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URANIUM IN GLASS, GLAZES AND ENAMELS: HISTORY, IDENTIFICATION AND HANDLING

Donna Strahan

Summary—A survey of over 400 glass, enamel and ceramic objects from museums and private collections was made to investigate the extent of uranium colorants. Widespread use of uranium was found in colored glass, enamels and ceramics produced between the 1830s and 1940s. Simple tests can be used to determine the presence of uranium in objects. This knowledge can be useful for authentication purposes; the presence of uranium may also compromise thermoluminescence dating of ancient objects stored nearby. Little health risk from uranium-containing objects was found unless many objects were stored in a small area, or if acidic or alkaline foods were stored in them and consumed in quantity.

Introduction

Uranium was widely used as a colorant in glass, glazes and enamels on decorative objects from the 1830s to the 1940s before the adverse effects of its radioactivity were understood. It is surprising to most people to find how many makers of glass, enamels and ceramic objects used uranium as a colorant. Those who are aware of the use of uranium tend to think of the bright red-orange of Fiestaware ceramics or the yellow-green of Vaseline glass, but generally are unaware of its use to create dark-green and black colors as well (Table 1). Uranium is found in objects ranging from souvenirs, trinkets, everyday dishes and glassware to exotic one-of-a-kind works of art, decorative lamps and stained glass. Whereas much work on uranium radioactivity has been done on mineral specimens, little has been reported on decorative objects. Because of the lack of awareness of how widespread the use of uranium colorants is, it is important to bring this information to museum personnel and conservators who work with and display these materials. Topics covered here include the historical use of uranium, manufacturing methods, radioactivity, identification and detection methods, authenticity studies, health risks, and suggestions for handling.

History and use of uranium colorants

Uranium is a radioactive element and was used to produce extraordinarily brilliant new colors that could withstand high temperatures in a wide range of glass, enamels and ceramics. These included buttons, everyday dishes, glassware, candlesticks, drinking glasses, painted porcelain, stained glass,

jewelry, lamps and novelties (glass flowers and fruit, paperweights, souvenirs, etc.). Numerous examples can be found in museums, private collections, auction houses, antique shops, flea markets and garage sales.

Europe

Elemental uranium was first discovered in 1789 by the German chemist Martin Heinrich Klaproth. Between its discovery as a colorant for glass/glazes in the 1830s and the last use of non-depleted uranium for this purpose in the 1940s, it was extensively used by commercial glass, enamel and ceramics industries and by numerous artists. It is not actually known when the first uranium glass appeared, but in 1831 at the Prague Exhibition a yellow-green fluorescent glass was shown on the stand of Count Harrach's Bohemian Neuwelt factory. In 1834 G.L.C. Müller, under the direction of

Table 1 Glass, glaze and enamel colors that may contain uranium

Object	Europe & USA	Asia
Glass	yellow yellow-green	yellow yellow-green
Enamel	yellow yellow-green	yellow yellow-green black gray
Ceramic glaze	orange orange-red yellow ivory	orange orange-red yellow black gray

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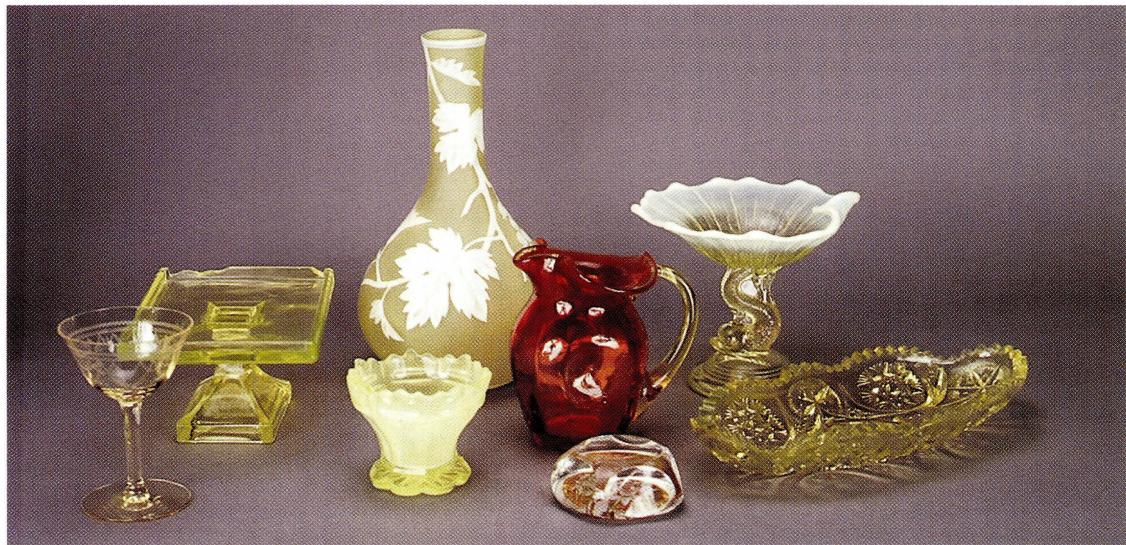


Figure 1 Examples of uranium glass objects.

Klaproth, published a paper on the use of uranium in glass [1]. Penberthy, in 1846, published information on uranium as a glass colorant in England. The brilliant yellow glass made with uranium was dubbed 'canary glass'. By the 1850s uranium as a colorant had become very popular throughout western Europe [2, p. 280]. It reached its peak in the latter half of the nineteenth century in Europe, spread to Japan and to the United States of America (Figure 1).

In Germany, yellow uranium glass was first produced by Josef Riedel of Bohemia, in the present day Czech Republic. The brilliant yellow glass was called *Annagelb* ('Anna glass'). The addition of copper sulfate to *Annagelb* produced a green uranium glass called *Annagrün*. Both were used as a souvenir glass in the spas of northern Bohemia. Many utilitarian and novelty objects were made of uranium glass, including egg cups, bottles, jars, beer mugs, candlesticks, bowls, drawer knobs, bell knobs, writing implements, tobacco pipes, perfume bottles, dishes and vases. By 1860 uranium oxide was used to achieve black and yellow designs on porcelain [2, p. 282].

The French glass houses of Baccarat and Saint Denis also made wide use of uranium colors in their art glass designs. The Baccarat glass factory first produced uranium glass (*cristal dichroïde* or *verre canari*) in 1843, shortly after the introduction of *Annagelb* by Riedel. Cut and gilded decorations on uranium glass made during the Biedermeier period (1820–60) were popular. Many glass artisans, including some of the most famous of the time, used uranium in highly imaginative designs,

beginning with Victorian glass. During the Art Nouveau period, artists such as Emile Gallé, René Lalique and Daum Frères made collectable studio glass using uranium. Gallé experimented with iridescence and used uranium to achieve many of his colors, such as his poppy vase, which has an

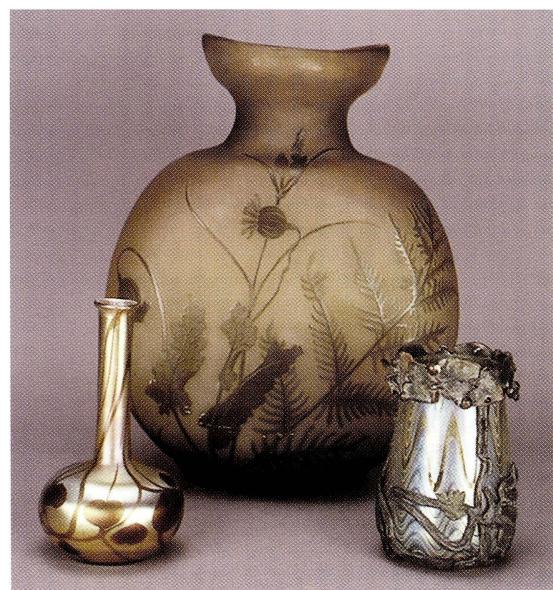


Figure 2 Uranium salts were used to produce the background color of these glass objects: Tiffany iridescent bottle (WAG 47.656), Tiffany cup (WAG 47.670), Gallé poppy vase (WAG 47.705).



