APPENDIX P - Depleted Uranium Test Data for Safety and Health Risk Assessments

P.1 Critical Review

Critical review and evaluation of published DU developer test documents and reports for relevant health and safety data for use in making human exposure assessments have been accomplished. Drafts of unpublished reports, which contain possible relevant data or comments, have been reviewed; however, evaluation of these data may need further assessment when completed and published.

The potential health concern from DU munitions is through inhalation and ingestion of DU particles created through interaction with armored targets, fires, and environmental corrosion of material left in the environment. Because uranium is a natural component in trace quantities of most of the earth's soils, the addition of DU particulates is unlikely to be detectable in the soil except where penetrator fragments are present. However, inhalation of aerosolized DU and other contaminant particulates in sufficient quantity may produce health effects.

Recent attention has focused on the issue of DU left behind on a battlefield and whether its presence could cause health effects to personnel involved in reconnaissance or cleanup and to the civilian population following the hostilities. A further question is whether its long-term presence would adversely impact further military operations in the area.

Experimental data of DU oxide particulate characteristics, especially those documented in tests conducted by PNNL in support of DOD initiatives, have been reviewed. Selected studies conducted by the U.S. Army and U.S. Air Force have also been reviewed.

- The characteristics/parameters specifically identified from these reports are the chemical composition, particle size, shape, morphology and solubility in lung fluid. These parameters are believed to have the greatest influence on whether a particle will be inhaled, where it may end up in the body, and whether it is more likely to pose a potential toxicological or radiological adverse health effect.
- These data were gathered to evaluate their usefulness in modeling atmospheric transport and environmental dispersion and to identify data gaps that must be filled to model inhalation, indirect ingestion, secondary ingestion (hand-to-mouth), and contaminated wound exposures adequately.

P.2 Identified Data Gaps

As with any modeling, the results at best are only as good as the input data and assumptions. Some need to refine the modeling and improve the database can always be identified. With this in mind, it could be said that data gaps occur with each parameter evaluated. The more important concern is how well the models predict the hazard and how much influence time has on the weathering and dispersion of the material.

Although sensitivity modeling may be required, some generalizations best reflect the apparent value and uncertainty of the data evaluated.

- The first and largest data gaps appear to be associated with DU aerosol production, both inside and outside the vehicle, at the time of Crew Compartment penetrations or with fires involving DU munitions, and over sequentially integrated time periods for at least 1 hour. The data gaps related to aerosol generation include:

  - DU airborne concentration
  - DU particle shape, size distribution and morphology (0.1 μm – 100 μm)
  - DU particle chemical forms and isotopic uranium composition
  - Elemental composition of the DU particle residue (radioactive and non-radioactive impurities in the DU)
  - Lung fluid dissolution rates for aerosolized DU

- The second serious concern is the lack of data on DU particle resuspension. Although there are values for a variety of circumstances (inside the vehicle versus outside the vehicle), the variation is substantial and the values have a large uncertainty.

  - Part of the reason for this data gap is the difficulty in obtaining representative samples under varying site conditions. While certain testing is warranted, site-specific factors that may not be quantifiable would still leave a significant level of uncertainty in the choice of a "reference" resuspension factor.

- Analysis of resuspension within vehicles has been attempted but is especially in need of further testing and data validation for short-term exposure to personnel. Efforts in resuspension should be directed toward reducing the uncertainty in the observed parameters.

- The third area where data are especially variable is with the particle size distribution of aerosolized DU.

The field data do establish general expectations based on type of incident, and this may be adequate. However, since particle size and shape drive settling, mixing, resuspension and the human intake of the material, additional data could only help to validate appropriate ranges of values in each circumstance.

A difficulty in sample collection, that may cause a slight underestimation of the fine particle fraction, is that material that could be suspended may have dispersed before sample collection begins. This effect is assumed to be minor, but the consequences could be significant if a large fraction of the material aerosolizes with the finer particles not being collected.

- The fourth serious concern is the lack of data relating to the effect of the fire suppression system and the EC/NBC system on the airborne concentration inside a vehicle following a DU perforation and sequentially integrated time periods.
- The fifth area of concern is the DU armor contribution to the production of DU aerosols in the vehicle following perforation of the package in the following scenarios:

- DU round perforating DU armor
- DU round perforating non-DU armor
- Non-DU round perforating DU armor

- The sixth area of concern is the production of DU aerosols in a BFV perforated by large and medium caliber DU penetrators (DU round on non-DU).
- The seventh area of concern is from a dosimetry modeling perspective. Much should be considered with particle settling and resuspension modeling. There is a small amount of experimental data that provides some understanding of what to expect. More detailed analysis and modeling would prove especially useful in estimating the exposure or calculating a dose to occupants of a tank or other confined space and recovery teams.
- The eighth area of concern is from the limited data available on weathering and corrosion of the DU munitions on the battlefield.
- The ninth area of concern is the lack of data on secondary ingestion (hand-to-mouth) transfer and the GI transfer coefficient for DU on the battlefield.
- The tenth area of concern is the verification of the gun-tube contamination following the firing of DU munitions and of the airborne levels of DU in the Crew Compartment from “blowback” or “flareback” during the firing of DU munitions.

