THE PROBLEM OF PROTECTING OF ARTWORKS FROM THEFT AND COUNTERFEITING USING INVISIBLE MARKING

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Relevance. Currently, there is a standard requirement in the museum sector to mark exhibits with identification information, including artworks. These markers must contain the museum's abbreviation and the inventory number of the work of art. Usually, these markers are applied in pencil or ink and placed in a visible location to ensure they can be found quickly. Their location, color, and application technique are regulated by the museum's internal protocols. In addition to these visible markings, many museums also use their own invisible identifiers to protect against theft and forgery. However, a standardized approach to such markers has not yet emerged.

The aim of the study is to analyze different types of artworks and identify how invisible marking can be applied to them in terms of effective protection and minimal impact on the artwork itself.

The objects of the study are various types of artworks found in museum collections (from coins or medals to paintings or sculptures). The research methodology involves a review of the most accessible methods of invisible marking. A comparative analysis of the protection of various works of art using chemical markers was performed.

Results. Analysis of various types of works of art and museum objects revealed difficulties associated with determining the optimal placement and size of invisible chemical markers. These markers serve as a deterrent against theft and play a decisive role in the detection and return of lost or stolen items. Each work of art should be marked with a unique code or digital identifier using fluorescent mapping technology. This system allows the marker to be read using portable devices. The results of the analysis indicate that the key issue is that markers should be applied to the artwork itself, rather than to frames or attached labels. Tests carried out as part of the European research project «AURORA» have experimentally confirmed the feasibility of using cost-effective, durable chemical markers.

Conclusions. Specific requirements for the methodology of applying chemical markers and their size have been formulated. Recommendations have been developed for selecting the location for applying markers depending on the type of artwork. To determine the optimal marking location, a preliminary in-depth analysis of the work should be performed. The analysis should include knowledge of the material or materials from which the work is made, their durability, their stability, etc. The marking location should be the point of least threat to the valuable characteristics of the work and, at the same time, be a sufficiently important point of identification. Depending on the optimal marking location selected, the appropriate shape and size of the chemical marker must be determined in advance. The type, shape, and size of the marker depend on the work of art itself. Marking can be applied manually or mechanically. The form of marking can vary from a dispersed dot structure to a stamp with an inscription, sign, logo, or QR code.

Keywords: artwork, chemical marking, anti-counterfeiting, theft protection.

ПРОБЛЕМИ ЗАХИСТУ ТВОРІВ МИСТЕЦТВА ВІД ВИКРАДЕННЯ ТА ПІДРОБОК МЕТОДОМ НЕВИДИМОГО МАРКУВАННЯ

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Актуальність. У наш час у музейному секторі діє стандартна вимога щодо маркування експонатів ідентифікаційною інформацією, включаючи твори мистецтва. Ці маркування повинні містити абревіатуру музею та інвентарний номер твору мистецтва. Зазвичай ці маркування наносяться олівцем або чорнилом і розміщуються на видимому місці, що гарантує їх швидке віднайдення. Місце їхнього розташування, колір та техніка нанесення регулюються внутрішніми протоколами музею. Окрім цих видимих позначок багато музеїв також самотужки використовують непомітні ідентифікатори для захисту від крадіжки та підробки. Однак стандартизований підхід до таких маркерів ще не з'явився.

Мета дослідження — проаналізувати різні види творів мистецтва та виявити, яким чином невидиме маркування може бути для них застосоване з позицій ефективного захисту та одночасних мінімальних впливах на сам твір.

Об`єктами дослідження є твори мистецтва різного виду, які зустрічаються у музейних колекціях (від монет чи медалей до живописних полотен чи скульптури). *Методика дослідження* передбачає огляд найбільш доступних методів невидимого маркування. Виконано порівняльний аналіз захисту різних творів мистецтва методом хімічного маркера.

Результати. Аналіз різних видів творів мистецтва та музейних предметів виявив складнощі, пов'язані з визначенням оптимального розміщення та розмірів невидимих хімічних маркерів. Ці маркери є стримуючим чинником проти крадіжки та відіграють вирішальну роль у виявленні та поверненні втрачених або викрадених предметів. На кожний твір мистецтва слід нанести окремий код або цифровий ідентифікатор у технології флуоресцентного картування. Ця система уможливлює зчитування маркера за допомогою портативних пристроїв. Результати аналізу вказують, що ключова проблема полягає в тому, що маркери слід наносити на сам витвір мистецтва, а не на рами чи прикріплені етикетки. У випробуваннях, виконаних у рамках Європейського наукового проекту «AURORA», експериментально підтверджено доцільність застосування економічно ефективних, довговічних хімічних маркерів.

