Weld World (2015) 59:145–150
DOI 10.1007/s40194-014-0197-9

Welding with non-consumable thoriated tungsten electrodes

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Received: 15 July 2014 / Accepted: 3 October 2014 / Published online: 31 October 2014

Abstract This document was prepared by the International Institute of Welding, Commission VIII Health and Safety under the chairmanship of the Author. It constitutes the considered judgement of this expert group on the hazards and risks added to arc welding by the use of thoriated tungsten electrodes and the specific protective measures which are required to control the risks and thus protect the health and safety of welders and those working with them directly or indirectly as in cleaning and maintenance. The experts have drawn on views expressed in previous Commission VIII documents on this topic and information on thorium and its compounds published in papers in the scientific literature. The experts recommend that use of thoriated electrodes ceases as soon as is practicable and that, until that change is completed, special care is taken to inform workers of the hazards and to implement all the other protective measures which are detailed in the report.

Keywords Welding · GTA welding · Plasma cutting · Thorium · Thoriated tungsten · Occupational health

1 Introduction and scope of the document

This document was prepared by the International Institute of Welding, Commission VIII Health and Safety. It constitutes the considered judgement of this expert group on the hazards and risks added to tungsten inert gas (TIG) arc welding by the use of thoriated electrodes and the specific protective measures which are required to control the risks and thus protect the health and safety of welders and those working with them directly or indirectly as in cleaning and maintenance. The experts have drawn on views expressed in previous Commission VIII documents and information reported in the published scientific literature on these and related topics. These are listed in the Bibliography.

This document provides guidance, based on published information and the knowledge and experience of experts, on the hazards and risks added to arc welding by the use of thoriated electrodes and the specific protective measures which are required to control the risks and thus protect the health and safety of workers who:

- Deliver, store and/or issue such electrodes
- Use TIG welding and those working with them
- Grind the electrodes to sharpen the tip
- Are otherwise located in or adjacent to welding or grinding sites
- Clean or maintain welding or grinding sites, associated ventilation systems and respirators
- Undertake the collection and disposal of spent electrodes, contaminated filters and grinding dust

2 Background

Tungsten inert gas shielded welding (TIG), also known as gas tungesten arc wedling (GTAW) is a process in which a non-consumable tungsten electrode forms one of the poles of an electric arc. Tungsten is used because it can withstand very high temperatures with minimal melting or erosion, i.e. "non-consumable". Tungsten electrodes are also used in plasma welding and cutting.

TIG/GTAW electrodes contain small quantities of metallic oxides to improve their current carrying capacity, increase life, facilitate arc starting, increase the arc's stability, and reduce the risk of weld contamination. One such additive is naturally radioactive thorium dioxide

Doc. IIW-2509, recommended for publication by Commission VIII "Health, Safety and Environment."

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(ThO_2). This material introduces specific risks of adverse effects on health which need to be assessed and controlled adequately. Alternative additives are available (see later).

For technical reasons it is necessary for the welding electrode to have a fine conical point. During use and each time it is touched down, it loses some of its sharpness. The pointed tips are initially created and then maintained by grinding in the workplace. In general, plasma arc electrodes have to be sharpened less frequently than those used in TIG/GTAW welding.

3 Hazards

Thorium (Th) is a radioactive element with a long half-life. It emits mainly alpha particles but also gamma and occasionally beta radiation.

3.1 Thorium in welding electrodes

The principal radiologically relevant isotope used in thoriated electrodes is thorium-232 (^{232}Th) which has a half-life of 14 billion (14×10^9) years. The two other isotopes which may be found are thorium-230 and thorium-228 which have half-lives of 75,400 and 1.9 years, respectively.

Airborne particles containing radioactive thorium may be emitted in dust generated when thoriated electrodes are stored, handled, ground to sharpen the tips and consumed during welding and from waste material generated during welding or grinding. Floors and working surfaces where welding or grinding are done are likely to become contaminated with such particles and serve as secondary sources of the hazard. All possible sources should be considered together when assessing the thorium intake of workers.

3.2 Sources of health effects of internal radiation

Thorium-containing particles derived from the electrodes may enter the body through inhalation and ingestion (directly or indirectly from contaminated food, water or other material such as a cigarette) and through open cuts and grazes. In the fullness of time, the resulting internal radiation may cause significant diseases, including cancers, in tissues where it is retained. These include the lungs, liver and bone. Inhalation is the greatest risk generally. This is reflected in regulatory exposure limits which are much lower for inhalation than ingestion.

