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Abstract

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Application of Radioactive Sources of Characteristic Radiation for X-ray Structural Studies

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There are several radioactive isotopes that decay by the scheme of capture of a K-electron by the nucleus without accompanying gamma radiation. Such isotopes emit characteristic X-ray radiation corresponding to the characteristic radiation of an X-ray tube whose anode has an atomic number one less than the atomic number of the isotope. Such isotopes include Fe^{55} (half-life $T = 2.9$ yr) and V^{49} ($T = 330$ days). The first isotope, upon K-electron capture, is transformed into Mn^{55} and emits the characteristic X-ray radiation of manganese ($\lambda K_\alpha = 2.103$ Å), while the second is transformed into Ti^{49}, emitting the characteristic radiation of titanium ($\lambda K_\alpha = 2.749$ Å).

Radioactive sources of long-wavelength characteristic X-ray radiation can be used in various X-ray structural studies of polycrystalline specimens and single crystals in place of high-voltage devices with X-ray structural tubes used for analogous purposes. It is known that a tube for X-ray structural analysis, along with useful characteristic radiation, simultaneously emits a bremsstrahlung spectrum. To eliminate it, a crystal monochromator is usually employed, which selects a monochromatic beam of rays. When sources of Fe^{55} and V^{49} are used, there is no need to monochromatize the radiation, since these isotopes emit an almost pure characteristic spectrum.

The principal condition for the application of such sources is an isotope activity sufficient for recording interference maxima within acceptable times. When highly sensitive X-ray film, high-aperture focusing methods of X-ray structural analysis, and a small distance from the focus of the tube to the specimen (30–40 mm) are used, the minimum quantity of electricity passing through the tube and sufficient for recording interferences is about 0.01 coulomb ($0.6 \cdot 10^{17}$ electrons). If the coefficient of conversion of electrons into quanta of characteristic radiation is taken to be 10^{-4}, then the yield in a solid angle 4π corresponds to $0.6 \cdot 10^{13}$ quanta. The isotope Fe^{55} emits one X-ray quantum for every three K-captures.

Taking these data into account, for an exposure of 10^4 seconds, to obtain $0.6{\cdot}10^{13}$ quanta a source of Fe^{55} with an activity of 50 mCi is required.

There are several methods for obtaining the isotope Fe^{55}. Under proton bombardment of Mn^{55} in an electrostatic generator, pure Fe^{55} isotope is formed in the surface layer of manganese (p—n reaction). However, the activity of radioactive-iron sources prepared in this way is very small. By irradiating the natural isotope Fe^{54} with slow neutrons, it is possible to prepare sources whose activity is several orders of magnitude greater than the activity of sources obtained by proton bombardment. But in this case, along with the isotope Fe^{55}, radioactive manganese Mn^{54} (T = 290 days), emitting gamma radiation with an energy of 835 keV, is formed through the n—p reaction. The activ-

The activity of Mn^{54} is about 2% of the activity of Fe^{55}. Despite the relatively small content of Mn^{54}, it is necessary to protect the X-ray film from fogging by gamma radiation.

In our experiments we used sources of radioactive iron obtained by irradiating foil of the isotope Fe^{54} with an integral flux of 10^{21} thermal neutrons per 1 cm^2. The content of the isotope Fe^{55} was 0.25%. The experiments were carried out in a specially made miniature Debye camera with a cassette diameter of 28.65 mm. The effective activity of the source inserted into the collimator of the camera was 5 mCi; the distance from the source to the specimen was 32 mm. Under these conditions it proved possible to record on X-ray film weak interferences from the (011) plane of an iron specimen in the form of a polished section, with an exposure of 5 hours.

These experimental data agree satisfactorily with the calculated estimates. For practical use of the isotope Fe^{55}, it must be separated from the isotope Mn^{54}. It is highly desirable to increase the content of the isotope Fe^{55} in the iron foil to 25–30%. The activity of such a source will exceed by two orders of magnitude the activity of the sources used in the present work. This will make it possible to switch to cameras of ordinary dimensions with exposures of the same order as on standard X-ray structural apparatus.

The thickness of the radioactive foil should be close to the range of the characteristic radiation. It is advisable to deposit a thin layer of chromium on iron foil containing Fe^{55}. In addition to anticorrosion protection, chromium is a selective filter for the K_β-radiation of manganese, and a source with such a coating will emit practically monochromatic K_α-radiation of manganese. When focusing methods are used (Bolin and Preston cameras, focusing in a narrow interval of Bragg angles), a radioactive source of characteristic radiation in the form of a narrow strip of foil can be placed directly on the focusing circle.

Enriched sources can be successfully used in diffractometry when the interference maxima are recorded by scintillation counters. Here the high stability of the radioactive radiation is especially important; it eliminates the need for monitors to check the intensity and for stabilization of the power supplies of the X-ray tube.

It is difficult to predict to what extent radioactive sources of characteristic radiation will replace existing installations with X-ray structural tubes. Most likely, by analogy with the use of Co^{60} and Cs^{137} in defectoscopy, such sources will be used alongside the traditional equipment of X-ray structural analysis.

Sources based on radioactive iron and vanadium require only very light shielding. Brass 1 mm thick attenuates the characteristic radiation of manganese by more than 10^6 times. There is no need for special windows for the exit of long-wavelength radiation separating the vacuum volume of the X-ray tube from the atmosphere. The latter circumstance is especially important for the titanium radiation of a V^{49} source. Such radiation is strongly absorbed in beryllium windows, which makes it difficult to manufacture structural tubes with a titanium anode.

Radioactive structural analysis eliminates from the equipment of an X-ray laboratory the high-voltage installation and the X-ray structural tube. Only the camera remains, in which the source of characteristic radiation is placed. There is no need for electrical energy. The latter is especially important in the analysis of the structure of minerals in geological prospecting. Investigations at high and low temperatures are also appreciably simplified.

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Note: Figure translations are in progress. See original paper for figures.

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