Висновки. Сформульовано особливі вимоги до методики застосування хімічних маркерів та їх величини. Розроблено рекомендації щодо методики вибору місця нанесення маркерів залежно від виду твору мистецтва. Для визначення оптимального місця маркування слід виконати попередній спеціальний поглиблений аналізу твору. Аналіз повинен включати знання про матеріал або матеріали, з яких виготовлено твір, їхню довговічність, їхню стійкість та ін. Місце маркування має бути точкою найменшої загрози для цінних характеристик твору та, водночас, бути достатньо важливою точкою ідентифікації. Залежно від обраного оптимального місця маркування необхідно попередньо визначити відповідну форму та розмір хімічного маркера. Тип, форма та розмір маркера залежать від самого твору мистецтва. Маркування може наноситися вручну або механічно. Форма маркування може варіюватися від дисперсної точкової структури до штампа з написом, знаком, логотипом, QR-кодом.

Ключові слова: витвір мистецтва, хімічне маркування, захист від підробок, захист від крадіжки.

Introduction. *Topicality of the Search.* Due to the illegal market for art and antiquities, many countries have developed special programs to safeguard museum collections, monitor the movement of artworks and other cultural assets, and combat their illicit trade. For example, since 2010, Poland has implemented the «Together Safer» program, which focuses on joint inspections and monitoring of sites containing cultural treasures. These inspections are combined with systematic work to document collections, including photographic (and more recently, 3D scanning) and descriptive records of movable artifacts, along with their special marking [1].

The program is implemented using modern technical tools designed to protect artworks in cases of emergencies or criminal activities. Coordinated activities under the program involve the police, border guards, customs authorities, the National Heritage Institute, the National Institute for the Protection of Museums and Collections, and provincial heritage protection offices. A key focus of the program is the effective protection of movable cultural heritage. The issue of protective marking of artifacts is particularly pressing for museums, private collections, and religious institutions (churches, synagogues, cathedrals, temples of other faiths) [2]. It is evident that protective marking is only one method among many to safeguard works of art from forgery, theft, or for their identification upon recovery. The war in Ukraine has highlighted the particular vulnerability of regional museums, whose collections were looted and scattered during the russian invasion. The war has also revealed another problem: the complete lack of protection for collections of sacred art in churches. As a rule, before the war, many churches did not have catalogs or descriptions of their church artworks. Churches may be monuments, but they are provided by the state for use by religious communities. Movable works of art in these churches are mostly unaccounted for. Their inventory and protective marking are particularly relevant in wartime. The war has shown that the protective marking technique should be relatively simple and quick to implement.

There are practical possibilities for employing various types of markings, including:

• Application of an invisible mark, code, or symbol;

• Application of a visible marker that cannot be removed and acts as a deterrent to criminals;

Marking with a hidden signal chip for locating the item in case of theft (this is typically recommended for very valuable artworks or exhibits).

When considering protective marking of this nature, we exclude other active protection methods such as motion detection, additional security measures, and alarm systems. If concealed marking of an artwork or object is deemed appropriate, selecting the location for the marking becomes a highly responsible task that must meet numerous criteria. It is evident that the marking itself (its substance, application method, and other characteristics) must also comply with specific requirements. However, this aspect is specialized and beyond the scope of our discussion. Here, we focus exclusively on the problem of selecting a location for applying the marking.

First and foremost, it should be emphasized that the choice of location depends both on the nature of the marking and on the type and form of the artwork. While it is impossible to enumerate all potential applications of this method, we will address the main principles of its implementation. This discussion is limited to the method of concealed chemical marking, which can only be read using specialized devices after being applied to the artwork.

Objective of the Study. The aim of the research is to analyze different types of artworks and identify which parts of these works are best suited for the application of chemical markers. Additionally, the study seeks to determine the optimal size of the marker for various types of museum artifacts and objects.

Research methodology. The unsatisfactory situation with the protection of works of art in museums and religious collections (sanctuaries) prompted a search for ways to protect movable works in particular. An assessment of the actual state of accounting in Lviv museums and archives was carried out using a pilot selective questionnaire survey of experts-museum directors or employees. The questionnaire contained questions about the availability of ways to protect works in exhibitions and storage facilities, and also offered a ranked answer — which works of art are most at risk of theft. It turned out that in museums, works of art are protected only in an active way — by organizing round-the-clock security by special security services. No protective marking of works was carried out. Only special catalog numbers are applied to works of art in museums, which are recorded in the receipt journals. These num-

bers do not perform any protective functions. They are used only for compiling a catalog of works in the museum. There are special instructions for applying them to a work, which determine the method and place where the marker number is applied [3]. In their responses about the types of artworks most at risk of theft, respondents ranked jewelry, medals, coins, and old prints at the top of the list, with paintings and sculptures at the bottom. However, all the experts surveyed agreed that invisible protective marking of works in collections is very necessary. Therefore, in this study, we reveal the methods of marking used to date.

