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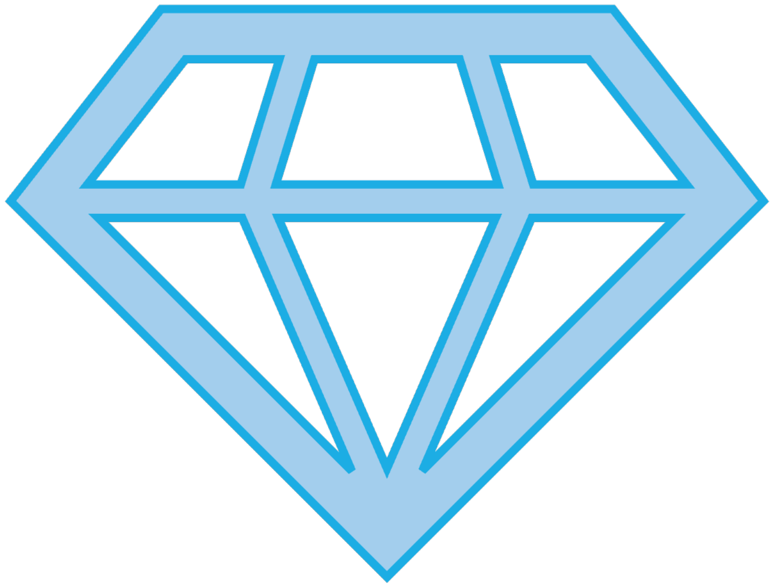
INITIAL STUDY OF RESIDUAL RADIOACTIVITY IN TOPAZ DURING NEUTRON COLOR TREATMENT AT TRIGA IPR-R1 REACTOR

Natalia Mendes

INTRODUCTION

The topaz, a naturally colorless silicate is often associated with low market quality.

- It is now gaining recognition for its remarkable ability to undergo color transformation, achieving excellent gemological standards
- There are several methods that utilize ionizing radiation to activate small impurities or inclusions within the gem matrix.



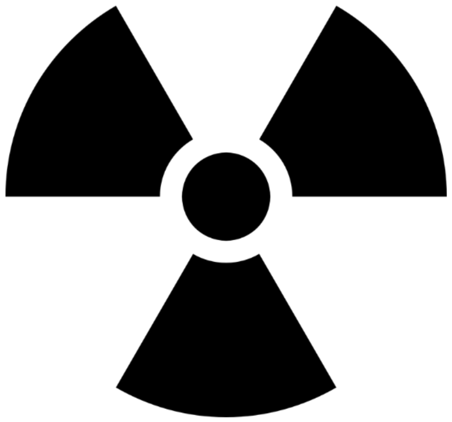
Source: Google, 2024

INTRODUCTION

The preferred method - nuclear reactors, instead of gamma irradiators

When topaz is exposed to gamma radiation it undergoes fading of its color over time

Neutron flux - induction of crystal structure change -results in color center stability and crystalline penetrability



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INTRODUCTION

The state of Minas Gerais in Brazil, in addition to being one of the largest mineral producers of topaz gems in the world - TRIGA MARK I IPR-R1

Topaz is the best example for color enhancement when subjected to neutron flux.

The biggest challenge - residual radioactivity, as once the gem is exposed to the neutron flux it becomes radioactive

Source: Google, 2024

METODOLOGY

- Colorless topaz samples
- Irradiation by nuclear reactor
- Thermoluminescent emission curve
- Thermal treatment
- Calculation the decay time
- Gamma spectrometry
- Analytical technique - FT-IR-ATR
- Density of topazes