Figure 3 Enamel palette with uranium yellow and green on the back cover of a book binding by Alfred Meyer (WAG 92.1).

unusual green color with yellow overtones (Figure 2). René Lalique perfected molded opalescent glass and often used uranium to color it. The Daum family made colored glass with enameled floral decoration. These artisans not only produced studio glass but also made mass-produced glass that was avidly collected by the public.

In England, uranium colorants were used in the finest Thomas Webb cameo ware. Glassworks in northeast England made small molded glass objects colored by uranium. Arts and Crafts Movement workers made designs of Sir Edward Burne-Jones and William Morris and stained-glass windows for churches, many of which included uranium colors. In the Art Deco years the forms of glass changed but uranium colorants were still used for brilliant colors. Even low-budget domestic wares such as 'Depression glass' contained uranium.

Elsewhere in Europe uranium colorants were used by Loetz in Austria, Swedish Graal ornamental glass by Orrefors Glasbruk, and Jugenstil

(German Art Nouveau) artisans. In Murano, Italy, uranium colorants were used by many famous glassmakers: Salviati, Barovier, Venini, Cenedese, Barbini. In Oslo, Norway, Art Nouveau artists such as Gustav Gaudernack in the firm of David Andersen produced delicate *plique-à-jour* vessels containing uranium. Russia's GUS crystal works produced uranium glass decanters, among other objects, in the early 1840s. In the mid-nineteenth century, the Imperial glassworks and Maltsov glassworks also produced uranium glass in Russia [3].

Enamelters also began to use uranium, due to its ability to create brilliant colors and to withstand high temperatures. The 1897 bookbinding of Jehan Rictus's *Les Soliloques de Pauvres* by French enamel artist Alfred Meyer contains an unusual enamel palette on the back cover (Figure 3). The enamel palette and the self-portrait on the reverse both contain uranium. Camille Fauré used uranium for yellow on an enamel box. Tiffany used it to produce rich, painterly designs and colors on objects such as an enamel jar (Figure 4).

The English began to experiment with new glasses during World War I when German glasses were no longer available. While uranium was mainly used for decorative purposes, it was also used — ironically — for some ultraviolet-absorbing eye-protective glasses [4, 5, p. 211]. Other specialty uses of uranium glass included late nineteenth-century photographic darkroom window glass and electric light bulbs produced in 1862. In the 1890s in Germany, uranium salts were also used for dyeing textiles, leather and paper. Dentists in England and the USA used 'uranium yellow' for coloring artificial teeth. It was also used to improve the elasticity and hardness of steels [6, p. 71].

Uranium glazes on European ceramics began appearing in commercial art potteries in the 1880s. Art potters experimented with inventive forms and

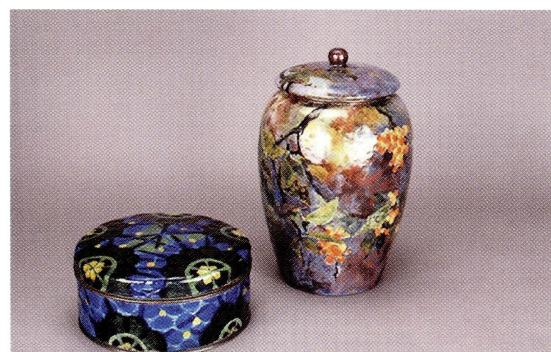


Figure 4 Fauré enamel box (WAG 44.692) and Tiffany enamel jar (WAG 44.589) with uranium colorants.

glazes for tableware, sculptural and functional objects. Art Nouveau iridescent glazes in the late nineteenth century in England (William de Morgan), Italy (Cantagalli) and Austria contain a small percentage of uranium. In the 1920s and 1930s, British pottery artisans such as Clarice Cliff probably relied on uranium for their brilliant orange-red colors. Studio potters in the late 1920s, such as Bernard Leach, may also have been responsible for the continued use of uranium glazes in Japan [7].

Asia

During the late nineteenth century, the technology of uranium glass and glazes was transferred to Asia. Japanese Meiji Period potters experimented with new application techniques and imported glazes including uranium oxide [8]. The use of uranium as a colorant in Japan was probably introduced by the German chemist Gottfried Wagner [9]. Wagner 'was invited to Japan in 1868 to help improve various industries, including cloisonné enameling, dyeing and ceramics' [10]. Wagner's research in Tokyo between 1874 and 1878 was devoted to work on enamels. In 1878–81 he was a chemistry teacher in a school and research laboratory in Kyoto (Kyoto Seimi Kyoku). His lectures on porcelain production included several recipes for uranium yellow colorants. One was a mixture of one part uranium oxide and two parts of potassium nitrate [11]. 'Asuka yellow' was an underglaze colorant for porcelain invented around 1894 in Japan. It used the radioactive mineral fergusonite, which contains thorium and uranium among other rare earths [12–14].¹ During the 1880s and 1890s Namikawa Sosuke was experimenting with new colors and techniques, including uranium colorants [15]. Uranium colorants have been identified in Makuzu Kozan's ceramic glazes and in Namikawa Sosuke's enamels. The main uranium colors are gray, black, orange-red and yellow. Two examples identified by Geiger counter were confirmed as containing uranium by X-ray fluorescence spectrometry at the Freer Gallery of Art, Smithsonian Institution. The gray of the rooster, chicken and grass in Sosuke's enamel vase (Figure 5) are uranium colors, as are many other examples of enamel made by him [16]. According to one study, uranium glass (*shinao*) manufacturing methods were introduced into Japan from the United States. The Iwaki glass company began producing uranium glass objects in 1899. A variety of objects continued to be produced in Japan during the Taisho era (1912–26) and into the mid-twentieth century [6, p. 32].

¹Fergusonite was first isolated by the Scottish scientist R. Ferguson (d. 1865).

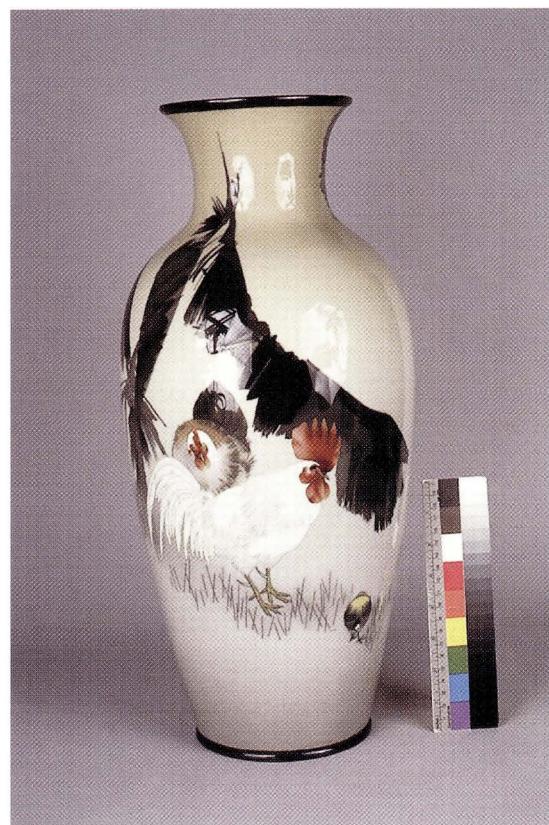


Figure 5 Sosuke enamel vessel with black and gray produced by uranium salts (WAG 44.691).