Presentation of the Study Material. In Ukrainian museums, as well as in museums of many other countries, it is mandatory to apply markings to exhibits, including works of art. These markings must include: a) The museum's abbreviation; b) the artwork's inventory number according to its registration in the accession book, along with the code of that book (or in a standard or specialized inventory book with an abbreviated code) [3].

The location and nature of such markings (placement, color, and method of marking depending on the category of the item) are determined by the museum's internal regulations in consultation with the museum's restorers. The markings must be applied manually, mechanically, or electronically without compromising the item's appearance or condition. If it is not possible to apply the code directly to the artwork, it is placed on the frame, case, mount, envelope, or a tag (label or ticket) made of sturdy cardboard attached to the item with strong thread (for metal icons, crosses, miniatures, small items like earrings, buttons, etc.). For textile items, labels are made of light, sturdy fabric (calico or canvas), with the code applied to the label using ink.

For large items such as framed paintings, furniture, or items made from thick, opaque paper, a specially prepared stamp is applied to the back of the item in the lower right or left corner. The stamp includes the museum's name and space for the code [3].

Specific methods for different types of works are as follows:

Paintings: The code is applied with oil paint to the top or bottom stretcher bar on the back left corner. For paintings without stretchers, it is applied to the canvas edge on the back, in the lower left corner. For large paintings, the code is applied in two places on the back: top and bottom, on the left side.

Engravings and drawings on thin, transparent, or old paper: The code is applied only to the matting or mounting.

Double-sided drawings: The code is applied to the side covered by the mat during display, or, if the composition does not permit this, to the mounting.

Watercolors, engravings, posters, and drawings on thick, opaque paper: The code is applied with a graphite pencil. Colored or chemical pencils, ink, or ballpoint pens are not allowed.

This standardized approach aims to balance the requirements of artifact identification and preservation while adhering to each museum's internal protocols.

Application Details for Protective Markings. In museums, various types of artworks and artifacts require specific approaches to the application of inventory markings, ensuring their preservation while maintaining clear identification. Below are the most used methods and guidelines for different objects [3] (table 1).

For books and book covers, the code is applied using enamel paint or ink between two layers of acrylic lacquer on the inner back side, bottom left. The code is also applied in pencil on the last page. For rare books and manuscripts, the code is applied in pencil on the reverse side of the title page, bottom left.

This system ensures secure identification without compromising the artifact's aesthetic or structural integrity, aligning with both preservation and anti-theft objectives.

For small items grouped in a single storage category (*Small Items and Negatives*), the inventory code is applied to the container holding the items or on a label attached to the container. For negatives and diapositives the code is applied with ink on the reverse side of individual photographic prints in the lower left corner. For prints in albums, the code is applied to the reverse of the album cover or title page. For negatives smaller than 9 x 13 cm, the code is applied to the envelope, while for small-format positives, it is applied to their mount.

It should be noted that large museums usually have so-called «Internal Museum Instructions for Accounting and Marking of Works». Each museum develops such internal instructions that define the marking system (applying inventory numbers), including a detailed description of the marking technique for each type of work of art or object. The introduction of new marking materials, such as glue or paint, according to the «Instruc-

Table 1

№	Art work	Markings
1.	*Drawings in Frames, Mounts, or with Matting*	Codes should be duplicated on the frame, mount, or matting. For complex mounts or those where dismantling may damage the item (e. g., pastels), the code should be applied to the matting.
2.	*Albums with Drawings or Photographs*	The code is applied to the back of the title page. On the back of each album sheet, a museum stamp is placed in the lower left or right corner.
3.	*Icons*	The code is applied using light paint (e. g., white or blue) on the edge or back. For double-sided icons, the code is applied on the edge.
4.	*Sculptures*	On the back of the base (plinth) in the lower left corner using enamel or oil paint. For small sculptures, the code is applied to the underside. For large sculptures or wall-mounted reliefs, the code is applied on non-visible edges in multiple locations.
5.	*Ceramic, Wooden, and Stone Artworks, Objects*	The code is applied to the base using oil paint or ink, sandwiched between two layers of acrylic lacquer to ensure visibility.
6.	*Metal Objects*	The code is applied using enamel paint or ink between two layers of acrylic lacquer. For coins, medals, cameos, and small archaeological finds, the code is placed on their mounts and individual packaging (envelopes, cases) along with a photograph
7.	*Opening Items* (e. g., Boxes, Cases)	The code is applied inside the object
8.	*Decorated Items* (Painted or Carved)	The code is applied in areas free from decoration. For lacquered items, labels with the code are affixed using fish glue, which is reversible
9.	*Textile Items*	Labels with codes are sewn on the reverse side. For stitched items (e.g., skirts), the label is sewn onto the bottom edge. For unstitched items (e. g., shawls, carpets), the label is sewn to one side. Pins, buttons, or similar attachments are prohibited to avoid rust or damage.
10.	*Furniture*	A stamp with the code is applied to a metal or hard cardboard tag attached to the back, underside, or frame of the furniture (e. g., sofas, chairs, tables). For cabinets, the code is applied to the inner side of the left door panel if unadorned. For particularly valuable or fragile furniture, the code is applied manually with enamel or oil paint.
11.	*Architectural Fragments*	The code is applied to non-visible parts using oil or enamel paint.
12.	*Weapons*	The code is applied using enamel paint or ink between two layers of high-quality acrylic lacquer or affixed with a label. Firearms: On a non-visible part or the inner side of the trigger guard. Bladed Weapons: On the hilt. Defensive Weapons (e. g., helmets, shields): On the inner side.

