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The role of underwater cultural heritage on dark matter searches: Ancient lead, a dual perspective

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ABSTRACT

New generations of dark matter detection experiments require extreme low levels of background radiation in order to verify complex particle physics theories. Ancient lead ingots from shipwrecks provide the necessary shielding material to perform these experiments due to their low intrinsic radioactivity, difficult to achieve by modern materials or commercial means. This situation generates a debate between two different perspectives: The preservation of cultural heritage or its use in scientific fundamental research. In this Article we present the scientific implications of the use of salvaged Ancient lead for dark matter searches as well as the consideration on underwater cultural heritage management. We finally highlight the three main dilemmas on the issue and articulate their analysis using the three main cultural heritage mainstays: (1) benefit of the humankind, (2) scientific interest and (3) commercial exploitation of the underwater cultural heritage. We conclude that the use of Ancient lead in dark matter experiments does not contravene the 2001 UNESCO Convention on the Protection of the Underwater Cultural Heritage, the foremost international legal reference for the protection of underwater cultural heritage. However, to prevent the uncontrolled utilization of the non-renewable Ancient lead we recommend the use of alternative shielding materials such as tungsten and a case-by-case benchmark against commercial ultra-low-alpha lead.

1. Introduction

The research on dark matter detection aims to underpin some of the most fundamental properties of the universe. It has been demonstrated experimentally that ordinary matter, i.e. elements of the periodic table, constitutes only 17% of the total matter of the universe whilst the remainder is attributed to dark matter (Komatsu et al., 2011). The understanding of the origin of the remaining 83% of the matter present in the universe remains one of the most fundamental open questions to humankind.

A 2000 year old shipwreck's cargo is planned to be used for these experiments (Nosengo, 2010). Italy's new neutrino detector, CUORE (Cryogenic Underground Observatory for Rare Events), at the Italian National Institute of Nuclear Physics, received from the National Archaeological Museum of Cagliari 120 archaeological lead ingots proceeding from a shipwreck recovered from the sea 20 years ago at the coast of Sardinia. The so-called "Ancient lead" (both Greek and Roman) will be used as a shield for the dark matter detectors because over the past 2000 years the lead has lost its intrinsic radioactivity due to natural radioactive decay to levels approximately 100,000 times lower than freshly mined lead.

"The use of these objects as stock for experimentation had never been an issue before, but now it is beginning to be deemed ethically questionable" (Perez-Alvaro, 2013a). Roman lead proceeding from a shipwreck under water for 2000 years is underwater cultural heritage and it is protected under the umbrella of the 2001 UNESCO Convention on the Protection of the Underwater Cultural Heritage (2001 Convention hereinafter) for being traces of human existence having a historical character which have been under water for more than 100 years (UNESCO).

Underwater cultural heritage faces numerous menaces from natural deterioration (Manders, 2004), to destruction by construction of ports or illegal salvage (Dromgoole, 2013). Legislative efforts have been focused on preventing these menaces (2001 Convention) (Aznar-Gomez, 2013; O'Keefe, 2002). However, underwater cultural heritage also suffers other threats, legitimate

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threats. From the lying of submarine cables (Perez-Alvaro, 2013b), to fishing (Article 5, 2001 Convention) or the focus of this Article, its use for experimental physics (Perez-Alvaro, 2013a). Policy makers have largely neglected these issues.

However, it is not only the use of this heritage that presents a concern, but also its recovery and documentation. In the CUORE case the excavations and documentation of the underwater cultural heritage were done by archaeologists under archaeological standards (INFN, 2010). However, in the case of other laboratories the Ancient lead is bought from private companies whose end is a profitable recovery where the archaeological standards are unlikely to be accomplished (Throckmorton, 1998):

> The CDMS team – *Cryogenic Dark Matter Search* – had to find old lead [...]. An Italian colleague mentioned that he had been using lead taken from two-thousand-year-old Roman ships that had sunk off the Italian coast. The CDMS team located a company that was selling lead salvaged from a ship that had sunk off the coast of France in the eighteenth century. Unaware that they were doing anything illegal, the researchers bought the lead. The company, however, got in trouble with French customs for selling archaeological material. Illegal or not, the lead worked (Ananthaswamy, 2010).

