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A Review of the Toxicology of Tungsten Based Heavy Metal Alloys

Executive summary

In the United States of America (USA) attention has turned towards tungsten alloys as the leading candidates to replace depleted uranium (DU) in munitions applications. This has arisen as a result of veterans', public and media concerns over the perceived adverse health and environmental effects of DU and an interest in enhancing anti-tank capability. Although tungsten has been used widely in industrial and military applications for many years, relatively little is known about human exposure to tungsten and its alloys, especially as embedded fragments.

Recent research carried out by the Armed Forces Radiobiology Research Institute (AFRRI) in the USA has raised concerns over the human health effects of tungsten alloys. This concern has arisen following the development of aggressive tumours, which metastasised to the lungs and showed some abdominal and lymphatic spread, in rats which had leg muscle implants of tungsten alloy pellets composed of tungsten, nickel and cobalt.

On the basis of the AFRRI results the United Kingdom (UK) Ministry of Defence (MoD) determined a need to establish what is known of the military and civilian use of tungsten alloy. As a result a comprehensive and critical review was proposed with the primary aim being to seek to understand and validate the USA animal experiments and the nature of the impact products arising when tungsten alloy projectiles impact armoured targets. A secondary aim was to identify gaps in knowledge and understanding of the human health effects of the heavy metal and heavy metal alloys, and their impact products, of military significance.

The review report identifies where gaps exist in the understanding of the human health effects of tungsten alloy and its components and recommends the research that will be required to enhance the UK's understanding of the results of the US study. It also addresses the implications of the current status of knowledge and understanding in the context of the tungsten alloys used by the UK armed forces.

The review has concluded that:

Little is known about the toxicology of tungsten based sintered heavy metal alloys (HMTAs) with the exception of the studies carried out in cell cultures and experimental animals at the AFRRI.

The AFRRI studies were well designed, peer reviewed and supported the conclusions that tungsten/nickel/cobalt alloys are carcinogenic in rats and may be able to increase tumorigenicity and promote cancer related genes on the cellular level.

The observations by the workers at AFRRI support the conclusion that HMTAs may corrode in the body to form metal salts that could include nickel oxide, which is carcinogenic and proven to form tumours after implantation. There is only limited information available on the interactions between the metals and any effects of the physicochemical form of the alloy.

There is insufficient evidence presently available to conclude whether the HMTAs used in UK or USA munitions are, or are not, carcinogens in humans.

Tungsten and iron are of low toxicity and exposure to these metals by implantation or by inhalation has not been positively associated with long term toxic effects.

Nickel compounds are toxic to the lungs and kidneys dependent upon route of exposure and have established long term toxicities. Nickel compounds are human carcinogens, though the pure metal is only a "possible carcinogen" to humans. Nickel is a proven sensitiser and must therefore be considered as a potential immunotoxicant.

Cobalt is toxic to the lungs by inhalation, and a possible human carcinogen after inhalation and implantation in muscle.

The evidence points to the metals only being toxic orally in high doses and there is no evidence of significant systemic toxicity after percutaneous exposure, except for irritation and sensitisation by nickel and cobalt.

There is no published information available on the effects of HMTAs on the immune or nervous systems.

There is insufficient evidence available to characterise the aerosols generated by impact of HMTA kinetic energy penetrators (KEPs) hence there is no information available on the toxicity of aerosolised impact products.

There is as yet insufficient data on the toxicity of tungsten alloys used in UK munitions to reach a firm conclusion as to whether or not they have a potential for causing human health hazards.

A study to address the probability of exposure to HMTA fragments or impact aerosols should be conducted. If it is deemed that the probability of exposure to HMTA fragments or impact aerosols warrants further research to gain an enhanced understanding of the risk of adverse health effects, then the following work is recommended:

The carcinogenesis studies reported by AFFRI should be repeated in another species to eliminate the possibility of a species specific effect.

Carcinogenesis studies should be carried out on HMTAs used in UK munitions i.e. tungsten/nickel/iron and tungsten/nickel/copper.

Research should be conducted to establish if the carcinogenic effect of implanted HMTAs is the result of one metal leaching out of the pellet and reacting with the tissues or from some synergistic effect between the metals, as appears to happen *in vitro*.

Research should be conducted to determine the chemical nature of the *in vivo* breakdown products of HMTA pellets when these are implanted into animal tissues.

The mechanism by which HMTAs transform cells *in vitro* to cancerous cells should be defined to allow a rational choice of the metal content of future munitions to be made.

Possible effects of HMTAs on the immune system and the nervous system should be investigated.

Research should be conducted to define the chemical and physical nature of the impact products of HMTA projectiles and common targets and the toxic potential of any dusts generated by impact should be assessed. During this research consideration should be given to the partitioning and retention of the metals in lung tissue with a view to developing a predictive model of clearance from, and retention in, the body.