ALTERING THE COLOR OF TOPAZ

By Kurt Nassau

The various techniques in use today to alter colorless topaz to produce brown, pink and, most commonly, blue stones are discussed. Special attention is given to the three irradiation sources—gamma rays, high-energy electrons, and neutrons—used to convert the colorless stones to hues in the yellow to brown range and the subsequent heat treatment required in most cases to turn the irradiated stones blue. The blue color produced by irradiation and subsequent heat treatment is stable to light. Currently, no routine gemological tests are available that can definitively determine whether the color of the topaz is natural or the result of treatment.

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Topaz is an aluminum fluorosilicate usually containing some hydroxyl; the formula can be written as $Al_2SiO_4(F,OH)_2$. Topaz occurs naturally in a wide range of colors: most commonly it is colorless, but the yellow to brown series, which includes the highly desirable gold to sherry ("imperial") colors, is perhaps best known. Topaz also occurs in blue and, more rarely, in green, orange, violet, and pink. The last of these is considered to be the most valued of all topaz colors. Natural pink topaz, however, is extremely rare; this color is usually obtained by heating certain yellow to reddish brown Brazilian material that contains the chromium required to produce pink. Some natural yellow to brown topaz, such as is found in Utah and in some Mexican locations, fades on exposure to bright light and is therefore not used in jewelry. In blue topaz, it is the depth of the color and the absence of a steely gray or a greenish tint that is considered desirable (see Webster, 1984, for a general discussion of gem topaz).

While natural blue topaz is available from a variety of localities, the successful treatment of colorless topaz to produce attractive shades of blue has greatly enhanced the availability and, consequently, the popularity of these stones during the course of the last decade. Although irradiation can convert most colorless topaz into the yellow to gold to sherry to brown sequence, these colors are usually unstable, and the stone will return to colorless in just a few hours of exposure to bright light. When this colorless topaz is irradiated and (in most cases) subsequently heated, however, an attractive blue stone may be produced (figure 1).

The production of blue topaz from colorless by irradiation was first reported by F. H. Pough in 1957 as one of a large number of color changes observed in a variety of materials subjected to such treatment, but little note appears to have been made of this in the years that followed. This same reaction was accidentally rediscovered by the

Figure 1. This 57.3-ct topaz derives its color from irradiation (in a linear electron accelerator) and subsequent heat treatment. It originally resembled one of the white topaz preforms on which it sits. Stones courtesy of P. Flusser, Overland Gems, Los Angeles, CA; photo © Tino Hammid.

present author in a faceted topaz that had been purported to be quartz. When this was reported in 1974 by Nassau, and in 1975 by Nassau and Prescott, many in the gemstone trade felt that it explained the large number of deeply colored blue topaz crystals that had recently appeared on the market without any new mines or significant new developments in existing mines to account for the abundance. Since that time, a number of firms have become involved in the treatment of blue topaz, with the result that literally hundreds of thousands of carats of blue topaz have entered the world market during the last 10 years. Also, the technique has been refined to the point that the blue color produced by treatment is often deeper and more intense than that seen in nature (figure 2).

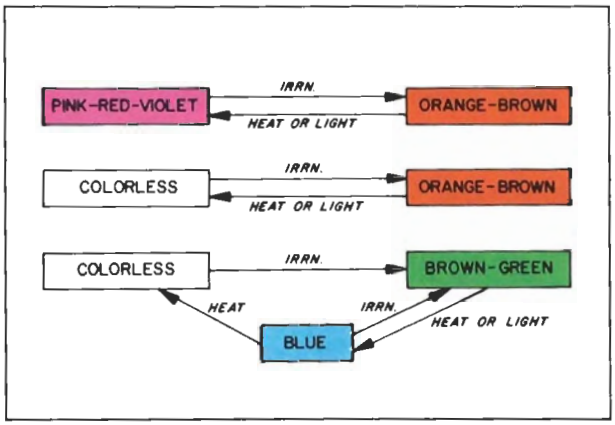
Very little is known about the causes of the colors in topaz. Only the chromium-caused origin of pink, stable to both light and heat, is certain. There are at least three types of yellow to brown colors; two fade in light, the other is stable. The former two can also be bleached by heating for a short time to 200°–300°C, the latter by a somewhat longer heating to 200°–400°C. The natural blue color and the blue produced with irradiation