METODOLOGY

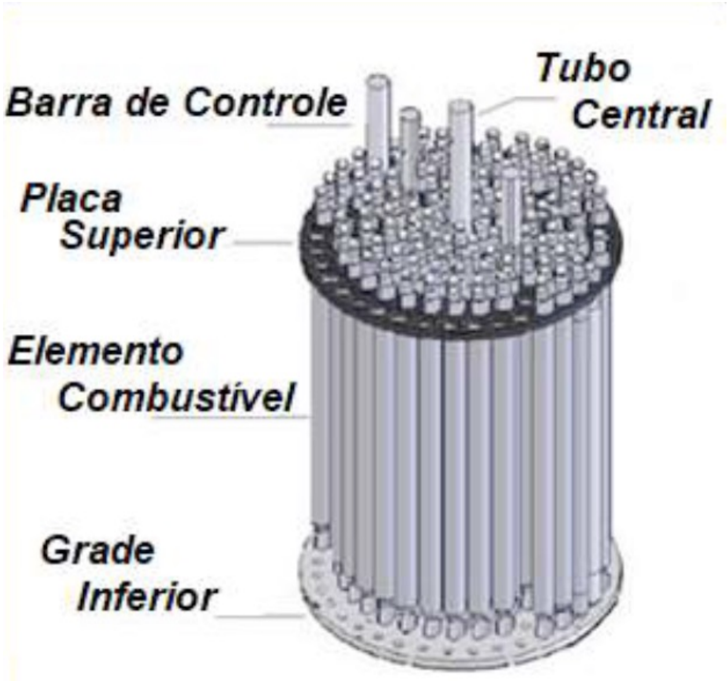
3 batches of colorless topaz (Minas Gerais, Teófilo Otoni, Rondonia)

Irradiated in the TRIGA Mark I IPR-R1 Reactor

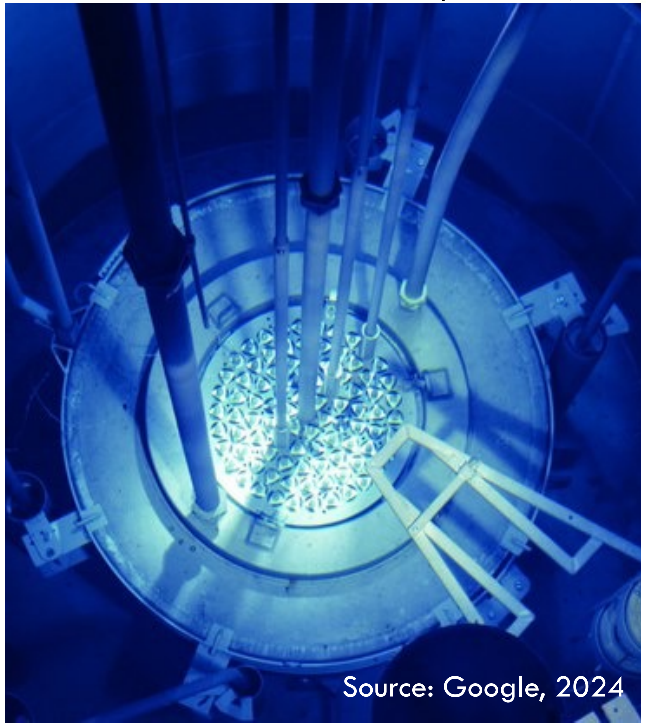
Central tube of the reactor - into a cadmium filter for thermal neutron filtering

The gemstones were stored in a suitable shielding (lead castle)

in the central tube, the values of thermal, fast, and epithermal neutron flux are, respectively, $(3,14\pm0,02)10^{12}$, $(2,48\pm0,01)10^{12}$ and $(0,24\pm0,01)10^{12}$ neutrons/(cm^2.s)



Source: Mesquita et al., 2021



Source: Google, 2024

METODOLOGY

Thermoluminescent emission curve

- two gemstones (T1 and T15) were selected to be read on the TL OSL Reader
- to better understand the thermoluminescent emission curve

Furnace

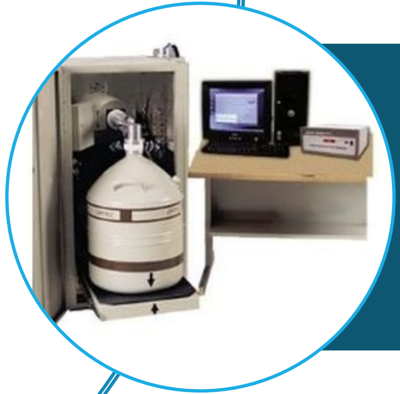
- two thermal treatments were carried out at 330°C and 230°C, with a heating rate of 5°C/min for 20 minutes in the Mufla HW500 furnace
- the aim of achieving a change in the color center

Source: Google, 2024

METODOLOGY

Geiger Miller Ludlun

- approximately 3 months was waited for the measurement of residual radiation



Gama spectrometer (ORTEC Gamma Vision)

- samples (T5 and T12) randomly selected and measured
- the distance between the sample and the detector was 5 cm

Source: Google, 2024

METODOLOGY

FT-IR-ATR

- measurements of samples T1 and T15
- spectral range of 400-4000 wave numbers per cm^{-1}

