.93×10^{-6}	0.1743	0.2742	-36.43
518	3.80×10^{-6}	0.1686	0.2797	-39.75

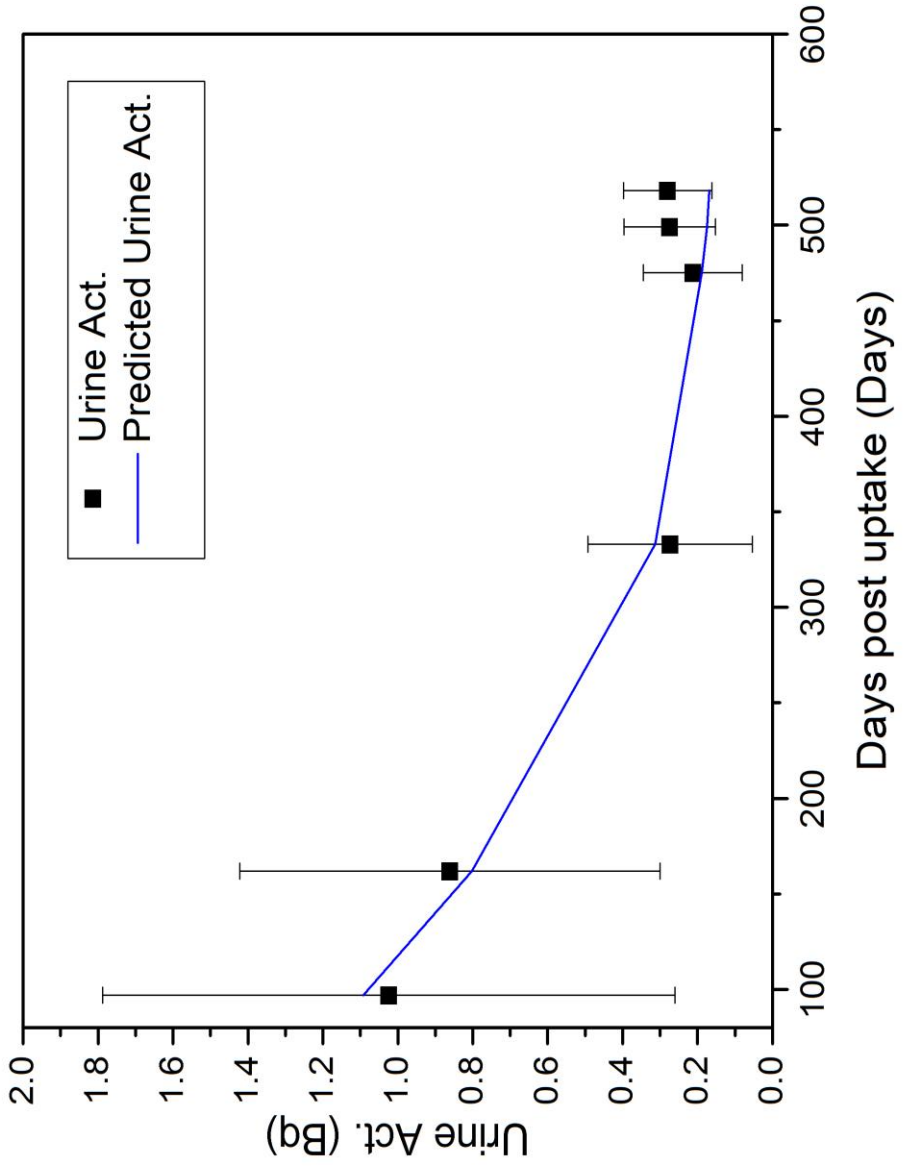

Figure 3.1. Predicted Urine Uranium Activity Levels vs. Actual Measured Urine Uranium Activity Levels from DU Shrapnel Wounds of AIPH Case #5