The issue introduces a new consideration on the treatment and the protection of underwater cultural heritage and its use for non-commercial/scientific experiments. The use of this material is also becoming popular in different scientific fields such as microelectronics (Ho-Ming Tong, 2013) and low background detectors (ORTEC). The dilemma, which was raised by Perez-Alvaro (2013a), has attracted the interest of different archaeological and physicist communities (Pringle, 2013b; Moskowitz, 2013, 2014; Gwynne, 2013).

The two different perspectives of the dilemma – experimental physics and cultural heritage – are the main concern of the following Article. In the first part, we present the analytical evaluation of dark matter searches: whether the use of this Ancient lead is indispensable for these experiments from the point of view of the dark matter physics, which other alternatives exist to Ancient lead and how much lead is necessary. The second part of this paper will be focused on analysing whether the use of Ancient lead on dark matter searches is legitimate from a cultural heritage rationale arising from three common principles:

- benefit of humanity
- scientific interest of the material
- concerns underlying commercial exploitation

These three mainstays of cultural heritage management have been subject to debate in similar cases:

Preservation for the benefit of humanity has been an issue in management of human remains in archaeology. A prime example of this is that of Kennewick Man, a 9300-year-old skeleton found in 1996 in a riverbank near the town of Kennewick in Washington state (Ackerman, 1997; Chatters, 2000). The finding of the skeleton triggered a nine-year legal clash between scientists, the US government and Native American tribes who claim Kennewick Man as an ancestor under the provisions of the Native American Graves Protection and Repatriation Act (NAGPRA). In February 2004, the United States Court of Appeals for the Ninth Circuit ruled that a cultural link between any of the Native American tribes and the Kennewick Man was not genetically justified, allowing scientific study of the remains to continue for the benefit of humanity (Bruning, 2006).

The scientific interest of pre-II World War steel from historical submarines and battleships has transcended its historical interest to be used in other domains, for example, medical research: 65 tons of steel from U.S.S. Indiana, scrapped in 1962, was used for shielding at an Illinois Veterans Administration hospital, and another 210 tons went into building a shielded room for in vivo radiation measurements at a Utah medical center (Lynch, 2007, 2011). Equally, steel salvaged from Scapa Flow shipwrecks has been used in low radiation detectors (Butler, 2006).

Commercial exploitation has been an issue in slave ship excavations. Between c1500 and 1860, European ships transported captive Africans from Europe to the Americans on what it has been called the “middle passage”. Despite of the importance of the subject, the excavated shipwrecks relating to slave shipping is undeniable small (Webster, 2008). “Nautical archaeologists have placed their collective heads in the sand and have been tossing potshots at opportunistic treasure hunters who have funded slave ship excavations” (McGhee, 1997). This situation has promoted the proliferation of commercial agreements between private salvage companies and archaeologist that use these discoveries for scientific investigation.

The quandary is not the use of Ancient lead for dark matter experiments alone, it is the growing extended use of this material for other kinds of experiments, from medicine to microelectronics. The question raises the necessity to set boundaries and protocols in the use of the underwater cultural heritage.

2. The perspective from physics

Today we know that dark matter is present in the universe but we do not know what it is made of. Particle physicists have proposed tens of possible dark matter candidates and have suggested different strategies to detect them such as direct detection by interaction of dark matter particles with target detectors in underground laboratories (Bertone, 2010). Direct detection requires extremely low levels of background signals to distinguish a particular dark matter event from collisions produced by cosmic rays (fast-moving particles that continuously shower the Earth from deep space) or by the intrinsic radioactivity of the environmental materials.

The effect of cosmic ray radiation is efficiently mitigated by setting the detector in underground laboratories. However, low-intrinsic radioactivity materials are essential to provide additional shielding and reduce the effect of spurious signals.

Laboratories underground adopt a combination of shielding materials of which one must be a high density element (Lang and Seidel, 2009). Among high density elements that could provide a

Table 1
Evaluation of low-alpha lead sources. Radioactive emission per kilo in milli-Becquerels per kilogram and price per pound in U.S. Dollars per pound for different types of lead.

