Table 1. Radium-thorium content of fuel residues.

No. of sample	Ra^{226} (pc/g)	Ra^{228} (pc/g)	Th^{228} (pc/g)
	Coal ash		
1	5.0	1.9	2.5
2	4.2	2.5	2.7
3	3.8	2.6	2.4
4	2.8	1.8	2.1
5	4.8	2.7	2.4
6	2.1	3.1	3.3
Mean	3.8 ± 0.4	2.4 ± 0.4	2.6 ± 0.4
	Petroleum ash		
1	0.14	0.45	0.67
2	0.18	0.32	0.52
3	0.30	0.70	0.83
Mean	0.21 ± 0.07	0.49 ± 0.16	0.68 ± 0.13

Samples of dust collected from the atmosphere of New York City were also analyzed. The dust contained in a 26,000-m^3 sample of air collected continuously during the month of December 1962 was found to contain, 1.5×10^{-4} pc/m^3, 0.8×10^{-4} pc/m^3, and 1.5×10^{-4} pc/m^3 of Th^{228}, Ra^{226}, and Ra^{228}, respectively. A person breathing 20 m^3 of air in 24 hours would thus inhale about 0.0046 pc of Ra^{226} plus Ra^{228} per day. This is a very small fraction of the radium ingested daily in food.

It is of interest to compare the quantities of natural radioactivity discharged by coal-burning plants with the quantities of radioactive substances discharged into the atmosphere by electrical generating stations that utilize nuclear energy as the source of heat. In order to make such a comparison it is necessary to find a method that makes it possible to compare radionuclides that have varying chemical, physical, and biological properties. The potential hazard of a radionuclide depends on many factors, including metabolic properties, half-life, and decay schemes. These factors are all taken into consideration in computing the maximum permissible concentration of a given radionuclide (*6*), and the relative significance of radioactive substances discharged into the atmosphere can therefore be compared if their maximum permissible concentrations are known.

Table 2. Comparisons of maximum permissible concentrations of certain radionuclides in air (*6*).

Nuclide	Half-life	Max. perm. conc.* (μc/cm^3)
Ra^{226}†	1620 years	0.5×10^{-11}
Ra^{228}†	5.7 years	1×10^{-11}
Kr^{85}	10.8 years	3×10^{-6}
I^{131}	8 days	3×10^{-9}

* The listed values are for 168 hours of continuous exposure. They are not intended to be used for exposure of the general population, but these values are applicable to our purposes since we are interested in their ratios. It is generally considered desirable to divide the values recommended by the International Commission on Radiation Protection by 10 when applying them to the general population. † Assumed to be in the insoluble form.

In Table 2 are listed the maximum permissible concentrations of Ra^{226} and Ra^{228}, and I^{131} and Kr^{85}, the two principal radionuclides present in the atmospheric effluents of reactors. The maximum permissible concentrations of Kr^{85} and I^{131} are much higher than the permissible concentrations for the radium isotopes. This is because of a combination of factors, among which are (i) radium isotopes give rise to a number of radioactive daughters, (ii) some of the isotopes in the decay chains emit alpha particles, and (iii) the radium isotopes are relatively long-lived and their energies are greater than those associated with the decay of Kr^{85} or I^{131}.

A 1000-Mw coal-burning plant having good fly ash control equipment will, as noted earlier, annually discharge about 28 mc of mixed radium isotopes into the atmosphere. From the ratios of the maximum permissible concentrations, 1 mc of radium, consisting of equal parts of Ra^{226} and Ra^{228}, is radiobiologically comparable, approximately, to 400,000 mc of Kr^{85} and 400 mc of I^{131}. The atmospheric effluents from a well-operated plant of this size thus contains naturally occurring radioactive substances equivalent, from the point of view of their hygienic significance, to about 10^4 c of Kr^{85} and 10 c of I^{131}. Plants that burn pulverized coal but which do not provide mechanical or electrical dust separators discharge radium in far greater amounts. Such a plant might discharge about 1 c/yr of mixed radium isotopes. This is equivalent to more than 4×10^5 c of Kr^{85} or more than 400 c of I^{131}. An oil-burning plant of 1000-Mw electrical generating capacity would discharge an amount of radium that is approximately equivalent to 200 c of Kr^{85} and 200 mc of I^{131}.

Conventional practice in the operation of nuclear reactors provides means for storing the waste gases so as to permit the short-lived radionuclides to decay. In most plants the waste gases can be stored sufficiently long to permit all the radioiodine to decay, leaving only the Kr^{85} to be discharged. The amounts of krypton actually available for discharge are miniscule and do not approach the amounts of this radionuclide equivalent to the amounts of radium discharged by fossil plants. For example, during 1961, the Yankee Nuclear Power Station at Rowe, Massachusetts, discharged only 1.9 mc of gaseous wastes into the atmosphere (*7*). This experience is consistent with that of other nuclear powered electrical generation stations in the United States.

Our measurements of the natural radioactivity of fossil fuels have thus led us to the conclusion that an electrical generating station that derives its thermal energy from such fuels discharges relatively greater quantities of radioactive substances into the atmosphere than many power plants that derive their heat from nuclear energy.