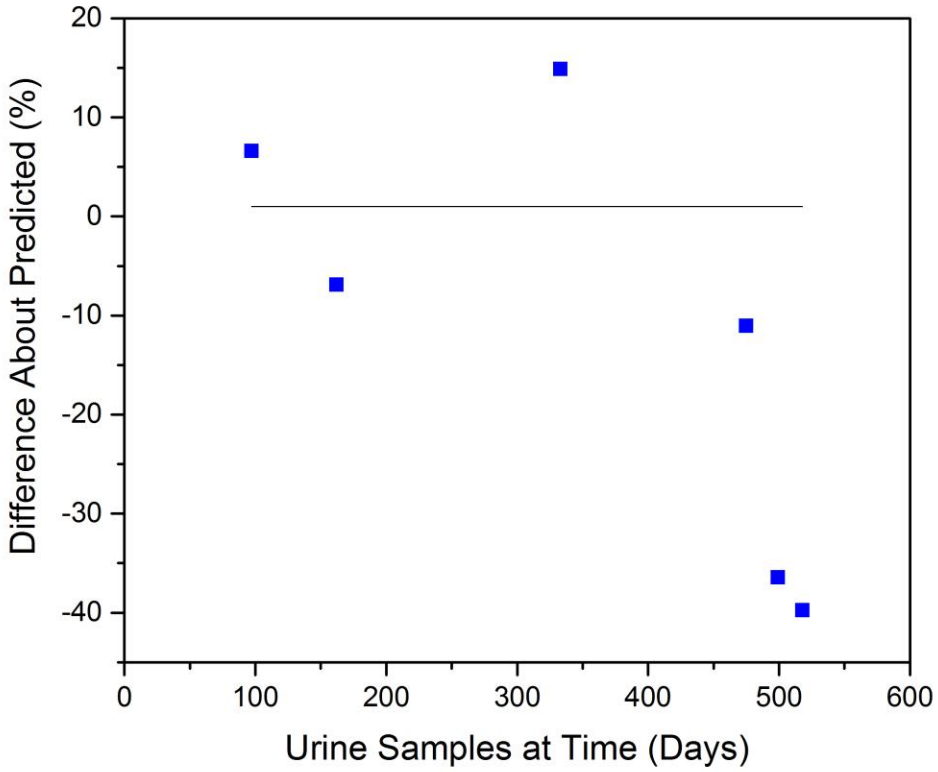

Figure 3.2. Percent Difference about the Predicted Urine Activity

The percent difference for the first four data points comparing the predicted versus the actual urine uranium activity level resulted in an average difference of 0.9%, which supported the null hypothesis that the NCRP Report No. 156 model does accurately predict the urine uranium concentration levels of embedded DU fragments. Long term predictions increasingly deviated from measured values. This difference was -39.75% by day 518.

Several factors could explain the larger percent difference for the latter post-uptake days as seen in Table 2.4. The NCRP 156 wound model prediction values are based on rat models with a specific amount of DU implanted into their musculature under

a controlled setting; whereas, the soldier in question from AIPH received his DU from shrapnel wounds with an unknown exact amount of DU throughout areas of his legs and feet to include muscles, bones, and other supportive tissues. Hence, there may be important physiological differences in the way DU was embedded into different types of tissues. The AIPH case may have involved uptakes into different body compartments with different retention rates which would not match the rat model specifically. The larger uranium activity in the urine at days 499 and 518 may be a result of the uranium leaching into the blood compartment and thusly into the urinary system due to the different excretion rates of DU in bone versus muscle. Also, the IRFs published in NCRP 156 were based on the predicted life expectancy of rats which have a much slower metabolism as they age; hence, the later IRF's may not account for the life expectancy of humans and their metabolic functions as they age.

Encapsulation rates and DU fragment mobility may also contribute to the disparity in the predicted versus actual urine uranium activity levels seen in this study. Encapsulation of DU fragments in the rat studies showed a resultant approximate 99% retention of uranium post one year implantation. AIPH case #5 did not reflect those same results as urine uranium excretion actually increased fourteen months after receiving the DU wound. Several factors altering encapsulation may attribute to the increased urine uranium excretion such as physical activity, medical procedures, chelating acting medications, or diet and nutritional changes. Therefore, more information would need to be obtained to better understand the function of DU encapsulation and excretion rates.

The intake retention factors may need to be adjusted to better fit the human data and account for the differences in rat and human physiology. More urine uranium

bioassay data is required to further validate the later published compartmental clearance rates in NCRP 156 in order to provide a better conclusion.

The AIPH case #5 ($\Sigma\chi^2 = 1.31$, $p = 0.934$) results indicated that an "optimum" fit to human DU contamination wound bioassay data is plausible when using the NCRP 156 wound model parameters. The AIPH DU bioassay data along with the NCRP 156 wound model was consistent with the null hypothesis.

3.3 IMBA RESULTS AND FRAGMENT VERIFICATION

The AIPH DU data was also tested with the IMBA software to verify that case #5 was an actual fragment case and not a particle (avid, weak, moderate, or strong) or colloidal situation. The NCRP 156 wound model fragment coefficients were modified with the appropriate coefficients for a particle, avid, weak, moderate, strong, or colloid wound model. The urine uranium activity of the DU fragment using the different model coefficients was plotted over time and compared to the actual measured urine uranium activity level (Appendix B). The IMBA results verified that the AIPH DU case #5 was a fragment case as the plotted urine uranium activity level curve most closely resembled the fragment curve model and not the particle, avid, weak, moderate, strong, or colloidal curve models.