Type of lead	Radioactivity (mBq/kg)	Price ($/lb)
Hot ores	4×10^6–200×10^3	0.3–1.1 (Heusser, 1995)
Cold ores	200×10^3–5000	50 (Heusser, 1995)
Low-alpha lead	260	110 (Heusser, 1995)
Ultra low-alpha lead	60	310–500 (Lee, 2000)
Super ultra low-alpha lead	24	680–1150 (Lee, 2000)
Commercial salvaged lead	12	80–150 (Lee, 2000)
Silvia lead	<7	24 (Nosengo, 2010)
Oristano lead	<4	24 (Nosengo, 2010)
Greek lead	<0.2–0.9	–[a] (Danevich et al., 2009)
Gold	–[b]	18,010 (NASDAQ, 2014)

[a] Non-commercial ultrapure archaeological Greek lead.
[b] Pure gold is composed of a single non-radioactive isotope.

suitable shield we find precious metals such as platinum, palladium, iridium and rhodium which approach the market price of gold $18010/lb (a suitable candidate as well) and rare and toxic metals such as osmium. None of these elements offer a viable solution due to cost or availability knowing that state-of-the-art dark matter detectors, such as CUORE, require around 4 tonnes of material. Only tungsten ($21/lb), with the potential to achieve extremely low-levels of intrinsic radioactivity (Danevich et al., 2003; Bernabei et al., 2013), could be a sensible element for shielding cryogenic detectors underground. However this is still 20 times more expensive than freshly mined lead (see Table 1) the most commonly used shielding material in radiation rich environments.

A number of dark matter search teams around the world use commercial lead as the gamma ray absorber stage due to its high density, high atomic number, low intrinsic radioactivity, ease of fabrication and availability at a reasonable cost ($0.3–1.1/lb).

However, freshly mined lead is naturally polluted by radioactive elements such as nuclei from the uranium, thorium and actinium decay chains. During the melting of the ore nuclide from these decay chains are removed to the slag (Danevich et al., 2009), except from ^{210}Pb. This radioactive isotope of lead emits continuous beta radiation in its decay process which contributes to most of the background in experiments searching low energy dark matter candidates (Alessandrello et al., 1998). Therefore a source of lead with low ^{210}Pb content (low-alpha lead) is a *sine qua non* condition for the successful outcome of direct searches:

2.1. Sources of low-emission lead

In the following we will state the prime examples quantified in terms of the level of intrinsic radioactivity in Becquerel/kg (or number of radioactive decays per second per kilogram of material) and price (U.S. Dollars per pound of material). Low-alpha lead can be currently obtained from a number of sources: "cold" ores, microelectronics grade lead and Ancient lead.

- **Cold ores**: Lead is mainly obtained from galena ores. The content of radioactive impurities varies from ore to ore ranging typical values of surface activity between of 4000 Bq/kg in the high-end and 5 Bq/kg at the low-end (see Table 1). In fact, lead manufactured post 1945 may contain radioactive products due to nuclear weapon testing in the atmosphere (Smith et al., 2008). Low-activity "ores" can provide a reasonable high quality lead that combined with optimized process production can yield alpha emission rates as low as 260 mBq/kg (Johnson&Mathey's) (Alessandrello et al., 1993). As an example, J&M lead was used in the Heidelberg–Moscow experiment (Klapdor-Kleingrothaus et al., 2001). In this case the residual content of ^{210}Pb contributed to 50% of the counting rate (see Table 2).

Table 2
Impact of low-alpha lead in dark matter searches. Origin of low alpha lead, radioactivity in milliBecquerels per kilogram and induced error rate in % of low-alpha lead used in several dark-matter experiments.

Experiment	Origin	Radioactivity (mBq/kg)	Error rate (%)
Heidelberg –Moscow	Johnson&Mathey's	240	50 (Alessandrello et al., 1998)
EDELWEISS-II	Roman lead	120	33 (Schmidt et al., 2013)
CUORE	Oristano lead	4	< 1 (Alessandria et al., 2011)