Density of topaz

- to calculate the density of each gem according to the principle of Archimedes

Source: Google, 2024

RESULTS AND DISCUSSION

- Density of topazes
- Analisys of thermoluminescent emission curve
- Color center through radiation
- Residual dose for commercialization
- Mesurament with gamma spectrometer
- Spectra of FT-IR-ATR

RESULTS AND DISCUSSION

Density of topazes

Batch 1

Gemstones exhibited an average density of 2,68 g/cm3 - density of quartz

QUARTZ

Batches 2 and 3

Teófilo Otoni and Rondônia showed average densities of 3.59 g/cm3 and 3.60 g/cm3 - characteristic of topaz density

TOPAZ

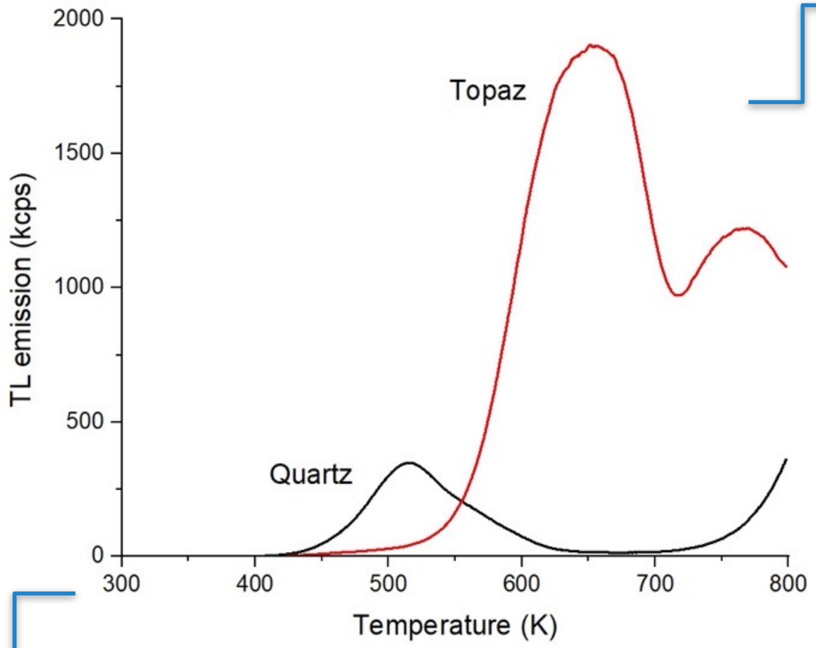
Since density is specific to each mineral, it can be stated that **batch 1** exhibits quartz - like characteristics, while **batches 2 and 3** exhibit characteristics of topaz

RESULTS AND DISCUSSION

Analisys of thermoluminescent emission curve

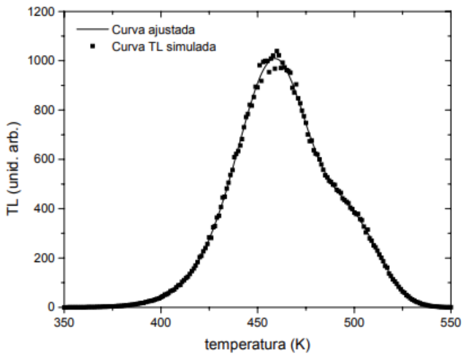
- The graph shows the behavior of thermoluminescence in the chosen quartz and topaz gemstones (T1 and T15)
- Due to the distinct behavior of the two TL emission curves, it can be affirmed that they represent **two different types of gemstones**

Topaz – 650 K^0



Quartz – 525 K^0

Source: Yukihara. E. G. 2001



RESULTS AND DISCUSSION

Color center and residual dose

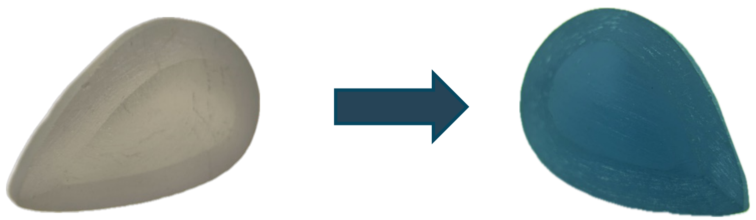
After subjecting the gemstones **to four exposures** of neutron flux, followed by **two thermal treatments**, there was a change in their color center