CHAPTER 4. CONCLUSION

Depleted Uranium (DU) munitions have been used with great success and also unfortunate detriment during the Persian Gulf Wars by U.S. military personnel. Friendly fire accidents are a part of war and will continue to cause deaths, injuries, and ongoing concerns for wounded veterans wounded with DU and who are left with DU embedded fragments. NCRP Report No. 156 was successfully used to predict uranium activity in urine. The quantity of DU in these cases is very small and is thought to present no immediate or long-term adverse health effects. Long term study of DU excretion in this and similar cases will provide valuable information for validating NCRP 156.

The urine uranium bioassay data from AIPH validated NCRP 156 based predictions of uranium urine excretion within 10% for periods of time up to 475 days post uptake. NCRP 156 predicted the measured levels of urine uranium activity within approximately 20%. More data corresponding with much longer post-uptake periods should be collected and analyzed to validate long term model performance, specifically considering physiological changes known to occur with age.

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APPENDIX A

Post-Deployment Health Assessment (PDHA)

DD Form 2796

This form must be completed electronically. Handwritten forms will not be accepted.

POST-DEPLOYMENT HEALTH ASSESSMENT (PDHA)

PRIVACY ACT STATEMENT

AUTHORITY: 10 U.S.C. 136, 1074f, 3013, 5013, 8013 and E.O. 9397.

PRINCIPAL PURPOSE(S): To assess your state of health after deployment in support of military operations and to assist military healthcare providers in identifying and providing present and future medical care you may need. The information you provide may result in a referral for additional healthcare that may include medical, dental or behavioral healthcare or diverse community support services.

ROUTINE USE(S): In addition to those disclosures generally permitted under 5 U.S.C. 552a(b) of the Privacy Act, to other Federal and State agencies and civilian healthcare providers, as necessary, in order to provide necessary medical care and treatment. Responses may be used to guide possible referrals.

DISCLOSURE: Voluntary. If not provided, healthcare WILL BE furnished, but comprehensive care may not be possible.

INSTRUCTIONS: Please read each question completely and carefully before entering your response or marking your selection. **YOU ARE ENCOURAGED TO ANSWER EACH QUESTION. ANSWERING THESE QUESTIONS WILL NOT DELAY YOUR RETURN HOME.** Withholding or providing inaccurate information may impair a healthcare provider's ability to identify health problems and refer you to appropriate sources for additional evaluation or treatment. If you do not understand a question, please ask for help.

DEMOGRAPHICS

Last Name _____ **First Name** _____ **Middle Initial** _____

Social Security Number _____

Today's Date *(dd/mmm/yyyy)* _____

Name of Your Unit during this Deployment _____

Date of Birth *(dd/mmm/yyyy)* _____

Gender
○ Male ○ Female

Service Branch
- ○ Air Force
- ○ Army
- ○ Coast Guard
- ○ Marine Corps
- ○ Navy
- ○ GS Employee
- ○ Other

Component
- ○ Active Duty
- ○ National Guard
- ○ Reserves
- ○ Civilian Government Employee
- ○ Other

Pay Grade
- ○ E1
- ○ E2
- ○ E3
- ○ E4
- ○ E5
- ○ E6
- ○ E7
- ○ E8
- ○ E9
- ○ O1
- ○ O2
- ○ O3
- ○ O4
- ○ O5
- ○ O6
- ○ O7
- ○ O8
- ○ O9
- ○ O10
- ○ W1
- ○ W2
- ○ W3
- ○ W4
- ○ W5
- ○ Other

Date of arrival in theater *(dd/mmm/yyyy)* _____

Date of departure from theater *(dd/mmm/yyyy)* _____

Name of Operation: _____

Location of Operation. To what areas were you mainly deployed *(land-based operations for more than 30 days)*?
(Please mark all that apply, including the number of months spent at each location.)

- ○ Country 1 _____ Time at location *(months)* _____
- ○ Country 2 _____ Time at location *(months)* _____
- ○ Country 3 _____ Time at location *(months)* _____
- ○ Country 4 _____ Time at location *(months)* _____
- ○ Country 5 _____ Time at location *(months)* _____

Occupational specialty during this deployment *(MOS/AOC, NEC/NOBC, or AFSC)*: _____

Combat specialty: _____

Current Contact Information:

Phone: _____
Cell: _____
DSN: _____
Email: _____
Address: _____

Point of Contact who can always reach you:

Name: _____
Phone: _____
Email: _____
Mailing Address: _____

This form must be completed electronically. Handwritten forms will not be accepted.