Fig. 1. A 1918 banknote of the Ukrainian People's Republic with a denomination of 50 karbovanets, printed in the Berlin printing house «Reichsdruckerei». Obverse and reverse (From the collection of M. Bevz)

tions» must be approved by restorers to ensure compatibility and safety of artifacts.

The above methods of inventory marking are very useful for museums. They allow keeping track of artifacts, creating catalogs, and quickly finding information about items in descriptive books by searching for inventory numbers. However, this method of marking works is not protective. Such a marker can easily be removed if a work is stolen. Therefore, in recent years, scientists and heritage experts have been actively working and searching for methods to protect works of art and museum objects from theft. Reports from the Ukrainian police, border service, and Interpol have recorded a large number of stolen cultural heritage items in recent years. The existence of a huge uncontrolled so-called «black» market for works of art, antiquities, and archaeological artifacts has been confirmed. Every year, law enforcement agencies around the world seize a large number of historical relics and objects, works of art that are illegally transported. Today, for the first time, there has been talk of Ukrainian heritage items appearing abroad. Some of them have turned up on illegal markets or have been seized while being attempted to be sold [4]. It is possi-

ble that they could have been taken out of the country in the early days of the russian invasion, when it was impossible to check the flow of refugees. Therefore, there is a great need for special invisible marking of items of Ukraine's museum cultural heritage. This initiative is also supported by the International Council of Museums (ICOM) and correspondented with The UNIDROIT Convention [5].

The work of Polish specialists is an example of a state strategy for the protection of cultural values. Based on recent researches by the Ministry of Culture in Poland (Narodowy Instytut Muzealnictwa i Ochrony Zbiorów), several approaches are being considered for protecting artworks from theft and forgery, particularly for movable artworks. Polish researchers consider the main problem with marking movable art objects and other museum collection items with various substances to be the lack of in-depth specialized studies proving that these substances are completely safe for valuable items [6]. That is, they do not chemically react with the material from which the artwork is made and are reversible and can be removed if necessary. For example, tests were conducted on the impact of marking substances using the so-called «ODDY» test. Specifically, the results of this test, conducted by the Polish police regarding the marking of bicycles to prevent theft, were analyzed. The results showed that ultraviolet pens used for marking bicycles damage the surfaces they are applied to. Therefore, in this implementation, they are not suitable for marking artworks.

Hidden marking methods studied and tested by Polish researchers [6; 7]:

A — *Phosphor-based preparations*: It is possible to obtain a substance that can be mixed with other (nonreactive) substances, creating a certain color when exposed to light of a specific wavelength. Theoretically, each production batch of the preparation can have its own unique characteristics. The downside of such substances is that they can only be read with special devices [7]. This method is being tested in the Aurora project. First of all, the tool will be tested on old prints, icons, textiles and banknotes (fig. 1).

B — *RFID tags*: Micro-emitters that activate when they come within the range of a radio wave of a certain frequency. This technology is similar to chips that trigger alarms. In this case, the reader can be portable and work at a certain distance. Tags vary in size and oper-

ating range (maximum distance at which they can be read). The main rule is that the smaller the tag, the shorter the reading distance. The downside of the method is that small tags can only be read at minimal distances. Tags are also very dependent on obstacles that block radio waves. Electromagnetic fields have a particularly blocking effect, causing attenuation. Benefits of Combining RFID with AI: AI brings intelligence to RFID systems by making the data useful with in time. Instead of raw tracking, operators get better visibility, quicker decisions, and accurate forecasting. Combining RFID system and AI allows for higher security and anomaly detection [8].

C — *Micro-hologram application method*: It is possible to create millimeter-sized holograms with text, codes, or logos. They can be read with a magnifying glass. The downside of the method is that it is more economically feasible to produce a series of holograms rather than a single hologram with a unique code. Factory-made micro-holograms contain substances that need to be additionally tested using the ODDY method or others to determine if they cause surface damage to the artwork.