All of them acquired hues of blue, with **T4** exhibiting characteristics closer to the so-called **London blue**, which is the most commercially accepted

Regarding the residual doses measured with the Geiger Miller Ludlun equipment, the values are expressed in Table

The count was carried out at the end of the last irradiation, with the values obtained being relatively low, - **3 months after the last irradiation**

Batches	Topaz	Irradiation time ($1x10^{12}$ n/cm^2.s)	Decay time (days)	CPS	Density (g/cm^3)
1	T1	14,10	90	1,9	2,6813
	T2	6,76	90	1,1	2,6798
2	T3	14,10	90	1,9	3,5886
	T4	14,10	90	5,2	3,5898
	T5	14,10	90	2,2	3,6017
	T6	14,10	90	3,1	3,6003
3	T7	14,10	90	1,3	3,5968
	T8	14,10	90	2,5	3,6029
	T9	14,10	90	1,9	3,6040
	T10	14,10	90	4,7	3,5997
	T11	14,10	90	2,5	3,6036
	T12	14,10	90	2,1	3,6039
	T13	12,76	90	1,4	3,6052
	T14	12,76	90	1,4	3,6004
	T15	12,76	90	3,4	3,6065



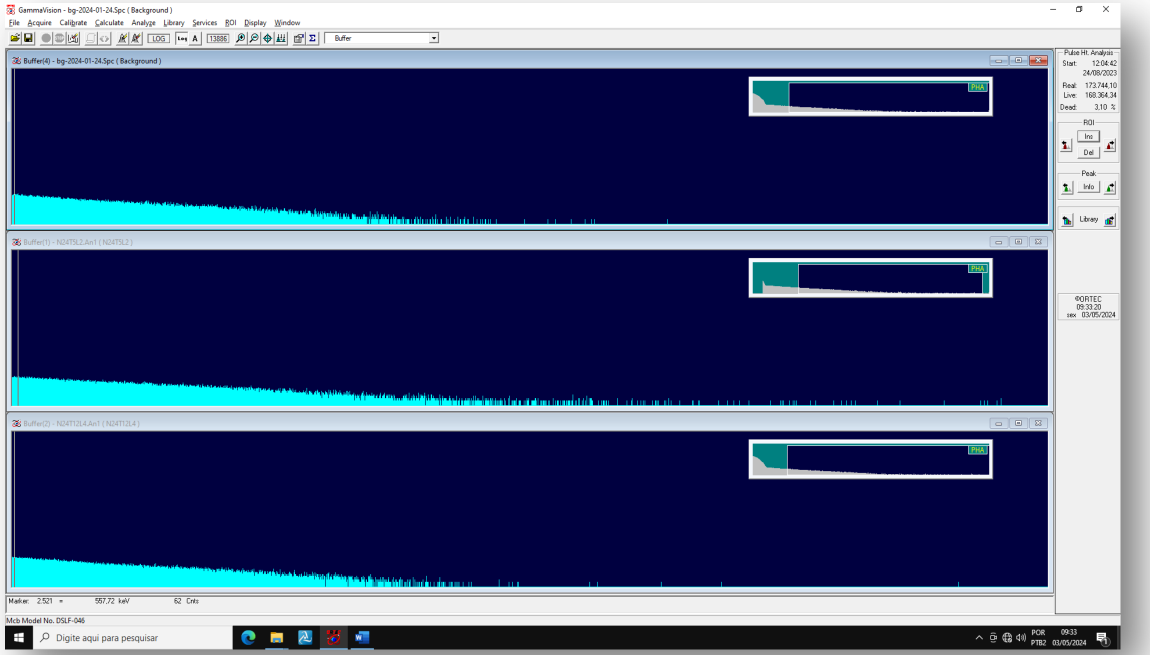
RESULTS AND DISCUSSION

Gamma spectrometer

The two samples (T5 and T12) measured on the gamma spectrometer exhibited spectra **similar to the background**

Since the counting was performed 3 months after the last irradiation, **no radioactive elements were identified in significant quantities in the samples**