Although much of the research on the adverse health effects of inhalation of thorium-containing particles has been in industries other than welding, the adverse effects identified are relevant to risk assessment for workers and others exposed to dust and fume from thoriated electrodes. These studies indicate that inhalation is also likely to be the more significant route of entry in the welding or cutting situation. The respirable fraction of the total aerosol generated during TIG/GTAW welding and related electrode grinding is 45 and 60 %, respectively [1]. Thus, inhaled thorium-containing particles may enter and release alpha particles along the entire respiratory tract including the deepest parts of the lung.

3.3 Sources and health effects of external radiation

It is unlikely that significant doses of radiation from thorium-containing electrodes or particles can be absorbed through intact skin. The risk of harmful external radiation from individual or small quantities of the electrodes is likely to be negligible. The risk increases with the number of electrodes present so special arrangements are required for safe transport and storage of bulk supplies.

3.4 Staff who may be at risk

Risk assessment and control measures should cover all those who may handle thoriated electrodes or be exposed to dust or fume arising from them. This includes not only those who are involved directly in welding, cutting and grinding but others including stores, cleaning and maintenance staff and those involved in disposing of used filters and dust and other waste such as electrode stubs.

4 Risks from TIG/GTAW welding and related processes

4.1 Exposure

Exposure to thorium-containing particles in the fume emitted during TIG/GTAW welding with a thoriated electrode will vary with welding conditions and is generally negligible or low—below the maximum permitted radiological protection limits for such radioactive substances [2–4]. Exceptionally, considerable intake has been reported to have occurred during AC welding when LEV is not used [5].

Grinding the electrodes is responsible for almost all electrode consumption [1] and usually produces a notably higher concentration of particles and level of potential exposure than welding [6]. This may [5] or may not [2] exceed radiological protection control levels.

4.2 Health effects

Very little research has been conducted on TIG/GTAW welders to determine the prevalence of actual adverse health effects that might be attributable to thorium exposure. This has not shown any excess risk. A Danish study of exposure and effects estimated a cancer incidence of less than three cases in a population of 1200 full-time TIG/GTAW welders during a

30-year working life [6]. An industry-based study in England showed intake of thorium to have been considerably less than the current recommended limit and there was no apparent evidence of adverse effects [7].

This lack of evidence of effect should not be taken as a reason for complacency or inactivity. The potential for serious disease to occur as a result of occupational exposure to dust and fumes from thoriated tungsten electrodes remains.

5 Conclusions

It is concluded that:

- Thoriated electrodes present a risk of occupational exposure to harmful levels of radioactivity. This is greatest when there is exposure to particles generated from grinding the tips of thoriated electrodes.
- The absence of evidence of resulting disease in those exposed to thorium-containing particles from TIG/GTAW welding and related activities should not be taken as a reason for not acting to protect all staff at risk of such exposure.

These risks should be controlled by an appropriate safe system of work to eliminate exposure and intake or at least to reduce these to within national and internationally agreed levels.

6 Recommendations for protective measures

Commission VIII recommends that thoriated electrodes are replaced by "thorium-free" electrodes, such as those containing cerium, lanthanum, yttrium and zirconium oxides—and this should be reflected in national and international regulations.

Until the change from thoriated electrodes has been completed:

- National and international regulations for protective measures related to TIG/GTAW welding and plasma welding and cutting using tungsten electrodes should include the requirement for a safe system of work and require an appropriately trained manager or supervisor to be given the responsibility and authority for the implementation and supervision of precautions for protective action and steps taken to ensure that workers know the name of this person and how he may be contacted.
- Inform workers that they are using thoriated tungsten electrodes and that these contain radioactive material.
- Educate workers in the hazards, risks and protective and control measures; train them in safe working practices and issue written instructions. Ensure they know the name of the supervisor with responsibility for implementing and monitoring the safe system of work.
- Select the technically acceptable electrode with the lowest amount of the potentially hazardous isotope.
- Keep records of stocks and issues to each welder.
- Keep the number of electrodes in store to a minimum. Store electrodes in steel cabinets or boxes bearing a prominent label incorporating the radiation trefoil. This will normally provide adequate shielding against external radiation from bundles of electrodes. Those storing thousands of electrodes may find it more convenient to store them in a separate room. The shielding properties of the wall of the room alone will be more than adequate. Since the occupancy of the room should be very low, metal cabinets within it should not be necessary. The door to the room should bear a warning notice incorporating the radiation trefoil.
- Set up safe and effective local ventilation extraction and collection system to control exposure to and collect fumes and dusts emitted during welding and grinding operations.
- Periodically formally verify the efficiency of the extraction system to monitor its effectiveness to control adequately personal breathing zone air concentrations and intakes of individual welders.
- Make adequate arrangements for supply, use and maintenance of personal protective respiratory equipment and for education and training of potential users and maintainers.
- Provide a high-efficiency vacuum cleaner to clean the grinding wheels daily. If the level of activity does not merit this provision, it may be sufficient to dampen the material to minimise dust and use an ordinary vacuum cleaner, a cloth or a brush.
- Ensure safe removal and disposal of spent electrodes, respirator filters, contaminated fume and dust and filters from ventilation and vacuum systems.
- Ensure that floors and work surfaces are cleaned once in each work shift using a vacuum cleaner or by damping the dust and then removing it by wiping or brushing into a container.
- Educate each welder to take care to minimise exposure, emphasising the importance of keeping his/her head out of the welding fume.
- Prohibit eating, drinking and smoking at the work site.
- Provide hand-washing facilities adjacent to the work site.
- Encourage workers to wash their hands before using the toilet.