Figure 2. A natural-color blue topaz (left) is notably lighter than its electron-irradiated counterpart (right). Although a wide variety of yellow to brown colors occur naturally or are produced by treatment, the two shades of brown produced by a short dose of gamma rays in the stones on the bottom left provide an interesting comparison with the natural-color yellow topaz on the bottom right.

are stable to light and are lost on heating to about 500°C. The yellow to brown and the blue colors are all clearly color centers (Nassau, 1983 and 1984) produced by the interaction of radiation with electrons on defects of unknown nature; what little is known has been summarized elsewhere (Nassau, 1974 and 1984; Nassau and Prescott, 1975). Not all colorless topaz will respond to treatment; in some cases one part of the crystal will be altered while the rest will remain unchanged. For the gemstone treater, it is very much a matter of trial and error.

The various heating and irradiation processes used on topaz are summarized in figure 3. Surprisingly, none of the many enhancement processes used on other gemstones appears to have been applied to topaz, except for the dyeing of water-worn pebbles in indigo dye pots as reported in Webster (1984). The following account of the major processes used to alter the color of topaz is based on a critical comparison of the author's own experiences, published data, and information provided by many experts in the field.

Figure 3. The changes in color produced by the treatment–irradiation and/or heat (or, in some cases, sufficient exposure to light)–of topaz.



THE IRRADIATION OF TOPAZ

Several types of irradiation can be used to alter the color in topaz: X-rays, gamma rays, neutrons, and high-energy charged particles such as electrons, protons, and the like. Some of these are not in common use: X-rays of the usual low energies have only a very shallow penetration, and high-energy particles other than electrons are more costly to generate and provide no advantage over electrons.

Further details on irradiation techniques and their application to gemstones are given in *Gemstone Enhancement* (Nassau, 1984). The comparative advantages and disadvantages of using gamma rays, high-energy electrons, and neutrons to convert colorless topaz to brown or blue are examined below.

Gamma Rays. Gamma rays are produced within a gamma cell, a device containing a quantity of a radioactive material, such as the mass 60 isotope of cobalt (Co-60), which emits these rays. Such

devices are commercially available in large sizes, require little upkeep, and continuously produce the rays with only a slow decay over many years. The rays are very penetrating and will produce uniform coloration if the material is uniform. Relatively little heat is generated during this process and this heat is produced uniformly throughout the specimen, so that cracking is not a problem; to avoid excessive temperatures, the rate of irradiation is kept at a reasonable level, usually less than 5 megarads per hour, depending on the size of the specimen.

When colorless or pale-colored topaz is exposed to gamma rays, a color in the sequence yellow to brown to reddish brown to very dark brown is usually produced, with significant color already appearing at quite low radiation doses (e.g., less than one megarad of Co-60). Because of variations in the nature of the topaz (impurities and other defects), these colors are frequently not uniform and will vary even among zones within a single crystal. The larger the dose of radiation used, the darker the color of any region up to a point controlled by the nature of that region. Different parts of a crystal may show different rates of coloration as well as different color limits. These yellow to brown colors usually fade on exposure to light, and can also be removed by heating to 200°–300°C for as little as a few hours.

If gamma irradiation is extended to relatively high doses (say, a few tens to many thousands of megarads of Co-60), then an olive-green component may be visible in the yellow to brown range of colors. The greenish component is derived from the presence of a light absorption which by itself leads to a blue color. If the stone is then heated to about 200°–300°C to remove the yellow to brown component, there may then be revealed a blue color, which is produced much more slowly by the gamma rays than is the brown color. This blue color is stable to light, and is destroyed by heat only if a relatively high temperature of about 500°C for a few hours is used; at this temperature, natural blue topaz will also turn colorless.

The blue color produced in colorless or pale topaz by practical doses of gamma rays (i.e., a few hundred to a few thousand megarads at most) and subsequent heating is usually not very intense; some topaz may show hardly any blue color even on extended gamma irradiation. There is no relationship between the rate of coloration and the maximum depth of the brown color and the rate of coloration and the maximum depth of the blue color. When the color is very intense, however, a "steely" blue may result (figure 4).

High-Energy Electrons. Electrons are accelerated to high energies in a variety of machines, including linear accelerators (linacs), Van de Graaff generators, and betatrons, among others. After reaching the selected energy, the beam of electrons is electrically deflected in a zig-zag pattern to cover an area, typically a few to many centimeters across, or a sample container is moved in such a way as to expose the whole specimen holder to the electrons. Such high-energy-electron facilities are large, complex, expensive to build, expensive to operate, and must be well shielded, hence the higher cost of electron irradiation versus gamma irradiation. For the coloration of blue topaz, irradiation energies in the 10 to 20 mega-electron-volt range are most commonly used.