D — *DNA System micro-tags in gel*: A special method of creating very small polymer balls up to 1 mm in size, with printed text, embedded in transparent glue. The gel may or may not be visible under ultraviolet light. Today, there are manufacturers who guarantee the durability of the marking and resistance to chemical agents in case of attempts to remove it. The downside of the method is the high cost and difficulty of reading on dark surfaces.

E — *SmartWater system*: The use of phosphor-based markers (which react to ultraviolet light) [9]. It is known that this method was used to protect monuments in Syria. The results and characteristics of the method are not yet sufficiently covered in the literature. The method may be similar to the one described in «A» and studied in the Aurora project.

Regulatory Framework and Challenges. The requirements and recommendations outlined above are encapsulated in paragraph 6 of the Ministry of Culture of Ukraine's special directive «On the Approval of the Instruction for Organizing the Accounting of Museum Objects,» dated July 21, 2016, No. 580 [3]. This directive provides detailed regulations on the accounting and coding of museum artifacts.

However, these inventory markings are not designed as protective measures. They primarily serve to document the object's presence in the museum's collection. If an artifact is stolen, the markings can only confirm its prior presence in the inventory, as recorded in inventory books.

Challenges in Current Practices:

• Inventory books often lack photographs of the items, complicating identification in case of theft;

• Despite a 2015 mandate requiring museums to photograph every artifact — whether on display or in storage — many institutions have not fully complied;

Without photographic documentation, it is challenging to provide law enforcement with visual aids to facilitate searches or confirm authenticity.

Vulnerability of Inventory Markings. Thieves can easily remove standard inventory markings, which are not designed as tamper-proof or protective. This highlights the critical need for a more robust marking system that:

• Functions as a protective measure;

• Enables clear and indisputable identification of stolen or counterfeit items.

A comprehensive approach to protective marking is essential for mitigating theft and ensuring the traceability and authenticity of cultural heritage objects.

The international project AURORA aims to fill this gap and, through a combination of means — chemical marking, the use of miniature devices, detailed scanning, and a blockchain platform — create a cost-effective, non-destructive, and non-invasive means of countering illegal activities in the protection of artifacts [10]. The technologies researched and implemented in project will be combined into a digital tool that will provide stakeholders — art dealers, collection curators, auction houses, logistics services, and law enforcement — with the means to easily verify the authenticity of artworks and their provenance, as well as to track the movement of artworks. The proposed protection technology is expected to be non-invasive, affordable, long-term stable, and ensure data reliability and confidentiality. The methodology will be based on a combination of advanced materials and digital technologies to create a nanotechnological chemical marker and a WSI embedded wireless tracking device, which will be integrated into a blockchain and IoT-based digital tool through which countermeasures against illegal activities with artworks can be implemented using portable devices, including smartphones [11].

Modern nanotechnologies allow the creation of anti-counterfeiting tags (chemical markers) that can be
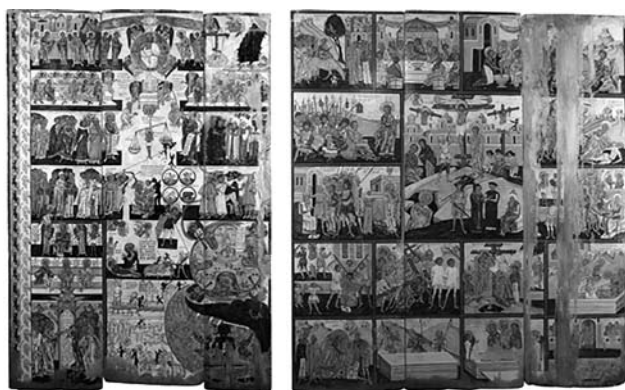
Fig. 2. Icons on wood: a) «The Last Judgment»; b) «The Passion of the Christ». Icons created at 60s—70s of the 16th century; unknown author; from the Church of the Ascension of the Lord in the village of Bagnuvate, Turka district, Lviv region, Ukraine Photo by P. Palamarchuk. Retrieved from: https://day.kyiv.ua/article/taym-aut/vpershe-za-80-rokiv (Last accessed: 10.01.2025) [12]

Fig. 3. Polychrome wooden sculpture, 18th century. Unnown author. Collection of St. Clement's Church. Lviv. Photo by M. Bevz

applied to artworks without causing damage. Protective tags can have a digital identifier obtained through X-ray fluorescence (XRF) mapping of artworks, and they can be read by simple portable devices (IR camera, UV lamp, and smartphone camera). The chemical marker will have specific measurable features that are difficult to counterfeit but easy to read. Embedding the «digital identity» of the artwork into the material itself and recording it using blockchain-based technology will ensure the preservation of authenticity and protect the artwork from counterfeiting. Key parameters of

the marker should include invisibility or visibility to the naked eye, adhesion, resistance to tampering and chemical influences, light and temperature stability, economic feasibility, and ease of use.