- Require workers to wash their hands and change from their overalls before taking breaks for food, refreshment or other purposes and before leaving the workplace.
- Require workers to cover all cuts and grazes when handling any thoriated material.
- Monitor to check that the procedures are being carried out correctly and that all systems are working effectively. Keep records of these checks.
- Ensure that welders and other employees understand and adhere to this safe system of work and:

  Retain no more than one day's supply of electrodes and do not be carry these on their person other than in approved carrier.
  Use the correct parameters in relation to the electrode diameter as maladjustment may increase emissions of radioactive thorium.
  Reduce blunting of electrodes, and thus the frequency of the need for grinding, by minimising touching down through improved designs and welder skills.
  Use grinding system which collects the dust or, when not available, the extraction system on the grinding machine.
  Use an extraction system when welding.
  Use the cleaning equipment supplied and procedure prescribed by the employer to clean the grinding wheels.

Acknowledgments The Author acknowledges C VIII "Health, Safety and Environment" of the International Institute of Welding (IIW) for the development of this document, and especially its former Chairman, Dr. Grant McMillan who supported its development of this document during his Chairmanship.

Previous IIW Commission VIII documents on thoriated tungsten electrodes.

Experts of Commission VIII worked extensively on the matter of welding with tungsten thoriated electrodes; the following documents represent discussion held during the meetings.

VIII-1582–91
Estimated radiation doses from thorium and daughters contained in thoriated welding electrodes.

VIII-1599–91
Soudage avec electrodes refractaires—Electrodes en tungsten thorie.

VIII-1657–92
Result of the radiometric evaluation of material sample.

VIII-1667–92
Assessment of thorium exposure due to grinding of thoriated tungsten electrodes.

VIII-1675–92
Radioactivity measurement of tungsten rods containing thorium.

VIII-1702–93
Health aspects in the use of thoriated tungsten electrodes

VIII-1771–95
Storage and use of thoriated tungsten electrodes (by UK Health and Safety Executive).

VIII-1800–97
Handling of thoriated, non-consumable electrodes (tungsten containing thorium oxide) in tungsten inert gas (TIG) welding.

Appendix 1—additional material

The following abstracts are not for publication; they are provided here for the assistance to Commission VIII

1. Jankovic JT, Underwood WS, Goodwin GM. Exposures from thorium contained in thoriated tungsten welding electrodes. Am Ind Hyg Assoc J. 1999 May-Jun;60(3):384-9.

Information provided in this article can be used for estimating the radiation dose associated with the use of thoriated tungsten electrodes in tungsten inert gas welding. Area and breathing zone concentrations of 232Th generated by welding and electrode sharpening along with particle size information; isotopic composition of electrodes from two domestic manufacturers and one European manufacturer; and process variables and estimates on the number of thoriated tungsten electrodes manufactured are presented. Past literature is reviewed and compared with the results of this study. Isotopic analysis of a nominal 2 % thoriated electrode found 0.6 ppm +/- 0.4 ppm 230Th and less than 0.1 ppm 228Th. Analysis of a ceriated tungsten electrode and a lanthanated tungsten electrode for 232Th found 124 ppm and 177 ppm, respectively. Electrode consumption during welding was primarily the result of tip sharpening. Less than 3 % of the weight loss was attributable to the welding process. The in-mask concentration of respirable thorium particulate in the welder's breathing zone was 0.002×10(-12) microCi 232Th/mL. The concentration of respirable thorium particulate from electrode sharpening was 1.3×10(-12) microCi 232Th/mL. The measured sharpening time was 20 sec per electrode. Estimates of the activity median aerodynamic diameters for the respirable fraction of the welding and electrode sharpening aerosols were 3.5 and 5 microns, respectively, when measured in the breathing zone at 0.3 m (12 inches) from the point of operation. The respirable fraction of the total welding and sharpening aerosols was 45 and 60 %.

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2. Crim EM, Bradley TD. Measurements of air concentrations of thorium during grinding and welding operations using thoriated tungsten electrodes. Health Phys. 1995 May;68(5):719-22.