High-energy electrons act quite differently from gamma rays. They produce considerable heat, with much of the heat generated at the surface of the specimen. The samples are usually cooled with cold running water during the radiation procedure; even so, cracking is common if

Figure 4. This 6-ct topaz illustrates the "steely" blue color that is often produced in stones subjected to gamma or neutron irradiation. Photo © Tino Hammid.

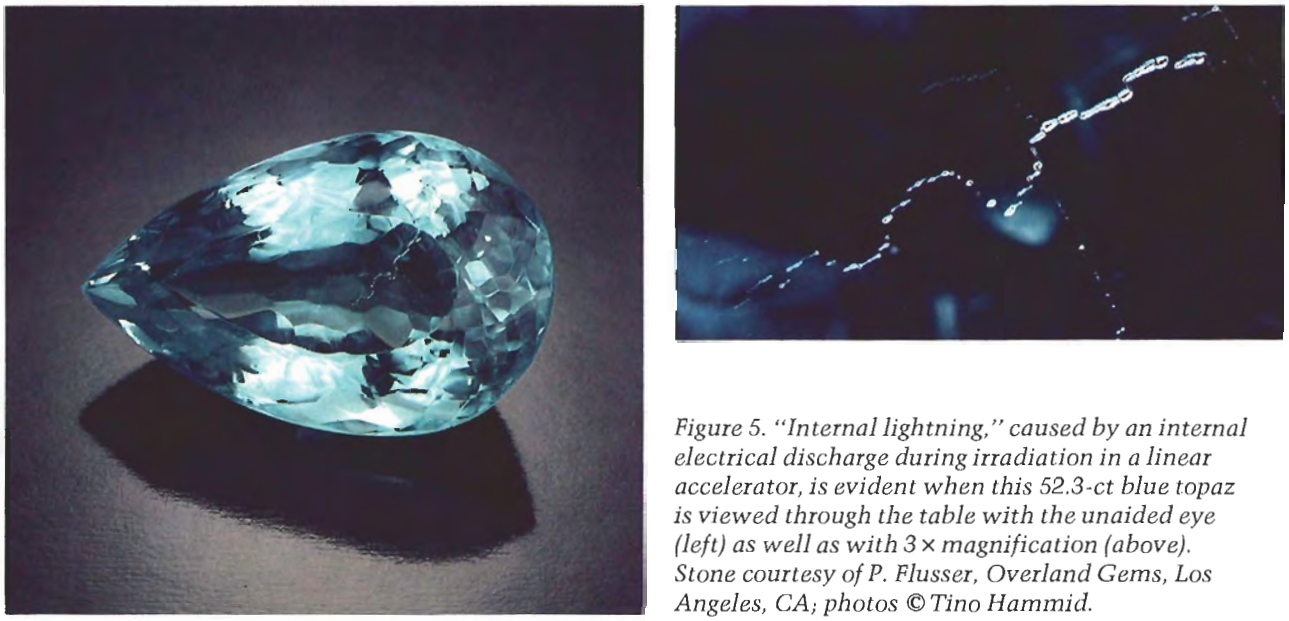


Figure 5. "Internal lightning," caused by an internal electrical discharge during irradiation in a linear accelerator, is evident when this 52.3-ct blue topaz is viewed through the table with the unaided eye (left) as well as with 3 × magnification (above). Stone courtesy of P. Flusser, Overland Gems, Los Angeles, CA; photos © Tino Hammid.

certain inclusions or defects are present, and melting can occur if the water supply is interrupted or the beam of electrons remains fixed in one spot. A large amount of negative electricity is also carried by the beam into the specimen, and an internal electrical discharge or "internal lightning" (also referred to as "treeing effect" or "Lichtenburg figure" in other contexts) can occur as shown in figure 5, and may cause severe damage. If the energy used is high enough, most of the beam can be made to pass through the specimen to avoid damage from this effect.