- **Microelectronics grade lead**: A commercially available solution to low-alpha lead is currently provided by different suppliers.[1] The production is based on laser isotope separation, a technique that selectively ionizes the target material making it separable and removable. Laser isotope separation can reduce the original ^{210}Pb concentration by 10–100 times and reaches levels as low as 60 mBq/kg for ultra-low alpha lead (Honeywell) and 24 mBq/kg for super ultra-low lead (Pure Technologies). However this technology is expensive and currently limited in capacity. As an example, the EDELWEISS-II dark matter detector at the *Laboratoire Souterraine du Modane*, uses lead at the 120 mBq/kg range and even at this level ^{210}Pb contributes to 33% of the background noise at the low energy end (Schmidt et al., 2013) (see Table 2).
- **Ancient lead**: Roman yearly production of lead has been estimated at 80.000 tonnes a year (Callataÿ, 2005) providing an important source of non-renewable low-alpha lead. In that sense, 2000-year old Roman lead recovered from the Mediterranean Sea has been studied in detail (Alessandrello et al., 1998) which has demonstrated extremely low levels of intrinsic radioactive emissions. ^{210}Pb is greatly reduced in these samples reaching levels as low as 7 mBq/kg (Silvia lead) and 4 mBq/kg (Oristano lead). This type of lead with unprecedented low levels of intrinsic radioactivity is planned to be used at the CUORE experiment. The predicted impact is less than 1% (Alessandria et al., 2011) (see Table 2). Another prime example is 2400-year-old Greek from silver–lead ores on Mount Lavrion (Attica) and recovered from the bottom of the Black Sea. The radioactivity is in the <5–17 mBq/kg range before melting (Danevich et al., 2009) and <0.2–0.9 mBq/kg after purification (Boiko et al., 2011) which is two orders of magnitude lower than microelectronics grade lead.

The reasons behind the extremely low ^{210}Pb content in salvaged ancient lead are due of a combination of natural radioactive decay, ancient ore refining and preservation under water. For a thorough discussion please see Supplementary Information.

To sum up, Ancient lead can provide the suitable shielding for modern dark matter searches due to the low levels of intrinsic radioactivity (Boiko et al., 2011). This low level of emission cannot be achieved by current lead manufacturing capabilities which are currently expensive and limited in capacity. Alternative high-density materials present a non-cost effective solution and therefore have not been characterized at the required level of radioactivity. Only tungsten with the potential to achieve an emission rate of 0.04 mBq/kg (Bernabei et al., 2013) could provide an alternative solution.

3. The perspective from cultural heritage management

In order to establish a fair comparative debate in the following this Article will aim to list the main core arguments in favor and against the use of the Ancient ingots from a point of view of the Cultural Heritage preservation.

Criteria in favor of the use of underwater cultural heritage items on experiments:

- **Importance of the experiments**: The research on dark matter aims to shed light on one of the most fundamental questions that modern astronomy, in particular, and humanity, in general, is facing: What is our Universe made of? A deeper

[1] Companies such as Teck mining, Amkor, Lemer Pax, Pure Technologies and Honeywell.

understanding of the properties of dark matter could clarify the origin of the Universe and the impact these new particles will have on its evolution.

- **Trade goods**: Some authors differentiate between cultural artifacts and trade goods (replicated elements) under considerations such as age, rarity and condition (Stemm, 2000). These trade goods may be sold or traded, but only with appropriate record and documentation complying with archaeological standards. In this regard, if, of a 1000-ingot shipwreck cargo carefully studied and documented, 300 are transferred for other uses such as dark matter experiments, there would not mean a loss of heritage.
- **Half products**: "Since the site of metal production was often far from areas of manufacturing or consumption, metals, once refined, were rendered into a convenient form for transport such as ingots" (Gale, 2011). Some of them were used as ballasts but most of them were half products, intermediate products (Manders, 2013). Its original function was to be transformed into something else. As a consequence, their use recovers their functionality.
- **Funding for excavations**: A new approach to finance underwater archaeological research is the exchange of Ancient lead in order to fund an archaeological intervention on the site. In this sense, the reasons of the Museum of Cagliari for transferring the ingots to the laboratory open two scenarios: First, the material might have been too accessible for treasure hunters or private companies and the museum decided to preserve it *ex-situ*. Looking for funding for the excavation they found the laboratory's willingness to establish an agreement – archaeological ends. Or second, the museum might have known that the laboratory was looking for Ancient lead and having a record in its archives of the existence of this specific shipwreck, decided to reach an agreement with the laboratory. In exchange of a number of ingots the Museum of Cagliari received the necessary funding for the excavation-commercial ends (INFN, 2010).

