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## RADIOACTIVE IRRADIATED SPODUMENE

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*During routine testing, a parcel of spodumene imported from Brazil was found to be radioactive. Detailed analysis showed that individual stones had levels of gamma ray emission far above those acceptable for jewelry purposes. Gamma ray spectroscopy revealed that they had been irradiated with neutrons. The colors of these stones are similar to those observed in citrine and have no counterpart in untreated spodumene. They range from brownish orange through orange to orange-yellow and greenish yellow.*

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A parcel of approximately 3,000 carats of faceted stones purchased as citrine in Sao Paulo, Brazil, was brought for examination to the Los Angeles office of the GIA Gem Trade Laboratory after it was observed during recutting that one of the stones did not respond like quartz. At the laboratory, the parcel was found to contain approximately 700 ct of spodumene; the remainder was citrine. The citrine-like color of the spodumene was unusual for that species, ranging from brownish orange through orange to brownish yellow and orange-yellow with an occasional greenish-yellow stone (figure 1). Additional testing with a Geiger counter revealed that the lot of spodumenes was radioactive. No radioactivity was detected in the citrine. Three representative spodumenes that showed readily detectable levels of radiation were removed from the parcel and forwarded to the laboratories of the California Institute of Technology for detailed analysis. They consisted of two emerald-cut stones, one greenish yellow and one orange-yellow, weighing 5.97 and 2.90 ct, respectively, and one orange oval-cut stone weighing 31.8 ct (again, see figure 1).

### RADIATION MEASUREMENTS

All three stones indicate radioactivity when tested with a Geiger counter survey meter. The most radioactive stone, the greenish-yellow spodumene, registered 0.7 milliroentgens per hour, or 420 counts per minute (cpm) when in contact with the detector. The large, orange stone had one

third the activity, while the orange-yellow stone had one tenth.

The observed count rate varies among different Geiger counters because it is highly dependent on the volume and efficiency of the detector and the geometrical proximity of the detector to the stone. For example, the stone that gave 420 cpm with a hand-held Geiger counter survey meter gave 6400 cpm with a more sensitive, large-volume, stationary Geiger counter. Because other types of laboratory radiation-detection instruments are even more sensitive than Geiger counters, detailed radiation measurements were performed with a 100-cubic-centimeter liquid nitrogen-cooled germanium detector, and an 8-in.-diameter sodium iodide scintillation detector. With the germanium detector, the 5.97-ct stone registered 43,680 cpm; with the scintillation detector, the same stone registered 152,880 cpm. When the observed count is corrected for the efficiency of the detector, the calculated true emission rate of the stone becomes 870,000 cpm, coming from both beta and gamma radiation.

Because the persistence of the radioactivity will depend on the half-lives of the radioactive species, and the penetration power of the radiation will depend on its energy, the identity of the radioactive elements was determined with a gamma ray spectrometer employing the germanium detector.

The gamma ray spectrum of the greenish-yellow spodumene showed that the isotope scandium-46 (half-life: 84 days) is the primary cause of the radioactivity. Minor amounts of man-

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### ABOUT THE AUTHORS

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Figure 1. Samples of radioactive neutron-irradiated spodumene. The large orange stone at the top (31.8 ct) was emitting about 249,000 gamma rays per minute at the time of the photograph. The greenish-yellow emerald-cut stone directly below and to the right (5.97 ct) emitted 870,000 gamma rays per minute. The third stone discussed in this article, a 2.90-ct orange-yellow emerald-cut spodumene, is directly below and to the right of the greenish-yellow stone studied.

ganese-54 (half-life: 303 days) and tin-113 (half-life: 115 days) were also observed. The activity from the smaller, orange-yellow spodumene came, in decreasing order, from manganese-54, tin-113, zinc-65 (244 days), iron-59 (45 days), antimony-125 (2.8 years), antimony-124 (60 days), and cobalt-60 (5.2 years). The large, orange spodumene contained manganese-54, tin-113, zinc-65, antimony-125, iron-59, and tantalum-182 (115 days). All of these isotopes emit energetic, penetrating gamma rays.

Although the radioactivity from the scandium-46 will largely decay within three years, the presence of the longer half-life isotopes ensures that these stones will be weakly radioactive for many years to come. The isotopes in these spodumenes and their half-lives indicate that the stones had been treated fairly recently with neutrons in a nuclear reactor, apparently the same treatment given to the radioactive topaz described by Crowningshield (1981).

### COLOR

When irradiated, the lavender variety of spodumene, kunzite, turns green, but the color is unstable and fades rapidly in sunlight. Other varieties of spodumene show little or no response to gamma radiation, which is usually used for such treatment. Gamma irradiation does not leave residual radioactivity. The orange color of the neutron-irradiated material is unusual and without natural counterpart in spodumene. It resembles the color of citrine. The absorption spectrum shows  $\text{Fe}^{2+}$  features in the infrared portion and an absorption edge beginning at 720 nm and rising

steadily toward shorter wavelengths (figure 2). A narrow, barely visible  $\text{Fe}^{3+}$  absorption band superimposed at about 438 nm is the only other feature observable. The initial test of the stability of this color to light produced no visually apparent fading after six hours' exposure to direct sunlight. Under the same conditions, green spodumene would have faded completely.