Because the energetic electrons have limited penetration, the coloration effect, like the heat, is most intense at the surface. The penetration depth can be increased by raising the energy of the electrons, but then induced radioactivity may occur. This last factor depends on the specific impurities present in a specimen, and for topaz it usually sets in above an energy of about 15 mega electron volts. A "cooling off" period of a few days to a few weeks may be necessary, during which time the induced radioactivity decays to an acceptable level.

A significant advantage to the use of electrons is that the dose rates available are much higher than those in gamma cells. It is practical, therefore, in reasonable time periods of a few hours to reach doses of many tens of thousands of megarads of energetic electrons, while it may take many days to achieve just a few thousand megarads of gamma rays. A high dose may be required since the coloration does not vary in a linear fashion with the dose.

Like gamma rays, high-energy electrons can produce both the brown and the blue colors in topaz, and heating is used to remove the brown if blue is desired. Since higher doses are practical, electrons can usually produce a more intense blue than gamma rays; the "inky" or "steely" blue often seen in stones treated with gamma or neutron irradiation does not seem to occur. In view of the potential electrical discharge problems and the tendency for greater interaction at the surface, the production by electrons of a deep blue color in specimens much larger than about 150 ct or much thicker than about 15 mm is usually not practical.

Neutrons. Neutrons, produced in nuclear reactors, can also induce radioactivity in all but the purest of topaz crystals. However, they have excellent penetration, so there are no surface heating or coloration problems, and the colors produced are usually uniform and deep. Because there is no risk of cracking, size is not the problem it is with high-energy electron irradiation. The neutrons in a nuclear reactor can be of varying energy and are also accompanied by gamma rays and other rays and particles. By placing the material to be irradiated into a cadmium-lined iron container, the thermal neutrons that do essentially all of the activating are absorbed by the metals, which then also generate additional gamma rays (Bastos, 1984). To use neutron irradi-

ation, however, the treater must have access to a reactor facility that is able to handle the very high radioactivities involved with the special cadmium-lined iron container. Doses of up to 1,000 megarads are said to be adequate to produce, after heating, a deep blue. The color may be darker than that produced by electrons, often "inky" or "steely." Zoning of color can be expected to be similar to that observed with other irradiation techniques used for the blue product.

The Restoration of Color. Irradiation can also be used to restore the natural yellow to brown or blue color in a topaz when this has been accidentally destroyed by overheating. Although irradiation will usually produce an additional yellow to brown component as well, this can be removed by a gentle heating or exposure to bright light, thus producing a restoration of the original color. The final color will be just as stable (or unstable) as the original natural one. It is also possible in this same way to return heated pink topaz back to its original color if, for example, the pink is too pale.

THE HEAT TREATMENT OF TOPAZ

A heating step is usually required to remove the yellow to brown color and reveal any blue that may be present. Just as not all colorless topaz will alter to the yellow to brown range with irradiation, not all irradiated yellow to brown stones will alter to blue; and variations in color from stone to stone, or even within a single stone, are possible (figure 6). While gamma and neutron irradiation in themselves can be conducted on quite large pieces of topaz, this is not true of high-energy-electron irradiation because of the three factors discussed above: limited penetration depth, heat generation, and the build-up of electrical charge. Heating, too, cannot be performed on large topaz specimens without loss.

It is well known that most topaz is very heat sensitive and often breaks, cleaves, or shatters on heating, even if temperatures as low as 200°C are applied very slowly and carefully. The presence of strains, flaws, inclusions (particularly liquid-filled ones), and cracks makes a specimen especially prone to damage.

The solution is obvious: perform these processes on faceted stones, or at least preforms (gemstones that have been roughed out but not finished) that are fashioned so that they do not contain stresses, flaws, or inclusions. An added advantage to using preforms is that irradiation fees are based on weight, and there is a large reduction in weight from the rough to the preformed or faceted stone. The yield of faceted product intended to become blue topaz is less than that for most other gemstone materials because all but the smallest of strains, flaws, and inclusions must be eliminated.

Figure 6. These topaz preforms are shown after they have been irradiated in a linear accelerator and just before (left) and after (right) heat treatment at 220°C for approximately one and a half hours. Note the variations in color within this lot of stones both before and after heating. Stones and furnace courtesy of P. Flusser, Overland Gems, Los Angeles, CA; photos © Tino Hammid.

Figure 7. Heat treatment over an open flame turned a yellow topaz from the same lot as the 2.5-ct stone on the lower right into the attractive pink topaz on the upper left. Stones courtesy of P. Flusser, Overland Gems, Los Angeles, CA; photo © Tino Hammid.