Service Member's Social Security Number:

1. **Overall, how would you rate your health during the PAST MONTH?**
   - ○ Excellent
   - ○ Very Good
   - ○ Good
   - ○ Fair
   - ○ Poor

2. **Compared to before this deployment, how would you rate your health in general now?**
   - ○ Much better now than before I deployed
   - ○ Somewhat better now than before I deployed
   - ○ About the same as before I deployed
   - ○ Somewhat worse now than before I deployed
   - ○ Much worse now than before I deployed

3. **During the past 4 weeks, how difficult have physical health problems** *(illness or injury)* **made it for you to do your work or other regular daily activities?**
   - ○ Not difficult at all
   - ○ Somewhat difficult
   - ○ Very difficult
   - ○ Extremely difficult

4. **During the past 4 weeks, how difficult have emotional problems** *(such as feeling depressed or anxious)* **made it for you to do your work, take care of things at home, or get along with other people?**
   - ○ Not difficult at all
   - ○ Somewhat difficult
   - ○ Very difficult
   - ○ Extremely difficult

5. **How many times were you seen by a healthcare provider** *(physician, PA, medic, corpsman, etc.)* **for a medical problem or concern during this deployment?**

6. **Did you have to spend one or more nights in a hospital as a patient during this deployment?**
   - ○ No
   - ○ Yes. Reason/dates:

SAMPLE

7. **Were you wounded, injured, assaulted or otherwise hurt during this deployment?**
   - ○ No ○ Yes

7a. **IF YES, are you still having problems related to this event?**
   - ○ No ○ Yes ○ Unsure

8. **For any of the following symptoms, please indicate whether you went to see a healthcare provider** *(physician, PA, medic, corpsman, etc.)*, **were placed on quarters** *(Qtrs)* **or given light/limited duty** *(Profile)*, **and whether you are still bothered by the symptom now.**

Symptom	Sick Call?		Qtrs/Profile?		Still Bothered?		Symptom	Sick Call?		Qtrs/Profile?		Still Bothered?	
	No	Yes	No	Yes	No	Yes		No	Yes	No	Yes	No	Yes
Fever	○	○	○	○	○	○	Dizzy, light headed, passed out	○	○	○	○	○	○
Cough lasting more than 3 weeks	○	○	○	○	○	○	Diarrhea	○	○	○	○	○	○
Trouble breathing	○	○	○	○	○	○	Vomiting	○	○	○	○	○	○
Bad headaches	○	○	○	○	○	○	Frequent indigestion/ heartburn	○	○	○	○	○	○
Generally feeling weak	○	○	○	○	○	○	Problems sleeping or still feeling tired after sleeping	○	○	○	○	○	○
Muscle aches	○	○	○	○	○	○	Trouble concentrating, easily distracted	○	○	○	○	○	○
Swollen, stiff or painful joints	○	○	○	○	○	○	Forgetful or trouble remembering things	○	○	○	○	○	○
Back pain	○	○	○	○	○	○	Hard to make up your mind or make decisions	○	○	○	○	○	○
Numbness or tingling in hands or feet	○	○	○	○	○	○	Increased irritability	○	○	○	○	○	○
Trouble hearing	○	○	○	○	○	○	Skin diseases or rashes	○	○	○	○	○	○
Ringing in the ears	○	○	○	○	○	○	Other *(please list)*:	○	○	○	○	○	○
Watery, red eyes	○	○	○	○	○	○							
Dimming of vision, like the lights were going out	○	○	○	○	○	○							
Chest pain or pressure	○	○	○	○	○	○							

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Service Member's Social Security Number:

9.a. During this deployment, did you experience any of the following events? *(Mark all that apply)*

(1) Blast or explosion *(IED, RPG, land mine, grenade, etc.)*	○ No	○ Yes
(2) Vehicular accident/crash *(any vehicle, including aircraft)*	○ No	○ Yes
(3) Fragment wound or bullet wound above your shoulders	○ No	○ Yes
(4) Fall	○ No	○ Yes
(5) Other event *(for example, a sports injury to your head)*. Describe:	○ No	○ Yes

9.b. Did any of the following happen to you, or were you told happened to you, IMMEDIATELY after any of the event(s) you just noted in question 9.a.? *(Mark all that apply)*

(1) Lost consciousness or got "knocked out"	○ No	○ Yes
(2) Felt dazed, confused, or "saw stars"	○ No	○ Yes
(3) Didn't remember the event	○ No	○ Yes
(4) Had a concussion	○ No	○ Yes
(5) Had a head injury	○ No	○ Yes

9.c. Did any of the following problems begin or get worse after the event(s) you noted in question 9.a.? *(Mark all that apply)*

(1) Memory problems or lapses	○ No	○ Yes
(2) Balance problems or dizziness	○ No	○ Yes
(3) Ringing in the ears	○ No	○ Yes
(4) Sensitivity to bright light	○ No	○ Yes
(5) Irritability	○ No	○ Yes
(6) Headaches	○ No	○ Yes
(7) Sleep problems	○ No	○ Yes

9.d. In the past week, have you had any of the symptoms you indicated in 9.c.? *(Mark all that apply)*