### DETECTION

Any spodumene with a citrine-like color should be tested for radioactivity. Large parcels of radioactive stones can be readily detected by Geiger counter survey meters, as can individual stones of comparatively high activity. However, casual investigation with a Geiger counter of a single stone of relatively low radioactivity may fail to detect its radioactivity. In conducting tests with a Geiger counter, it is necessary to hold the probe close to the stone and give the counter enough time to respond (several seconds). In our tests, a flat, "pancake" style probe for the Geiger counter was more than twice as sensitive as the cylindrical probe because of the greater sensitivity of the flat probe to beta radiation, and its larger sensitive area.

Because gamma radiation is highly penetrating, it deposits very little energy over the thickness of a photographic film. In a test with an instant film, 20 hours' exposure to the most radioactive stone did not produce an autoradiograph. This contrasts with the response of the old radium-treated diamonds, which produced autoradiographs rapidly (Hardy, 1949). They emitted alpha particles which had very limited penetra-

tion ability and thus deposited most of their energy in the layer of film. Specially formulated dosimeter films with enhanced sensitivity to beta and gamma radiation exist, but they require special processing and are not available at photographic supply companies. Given that an irradiated gemstone emitting gamma rays will not affect a film whereas an irradiated diamond emitting alpha rays would, the reader should not rely on this test as assurance of the safety of a stone.

## DISCUSSION

An emission rate of nearly one million gamma rays per minute from a gemstone is undesirable and should be a matter of concern for both buyers and sellers. Although the levels of radiation are comparatively low, the use of these stones would represent a source of radiation to the body that is both unnecessary and avoidable. To put into perspective the level of radiation that an individual stone represents, it is useful to compare the most intensely radioactive spodumene to natural background levels of radiation. If the stone that emits 0.7 milliroentgens per hour were worn in direct contact with the skin for 10 hours per day, 5 days per week, in about 2½ weeks it would expose the wearer to an amount of radiation that would normally be received in one year from natural sources such as cosmic rays and radiation from soil and air. If it were worn 24 hours per day, seven days a week, in one year the total dose absorbed by the body would be about 4.2 rem\*. This is above the United States federal standard for radiation dose to the general population (0.5 rem per year) but below the federal standard for occupational exposure of workers (5 rem per year whole body dose, or 18.75 rem per quarter year for dose to the extremities such as fingers). A statement from the Nuclear Regulatory Commission to the effect that these stones would not be desirable for extended personal wear was reported by Crowningshield (1981).

While some investigators conclude that occasional exposure to such low doses does not constitute a significant health risk, others are of the opinion that even very low doses of radiation present a statistical risk of biological effects (Upton,

\*A source emitting 1 roentgen of gamma radiation will cause the body to absorb a dose of about 1 rem (a rem refers to the biological effects of the radiation).

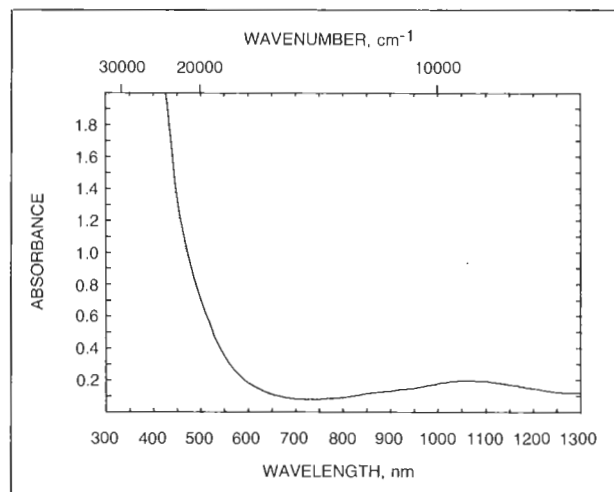


Figure 2. Optical absorption spectrum of orange, irradiated spodumene taken with unpolarized light through a 1.2-cm path.

1982). Even though the medical implications of such a stone are debatable and a matter of current controversy, it would be prudent to avoid the unnecessary exposure to radiation that these stones represent. This is particularly true for items designed to be worn on the chest or neck which could expose internal organs to radiation from the penetrating gamma rays. A dealer who unknowingly handles hundreds of radioactive stones at a time is faced with a much less desirable situation. The dose he receives would depend on many factors, such as length of exposure and proximity of the stones to the body, but in a day it could reach the level that an individual with a single stone would reach in a year. Even though the authors understand that several efforts are being made by U.S. regulatory agencies and commercial interests to stop the production of radioactive gemstones, the importance of the recommendation by Crowningshield (1981) that jewelers who handle large parcels of gemstones should check their stones with a Geiger counter is reinforced by the commercial availability of radioactive spodumene.

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