Knowing how the application of marking is regulated in Ukrainian museums (as described above — «Instruction…» [3]), we will try to demonstrate whether it is possible to apply a similar method of selecting the marking location for the chemical marking technology of the Aurora project. It should be agreed that the marking of the artwork can only be done with the consent of the museum restorers. The marking of artworks can be done in various ways, but without damaging their appearance and preservation. However, the next position of the Instruction (that if it is impossible to apply the marker to the artwork, it is applied to the frame, case, mat, envelope, etc., or to the label or tag) is unacceptable for application. We believe that the marker must be on the artwork. It can be additionally applied to the frame or case. For fabric items, the marker should also be applied to the fabric, not the label.

For large items (framed paintings, furniture, etc.), for items made of thick opaque paper, the marker can be applied to the back of the item. The location of the marking is not of fundamental importance.

For paintings, the marker should be applied to the front or back surface, as well as to the top or bottom bar of the stretcher. For paintings without stretchers, it should be applied to the edge of the canvas on the front and back sides of the painting. For large paintings, the marking should be applied to the front surface, as well as in two places on the back of the painting: at the top and bottom. For engravings and drawings on thin transparent or old paper, the marking is applied only to the peripheral parts without the drawing and to the framing or mounting. Similarly, for double-sided drawings, the marker is applied to the side of the sheet that is covered by the end of the mat when displayed. For watercolors, engravings, posters, drawings made of thick opaque paper, the marker should be applied to the back side. In these cases, it is necessary to ensure the neutrality of the marker with respect to the paper and the paint material.

For drawings in frames, mats, or with borders, it is recommended to duplicate the marker on the frames, mats, and borders. For albums with drawings or photographs, the marker should be applied to all sheets-drawings on the reverse side.

For icons painted on wooden boards, the marker should be applied to areas without figurative images, as well as to the edge or the back of the item. Similarly, for double-sided icons, the marker is also applied to the edges of the icon. On multi-scene icons (fig. 2), the marker should be applied to each scene.

For sculptures (reliefs), the marker can be applied to secondary areas of the plastic on the front and back, as well as on the plinth. For small-sized sculptures, the marker should be applied to the back and the base. For large sculptures, on reliefs attached to the wall, the marker should be applied to non-exhibition areas, edges in several places from different sides. We believe that the marking must be done on the back of the head of the sculpture (fig. 3).

For ceramic items and artworks (clay, porcelain, faience, etc.), for items and works made of wood and stone, the marker should be applied to flat areas on the sides, as well as on the base. *For large items or works of art made of metal*, it is recommended to apply the marker in non-exhibition areas. If the effect of the marker on the metal is unknown, it can be applied between two layers of reversible durable acrylic varnish in non-exhibition areas.

In all the above cases, the size of the marker should correspond to the size of the work, trying to make the marking as small as possible to minimize the negative impact on the work itself and to make it difficult to detect.

On the other hand, applying markings to *coins*, *awards*, *gems*, and small archaeological finds is problematic. The appropriate size of the marker on coins can be 0,2—0,5 mm, as such marking is recommended to be applied to the edge of the coin, not the obverse sides (fig. 4). On the obverse surfaces of coins or medals, the marker can be applied between two layers of reversible durable acrylic varnish in areas without plastic. With small marker sizes, the question arises whether it is appropriate to use it or replace it with another method, such as a micro-hologram.

For *items that open* (e. g., caskets, boxes, snuffboxes, etc.), the marker can also be applied inside the item. For items decorated with painting or carving, the marker should be applied to areas free of painting or carving. For items covered with varnish, the marker should be applied to the side surfaces or on a thin layer of fish glue (due to its reversibility).
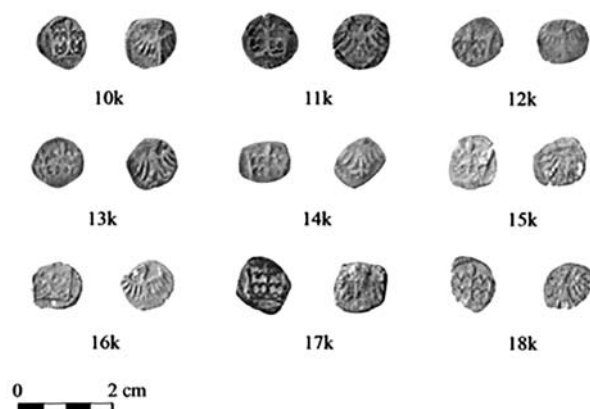

Fig. 4. Coins from archaeological research conducted from 2010 to 2016 at the castle in the city of Chełm [13, p. 283—284]

Fig. 5. Medallion with a polychrome icon of the Virgin Mary; size 4 cm. From archaeological research at the castle in the city of Chełm [13, p. 266]

For small items, the choice of location is very individual. Generally, the marker should be very small (fig. 5). Marking jewelry is particularly difficult. In these cases, we consider the application of markers to be the biggest problem. The size of the marker in many cases can be very small, in millimeter sizes or even less. When applying markings to metal works, there must be a guarantee that there will be no chemical reaction between the marker substances and the metal. This is a big problem as it requires preliminary non-invasive studies of the metal composition. For lacquered or painted surfaces, it is also necessary to guarantee the absence of reactions.