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Amethyst: Optical Properties and Paramagnetic Resonance

Abstract. *Color centers in amethyst are produced by the action of ionizing radiation on precursor centers that arise from substitution of Fe^{+3} for Si^{+4} in the α-quartz structure. These Fe^{+3} centers provide the dominant features of the electron paramagnetic resonance spectrum of amethyst. The three equivalent Si^{+4} sites are unequally occupied by Fe^{+3}, a circumstance that explains the optical biaxiality of amethyst.*

The origin of color in amethyst, a form of α-quartz, has excited attention for centuries. We have accumulated evidence that color centers are gener-

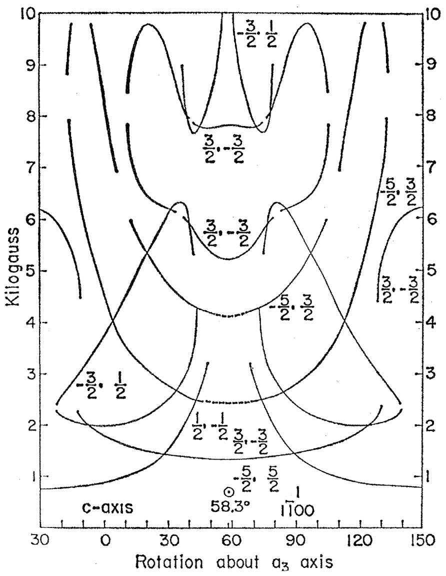

Fig. 1. Angular variation of electron paramagnetic resonance spectrum at 20°C (9.501 Gc) for Fe^{+3} centers in amethyst (dashed lines were not observed).

ated by natural ionizing radiation from precursor centers which arise from substitution of Fe^{+3} at silicon sites. The same Fe^{+3} centers are responsible for the dominant features of the electron paramagnetic resonance (EPR) spectrum of amethyst. The substituent Fe^{+3} is not distributed equally among the equivalent sites in natural crystals.

The color of amethyst is bleached by heat treatment in air at 400°C, but it is restored by x- or γ-radiation. Amethyst is markedly pleochroic, and Pancharatnam (*1*) has shown that there are three principal color directions, namely, along one twofold axis, and two directions perpendicular to this axis. Moreover amethyst is optically biaxial with the acute bisectrix containing this same twofold axis. Both of these facts are in direct conflict with the trigonal symmetry of α-quartz. Laue x-ray photographs of the optically biaxial amethyst crystals show only very minor distortions from holotrigonal symmetry.

Using an X-band paramagnetic-resonance spectrometer, we have identified the transitions of Fe^{+3} centers in sites having the twofold axes of α-quartz. The angular variation of the spectrum (Fig. 1, for rotation about the a_3-axis) indicates that the center is strongly anisotropic, with an axial distortion along the twofold axis, but with a still stronger orthorhombic distortion. The anisotropy of the center could be caused by a charge-compensating ion on the twofold axis. This model is supported by a barely resolvable four-line hyperfine structure of one of the transitions, indicating an interaction with a nuclear spin of 3/2, which could be an alkali or alkaline-earth cation acting as charge compensator.

A most important feature of the electron paramagnetic resonance spectrum is that, although three sets of spectra from the three equivalent sites in the crystal are observable, these are of greatly unequal intensity, in the order 10.0 : 1.2 : 0.8 in the most studied crystal. The twofold axis corresponding to the center of highest concentration is the same as that for the color and the optical biaxiality. The intensity of the electron paramagnetic resonance centers is increased slightly by the heat treatment at 400°C that destroys the color; hence, the electron paramagnetic resonance center is not identical with the color center, but appears to be directly related to it as a precursor which can be converted to the color center by radiation. Further evidence for this relationship comes from the heat treatment at 650°C which equalizes the intensities of the equivalent electron paramagnetic resonances, removes the optical biaxiality, and also removes the pleochroism of a basal section in a specimen recolored by x-rays.

Although the three sites are equivalent in the crystal structure, they can be markedly distinguished relative to developing faces during the growth of the crystal. We have observed that the electron paramagnetic resonance centers occur only in those regions of a synthetic crystal that contain Fe^{+3} that can be subsequently colored amethyst by x- or γ-radiation. These regions lie below the positive rhombohedral faces of the crystal, as do the colored regions in natural crystals. Relative to these faces, the silicon sites have quite dissimilar positions, and the difference in population of Fe^{+3} substituted in these sites can readily arise during the hydrothermal growth of the crystal. Thus, quantitative study of the incorporation of Fe^{+3} in synthetic crystals should provide a basis for geochemical conclusions concerning the conditions of natural growth. The proposed mechanism also serves to rationalize the observations of Melankholin and Tsinober (*2*) on synthetic quartz containing Fe^{+3}.

The optical biaxiality of amethyst is a direct consequence of the unequal occupation of crystallographically equivalent sites by the color centers, the concentrations of which are too low to distort the x-ray symmetry of the crystal as a whole.

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Fossil Microorganisms: Possible Presence in Precambrian Shield of Western Australia

Abstract. *A quartzite believed to be at least 2700 million years old contains pockets of minute red or yellow objects presumably composed of hematite and goethite, respectively. The size and morphology of the objects suggests that most of them may be the remains of microorganisms of at least two species.*

In the vicinity of Southern Cross, Western Australia, a fine-grained quartzite is associated with a banded-iron formation in a belt of "greenstone", which has been intruded by granite and lithium-bearing pegmatites; the latter have been dated by rubidium-strontium and potassium-argon methods and are estimated to be about 2700 million years old (*1*). By the uranium-lead method of dating, galena from an auriferous lode in the same zone of banded-iron formation in greenstone at Bullfinch, 35 km north of Southern Cross, was estimated to be about 2340 million years old; this is taken as the age of the mineralization which brought in the gold, and is assumed to be associated with a later period of granite intrusion (*1*). As it therefore appears that the age of the greenstones and associated banded-iron formations and quartzites is not less than 2700 million years, it was with some surprise that one of us (C.G.A.M.) discovered, within a sample of the quartzite from near Southern