Criteria in favor of the preservation of underwater cultural heritage items:

- **Importance of the Heritage**: "Where does it all stop, if we accept that evidence of our past can be converted into something that people can buy and take home? " (Pringle, 2013a)
- **Future information**: In the future archaeological methods may developed allowing to obtain additional information from the ingots. This could facilitate the reconstruction of the historical context through processes such as trade or ancient commercial routes. Once the objects are processed and melted for experimentation the historical information is lost.
- **Alternative materials**: Current lead manufacturing capabilities cannot reach the level of intrinsic radioactivity for state-of-the-art dark matter searches but with further technological development this might become a competitive solution. On the other hand, tungsten can be purified to similar levels of intrinsic radioactivity than Ancient lead and could provide an alternative shielding material (Danevich et al., 2003; Bernabei et al., 2013). Currently low-radiation tungsten is not commercially available and production costs are undetermined. However, if the price is the only issue, it raises concerns about the commercial exploitation of the underwater cultural heritage.
- **Decision on the excavations**: Selecting sites for commercial reasons is a sliding scale. Excavating sites should be done either because the sites are being threatened and the only way to protect is *ex situ* or because the scientific questions are important enough to justify this excavation. Excavating sites because it is of interest for scientific experiments eventually leads to selecting areas only for this reason and ends up with a monotone research of the same kind of sites that we already know a lot about.
- **Size of the collection**: There is a difference between seeing an exhibition of 1000 ingots instead of seeing only 700 (Yorke, 2013).

4. The perspective from law

The foremost international legal reference for the protection of the underwater cultural heritage is the 2001 UNESCO Convention on the Protection of the Underwater Cultural Heritage. The Convention aims at protection of "all traces of human existence having a cultural, historical or archaeological character", which have been under water for over 100 years (UNESCO).

The most important conclusions of the 2001 UNESCO Convention on the Protection of the Underwater Cultural Heritage are (1) the priority of the preservation *in situ*, (2) the rejection of commercial recovery of underwater cultural heritage since it is incompatible with its preservation and (3) the principle of cooperation between interest groups such as scientific institutions, archaeologists and divers, as well as between countries. However, there are also some weaknesses in the Convention: the vague definition of underwater cultural heritage; issues of ownership and abandonment; question of warships and other state-owned vessels; and the determination of the geographical scope of the convention. In addition, the Convention does not contemplate new uses of the underwater cultural heritage, such as its use on dark matter detection experiments. The debate, under the Convention, is then ambiguous.

The analysis of international law is not the core of this paper. However, the dilemmas articulated in the following section will be supported by the articles of the Convention that open the legal vacuums where the ethical controversies are born.

5. Dilemmas

Our next goal is the articulation of the dilemma around the use of underwater cultural heritage as a stock for scientific experiments through three main cultural heritage mainstays: (1) preservation of the underwater cultural heritage for the benefit of humanity, (2) *in situ* preservation of underwater cultural heritage, and (3) prohibition of commercial exploitation of underwater cultural heritage. These statements, translated into a legal language by the 2001 Convention, conflict with the usage on research experiments. Firstly, the arbitrary use of *benefit of humanity* makes the underwater cultural heritage an option for any endeavor beneficial to humanity, including fundamental research. Secondly, since the preservation *in situ* is the preferred (but not the only) option, the recovery of Ancient lead for experiments does not observe this rule. And finally, it is arguable whether these experiments are of commercial nature.

5.1. For the benefit of humanity: which benefit?

Benefit of humanity is a term that has traditionally been applied to the exploration of the Antarctic and the exploration of outer space, including the Moon. It was also applied under the Law of the Sea for using the sea bed resources in the interests of mankind (Churchill and Lowe, 1999). The concept is usually assigned to vulnerable sites to make them available to all and property of no one, and to preserve them for future generations (Tenenbaum, 1990).

Article 2.3 of the UNESCO Convention, for instance, reads:

> States Parties shall preserve underwater cultural heritage for the benefit of humanity in conformity with the provisions of this Convention.

No definition of the term *benefit of humanity* has been given and it leaves unclear what "benefit" means: economic, emotional, educational or cultural benefit. In this sense, the dilemma is that its preservation benefits humanity, but also its use for experiments on dark matter searches following UNESCO recommendations. "Fundamental research is the expression of human curiosity: of the need to understand the structure of matter, life, the structure and evolution of the Universe, which are the main subject of fundamental research, so that we can decode our past and predict our future" (Revol, 2007).

