Standard procedures for radioactive material use in the ThO EDM experiment

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Thorium monoxide (^{232}ThO) is being used in an electron electric dipole moment search experiment. The experiment uses a cold beam of ThO molecules, produced by pulsed laser ablation inside a neon-filled cell at 15 K. The ablation target is a disk of solid thorium dioxide (ThO_2). The target is glued in thermal contact with the walls of a copper cell which is enclosed inside a copper shield at 4 K, an aluminum shield at 50 K, and a sealed aluminum vacuum chamber. At any given time, the amount of $^{232}ThO_2$ inside the experimental chamber is less than 10 g. In the following we estimate the radiation dose from the samples used in the experiment, and we describe the procedures in place to prevent contamination and exposure.

Isotope	Half-life	Energy (MeV) Alpha	Beta	Gamma
^{232}Th	1.4×10^{10} y	4.098		
^{228}Ra	6.7 y		0.005	
^{228}Ac	6.13 h		0.874	
^{228}Th	1.9 y	5.351		0.002
^{224}Ra	3.64 d	5.666		0.009
^{220}Rn	55 s	6.290		
^{216}Po	0.15 s	6.780		
^{212}Pb	10.64 h		0.362	0.122
^{212}Bi	60.6 m	2.122	1.379	0.081
^{212}Po	304 ns	5.707		
^{208}Tl	3.01 m		0.554	1.201
Total		36.013	3.175	1.885

Table 1: Radiation data: ThO_2 and decay daughters (Table 4.1 of [1]). Abbreviations used are: m=minutes, h=hours, d=days, y=years

Table 1 summarizes the decay chain of ^{232}Th and the radiation emitted during a decay. It can be seen from Table 1 that the emitted energy in β and γ radiation is small and poses no concern for any reasonable exposure time. We estimate that a worker who spends 10 days per year in close (1 ft.) proximity to 100 g of ^{232}Th, while preparing targets for example, will receive a dose of less than 15 mrem due to external β and γ exposure.

The largest dose of radiation is in the form of α-particles. The construction of the cell and surrounding structures is more than sufficient to contain all the emitted α-radiation. This has also been verified with a radiation survey meter. The main concern therefore is from the inhalation of airborne ThO_2 dust that might be produced during preparation or laser ablation of the target. The region surrounding the gas outlet into the vacuum chamber contains cold surfaces and charcoal sorbs that will trap the dust. There are 10 micron stainless steel dust filters on the neon gas inlet and on the pumping line for the vacuum chamber to prevent any radioactive contamination from leaking back into either of those lines. The procedures to be used for various tasks related to the experiment, in order to eliminate the risk of exposure to ThO_2 dust, are detailed later. In Table 2 we estimate the radiation dose from accidental inhalation of dust.

Dose calculation	
Inhaled quantity	1 mg/yr (maximum)
ThO_2 activity	4 kBq/g
Radiation absorbed dose (60 kg human)	1.21×10^{-5} Gy
Radiation weighting factor for α-	20
Tissue weighting factor for lungs	0.12
Equivalent dose	0.24 mSv

Table 2: Estimate of radiation dose from accidental exposure to ThO_2 dust. For comparison, the standard background dose from cosmic radiation and other sources is 3 mSv/yr.

For the amount of ThO_2 that we intend to use, the equivalent dose in the unlikely event of accidental exposure to dust is still significantly smaller than the background radiation dose.

1 Procedures

1.1 Chamber assembly

The cell that will contain the target is prepared in advance. Windows and blanks are indium-wire sealed in place prior to placement of the target. The cell is then bolted onto the cold plate of the dewar, and relevant thermal and electrical connections are made.

The ThO_2 target is then prepared for mounting in the cell. Standard radiation safety measures, consisting of double gloves, P-100 or N-100 dust mask, lab coat, and bouffant cap, are used while handling the target. In the designated fume hood in Lyman 31, the ThO_2 target is weighed, epoxied onto the copper target holder piece, and weighed again. After the epoxy is cured, the target and its holder are placed inside the prepared cell which is then closed and the holder sealed in place.

A dust-catching piece of aluminum foil is spread over the bottom of the 4 K shield under the cell and initial beam collimator. The 4 K and 50 K shields and the vacuum chamber are then closed up, and the outside of the chamber is wipe tested to ensure that there is no contamination. The presence of dust filters on the gas inlet and vacuum pump lines is re-checked before evacuating the vacuum chamber.

1.2 During experiment

The vacuum chamber stays closed and sealed for the duration of the experiment, so there is no risk of exposure during this phase.

1.3 Opening up

Operators must be equipped with double gloves, lab coat, bouffant cap, and P-100 or N-100 grade dust filters before opening up the beam box chamber. In sequence, the outer vacuum chamber and 50 K shield are opened and immediately surveyed for signs of radioactive contamination and visual signs of dust.

As soon as the dust-catching foil is exposed, a damp paper towel is placed over it, and it is carefully folded up and disposed of according to the appropriate procedures (see Section 2.1). All surfaces exposed to the beam are cleaned with a wet wipe and surveyed to ensure that the contamination is below acceptable levels. Any contamination or dust above acceptable levels (a total of 0.5 g of loose dust in the beam chamber) is cleaned up with a paper wipe that is wetted in isopropanol, followed by surveys to ensure that the radioactivity is consistent with acceptable levels. Contaminated wipes are disposed of as described in Section 2.1.