(1) Memory problems or lapses	○ No	○ Yes
(2) Balance problems or dizziness	○ No	○ Yes
(3) Ringing in the ears	○ No	○ Yes
(4) Sensitivity to bright light	○ No	○ Yes
(5) Irritability	○ No	○ Yes
(6) Headaches	○ No	○ Yes
(7) Sleep problems	○ No	○ Yes

10. Did you encounter dead bodies or see people killed or wounded during this deployment? *(Mark all that apply)*
○ No ○ Yes (○ Enemy ○ Coalition ○ Civilian)

11. Were you engaged in direct combat where you discharged a weapon?
○ No ○ Yes (○ land ○ sea ○ air)

12. During this deployment, did you ever feel that you were in great danger of being killed?
○ No ○ Yes

13. Have you ever had any experience that was so frightening, horrible, or upsetting that, IN THE PAST MONTH, you ....

a. Have had nightmares about it or thought about it when you did not want to?	○ No	○ Yes
b. Tried hard not to think about it or went out of your way to avoid situations that remind you of it?	○ No	○ Yes
c. Were constantly on guard, watchful, or easily startled?	○ No	○ Yes
d. Felt numb or detached from others, activities, or your surroundings?	○ No	○ Yes

14. Over the PAST MONTH, have you been bothered by the following problems?

	Not at all	Few or several days	More than half the days	Nearly every day
a. Little interest or pleasure in doing things	○	○	○	○
b. Feeling down, depressed, or hopeless	○	○	○	○

15. Alcohol is occasionally available during deployments, e.g., R&R, port call, etc. Prior to deploying or during this deployment:

a. Did you use alcohol more than you meant to? ○ No ○ Yes

b. Have you felt that you wanted to or needed to cut down on your drinking? ○ No ○ Yes

c. How often do you have a drink containing alcohol?
○ Never ○ Monthly or less ○ 2 to 4 times a month ○ 2 to 3 times a week ○ 4 or more times a week

d. How many drinks containing alcohol do you have on a typical day when you are drinking?
○ 1 or 2 ○ 3 or 4 ○ 5 or 6 ○ 7 to 9 ○ 10 or more

e. How often do you have six or more drinks on one occasion?
○ Never ○ Less than monthly ○ Monthly ○ Weekly ○ Daily

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Service Member's Social Security Number:

16. Are you worried about your health because you were exposed to: *(Mark all that apply)*	No	Yes
Animal bites	○	○
Animal bodies *(dead)*	○	○
Chlorine gas	○	○
Depleted uranium *(If yes, explain)* _____	○	○
Excessive vibration	○	○
Fog oils (smoke screen	○	○
Garbage	○	○
Human blood, body fluids, body parts, or dead bodies	○	○
Industrial pollution	○	○
Insect bites	○	○
Ionizing radiation	○	○
JP8 or other fuels	○	○
Lasers	○	○
Loud noises	○	○
Paints	○	○
Pesticides	○	○
Radar/Microwaves	○	○
Sand/dust	○	○
Smoke from burning trash or feces	○	○
Smoke from oil fire	○	○
Solvents	○	○
Tent heater smoke	○	○
Vehicle or truck exhaust fumes	○	○
Other exposures to toxic chemicals or materials, such as ammonia, nitric acid, etc.: *(If yes, explain)* _____	○	○

17. Were you exposed to any chemicals or other hazard *(industrial, environmental, etc.)* **that required you to seek immediate medical care?**

○ No ○ Yes

18. Did you enter or closely inspect any destroyed military vehicles?

○ No ○ Yes

19. Do you think you were exposed to any chemical, biological, or radiological warfare agents during this deployment?

○ No ○ Don't know ○ Yes, explain with date and location _____

_____

20. This question assesses your personal risk for exposure to tuberculosis or other local infectious diseases. Would you say your INDOOR contact with local or 3rd country nationals was:

○ None ○ Minimal *(less than 1 hour per week)* ○ Moderate *(1 or more hours per week, but not daily)* ○ Extensive *(at least 1 hour per day, every day)*

21. Force Health Protection Measures. Please indicate which of the following items you used during this deployment and how often you used them.