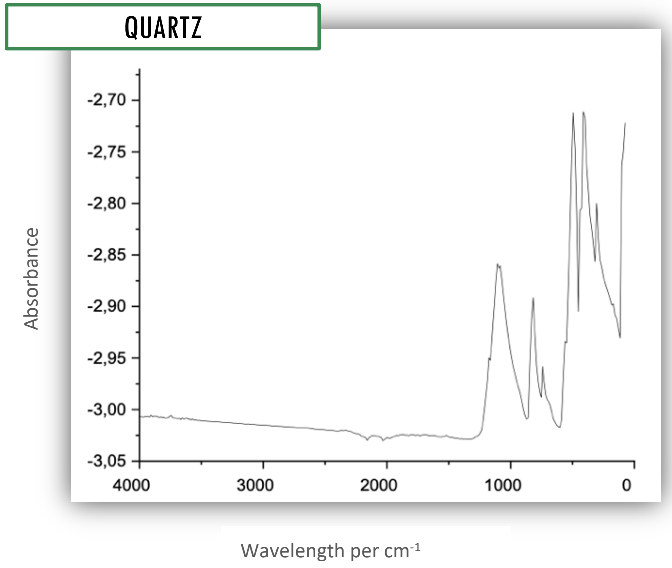
IATA - values for transportation must adhere to limits below or equal to **56 Bq/g**

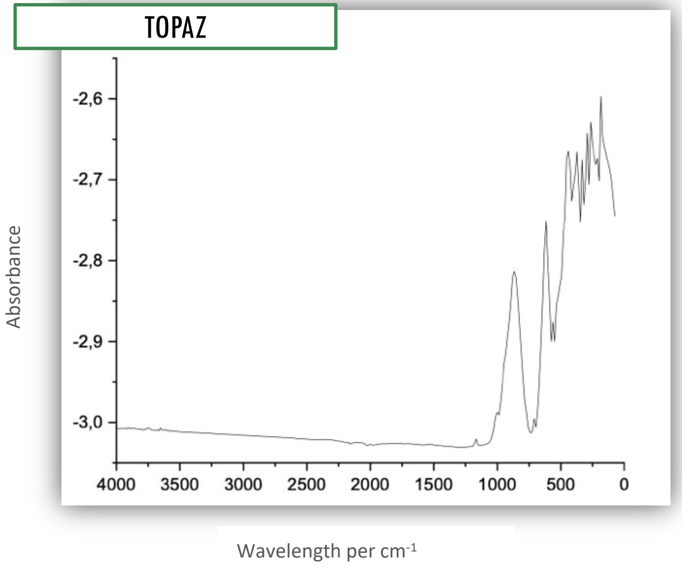


RESULTS AND DISCUSSION

Spectra of FT-IR-ATR

- The absorbance spectra obtained from samples T1 and T15 in the FT-IR-ATR exhibited **distinct characteristics** from each other
- This analysis was conducted by comparing the spectra with those from a **database RRUFF**
- The obtained **result validates** the specific densities measured for samples T1 and T15, corresponding to quartz and topaz, respectively





CONCLUSION

- Identification of gemnstones
- Color center
- Residual activity

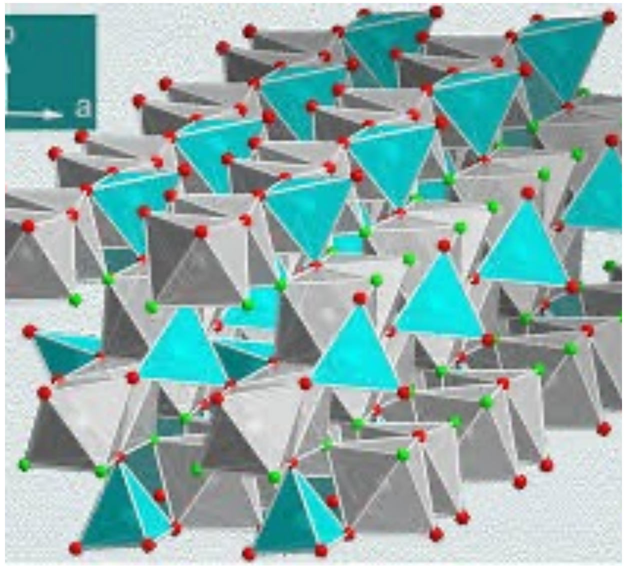
CONCLUSION

- The three batches studied, only one **batch consisted of quartz**
- The topaz underwent **a change in their color center** due to exposure to neutron flux, resulting in various shades of blue
- There was a **change in the chemical composition or crystalline structure** of the gem
- The radioactive decay is not prolonged due to traces of elements with a **short half-life**
- Gamma spectrometer - the specific activity **must be below the limits** presented in the CNEN 5.01 standard, Table II
- It would be ideal to carry out **more experiments** to better determine **residual radiation in order to meet national and international standards**
- There is still **no suitable regulation** that allows for the definition of the safe residual dose limit for the **transportation and commercialization of gemstones**