An evaluation was performed to determine whether thorium was present in concentrations above the derived air concentration during grinding and welding operations using thoriated tungsten electrodes. A few of the advantages of using thoriated tungsten electrodes in industry include easier are starting, greater stability, and reduced weld metal

contamination. The electrodes used in this evaluation contained 2 % thoria (thorium oxide) and were either 2.4 mm or 3.9 mm in diameter. Personal breathing zone and area air samples were collected for the experienced welders participating in this evaluation during grinding operations. The results during the grinding operations for personal and area air samples were generally below the derived air concentration (DAC) for 232Th for solubility class Y of 0.04 Bq m-3 (1×10(-12) microCi mL-1) as per 10 CFR 20. The area samples collected during welding operations were below the DAC.

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3. Gafvert T, Pagels J, Holm E. Thorium exposure during tungsten inert gas welding with thoriated tungsten electrodes. Radiat Prot Dosimetry. 2003;103(4):349-57

The exposure to 232Th from TIG welding with thoriated electrodes has been determined at five different workshops. Welding with both alternating and direct current was investigated. The exposure levels of 232Th were generally below 10 mBq m(-3) in the breathing zone of the welders. Two samples from AC welding showed significant higher exposure levels, probably due to maladjustment of the TIG welding power source. Samples of the respirable fraction of 232Th from grinding thoriated electrodes were also collected showing exposure levels of 5 mBq m(-3) or lower. A dose estimate has been made for two scenarios, one realistic and one with conservative assumptions, showing that the annual committed effective dose from inhalation of 232Th, 230Th, 228Th and 228Ra, for a full-time TIG welder, in the realistic case is below 0.3 mSv and with conservative assumptions around 1 mSv or lower. The contribution from grinding electrodes was lower, 10 microSv or lower in the realistic case and 63 microSv or lower based on conservative assumptions. The study does not exclude occurrence of higher exposure levels under welding conditions different from those prevailing in this study.

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4. Saito H, Hisanaga N, Okada Y, Hirai S. Thorium-232 exposure during tungsten inert gas arc welding and electrode sharpening. Ind Health. 2003 Jul;41(3):273-8.

To assess the exposure of welders to thorium-232 (232Th) during tungsten inert gas arc (TIG) welding, airborne concentrations of 232Th in the breathing zone of the welder and background levels were measured. The radioactive concentrations were 1.11×10(-2) Bq/m3 during TIG welding of aluminium (TIG/Al), 1.78×10(-4) Bq/m3 during TIG welding of stainless steel (TIG/SS), and 1.93×10(-1) Bq/m3 during electrode sharpening, with 5.82×10(-5) Bq/m3 background concentration. Although the annual intake of 232Th estimated using these values did not exceed the annual limit intake (ALI, 1.6×10(2) Bq), we recommend reducing 232Th exposure by substituting thoriated electrodes with a thorium-free electrodes, setting up local ventilation systems, and by using respiratory protective equipment. It is also necessary to inform workers that thoriated tungsten electrodes contain radioactive material.

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5. Ludwig T, Schwass D, Seitz G, Siekmann H. Intakes of thorium while using thoriated tungsten electrodes for TIG welding. Health Phys. 1999 Oct;77(4):462-9.

Thoriated electrodes are used in TIG welding. TIG welders, along with persons who grind thoriated electrodes and persons located near relevant welding and grinding sites, might be at risk of thorium intake. The isotopes of radiological relevance are 232Th, 230Th, and 228Th. The studies described in the literature do not provide a consistent picture of the actual hazards, and changes in European and German radiological protection laws have now made it necessary to determine the risks. To accomplish this, a field test was conducted under real working conditions in 26 different welding shops. The airborne activity generated through welding, and through grinding of electrodes, was measured using personal air samplers. Stationary samplers were also used. The filters' samples were evaluated by means of direct alpha spectrometry with proportional counting and by means of gamma spectrometry following neutron activation. The results clearly showed that considerable intake can occur during both alternating-current welding and electrode grinding, if no suction systems are used. The range of 232Th intakes to welders were estimated from 0.1 Bq y(-1) to 144 Bq y(-1) during welding and from 0.02 Bq y(-1) to 30.2 Bq y(-1) during grinding. In 6 of the 26 cases the recent annual limit on intake derived from the most recent ICRP publications was exceeded–in the worst case it was exceeded by a factor of 10–if it is assumed that the persons studied were not exposed workers (not routinely monitored for radiation exposure). When the significantly more restrictive German limits are applied, the amounts by which the limits were exceeded were even greater. Because many qualified welders have very long careers, the risks can thus be considerable. The paper also discusses parameters that influence exposure, and it presents a catalogue of recommended measures for dosage reduction.

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