In contrast to nineteenth-century Japanese glass, enamels and ceramics, only one Chinese glass bowl of the same period in the extensive collection of The Walters Art Museum was found to contain uranium. This bowl, along with a collection of Chinese export glass belt-hooks, beads and toggles at The Corning Museum of Glass that contain uranium, was probably made from raw glass imported into China from Bohemia. Bright orange enamel on certain cloisonné jewelry made in China in the 1950s, which contained uranium, actually caused blistering on a wearer's wrist. Although the percentage of uranium in the bracelet was not measured, it was probably higher than most other objects [17]. The presence of uranium in objects from other Asian countries has not yet been studied. The author welcomes correspondence to broaden understanding of uranium in glass, enamels and ceramics elsewhere.

United States of America

In the United States, Steuben Glassworks and the

Boston and Sandwich glassworks were making everything from molded forms and pressed glass to hand-blown wares using uranium colors. Even Woolworths 'Five & Dime' stores sold uranium glass trinkets in the 1920s and 1930s. McKee Brothers in Pittsburgh in the 1860s made the so-called 'petti-coat' dolphin compote. The Boston and Sandwich Company made dolphin candlesticks in 'Vaseline yellow' and many other glass items [18]. These items are often referred to as 'Vaseline glass' because the glass appears as if coated with Vaseline. American firms that produced Vaseline glass include Heisey, Imperial, McKee, US Glass, Fostoria, Coudersport Tile and Ornamental Glass Co. The formula for 'Burmeese glass', patented in 1885 by the Mt Washington Glass Company, included 0.01% uranium oxide which turned white opaque glass yellow. 'Amberina glass' also obtained its yellow coloring by the use of uranium [19]. Victor Durand and the firms of Quezal Art Glass & Decorating Co. and Tiffany Studios were all using uranium colors in their glass. It is especially apparent in Tiffany's iridescent glass objects and tiles (Figure 2).

American art pottery innovations from the 1880s through the 1940s included uranium glazes. Only a few examples can be mentioned here: Rookwood, Roseville, Weller, H.R. Wyllie, Gladding McBean, Hall China, Vernon Kilns, Early California, and Red Wing (Figure 6). Many other potters in America at this time likely used uranium as a colorant. Cowan Pottery in Ohio, which produced red uranium glazes in the 1930s, discovered that if they saturated the kiln environment with uranium vapors during firing they could produce an attractive red glaze with black mottling [20].

Begun in Ohio, Homer Laughlin's 'Fiesta' dinnerware was designed by English ceramist Frederick H. Rhead and introduced in 1936. Among the

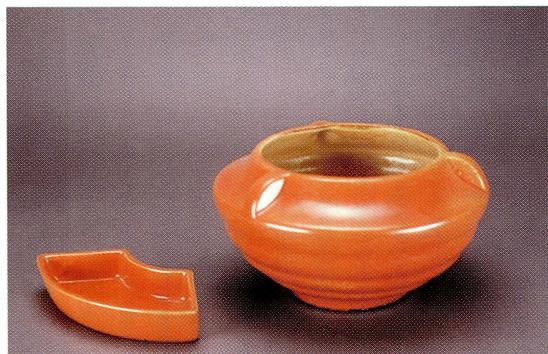


Figure 6 The Fiestaware dish and Rum Rill vessel both use uranium to produce the brilliant orange-red glaze.

Fiestaware colors available was a brilliant uranium red which continued to be used until 1943 when uranium was removed from the open market. Depleted uranium became available in 1959 and the Homer Laughlin China Company produced depleted uranium glazed dishes until 1972 [21]. Thus post-1943 Fiestaware does not contain non-depleted uranium.

The use of non-depleted uranium for atomic energy in the USA in the 1940s increased its value and the understanding of its health hazards. At that time restrictions were placed on the procurement and use of uranium. In 1943 the US government prohibited its use for non-military purposes; it soon disappeared from glass, enamels and ceramics [22]. Depleted uranium oxide was made available after 1959 as a by-product of nuclear energy processing. Non-depleted uranium contains about 0.7% ^{235}U and 99.3% ^{238}U . Depleted uranium has about 0.3% ^{235}U and 99.7% ^{238}U . Although the activity of ^{235}U is about six times that of ^{238}U , most of the radioactivity comes from the latter. It is not possible to tell the difference between the non-depleted and depleted varieties of uranium in glass, enamels and ceramics using the methods described in this paper [23]. Depleted uranium produces the same brilliant colors as non-depleted uranium. Although not commonly produced today, depleted uranium is found in artworks and some utilitarian objects. One of the more unusual uses of pre-1940s Fiestaware is the 'nuclear sculpture' by Seattle artist James L. Acord, Jr [24].

Methods of manufacture

The chief source of uranium is the mineral ore pitchblende, a variety of uraninite. It is a combination of uranium oxides and salts. Uranium forms a series of salts in which the element occurs in different states of valency (3, 4, 5, 6, with 4 and 6 stable enough to be used in glass). Up to 15% of uranium salts may be added to glass or glaze to produce a wide range of colors. The color is dependent on the amount of uranium, as well as the type and amount of additives mixed in the glass. The addition of various other color additives produced a wide variety of uranium glasses. The salts can withstand temperatures up to 1050°C, which makes them particularly useful for glass, porcelain painting, enamels and glazes [25]. Colored glasses that have been analyzed contain between 0.88% and 1.56% uranium oxide by weight [26]. However, experiments have shown that uranium oxide (UO_2) is soluble up to 50% [6, p. 48].

The chemistry of uranium colors in glasses is complicated and will only be briefly described here.