	Daily	Most days	Some days	Never	Not available	Not required
DEET insect repellent applied to skin	○	○	○	○	○	○
Pesticide-treated uniforms	○	○	○	○	○	○
Eye protection *(not commercial sunglasses or prescription glasses)*	○	○	○	○	○	○
Hearing protection	○	○	○	○	○	○
N-95 or other respirator *(not gas mask)*	○	○	○	○	○	○
Pills to stay awake, like dexedrine	○	○	○	○	○	○
Anti-NBC meds	○	○	○	○	○	○
Pyridostigmine *(nerve agent pill)*	○	○	○	○	○	○
Nerve agent antidote injector	○	○	○	○	○	○
Seizure/convulsion antidote injector	○	○	○	○	○	○
NBC gas mask	○	○	○	○	○	○
MOPP over garments	○	○	○	○	○	○

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Service Member's Social Security Number:

22. Did you receive any vaccinations just before or during this deployment?

- ○ Smallpox *(leaves a scar on the arm)*
- ○ Anthrax
- ○ Botulism
- ○ Typhoid
- ○ Meningococcal
- ○ Yellow Fever
- ○ Other, list: _____
- ○ No
- ○ Don't know

23. Were you told to take medicines to prevent malaria?

○ No ○ Yes

If YES, please indicate which medicines you took and whether you missed any doses. *(Mark all that apply)*

Anti-malarial medications	Took All Pills
○ Chloroquine (Aralen®)	○ No ○ Yes
○ Doxycycline (Vibramycin®)	○ No ○ Yes
○ Mefloquine (Lariam®)	○ No ○ Yes
○ Primaquine	○ No ○ Yes
○ Other : _____	○ No ○ Yes

24. Would you like to schedule a visit with a healthcare provider to further discuss your health concern(s)? ○ No ○ Yes

25. Are you currently interested in receiving information or assistance for a stress, emotional or alcohol concern? ○ No ○ Yes

26. Are you currently interested in receiving assistance for a family or relationship concern? ○ No ○ Yes

27. Would you like to schedule a visit with a chaplain or a community support counselor? ○ No ○ Yes

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Service Member's Social Security Number:

Health Care Provider Only

Post-Deployment Health Care Provider Review, Interview, and Assessment

1. **Do you have any medical or dental problems that developed during this deployment?** ○ Yes ○ No
   If yes, are the problems still bothering you now? ○ Yes ○ No

2. **Are you currently on a profile (or LIMDU) that restricts your activities (light or limited duty)?** ○ Yes ○ No
   If yes: For what reason? _____ ○ NA
   Is your condition due to an injury or illness that occurred during the deployment? ○ Yes ○ No ○ NA
   Did you have similar problems prior to deployment? ○ Yes ○ No ○ NA
   If so, did your condition worsen during the deployment? ○ Yes ○ No ○ NA

3. **Ask the following behavioral risk questions. Conduct risk assessment as necessary.**
   a. Over the PAST MONTH, have you been bothered by thoughts that you would be better off dead or of hurting yourself in some way? ○ Yes ○ No
      IF YES, about how often have you been bothered by these thoughts? ○ A few days ○ More than half of the time ○ Nearly every day
   b. Over the PAST MONTH, have you had thoughts or concerns that you might hurt or lose control with someone? ○ Yes ○ No ○ Unsure

4. **If member reports YES or UNSURE responses to 3.a. or 3.b., conduct risk assessment.**
   a. Does member pose a current risk for harm to self or others? ○ No, not a current risk ○ Yes, poses a current risk ○ Unsure
   b. Outcome of assessment ○ Immediate referral ○ Routine follow-up referral ○ Referral not indicated

5. **Alcohol screening result**
   ○ No evidence of alcohol-related problems
   ○ Potential alcohol problem (positive response to either question 15.a. or 15.b. and/or AUDIT-C (questions 15.c.-e.) score of 4 or more for men or 3 or more for women).
   Refer to PCM for evaluation. ○ Yes ○ No

6. **During this deployment have you sought, or do you now intend to seek, counseling or care for your mental health?** ○ Yes ○ No

7. **Traumatic Brain Injury (TBI) risk assessment**
   ○ No evidence of risk based on responses to questions 9.a. - d.
   ○ Potential TBI with persistent symptoms, based on responses to question 9.d.
   Refer for additional evaluation. ○ Yes ○ No

8. **Tuberculosis risk assessment, based on response to question 20.**
   ○ Minimal risk
   ○ Increased risk
   Recommend tuberculosis skin testing in 60-90 days ○ Yes ○ No

9. **Depleted Uranium (DU) risk assessment, based on responses to question 16 (DU, Yes) or question 18 (Yes).**
   ○ No evidence of exposure to depleted uranium
   ○ Potential exposure to depleted uranium
   Refer to PCM for completion of DD Form 2872 and possible 24-hour urinalysis. ○ Yes ○ No

10. **Do you have any other concerns about possible exposures or events during this deployment that you feel may affect your health?** ○ Yes ○ No
    Please list your concerns: _____

11. **Do you currently have any questions or concerns about your health?** ○ Yes ○ No
    Please list your concerns: _____

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Service Member's Social Security Number:

Health Assessment

After my interview/examination of the service member and review of this form, there is a need for further evaluation and follow-up as indicated below. (More than one may be noted for patients with multiple problems. Further documentation of the problem evaluation to be placed in service member's medical record.)