In both cases it has to take into account "intra and intergenerational interests" (Boesten, 2002). However, intergenerational interests imply "preservation for future generations" which involves evaluating now on behalf of future interests (Manders, 2013). "To save the heritage for future generations undermines the ability of the present" (Smith, 2006). The decision to preserve or not the Ancient lead for future generations disempowers stakeholders to take decisions about the present.

5.2. Scientific interest of the material: which scientific interest?

After being recovered, small samples of the ingots were analyzed and recorded by the laboratory (Alessandrello et al., 1998). The inscriptions on the ingots with historical information of the makers were cut and preserved at the Museum of Cagliari.

Study and documentation of the shipwreck site is essential for the recovery of information (Villegas Zamora, 2008). The archaeological practice is a process that reconstruct the puzzle of history, for instance, the position of the objects sheds light on the wreck circumstances. For this reason "heritage agencies throughout Europe are increasingly seeking to preserve archaeological sites and their associated artifacts *in situ* through legal protection and minimization of excavation" (Caple, 2008). Preservation *in situ* is the first option since it slows down degradation (Manders, 2004, 2008), but it is not the only option (Manders, 2008; Maarleveld et al., 2013).

The 2001 Convention also recommends it:

> Article 2.5 The preservation *in situ* of underwater cultural heritage shall be considered as the first option before allowing or engaging in any activities directed at this heritage.

As a consequence, the ingots should have remained under water as the first option: The archaeological context is essential for obtaining information. Only the adequate process of study, analysis and excavation guarantees a right interpretation of the objects. And even if the procedure is followed, recovering and destroying the object, even if due record is kept, still eliminates evidences of our past that new technology in the future could re-interpret or discover.

This leads us to the dilemma: The deposition should not prejudice the "scientific interest" of the material (Dromgoole, 2013). Rule 2 of the 2001 Convention Annex says:

> [...] (b) deposition of underwater cultural heritage should not prejudice the scientific or cultural interest or integrity of the recovered material [...]

Dark matter experiments and their promise to shed light on the constituencies of the Universe are of scientific interest – as well as the archaeological information revealed by the ingots – and hence fulfill the recommendations of the UNESCO 2001 Convention. The quandary is which scientific interest should prevail.

5.3. Commercial exploitation: is it commercial exploitation?

There is a danger of focusing the debate just around the cultural objects, this is, the Ancient ingots. As said, the real concerns on the issue are both the salvage method used to recover the material and the extended application of this material on other industries. The arguments against its use are not the necessity of retaining the objects, but the consequences of not preserving them.

Commercial exploitation of cultural heritage can be done in different forms. Treasure hunting is just one practice. But also tourism is, as well as merchandising, paid exhibitions, and sale of reproductions (Dromgoole, 2013). But not all the procedures are so straightforward. It is the reasons and the goals underlying those actions what converts those uses into commercial exploitation.

This Article proposes four points of analysis for future debate in relation to commercial exploitation of Ancient lead:

5.3.1. Trade of ancient lead ingots in exchange for funding for excavations

Commercial exploitation using methods that do not involve the sale of underwater cultural heritage (or other exchange) are not an infringement, unless they result in the dispersal of the material (Dromgoole, 2013). Rule 2 of the Annex says:

> Underwater cultural heritage shall not be traded, sold, bought or bartered as commercial goods

Exchanging the ingots as a *quid pro quo* for the transaction is not allowed under the 2001 Convention (Maarleveld et al., 2013):

> All archaeological activity can be governed by commercial principles, as long as the activities are authorized in conformity with the Convention, and as long as the finds that belong to the site are not part of the commercial equation.

5.3.2. Economic profit for the laboratories

Archaeologists and museums are expected to act under policies that offer part of the heritage only for experiments beneficial for the humanity – dark matter detection – and not for the benefit of companies like semiconductor industries (Lee, 2000). Intending to profit a few at the expense of many is incompatible with the protection of the underwater cultural heritage. It could be arguable that particle physics laboratories could obtain an economical benefit from patenting secondary technology developed for the successful outcome of the experiments. It could be arguable that if that a component of that technology were Ancient lead this would contravene the UNESCO 2001 Convention. However, the primary use of Ancient lead on particle physics experiments is aimed to perform basic research, not motivated by profit and hence does not form part of a commercial equation. Microelectronics industries, on the other hand, aim to achieve a commercial gain. And even if those laboratories would achieve an economic profit, it has to be evaluated if that profit is incompatible with the knowledge for the benefit of humanity.