For the heating step used to remove the brown color from irradiated topaz (and possibly to improve the "steely" blue of the gamma- and neutron-irradiated products) temperatures in the 200°–300°C range are used, usually for one to two hours. At higher temperatures, about 500°C, the blue color itself begins to fade. The fading occurs as the electrons return to the original location from which they were displaced by the irradiation that had formed the color center (Nassau, 1983; Nassau, 1984). A wide variety of different color centers can form in topaz (Nassau, 1984), including slowly and rapidly fading yellows to browns, stable yellows to browns, a stable blue, and the "steely" blue–causing component. Although formation rates of these color centers can be quite different even in different parts of the same crystal, the temperature-induced fading behavior is usually quite consistent: the unstable yellow to brown colors require only a short time (an hour or less) at temperatures as low as 200°C, the stable yellow to brown colors require a longer time (a few hours) at 200°–400°C, and the stable blue requires about 500°C to make it fade.

Any type of furnace can be used, and heating in air is perfectly adequate. Heating may be performed with the topaz wrapped or buried in some inert substance such as clean dry sand. This is placed into a cold furnace and heated to the treatment temperature very gradually; the larger the stones, the slower the heating rate that needs to be used. After the required time at temperature, the furnace is often cooled at an equally slow rate and the stones are not removed until they have returned to room temperature.

In an original modification (C. Key, unpublished observation) of the electron irradiation and heating process described above, the rough topaz is first heated without any of the usual precautions so that all of the potential fracturing occurs before the cutting, irradiation, and subsequent heating steps. In this way there is essentially no cracking in these later steps, leading to a considerable economy in the processing.

Heating of yellow to reddish brown topaz from Ouro Preto, Brazil, has been long practiced (Webster, 1984) to develop a salmon-pink to purple-red color (figure 7) that appears only if chromium is present in the topaz. By heating in the 400°–500°C range, the yellow to brown component is bleached. There is little doubt that a similar heating can be used on green topaz, for example, from the Urals, to produce blue. It also can be used to convert purplish or bluish pinks to a pure pink by removing the blue component, the latter at perhaps a somewhat higher temperature.

COMMERCIAL FACTORS

The supply of treated blue stones has remained strong since the early 1970s, when they were first identified in the marketplace, until the present. It might have been expected that the existence of the irradiation process would cause a significant increase in the value of colorless topaz but this has not happened, possibly for two reasons. First, the costs of cutting and irradiation are sufficiently greater than the cost of the colorless topaz itself, so that these steps appear to account for 90% or more of the entire cost of the blue topaz produced.

Second, the supply of mined colorless topaz, even though not large, is apparently still larger than the past and current demand for blue topaz; in addition, there are believed to be sufficient amounts of unmined (because of the lack of previous demand) colorless topaz suitable for treatment should any additional demand arise. As discussed above, there is much variability in the behavior of topaz on irradiation; colorless material that could be guaranteed to turn a deep blue would obviously command a premium.

The irradiation of gemstones is such a small fraction of the total irradiation business that there are no dedicated facilities. Industrial irradiation facilities are commonly used for such purposes as medical supply sterilization, food preservation, the modification of plastic products, semiconductor treatment, and so on; gemstone irradiation is carried out between such activities (Nassau, 1984). Commercial gemstone irradiation firms frequently act only as intermediaries; they accumulate material and then have the irradiation performed at an industrial facility.

It is probably true that for most topaz the impurities or defects that provide the potential to form blue are the same for the different forms of irradiation; the impurities or defects giving the potential to form brown are different from these. By a preliminary low-cost, medium-dose gamma-ray irradiation and subsequent heating to the blue stage, the fraction of material least likely to yield a more intense blue color could be eliminated from the more costly electron irradiation without, however, any significant change in the overall yield of the deep- and medium-blue products.

IDENTIFICATION OF NATURAL AND TREATED TOPAZ

The properties used to distinguish topaz from other gemstone materials are well known (Webster, 1984). The necessity for distinction from a synthetic does not arise, since so far only tiny topaz crystals have ever been grown in the laboratory and these have been done by the hydrothermal method, which is slow and costly (Nassau, 1980).