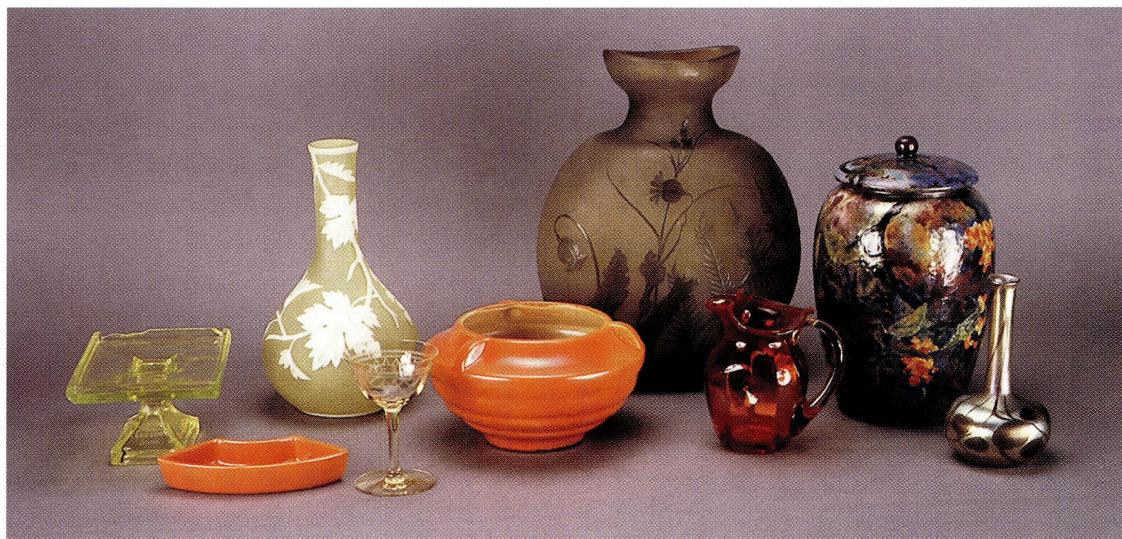


Figure 7 A selection of objects that use either oxidized or reduced uranium colorants to produce a wide range of colors.

Uranium can be added to a glaze as either sodium uranate (Na_2UO_4) or uranium oxide (UO_2). Sodium diuranate ($\text{Na}_2\text{U}_2\text{O}_7$) was used to produce yellow, green, ivory, orange and red colors in glasses and glazes. Yellow was the most common color produced commercially [27, 28]. Sodium uranate (Na_2UO_4), a yellow to red powder, was used to produce shades of ivory through yellow in glasses and glazes. The oxides of uranium can also be used to produce a variety of colors. While there are many oxides of uranium, UO_3 (uranium trioxide) and U_3O_8 (triuranium octaoxide) are the most stable and were the most common uranium oxides used for glass, enamels and ceramics [5, p. 205]. Under oxidizing conditions (usually UO_3 , uranic oxide or uranium trioxide) they produce brilliant yellow and orange-reds. Under reducing conditions uranium oxides (U_3O_8 , U_2O_5 , UO_2) produce a range of dark greens and dense blacks. Some objects use both reduced and oxidized colorants for a broad palette of colors (Figure 7).

Glass composition will also have a pronounced effect upon the color produced by the addition of uranium. Studies have shown that basic glasses — high content of Na_2O (sodium oxide) and BaO (barium oxide) — with little or no lead will produce brilliant yellows under oxidizing conditions. High boric oxide content will change the pure yellow to a green-yellow. Glasses with high K_2O (potassium oxide) and CaO (calcium oxide) will also cause uranium yellows to become greenish-yellow. Uranium in glazes rich in lead or bismuth produces an

orange-red or vermillion color from precipitated bismuth and lead uranates. In heavy lead glasses, uranium produces a yellow without the green fluorescence, such as Bohemian *Annagelb*. Uranium could also be mixed with antimony to obtain a stable yellow in lead glasses [5, p. 207].

Radioactivity of uranium

Uranium has 22 isotopes, all of which are radioactive. The radioactivity of uranium was discovered by chance by Henri Bequerel in 1896 in Paris [2, p. 256]. He placed uranium compounds on photographic plates wrapped in black paper and after several days found exposures similar to radiation by X-rays. Marie and Pierre Curie showed that uranium radiation was a naturally occurring phenomenon whereby it continually decays from uranium to thorium, to radium, to polonium, until it finally becomes lead [29]. As each material disintegrates it releases energy in the form of radiation. Uranium atoms break down spontaneously through a multi-step process, forming a series of radioactive progeny products. Over a long period of time these also break down, eventually forming non-radioactive lead atoms. The decay scheme of ^{238}U to ^{206}Pb has a half-life of 4.51×10^9 years [30].

As uranium decays it emits alpha, beta and gamma rays. Alpha and beta radiation are relatively rapidly absorbed in air and do not travel far. However, gamma radiation travels much further

Table 2 Radiation unit relationships

Radiological quantity	Old unit	SI unit	Relationship between units
Activity	curie (Ci)	becquerel (Bq)	$1 \text{ Bq} = 2.7 \times 10^{-11} \text{ Ci}$
Absorbed dose	rad (rad)	gray (Gy)	$1 \text{ Gy} = 100 \text{ rad}$
Dose equivalent	rem (rem)	sievert (Sv)	$1 \text{ Sv} = 100 \text{ rem}$

and is more penetrating than X-rays. The main hazard of external exposure for humans is largely from the gamma radiation. The greatest hazard is from internal exposure to alpha and beta radiation emissions coming from the uranium and its progeny products inside the body via inhalation or ingestion.

Unlike its radioactivity, the poisonous effects of uranium have been known since the 1830s; however, regulations concerning its use were not made law until 1894. Prior to that time, uranium was actually used for its healing effects. Uranium waters were used in bath-houses and small doses of uranium derivatives were used to treat patients [2, p. 256]. The first discussions of controlling the use of uranium in medicine began in the 1890s. By the early 1940s in the United States, legislation was written introducing safeguards and controls for radioactive substances. Since that time the use of non-depleted uranium for glazes, enamels and glasses has been discontinued throughout the world.

Other radioactive elements found in glass, enamels and glazes are thorium (^{232}Th) and radioactive potassium (^{40}K). The radioactivity emission of these elements is low compared to uranium (^{235}U and ^{238}U) and will not be discussed in this paper. The presence of thorium is accidental, as an impurity and not as a colorant. Neither thorium nor potassium fluoresces under ultraviolet light. Further information can be found in the papers by Sheets listed in the references [48, 51].

Human exposure to radiation is normally measured in a unit called a rem (roentgen-equivalent man).² It is also reported in millirems or mrem (1 mrem = 1/1000 rem), a unit expressing an amount of radiation (any type of radiation) which produces a biological effect equivalent to that received from one roentgen of X-radiation. Table 2 will aid in understanding the terminology used in measuring radiation, which has changed over the years, giving rise to confusion. At present the US Nuclear Regulatory Commission (NRC) restricts the public dose of radioactivity to 100mrem per year and 2mrem in any one hour [31, pp. 4–5].

Radiation is present in our daily lives and is nor-

mally considered as natural background energy originating from a variety of sources that include cosmic radiation, terrestrial radiation and artificial radiation. The average radiation dose at sealevel along the equator is about 20mrem per year. Terrestrial radiation is also emitted from various rocks and soils, mainly from uranium and thorium and their progeny products. The amount of emitted radiation varies depending on the geographic location [32].

Detection methods

The radioactivity of uranium objects is markedly variable depending on the type of uranium and its total proportion. Aside from instrumental analysis, uranium in the glass, enamels and glazes of objects can be detected by the use of a Geiger-Müller survey meter (Geiger counter), ultraviolet light examination, or by testing with photographic film. Geiger counters are used to measure the sum of beta, gamma and X-ray intensities present. The intensities are measured in counts per second or minute. The limit of detection of today's Geiger counters corresponds to a concentration of about 0.2% uranium (2000 ppm). Using a calibration curve from certain manufactured glasses with specific uranium contents, Brill demonstrated that the uranium content in wt% was proportional to the net counts per minute by a Geiger counter. His detector measured uranium down to a level of about 200 ppm in glass [33, 34]. The intensity of the radioactivity will differ because of the size and shape of objects. Radiation blocking agents present in the glass, such as lead and iron, may also lessen the amount of radiation emitted [35].