5.3.3. Private trade and market of ancient lead

Legally, or illegally, there is a market for Ancient lead: One the third low alpha lead is obtained through sea salvage companies, for instance Aloveo and Sea Recovery Ltd. (Lee, 2000). It has been also known that Odyssey Marine Exploration (Channel, 2009) operates on the same business. These companies have identified or located about 600 tonnes of Roman lead.

The use of these objects triggers more salvage: Just by a quick search on Google with the words "low-alpha lead" it is possible to find some forums of sale and buy of Ancient lead. This market is becoming more appealing for more groups and industries and it is generating big controversies (Pringle, 2013b). Other sources range from lead obtained from water pipes in ancient Roman cities or lead on the roof of old churches. In fact, AFAIR, is a company that offers to re-roof old churches free if they can keep the old lead it removes.

The most inefficient treasure hunt spent $500,000 for 16 days at sea (Throckmorton, 1998). Private companies looking for an economic benefit speed their recovery, paying little or no attention to archaeological record, and try to obtain a profit selling the objects to any company despite their ultimate goals (UNESCO).

5.4. Setting standards and boundaries

It is necessary to set boundaries and to decide which science "deserve" a part of the past. It might be decided that underwater cultural heritage is not a stock for any kind of experiment or that only experiments aimed to cure diseases will be allowed. It might instead be decided that if the experiments offer answers for the knowledge of the human being are justified, or that it is worth to open the range of experiments to include businesses such as microelectronics. And this would entail the risk to allow any kind of industry to use the underwater cultural heritage. A protocol has to be established.

6. Conclusions

This Article aimed to analyse the use of Ancient lead in dark matter searches and the consequences from the point of view of physics and cultural heritage management. Using three main pillars in preservation of underwater cultural heritage – benefit of humanity, scientific interest and non-commercial exploitation – we conclude that experiments on particle physics using underwater cultural heritage comply with these three mainstays.

- Benefit of humanity: Since the definition of benefit of humanity is ambiguous, acquired knowledge through scientific research falls within the broad spectrum of the term: Dark matter searches aim to help understand the origin and evolution of the Universe, knowledge that benefits humanity.
- Scientific interest: Scientific interest of the material can be applied both to the archaeological information provided by the ingots, but also to the scientific information unveiled by dark matter searches. The only concern is that the recovery of the ingots does not comply with the preservation *in-situ*. Although preservation *in-situ* is the preferred option, is not the only option under the 2001 Convention.
- Non-commercial exploitation: Laboratories do not obtain a direct economic profit from the use of Ancient lead in experiments. As a consequence, if Ancient lead is obtained through a legal agreement between archaeologists and museums, cultural objects cannot be considered as commercial goods. In this regards, only the exchange of ingots as part of a commercial equation would contravene the 2001 UNESCO Convention.

7. Recommendations

State-of-the-art direct dark matter searches require shielding materials with intrinsic contamination levels in the few mBq/kg range. This low levels of emission cannot be achieved by modern lead manufacturing capabilities. Ancient lead can reach unprecedented levels of low intrinsic radioactivity fulfilling these requirements. However, Ancient lead is a non-renewable source and refined mass-production techniques or alternative materials, could be explored if these activities were to expand. Tungsten with the potential to achieve an emission rate well within the thresholds required by dark matter searches could provide an alternative solution.

In any case, sacrificing underwater cultural heritage has to be evaluated and weighted. As a recommendation, each sample of salvaged lead must be analyzed and benchmarked against the commercial ultra-low-alpha lead. Once demonstrated that the level of purity required by each individual experiment is lower that what commercial means can provide then Ancient lead could be used. Even if the dilemma could be resolved by adopting a case-by-case evaluation, there is a risk of a growth on the use of Ancient lead for other kind of experiments motivated by market expectations and not by knowledge. Its use should be regulated so the extraction and documentation is done under archaeological standards.

There is a need to find a common place because new cases unforeseen by underwater cultural heritage policy makers question principles taken from granted.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.ocecoaman.2014.11.009.

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