P.3 Areas For Data Improvement

The reviewed documents indicate data exist with regard to the formation of uranium or DU oxides and to the resulting simulated lung fluid solubility and particle size from hard target impact and ammunition fires involving DU munitions. These data could be used as input for health hazard/risk assessment models. However, large uncertainties exist in the data.
The following are examples of the limited data that exist on dissolution rates for DU oxides.

- Most fires produce an oxide that is predominately insoluble with a large percent of the particles greater than 10 μm AED.
- Impacts with armor tend to increase the percentage of soluble oxide compounds and decrease the particle size. Variation in the behavior of DUO_2 and DU_3O_8 was observed with some tests indicating Class W (or Type M) behavior and others Class Y (or Type S).
- Human studies have shown that DUO_2 and DU_3O_8 are primarily insoluble and generally considered being Class Y (or Type S). Studies show that DUO_3 is generally Class W (or Type M); however, DU munitions test reports state that DUO_3 is Class D (or Type F).

Basing the source term from DU fires on the results of oxidation in field studies is a good step but should be refined based on objective observations of powder or dust versus metal remains, if possible (that is, mass balance).

Using field data directly, rather than attempting to model atmospheric conditions, is preferable for accident circumstances similar to those of the field tests.

In an evaluation of results from the reviewed tests, the quality of data is generally believed to be too variable. The large uncertainties arise from the difficulty of appropriately sampling very low levels of particulate matter in a hostile environment and under testing conditions designed to evaluate system performance rather than dedicated testing for health and safety purposes. Even with these caveats, the current published data are being used to estimate the magnitude of dispersion and potential bounds on health effects.

- The uncertainties in quantifying the aerosol source term and modeling the actual behavior of the components that lead to personnel exposures are likely to be at least as great as the uncertainties associated with the measurements of the various aerosol characteristics.
- Field measurements over a variety of well-defined and controlled circumstances would lead to the generation of more robust data for use in health and safety assessments.

P.4 Evaluation of the Environmental Fate and Effects of DU on U.S. Test Ranges

The following is an attempt to collate past environmental data gathered from tests conducted on U.S. test ranges. The objective of these tests was to test DU munitions that resulted in DU-contamination of the environment.

- A better understanding of levels of DU-contamination at the test ranges could produce data and models that may be transferable to other sites, to include the battlefields.
- Review environmental and health hazard data obtained to date to ensure that the data are consistent and scientifically defensible.
- Develop environmental fate and effect models to determine the relative risk as a function of DU migration. These models must be robust enough to provide defensible estimates of the air, surface water, ground water and soil migration of DU on the U.S. test ranges and other DU-contaminated sites.
- Develop and conduct experiments to generate the requisite data to fill the gaps that are scientifically defensible.

The following have been extracted from Shelton et al., (1995)[25].

- Evaluate the environmental fate and effects of DU on U.S. test ranges.
- Review environmental monitoring data that has been obtained to date to ensure consistency and scientific defensibility.
- Review DU particle data from Army studies and elsewhere to determine data gaps and to conduct experiments to generate the requisite data to fill these gaps. The data must be scientifically defensible.
- Develop a better understanding of DU particles generated from impacts/perforations or burning munitions.

- Develop environmental fate and effect models to determine relative risk as a function of migration.

P.5 Future Studies

To better understand potential adverse health effects resulting from exposure to DU, future studies should address the following:

- Toxicity of DU oxides following single and repeated inhalation exposures (acute and sub-acute exposures). Endpoints assessed should include effects on known targets of uranium, such as the kidney, as well as other potential targets including the liver, bone, reproductive system, immune system, endocrine system, and nervous system. Exposure concentrations should be correlated with both target organ effects and target organ concentrations.
- The potential for interaction between the radiological and chemical effects of DU.
- Potential for DU to interact with other battlefield unique compounds to which soldiers may have been exposed.

Military Air Guidelines – Short Term (MAGs-S) for deployed military personnel should be established for DU oxides. Guidelines such as these are developed specifically to assist deployed military personnel when assessing the risks associated with potential chemical exposures (USACHPPM TG 230A, 1999).

The protective mask should be evaluated to determine the protection factor for airborne radioactive material during battlefield conditions.

P.6 Conclusions

Data gaps have been identified and areas for data improvement have been discussed.

For identification of data gaps and validation of any DU exposure assessments, recommendations for further refinements of the process must be provided. Such recommendations include—

- A validation of the exposure, environmental transfer, intake and dosimetry models, with comparisons of clinical evaluations of exposed individuals.
- Uncertainty and sensitivity analysis of the parameters and models, and laboratory experiments, mock-ups, and live-fire tests with data collected specifically for health and safety and environmental assessments.

A series of dedicated tests are being planned and will be conducted in order to obtain the appropriate data for human exposure assessment and health risk characterization. This undertaking will be a team effort.

The data from these tests must be defensible in order to be used in a human health risk characterization. All test protocols must be established and peer reviewed before the actual testing. Well-defined DQOs for obtaining and using the data in subsequent health risk characterizations, not just safety analyses, must be contained in the test protocols. All test reports must be peer reviewed and the data validated prior to use in any health risk characterization.