After measuring the background radiation, the Geiger counter tube is placed alongside the object for one minute (Figure 8). A series of five measurements should be taken and averaged. The amount of radiation given off by the various ceramics, enamel and glass discussed in this article ranged from 0.04 to 10mrem.h⁻¹ where the background reading was between 0.01 and 0.02mrem.h⁻¹. This is less than one-thousandth of the amount of exposure per year allowed by the NRC.

Much research has been done on the handling,

²The SI unit is the sievert (Sv), where 1 Sv = 100 rem.

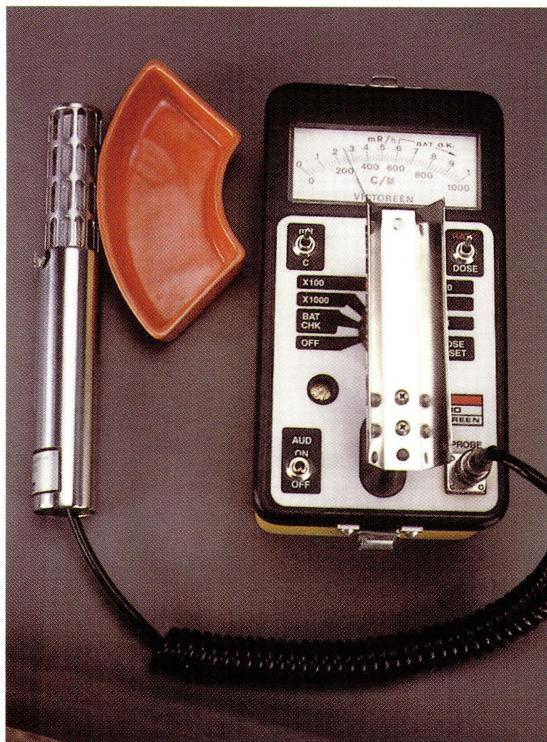


Figure 8 Geiger counter measuring the radiation emitted by a Fiestaware dish.

display and storage of natural mineral specimens containing uranium [36]. The methods described can be directly applied to man-made objects, although the levels of radioactivity in mineral specimens are generally higher than in most man-made objects. Mineral specimens producing a reading of 1mrem.h^{-1} or higher above normal background levels at a distance of 10mm from the surface of the specimen were classed radioactive and removed to specially designed storage and display locations. Normal background level of 0.02mrem.h^{-1} was the condition when this standard was established [37, p. 74].

The simplest method for determining the presence of uranium in a ceramic, enamel or glass object may be through the use of long-wave or short-wave ultraviolet (UV) light to induce fluorescence. Fluorescence in uranium-containing glass is due to the uranyl unit (UO_2^{2+}) in the mineral. When the uranyl unit is present, it emits light between 470 and 550nm [38]. As an impurity in minerals, uranium may be detected by UV fluorescence at concentrations as low as 1 ppm. Uranium in high states of oxidation gives the strongest fluorescence. Compounds containing uranium in the

tetravalent state (U^{4+}) are non-fluorescent while those containing uranium in the hexavalent state (U^{6+}), such as the uranyl unit, are fluorescent. A Japanese enamel vase by Sosuke (Figure 5) registered strongly on the Geiger counter. Some areas containing uranium readily fluoresced under long-wave UV light, indicating that a uranyl group was present. Under UV light, uranium colorants containing the uranyl group UO_2^{2+} will most often fluoresce a brilliant yellow-green. While this will not provide an actual count of the amount of radiation given off, it will allow the detection of uranium in an object. Aside from yellow-green, some uranium minerals may fluoresce green-white, yellow, orange or brown (Figure 9).

However, one cannot always depend on objects containing uranium to fluoresce under UV light. Under certain conditions, fluorescence of glasses with the UO_2^{2+} unit may be quenched by the presence of excessive alkali or of iron [5, pp. 474–481; 6, p. 23]. Excessive alkali will convert uranyl groups to uranates, which do not fluoresce. Highly alkaline lead glazes with uranium, such as orange Fiestaware, do not fluoresce. Iron in glasses also acts as a quencher of fluorescence by absorbing UV light. Be aware that uranium is not the only substance that fluoresces. The presence of uranium can therefore not be confirmed using UV light alone.

Placing objects on or wrapping them with high-speed photographic film can also test for the presence of uranium radiation [39].³ Developed film will be fogged where uranium exists on the object. The author tested five uranium-containing objects in the following manner. Each object was wrapped in or placed on top of the light-protected film for a period of 24 hours. The radiation fogged the film in the areas containing uranium, similar to the way in which its radioactive properties were once discovered. Those objects registering the highest radiation level by Geiger counter also produced the most fogged film (Figures 10 and 11).

Authenticity studies

Since non-depleted uranium was only used as a colorant between the 1830s and 1940s, these dates can be used as parameters for authenticity studies. Uranium was also used as a colorant in enamel restorations and repairs during the nineteenth and twentieth centuries. Identification of uranium in an object may help to determine authenticity or to highlight and date restorations. The author sur-

³Kodak BioMax MS film provides maximum sensitivity for penetrating isotopes and was used to test for the presence of uranium in decorative art objects.



Figure 9 Objects illustrated in Figure 7 under ultraviolet light. All contain uranium but only certain valences will fluoresce.

veyed a large number of objects in museums and private collections with a Geiger counter to study the prevalence of uranium-containing objects (Table 3). Caution should be used when interpreting the presence of uranium. Uranium anomalously found in an object may make one doubt its authenticity while in fact it may only indicate a restoration. This can allow the restoration to be dated. For example, the enamels on a Renaissance pendant in The

Walters Art Museum were analyzed by proton induced X-ray emission spectroscopy (PIXE) and found to contain uranium, but only in the restored yellow areas; the original yellow does not contain uranium. Over 4% uranium was detected in the restored yellow area of the pendant [40].

According to collectors' guidebooks, modern glass fakes and reproductions are common. Those most often referred to include Loetz, Burmese and

Table 3 Summary of objects surveyed

Collection	Glass	Enamel	Ceramics
Walters Art Museum	59	40	87
Baltimore Museum of Art	15		20
Corning Museum of Glass	45		
Private Japanese enamel collection		30	
Private Japanese ceramic collection			40
Private glass collections	33	10	
Private ceramic collections			25
Total (404)	152	80	172



Figure 10 The bottom of an orange-red Fiestaware dish showing puddles of glaze that contains uranium.

Vaseline glass, as well as works by the Art Nouveau artists Tiffany and Gallé [41–43]. The lack of uranium in colors where it is expected may help separate the fakes from authentic objects, or later pieces from earlier ones. For example, strong registration on a Geiger counter will confirm the uranium content in Fiesta dinnerware, thus dating it prior to 1943. As discussed above, many glasses, enamels and ceramics contained uranium, too numerous to name here. Modern forgeries and reproductions of these pieces would usually not contain non-depleted uranium in yellow, green, orange-red or gray and black areas, as would originals.

Mention must also be made of the effects of uranium radiation on other objects in close proximity. Uranium radiation can affect the authenticity study of an object undergoing thermoluminescence (TL) dating [44]. Long-term exposure to radiation emitted from objects containing uranium may alter the TL of other objects stored next to them. Objects that may be affected include ancient and historic ceramics, as well as bronzes with clay core materials. While it is possible to correct TL results by measuring environmental radiation from suspected objects, TL analysts must be told of their possible exposure *a priori*.