For valuable furniture, the marker should be applied to the side parts of the work. In case of particularly fragile furniture, the marker can be applied to the internal parts of the item, under the seat, tabletop, or frame (on a sofa, chair, armchair, table, etc.), on the inner side of the cabinet door that does not have artistic treatment.

For architectural fragments, the marker is applied to the non-exhibition part.

It should be considered that the marker must be sufficiently protected. Besides recommending making it invisible, it is important to apply it in such a place that, if the marker is detected, its removal would be impossible or problematic for the thief. Therefore, placing the marker inside the cabinet is not always a good solution. This could allow the criminal to remove a layer of wood along with the marker.

For covers, bindings of old prints, and books in bindings, the marker can be applied between two layers of reversible acrylic varnish on the reverse inner side of the binding. The marker can also be applied to selected pages of the book. For rare books and handwritten texts, the marker is applied only if its neutral effect on the paper is ensured.

For weapons, the marker can be applied between two layers of high-quality reversible acrylic varnish: a) for firearms — on the non-exhibition part or the inner side of the trigger guard; b) for cold weapons — on the handle; c) for defensive weapons (helmets, shields, etc.) — on the front or edge side.

For negatives and slides, it is recommended to apply the marker on the reverse side in some corner. For small-format negatives and positives, the marker should be applied to the peripheral part.

We note that one of the most effective ways of protective marking is the creation of a very precise 3D digital electronic model of the artwork or item. Such a model will be useful for searching for the artwork, recognizing and identifying it, determining authenticity in case of forgery, and other cases. This method has been adopted by the British Museum today, following the discovery of the disappearance of about two thousand exhibits. Among the stolen items were gold rings, earrings, and other jewelry from the ancient Greek and Roman periods, as well as other small items such as precious stones set in rings, etc. The proposed digitization project will take approximately 5 years, during which 2,4 million records need to be uploaded or updated. According to the museum's website, its collection includes at least 8 million items [14]. However, the museum sees this approach as a prospect aimed not at closing its collection but rather at greater openness while ensuring reliable protection. A detailed digital copy does not require any marking or other actions with the exhibit, but it al-

lows for easy verification of the authenticity of the artwork. This method is a passive way of protection, but it guarantees 100% «recognition» of the artwork. Combining this method with active methods, such as marking with a chemical tag or a chip with radio signals, would provide the most reliable way to search for the artwork in case of theft.

Since thefts occur even in very famous and advanced museums (for example, the British Museum), the protection of collections becomes a primary issue. In October 2023, representatives of the British Museum began digitizing the entire museum collection. They explained this not only as a necessity to ensure the preservation of the works but also to open access to them to the public. The museum is currently dealing with the aftermath of the theft, which revealed internal shortcomings and led to the dismissal of the director [14]. According to the museum's management, only about 350 artifacts are in the process of being returned.

As we can see in this situation, specialists associate the rescue from theft with the creation of a digital model of each exhibit. However, this method has another problem — ensuring the preservation and inviolability of the digital work itself. Any interference with this model would essentially mean the impossibility of identifying the authenticity of the work if needed. Notably, among the items stolen from the British Museum [14], small-sized works dominated — these included jewelry and precious stones.

A similar method of protecting works and museum collections through digitization was adopted in Ukraine in 2023. A public initiative was created to support museums in digitizing their collections [15; 16]. In the context of the war, this initiative is extremely relevant.

The fight against the theft of artworks and their illegal circulation cannot be limited to the creation of proper protection and safe conditions for exhibition or storage, marking, and maximum isolation of items from criminal hands. It is also important to have an effective system for reporting thefts and controlling illegal operations. In this area, it is important to have photos and digital information about the works for the rapid dissemination of data [17] among control authorities — police, customs service, border guards, etc.