11. Identified Concerns	Minor Concern	Major Concern	Already Under Care	
			Yes	No
○ Physical Symptom(s)	○	○	○	○
○ Exposure Symptom(s)	○	○	○	○
○ Environmental	○	○	○	○
○ Occupational	○	○	○	○
○ Combat or mission-related	○	○	○	○
○ Depression symptoms	○	○	○	○
○ PTSD symptoms	○	○	○	○
○ Anger/Aggression	○	○	○	○
○ Suicidal Ideation	○	○	○	○
○ Social/Family Conflict	○	○	○	○
○ Alcohol Use	○	○	○	○
○ Other:_____	○	○	○	○

12. Referral Information	Within 24 hours	Within 7 days	Within 30 days
a. Primary Care, Family Practice	○	○	○
b. Behavioral Health in Primary Care	○	○	○
c. Mental Health Specialty Care	○	○	○
d. Other specialty care:			
Audiology	○	○	○
Cardiology	○	○	○
Dentistry	○	○	○
Dermatology	○	○	○
ENT	○	○	○
GI	○	○	○
Internal Medicine	○	○	○
Neurology	○	○	○
OB/GYN	○	○	○
Ophthalmology	○	○	○
Optometry	○	○	○
Orthopedics	○	○	○
Pulmonology	○	○	○
Urology	○	○	○
e. Case Manager, Care Manager	○	○	○
f. Substance Abuse Program	○	○	○
g. Health Promotion, Health Education	○	○	○
h. Chaplain	○	○	○
i. Family Support, Community Service	○	○	○
j. Military OneSource	○	○	○
k. Other: _____	○	○	○
l. No referral made ○			

13. Comments:

I certify that this review process has been completed.

Provider's signature and stamp:

This visit is coded by V70.5 _ E

Date *(dd/mmm/yyyy)*

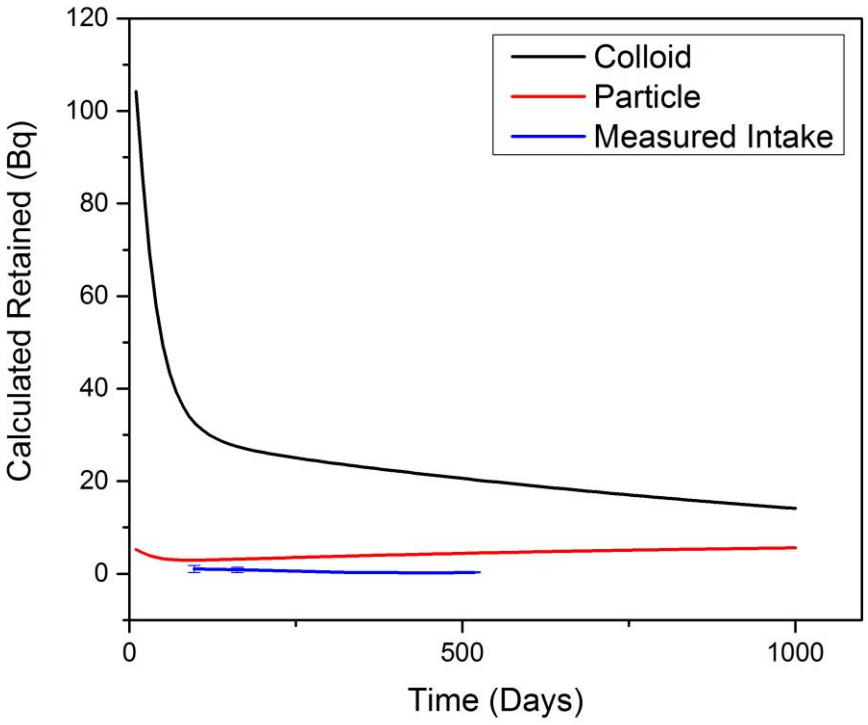
SAMPLE

Ancillary Staff/Administrative Section

14. Member was provided the following:	15. Referral was made to the following healthcare or support system:
○ Medical Threat Debrief	○ Military Treatment Facility
○ Health Education and Information	○ Division/Line-based medical resource
○ Health Care Benefits and Resources Information	○ VA Medical Center or Community Clinic
○ Appointment Assistance	○ Vet Center
○ Service member declined to complete form	○ TRICARE Provider
○ Service member declined to complete interview/assessment	○ Contract Support: _____
○ Service member declined referral for services	○ Community Service: _____
○ LOD	○ Other: _____
○ Post-deployment blood specimen collected (if required)	○ None
○ Other: _____	