Uranium radiation measurements can be taken by placing dosimeters in the area of interest for several weeks. Dosimeter measurements can then be used to calculate and correct TL results. However, this precludes the object having been moved, and the length of time it was present on the shelf must be known. The TL dates of vessels stored in the vicinity of a radioactive source would make them appear older than they actually are. If it is not known how long or how close to the source they were stored, it would be difficult to correct the TL date. Analysts can detect the extent to which the age of an object has been altered by performing additional tests using

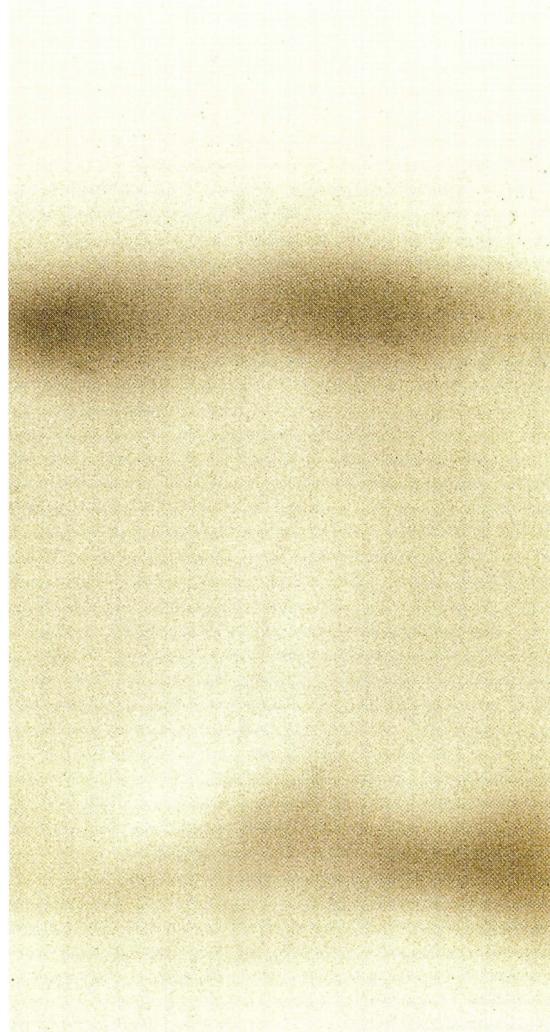


Figure 11 BioMax film developed after the Fiestaware dish was placed on it for 24 hours. The dark fogged areas match the glaze puddles illustrated in Figure 10.

various grain-sizes in the clays. Ideally, uranium-containing objects should be identified and stored away from any objects for which TL dates may be needed in the future.

Health risks and handling

There are known health risks associated with exposure to radiation [31, 3:17–18; 45]. Low doses of radiation over a long period of time are less injurious than the same total dose all at once. Indirect

effects of radiation may produce products that are chemically poisonous to cells. Direct effects of radiation on cells may physically damage DNA. Over time this may cause tumors, cancers, or genetic modification. However, with awareness and precautions, there is no need for concern. Working a total of five hours with objects that measure 0.02mrem.h^{-1} produces less radiation exposure than a dental X-ray [46].

When considering radiation, the intensity and the exposure time must be taken into account. As noted earlier, the amount of radiation exposure permissible by law for humans is small. Exposure will vary depending on intensity, distance and time. The radiation intensity is inversely proportional to the square of the distance to the source [47, p. D4]. For example, if the distance from the source is doubled, the dose falls off by four times. Empirical measurements with a Geiger counter were made by the author at distances of 1, 10, 30 and 60cm from 25 uranium-containing objects. At 1cm the highest level detected was 4mrem.h^{-1} . In all but two cases, no radiation was detected 60cm from the object, no matter how high the reading next to the object had been. At 10cm even the highest level of radiation detected was remarkably low, at 1mrem.h^{-1} (Table 4). Similar results were reported by Sheets and Turpen [48].

The exposure time is important. Continual close proximity to a uranium-containing object may slowly add to an individual's yearly allowable dose [48, p. 170]. Long-term direct contact such as wearing uranium-containing enamel or glass jewelry directly next to the skin should be avoided [49]. As with lead-containing objects, those with low levels of uranium need no special precautions in handling, but they should never be used for food. Acidic solutions and foods such as wine, tomatoes or citrus fruits may dissolve small amounts of the glaze or glass and thereby allow the ingestion of uranium [50]. Basic solutions such as soft drinks and dairy products may cause the breakdown of the glass network, thereby freeing some uranium and allowing it to go into solution, available for ingestion [51].

The rate of radiation emission at any given time is proportional to the amount of uranium in an object. Guidelines for the display of mineral specimens have been available since 1973 [52]. Both Henderson and Hicks provide details on storage and display for uranium minerals, including special cases [53, 54]. But the radiation level of geological minerals is generally much higher than any of the man-made objects surveyed to date, and extreme care is not necessary for museum object collections. In general it is a good idea not to store all uranium-containing objects together as this will increase the amount of emission in one location. Spreading them out in the storage

*Table 4 Radiation (in mrem.h^{-1}) from uranium-containing objects sitting on a table**

Object	Distance from object			
	1cm	10cm	30cm	60cm
Glass block	0.20	0.06	0.02	0.02
Glass cup	0.20	0.05	0.02	0.02
Glass block	0.35	0.08	0.02	0.02
Glass cullet fragment	0.15	0.02	0.02	0.02
Rum Rill pot	4.00	1.00	0.25	0.08
Fiesta dish	2.00	0.40	0.06	0.03
Fiesta plate	2.00	0.40	0.05	0.03
Webb cameo bottle	0.32	0.08	0.02	0.02
Enamel jar	0.55	0.09	0.02	0.02
Glass vase	0.30	0.08	0.02	0.02
Paperweight	0.04	0.02	0.02	0.02
Tiffany bottle	0.10	0.02	0.02	0.02
Tiffany cup	0.06	0.02	0.02	0.02
Enamel box	0.55	0.15	0.02	0.02
Glass fragment	0.25	0.04	0.02	0.02
Glass block	0.10	0.03	0.02	0.02
Glass fragment	0.07	0.02	0.02	0.02
Glass fragment	0.04	0.02	0.02	0.02
Glass tube	0.55	0.03	0.02	0.02
Wine glass	0.07	0.02	0.02	0.02
Wine glass	0.07	0.02	0.02	0.02
Glass celery dish	0.85	0.10	0.04	0.02
Depression glass	0.10	0.03	0.02	0.02
Depression glass	0.20	0.04	0.02	0.02
Dolphin compote	0.18	0.06	0.02	0.02

*Background radiation of 0.02mrem.h^{-1}

area will lessen the concentration of radiation emissions at any one location and prevent 'hot spots'. Sheets and Turpen measured radiation from open displays of dinnerware and found that large groups of orange ceramics provided more than twice the background radiation level at a distance of 2.5 meters [48, p. 168]. To determine if a concentration of uranium-containing objects is emitting radiation high enough to be considered a hazard, a radiation survey should be made of the area [37, pp. 65–80].