All practical measures are taken to prevent the release of dust into the environment. Vacuum chamber ports are kept closed unless work is actively being done in them. If a cell port is opened, it is sealed with tape until it can be closed up again. Any parts that are removed from the beam box are placed in a sealed bag before being taken out of the beam box. A radon detector below the primary access flange of the beam box is periodically monitored to ensure that the activity level in the lab air remains normal.

The time spent in contact with any contaminated surfaces is minimized in accordance with the ALARA ("As Low As Reasonably Achievable") policy.

1.4 Replacing targets

Operators must be equipped with P-100 or N-100 grade dust masks, lab coats, bouffant caps, and double gloves for this procedure. The entire operation with a used sample-containing cell must be carried out either in the beam chamber or under a fume hood. The used target holder and residual ThO_2 adhering to it are removed from the cell and immediately disposed of appropriately (see Section 2.1). Sample holders will not be recycled: the entire used sample holder must be disposed of. The inside of the cell is examined for excessive dust (more than 5 g loose dust in the cell), and if necessary, the cell is disposed of as well. Regardless of measured contamination levels, the entire cell is disposed of and replaced once per year.

1.5 Replacing dust filters

Any element of the gas inlet line and vacuum pump line *following* the dust filter must be considered to be potentially contaminated. The line is opened up before the dust filter, capped off and surveyed for any contamination. The filter and the downstream line are thoroughly wetted with isopropanol before opening them up. After dismantling the line the filter is immediately labeled and disposed of in a radioactive waste container (see Section 2.1). The downstream line is surveyed for signs of contamination, and a new filter is placed into the line as quickly as possible. The assembled line with a new filter is surveyed, cleaned if necessary, removed from the fume hood and replaced into the gas inlet line or vacuum pump line.

1.6 Target preparation

Target preparations take place in the designated area in the LPPC (Laboratory for Particle Physics and Cosmology). ThO_2 powder is calcined in a closed crucible inside a laboratory furnace. The calcined powder is meshed inside a glove box, dissolved in water, mixed with Nb_2O_5 powder in a sealed ball mill, and dried. The dried, calcined powder is then pressed in a stainless steel pressing die in a benchtop hydraulic press while inside double sealed bags. This pressed, compactified target is placed in a closed crucible inside the lab furnace and sintered for about 2-4 hours before cooling down. The pressed, sintered target is then used in the experiment as described above.

Any operations requiring ThO_2 to be exposed to lab air will be carried out by operators wearing full and adequate personal protective equipment (P-100 grade dust masks, double gloves, lab coat, bouffant cap). When the ThO_2 is not exposed to the air, as when it is in the glovebox, ball mill, furnace, or pressing bag, only a lab coat and double gloves are required. The work areas will be surveyed regularly for signs of contamination. The equipment used for target preparation (pressing dies, glove boxes, hydraulic press, crucibles, furnace) will be dedicated solely to this purpose, labeled clearly as such, and not interchanged with other laboratory equipment. Used consumables that have come in contact with the ThO_2 will be disposed of as appropriate for radioactive waste (see Section 2.1).

2 Radioactive materials management

2.1 Waste disposal

All radioactive waste must be bagged in the designated, distinctively marked radioactive waste bags and sealed. Bags must be labeled with "Radioactive waste," a radioactive symbol, and the isotope and activity. The radioactive waste pickup points are the labeled acetal waste bin in the white tent in the LPPC and the labeled bin in the Lyman 31 fume hood room. All generated waste must be deposited at these points and tagged with an official Harvard radioactive waste tag. During target changes or other radiation work in the main lab, LISE G14, the bin may be brought from the fume hood to the lab to collect waste; however, it must be returned to the fume hood immediately when the procedures are complete. When a bin is full or nearly full, the Harvard University Radiation Office must be called to make a pickup.

2.2 Storage

The primary storage location for thorium-232 is in the black, locked cabinet in the white tent in the LPPC.

It is also acceptable to keep thorium-232 in the following locations during active target preparation, changing, and use:

1. The designated target preparation area in the LPPC (white tent and furnaces).

2. The right-hand fume hood in Lyman 31. While in use and until it is decontaminated, the fume hood must be labeled "Warning: radioactive thorium-232, [activity level in μCi]. Do not use," in addition to the operator's name and the date.

3. The ThO beam source, in the manner described above.

3 Personnel Training

Before performing any of the operations described herein, all personnel must undergo the following training:

1. The Harvard University Radiation Safety Training module must be completed, and the refresher training must be up-to-date.

2. The operator must read and understand this protocol.

3. The operator must read and understand the protocol pertaining to usage of the Lyman 31 fume hood, “Lyman 31 Radiation Certification.”

4. If the operator will be engaged in target making, he must read and understand the procedure pertaining to target preparation, “Procedure for ThO2 Ablation Target Pressing and Sintering.”

5. New operators must perform each of the procedures described herein under the supervision of an experienced senior researcher before they are permitted to perform them alone.

Each of these training requirements will be documented in a training log book kept by the lab radiation safety officer. The trainees will be required to certify that they have received the required training before being permitted to work with thorium-232.

References

1. Herman Cember, *Introduction to Health Physics*, 2nd ed., Maxwell Macmillan (1989)

2. P. Duport and F. Horvath, *Practical aspects of monitoring and dosimetry of long-lived dust in Uranium mines and mills - determination of the annual limit on intake for Uranium and Uranium/Thorium ore dust*, Radiation Protection Dosimetry, Vol. 26, pp.43-48 (1989)