APPENDIX B

IMBA VERIFICATION CURVES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Calculated Retained (Bq)
Time (Days)
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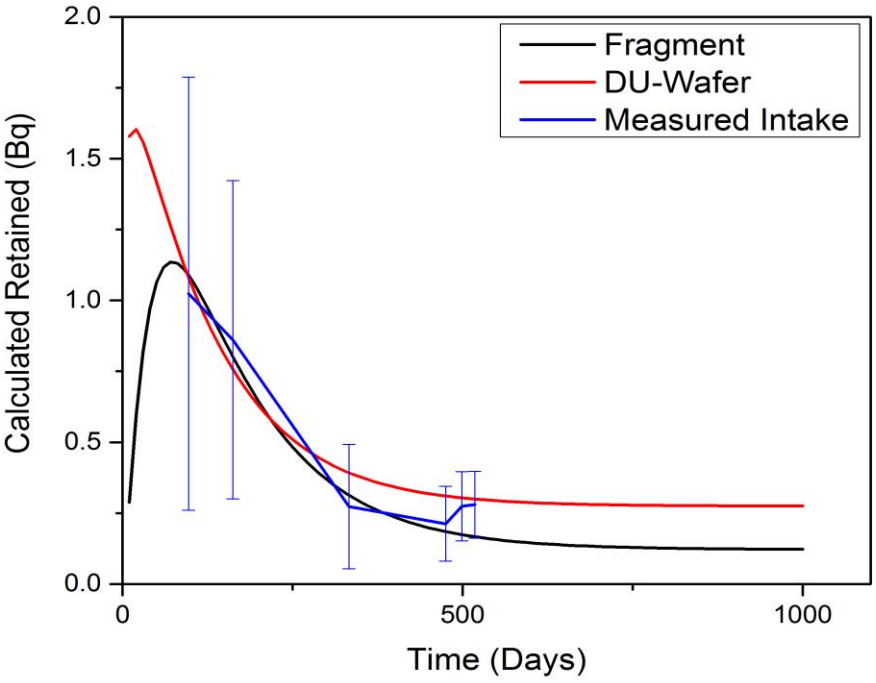
100
80
60
40
20
0
0
500
1000


Fragment
DU-Wafer
Measured Intake
Calculated Retained (Bq)
Time (Days)
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1.5
1.0
0.5
0.0
0
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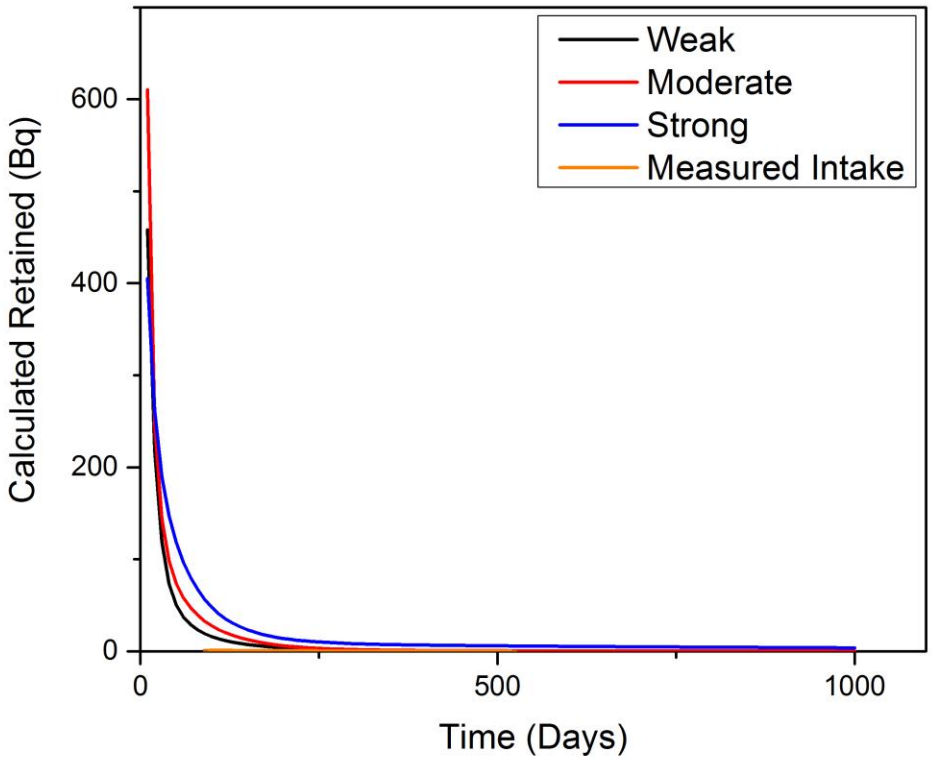
Weak
Moderate
Strong
Measured Intake
Calculated Retained (Bq)
600
400
200
0
0
500
1000
Time (Days)