TABELA II
VALORES DE A_1, A_2 E NÍVEIS DE ISENÇÃO

ELEMENTO E NÚMERO ATÔMICO	RADIONUCLÍDEO	Valores de A_1	Valores de A_2	Níveis de Isenção	
		A_1 (TBq)	A_2 (TBq)	CONCENTRAÇÃO DE ATIVIDADE PARA MATERIAL ISENTO (Bq/g)	LIMITE DE ATIVIDADE PARA EXPEDIÇÃO ISENTA (Bq)
Actínio-89	Ac-225(a)	8×10^{-1}	6×10^{-3}	1×10^{1}	1×10^{4}
	Ac-227(a)	9×10^{-1}	9×10^{-5}	1×10^{-1}	1×10^{3}
	Ac-228	6×10^{-1}	5×10^{-1}	1×10^{1}	1×10^{6}
Alumínio-13	Al-26	1×10^{-1}	1×10^{-1}	1×10^{1}	1×10^{5}
Amerício-95	Am-241	1×10^{1}	1×10^{-3}	1×10^{0}	1×10^{4}
	Am242m(a)	1×10^{1}	1×10^{-3}	1×10^{0} (b)	1×10^{4}(b)
	Am-243(a)	5×10^{0}	1×10^{-3}	1×10^{0} (b)	1×10^{3}(b)
Antimônio-51	Sb-122	4×10^{-1}	4×10^{-1}	1×10^{2}	1×10^{4}

Source: CNEN 5.01, 2021



Source: Google, 2024

ACKNOWLEDGEMENTS

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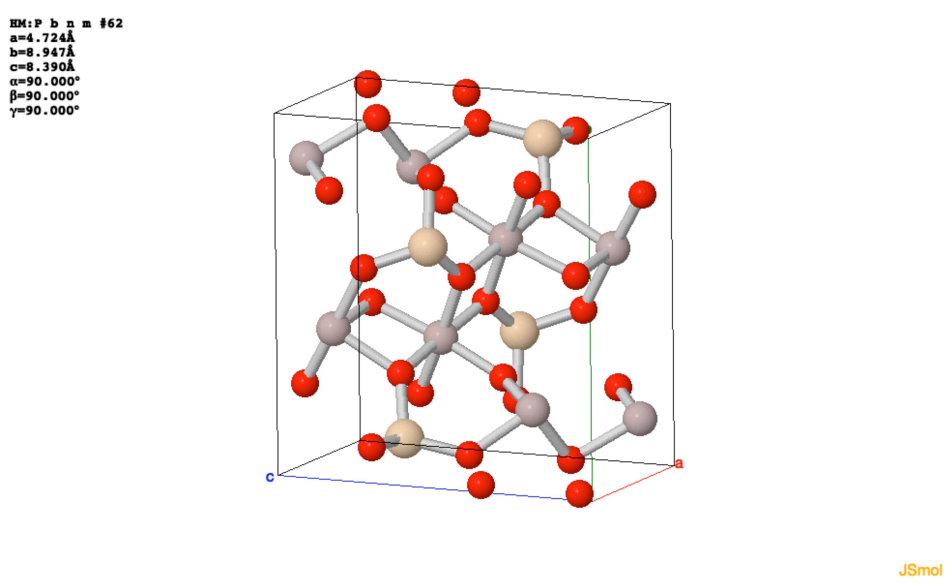
OBRIGADA!

RESULTS AND DISCUSSION

- According to Safwat - after the irradiation of topaz by neutrons, theoretically, their residual radioactivity did not reach values permissible for transport.
- This consideration is due to the chemical constitution of the mineral it presents (fluorine, aluminum, oxygen and silicon) and which have half-lives ranging from seconds to hours.
- Therefore with a view to commercializing these gems, other factors must be analyzed more carefully, complying with radiological protection measures.
- Although gamma spectrometry is quite effective for evaluating the radioactive traces of the gem, for a better evaluation, more experiments such as optical experiment, Electron Paramagnetic Resonance (EPR) and Positron Annihilation Spectroscopy (PAS) would be necessary



Source: Mindata, 2024