Additional requirements for the marking of artworks. An important principle is the controlled reversibility of the marker material. The marker should help

Table 2

№	Type of Artwork	Appropriate Size of Marker	Optimal Location for Applying the Marker
1.	Numismatics, coins (metal)	0.5—5 мм	Edge, or exceptionally the obverse side
2.	Banknotes	5—10 мм	Edge
3.	Medals	0,5—5 мм	Edge, or exceptionally the reverse side
4.	Jewelry made of metal	0,2—3 мм	At the stamp or hallmark
5.	Jewelry with stones	0,1—1 мм	On the back side
6.	Oil painting	5—15 мм	Edge of the painting
7.	Icons on wood	5—15 мм	Front and edge side
8.	Sculpture	5—20 мм	Front, back parts
9.	Furniture	10—20 мм	Side parts, inside
10.	Church attributes, utensils (metal)	2—10 мм	Front, base, or back parts
11.	Church attributes, utensils (wood)	2—20 мм	Front, base, or back parts
12.	Fabrics	10—20 мм	Back side
13.	Graphics	2—20 мм	Paper field without image
14.	Weapons	5—20 мм	Back or inner parts

preserve the authenticity of the work without affecting its structures and, if necessary, should be easily removed in a way known only to the owner. Another issue that determines the choice of marking method is the number of symbols that can be included in the marker, which also depends on the size of the marker.

The main requirements for chemical marking of an artwork or item can be outlined as follows:

• Non-invasive, inert to the artwork itself; the marker should not affect the authentic substances in any way;

• Invisibility;

• Miniaturization, if necessary;

• Resistance to influences (sun, light, radiation, temperature, etc.);

• Compatibility with various materials — stone, wood, paint, metal, glass, textiles, etc;

• Ability to be easily read only in specified cases using special devices; difficult or impossible to read during unauthorized attempts;

• Resistance to removal, manipulation, and chemical influences;

• Controlled reversibility;

• Ability to digitally or otherwise record the marker to confirm its authenticity and originality;

• Ease of application;

• Adhesion;

• Anti-counterfeiting of tags (chemical markers);

• Economic feasibility of the method.

This list of requirements for the marking method is not exhaustive and depends on the type of artwork that needs protection. In some cases, the marker can be encoded and visible to the naked eye. However, in such cases, it must be very precisely recorded, and there must be a digital copy of it. If the artwork is a composition of different elements, the marking should be applied to all important and valuable elements of such a work. An example of such a work is the recently stolen sacred artwork by sculptor Joseph Chaumet in the Hierona Museum in the municipality of Paray-le-Monial [18] (fig. 6). How markers of this type related to different types of exhibits or works of art can be illustrated by examples that show the most typical requirements for marker size and optimal placement (Table 2).

From the table, it is clear that the requirements for the location of the marker vary greatly. The require-

Fig. 6. «Life of Christ» — artwork by the famous Parisian jeweler Joseph Chaumet, housed in the Hierona Museum in the municipality of Paray-le-Monial, stolen in December 2024. The height of the artwork is about 3 m. Photo: Rachida Dati/X. Retrieved from: https://novosti-n.org/ua/news/U-Francziyi-grabizhnyky-zuhvalo-vkraly-z-muzeyu-skulpturu-za-7-mln-yevro-304233. (Last accessed: 10.01.2025) [18]

ments for the size of the marker also differ, sometimes by 20—30 times. On coins, which often have a diameter of 10 mm and a thickness of 0,5 mm, the marker should be 0,2—0,5 mm in size. It is advisable to place it on the edge, which can be very thin, 0,3—0,5 mm (fig. 3).

Conclusions. The application of chemical marking is a promising but not universal method. It should also be understood that developing a single universal marker is very challenging. In reality, depending on the size and nature of the artwork, it will be necessary to recommend using different types of markers based on their properties. Marking artworks with a combined nature and consisting of many elements is particularly difficult.

The choice of the marking location for an artwork or artifact requires a preliminary special in-depth analysis of the work. This analysis should include knowledge about the material or materials from which the work is made, their durability, etc. The marking location should be the point of least threat to the valuable features of the work and, at the same time, be a sufficiently important identification point. Depending on the chosen optimal marking location, it is necessary to preliminarily determine the appropriate form and size of the chemical marker.

The type, form, and size of the marker depend on the artwork itself. Marking can be applied manually or mechanically. The form of marking can vary from a dispersed dot structure to a stamp with an inscription, sign, etc.

The basis of effective marking is the selection of a marker of a certain composition suitable for the given material, and the marker itself is a secondary element. The choice of marking method and type of marker should be made in accordance with the properties and characteristics of the artwork or artifact.

At present, the most appropriate marker is considered to be one with information encoded in the form of QR codes. It is advisable to use devices that allow the size of the marker to be reduced or increased depending on the requirements of the application location.

The marking location should be chosen by the restorer and the custodian of the work, who are well acquainted with its characteristics.

In addition to marking, an important task for the return of stolen cultural values is the preparation of reliable documentation, including a detailed description and images of places and elements characteristic of the object, such as individual traces of use, for example: cracks, dents, all types of damage, etc. Such documentation is the basis for recognizing collections and confirming ownership in future legal proceedings.

Disclosure statement. No potential conflict of interest was reported by the authors.

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