The identification of the origin—natural or treated—of the various shades of pink, brown, and blue presents many difficulties. The "burned" pink is reported to have a much greater dichroism (dark cherry red and honey yellow) than the very rare natural pink topaz (Bauer, 1968), but the origin of the color cannot be established concretely by routine gemological methods. Both the irradiated brown and the blue colors show the same absorption spectra as the equivalent natural stone (Nassau, 1974; Nassau and Prescott, 1975; Petrov et al., 1977; Petrov and Beredinski, 1975). With the blue material there is a difference in the thermoluminescence as reported by Petrov et al. (1977); as the temperature is raised, there is an emission of light in the irradiated blue topaz that is not present in the natural blue topaz. Similar thermoluminescence results have been reported by Rossman (1981). Such a test could be performed on a microscopic specimen scraped from the girdle of a stone, but extensive research would be required to ensure that this is a consistent and reproducible test which could not be negated by a selective preliminary heating of the stone. Also, the equipment required makes the test impractical for the average jeweler/gemologist. Although the origin of color (treated) appears to be obvious in the deepest of blue topaz, it is not possible to definitively establish the origin of the blue color with certainty using routine gemological tests.

Finally, for the yellow to brown shades of topaz, there is the problem of distinguishing the stable from the fading colors, either natural or irradiated. At present, no gemological test is known for this identification other than a direct fade test; this should always be performed if there is any question as to the permanence of the color.

As mentioned above, radioactivity can be induced into topaz during irradiation; such radioactive material was indeed found in the trade in 1981 (Crowningshield, 1981), its origin traced to irradiation operations in Brazil, but no additional occurrences have been reported since that time.

CONCLUSION

Although topaz has been subjected to heating alone (to turn yellow to reddish brown stones pink to red) and some dyeing, by far the most common technique used on topaz today is irradiation and subsequent heat treatment to alter colorless stones to blue. Literally hundreds of thousands of carats of attractive blue topaz have been produced in this fashion during the last 10 years.

Irradiation has also been used on other gemstones to effect a variety of color changes. In some instances, such as Maxixe beryl and irradi-

ated yellow sapphire, these colors are unstable and will fade on exposure to light, as does the irradiated yellow to brown topaz color. In other instances, such as irradiated smoky quartz and irradiated diamond, the color is stable to light, as is the irradiated blue topaz (Nassau, 1984). Blue topaz, however, is currently the most common gemstone being irradiated. The blue color that results after heating is stable and has shown wide consumer acceptance. The treated material cannot be distinguished from its natural blue counterpart by gemological testing at this time.

REFERENCES

Bastos F.M. (1984) Irradiated topaz and radioactivity. *Gems & Gemology*, Vol. 20, No. 3, p. 179.

Bauer M. (1968) *Precious Stones*. Dover Publications, New York.

Crowningshield R. (1981) Irradiated topaz and radioactivity. *Gems & Gemology*, Vol. 17, No. 4, pp. 215–217.

Liddicoat R.T. Jr. (1967) Irradiated topaz. *Gems & Gemology*, Vol. 12, No. 5, p. 155.

Nassau K. (1974) The effects of gamma rays on the color of beryl, smoky quartz, amethyst, and topaz. *Lapidary Journal*, Vol. 28, No. 1, pp. 20–26, 30, 36–40.

Nassau K. (1980) *Gems Made by Man*. Chilton Book Co., Radnor, PA.

Nassau K. (1983) *The Physics and Chemistry of Color*. Wiley & Sons, New York.

Nassau K. (1984) *Gemstone Enhancement*. Butterworths, London.

Nassau K., Prescott B.E. (1975) Blue and brown topaz produced by gamma irradiation. *American Mineralogist*, Vol. 60, No. 7/8, pp. 705–709.

Petrov I., Beredinski W. (1975) Untersuchung künstlich farbveränderter blauer Topase. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, Vol. 24, No. 2, pp. 73–80.

Petrov I., Beredinski W., Bank H. (1977) Bestrahlte gelbe und rotbraune Topase and ihre Erkennung. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, Vol. 26, No. 3 pp. 148–151.

Pough F.H. (1957) The coloration of gemstones by electron bombardment. *Zeitschrift der Deutschen Gesellschaft für Edelsteinkunde*, No. 20, p. 71.

Rossman G. (1981) Color in gems: the new technologies. *Gems & Gemology*, Vol. 17, No. 2, pp. 60–71.

Webster R. (1984) *Gems: Their Sources, Descriptions and Identification*, 4th ed. Revised by B. W. Anderson. Butterworths, London.

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