The author used a Geiger counter to survey over 400 objects in museum and private collections (Table 3).⁴ From these data, and the scientific studies previously cited, it can be determined that the radiation exposure from individual uranium-containing art objects is very low. Nonetheless, the levels of radioactivity should be determined and appropriate steps and precautions taken to minimize the risks

⁴Radiation emissions were counted with a Thayac IV survey meter model 290 by Victoreen Inc., 6000 Cochran Road, Cleveland, OH 44139, USA.

from the objects, particularly if they are stored together. If the level of radiation is determined to be high, maximize the distance between the viewer and the object and minimize the time of exposure. The most significant hazard from external exposure is the effect of gamma radiation on skin resulting from prolonged, close contact. Handling of the object should be kept to a minimum [47, p. D3]. Lead aprons are not necessary for protection from the small amount of radioactivity in art objects.

Internal exposure through ingestion or inhalation is more significant. If a radioactive agent gets into the body, the exposure to alpha and beta radiation is higher because of its local intensity. Uranium and its progeny products would not be expected to transfer from objects to hands or mouth unless decomposition of the glass is occurring. If unstable glass is used to serve foods, minute amounts of uranium may be free on surfaces and could be ingested. Certain precautions for handling any work of art, such as wearing gloves or washing hands after handling objects, are recommended.

Several scientists have tested the leaching of uranium from glassware and glazes using acetic acid and nitric acid [48, 50, 51]. Their results indicated that minimal quantities of uranium were leached from glass (maximum of $30\mu\text{g.l}^{-1}$) but significant quantities were removed from ceramic objects (a maximum of $300,000\mu\text{g.l}^{-1}$) [50, p. 347]. Ingestion of 28ml of vinegar left for 24 hours in uranium-orange dishes would result in an intake of 2–14mg uranium, thus regular use of this uranium-orange dinnerware would equal or exceed International Committee on Radiation Protection recommendations [48, p. 170]. Sheets and Turpen also found that the radiation exposure from the uranium-orange dinnerware was many times higher than normal background levels. As a result, the Bureau of Radiological Health recommends that uranium tableware not be used for the storage or serving of food and that exposure be minimized.

The author ran a test to determine whether any radiation was removed by handling stable objects. Commercial radiation wipes were rubbed across 13 objects known to contain uranium. The radioactivity of the wipes was counted in a scintillation detection system, which detects and counts gamma emitters of very low activity.⁵ Two out of 13 wipes tested may have been radioactive but the level was barely above background rate, so any activity removed was so small as to be inconsequential.

⁵Robert Hiscock provided the rad-wipe pads and took the readings in a Picker Spectroscaler IV scintillation detection system having a 3" sodium iodide scintillation crystal. The scintillation detection system measures radiation down to 0.25 microcurie.

In commercial conservation/restoration work, where smoothing, polishing or drilling holes is carried out, the ingestion of uranium-containing dust is a danger. Dust masks and nitrile or latex gloves should be worn when producing fine particles while working with objects suspected of containing uranium colorants.

Conclusion

Although uranium was extensively used as a vibrant colorant in glass, glazes and enamels between the 1830s and 1940s, its use throughout the world and its wide color range have only recently been studied.

The presence of uranium can be easily determined without extensive scientific analyses. Objects containing uranium can be identified under ultraviolet light, by Geiger counter, or by placing the object in contact with high-speed photographic film. Detection of uranium can assist in authenticating objects or in determining forgeries, reproductions and restorations. Radiation emitted from uranium-containing objects may affect authenticity studies on objects stored next to them by altering their thermoluminescence dates.

Both the author's Geiger counter surveys and the scientific literature on the emission of radiation from uranium objects revealed that radiation levels emitted from these objects are well below the doses allowed by the US Nuclear Regulatory Commission. However, certain precautions should be taken by practising conservators and collection managers, and handling of these objects should be minimized. If large groups of objects with uranium colorants are to be stored together, a Geiger counter survey should be made to determine the level of total radiation in that localized area. Separating objects and storing them apart can reduce high levels of radiation. No foods, especially acidic or alkaline solutions, should be served or stored in objects containing uranium colorants. Display and storage cabinets constructed of glass or metal provide the best insulation from the low-level radiation emitted by uranium-containing objects [55].

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References

- 1 GROS, G., *Coloured Glass in Bohemia — c. 1810–1850*, Circle of Glass Collectors [paper] no. 159 (1975) 5.
- 2 KIRCHHEIMER, K., *Das Uran und seine Geschichte*, E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart (1963).
- 3 ASHARINA, N., MALININA, T., and KAZAKOVA, L., *Russian Glass of the 17th–20th Centuries*, The Corning Museum of Glass (1990) 164.
- 4 POWELL, H.J., *Glass-Making in England*, Cambridge University Press (1923) 169.
- 5 WEYL, W.A., *Coloured Glasses*, The Society of Glass Technology, Sheffield (1951).
- 6 TOMABECHI, K., *Uranium Glass*, Iwanami Book Service Center, Tokyo (1995).
- 7 LEACH, B., *A Potter's Book*, Faber and Faber, London (1976) 174.
- 8 KIZAN, I., TOYOJIRO, H., and POLLARD, C., 'Meiji kindai togei no makuake' [The beginning of Meiji modern ceramics], *Me No Me* 213 (July 1994) 22.
- 9 BLAIR, D., *A History of Glass in Japan*, Kodansha International, New York (1973).
- 10 EMERSON-DELL, K., *Bridging East and West: Japanese Ceramics from the Kozan Studio*, The Walters Art Gallery, Baltimore (1994) 11–12.
- 11 YAMASAKI, K., personal communication (1995).
- 12 SHIBATA, Y., and KIMURA, K., 'The chemical investigation of Japanese minerals containing rarer elements', *Japanese Journal of Chemistry* 2 (1) (1923) 3.
- 13 KOTARO, A., 'Jiki yuka kirro ganryo hakken no yurai' [The origins of the discovery of an underglaze yellow pigment for porcelain], *Dai Nihon Yogyo Kyokai Zasshi* (1899–1900) 69–73.
- 14 NORITAMA, T., 'Fueruganaito (jiki kiyo ganryo ni tuite)' [Fergusonite and yellow pigments for porcelain], *Dai Nihon Yogyo Kyokai Zasshi* (1899–1900) 527.
- 15 NAOTERU, U., *Japanese Arts and Crafts in the Meiji Era*, Pan-Pacific Press, Tokyo (1958) 133–134, 147.
- 16 GARNIER, M., 'Meiji period artistic innovations in the ceramics of Miyagawa Kozan (1842–1916): from satsuma to porcelain', master's thesis, University of Maryland (1994) 92.
- 17 HISCOCK, R., personal communication.
- 18 PHILLIPS, P., *The Encyclopedia of Glass*, Crown Publishers Inc., New York (1981) 187.
- 19 REVI, A.C., *Nineteenth Century Glass: Its Genesis and Development*, Schiffer Publishing Ltd, Atglen (1967) 35–36.
- 20 BARBERO, K.H., *Cowan Pottery: A Ceramics Monthly Portfolio*, The Cowan Pottery Studio, Cleveland (1985) 26.
- 21 PIÑA, L., *Pottery: Modern Wares 1920–1960*, Schiffer Publishing Co., Atglen (1955) 55.
- 22 HUXFORD, S., and HUXFORD, B., *The Collector's Encyclopedia of Fiesta*, Collector Books, Paducah (1992).
- 23 SHEETS, R., personal communication.
- 24 SCHYULER, P., 'Moving to Richland – II', *The New Yorker Magazine* (1991) 62–107.
- 25 HAMER, F., and HAMER, J., *The Potter's Dictionary of Materials and Techniques*, A & C Black, London (1975) 332.
- 26 BRILL, R.H., *Chemical Analyses of Early Glasses*, Volumes 1 & 2, The Corning Museum of Glass (1999) Sections XIX B 1.
- 27 RHODES, D., *Clay and Glazes for the Potter*, Chilton Book Company, Radnor (1973) 212–213.
- 28 KANTZ, K., 'The effect of glaze composition upon the colors produced by sodium uranate', *Journal of the American Ceramic Society* 17 (1934) 8–10.
- 29 TYLCOTE, R.F., *A History of Metallurgy*, The Metals Society, London (1976) 162–163.
- 30 LYNCH, C., *Handbook of Materials Science*, CRC Press Inc., Cleveland (1980) 54.
- 31 WILLIAMS, O., *Radiation Protection Manual*, Manual No. 385–1–80, US Army Corps of Engineers, Washington DC (1997) 4–5.
- 32 MARTIN, A.D., and HARBISON, S.A., *An Introduction to Radiation Protection*, Chapman and Hall, London (1986) 47–48.
- 33 BRILL, R.H., 'Applications of fission-track dating to historic and prehistoric glasses', *Archaeometry* 7 (56) (1964) 153.
- 34 FESTAG, J.G., GENTNER, W., and MULLER, O., 'Search for uranium and chemical constituents in ancient Roman glass mosaics' in *Applicazione dei Metodi Nucleari nel Campo delle Opere d'arte*, Accademia Nazionale dei Lincei, Rome (1976) 497.

- 35 SHEETS, R.W., personal communication.
- 36 HOWIE, F.M., *The Care and Conservation of Geological Material*, Butterworth-Heinemann, Oxford (1992).
- 37 LAMBERT, M.P., 'Ionising radiation associated with the mineral collection of the National Museum of Wales', *Collection Forum* 10 (2) (1994).
- 38 ROBBINS, M., *Fluorescence: Gems and Minerals Under Ultraviolet Light*, Geoscience Press, Phoenix (1994) 5, 146, 148, 189.
- 39 HUDSON, P.O., and NEWTON, R., 'A means for the in-situ identification of medieval glass by the detection of its natural radioactivity', *Archaeometry* 18 (2) (1976) 229–232.
- 40 MARTIN, M., internal report, The Walters Art Museum Conservation Department files for pendent 44.442.
- 41 GLICKMAN, J.L., *Yellow-Green Vaseline! A Guide to the Magic Glass*, Glass Press, Marietta (1991) 46.
- 42 KNOWLES, E., *Miller's 100 Years of the Decorative Arts: Victoriana, Arts & Crafts, Art Nouveau & Art Deco*, Reed Consumer Books Ltd (1998) 65.
- 43 DAVIS, S.C., *The Picture Book of Vaseline Glass*, Schiffer Publishing Ltd, Atglen (1999) 8–9.
- 44 GOEKSU, H.Y., personal communication.
- 45 RICHARDSON, H.D., *NDT Radiography Manual*, US Atomic Energy Commission (1968) 61–72.
- 46 HISCOCK, R., personal communication.
- 47 BRUNTON, C.H.C., BERSTERMAN, T.P., and COOPER, J.A., *Guidelines for the Curation of Geological Materials*, Geological Society Miscellaneous Paper No. 17, Geological Curators' Group, The Universities Press, Belfast (1985).
- 48 SHEETS, R.W., and TURPEN, S.L., 'Release of uranium and emission of radiation from uranium-glazed dinnerware', *Journal of Radioanalytical and Nuclear Chemistry* 235 (1–2) (1998) 167–171.
- 49 SKELCHER, B., 'Is uranium glass a health hazard', *The Glass Cone* 4 (1996) 8.
- 50 LANDA, E.R., and COUNCELL, T.B., 'Leaching of uranium from glass and ceramic foodware and decorative items', *Health Physics* 63 (3) (1992) 343–348.
- 51 SHEETS, R.W., and THOMPSON, C.C., 'Accidental contamination from uranium compounds through contact with ceramic dinnerware', *Science of the Total Environment* 175 (1995) 81–84.
- 52 *Code of Practice for the Display of Sources of Ionizing Radiations at Exhibitions*, National Radiological Protection Board, HMSO, London (1973).
- 53 HENDERSON, P., 'Hazards in the curation and display of mineral and rock specimens with especial emphasis on radioactivity', *Geological Curator* 3 (5) (1982) 292–296.
- 54 HICKS, R.P., 'The public exhibition of uranium minerals: a novel technique', *Geological Curator* 3 (5) (1982) 297–299.
- 55 KIERZEK, J., and KUNICKI-GOLDFINGER, J., 'Measurements of natural radioactivity in historical glasses', *Glastechnische Berichte* 73 (11) (2000) 354.

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Résumé—L'examen de plus de 400 objets de verre, d'email et de céramique provenant de musées ou de collections privées a été effectué afin d'estimer l'importance des colorants à l'uranium. On a observé un usage très répandu de l'uranium dans les verres colorés, les émaux et les céramiques produits entre les années 1830 et les années 1940. Des tests simples permettent de déterminer la présence d'uranium dans les objets. La présence d'uranium peut être utile pour authentifier un objet mais pourrait altérer les résultats de datation par thermoluminescence d'objets anciens entreposés à proximité. Les objets contenant de l'uranium posent peu de risques pour la santé à moins qu'ils ne soient entreposés en grand nombre dans un petit espace ou utilisés pour contenir de la nourriture acide ou alcaline ensuite consommée en quantité appréciable.

Zusammenfassung—Um das Ausmaß der Verwendung von Uranfarben in Gläsern, Emails und Keramiken zu untersuchen, wurde eine Studie mit mehr als 400 Objekten aus Museen und privaten Sammlungen durchgeführt. Die Studie zeigte, daß Uranfarben in Gläsern, Emails und Keramiken zwischen 1830 und 1940 häufig

verwendet wurden. Uran kann in den Objekten mit einfachen Tests nachgewiesen werden. Dies kann vor allem für Echtheitsprüfung von Bedeutung sein, könnte jedoch die Ergebnisse von Thermoluminiszenzdatierungen verfälschen. Es konnte gezeigt werden, daß von den Objekten nur ein geringes Gesundheitsrisiko ausgeht, auch wenn viele Objekte in kleinen Räumen gelagert, oder wenn saure oder basische Speisen in ihnen gelagert und in großen Mengen verzehrt werden.

Resumen—Una serie de unos 400 objetos cerámicos, de vidrio y esmaltes procedentes de museos y colecciones particulares se analizaron con el fin de investigar la presencia de colorantes derivados del uranio. Un amplio uso de este tipo de compuestos se detectó en vidrios coloreados, esmaltes y cerámica producidos entre 1830 y 1940. Pruebas simples pueden ser utilizadas para determinar la presencia de uranio en objetos. Esto puede ser útil con fines de autenticación pero podría alterar las pruebas de datación por termoluminiscencia en antigüedades. El riesgo para la salud es mínimo con los objetos que contienen uranio, excepto en el caso de que muchos objetos sean guardados en un área muy pequeña o si se almacenan en ellos alimentos de carácter alcalino y son éstos consumidos en cantidades considerables.