NEUTRON-ACTIVATION ANALYSIS

This powerful analytic tool is now routinely used in a wide range of disciplines to measure the concentrations of trace elements, often in amounts less than a billionth of a gram

by Werner H. Wahl and Henry H. Kramer

In most physical or chemical investigations impurities are regarded as a nuisance. In recent years, however, experiments in a wide range of fields have been devoted to the painstaking analysis of just such "trace elements." Part of the impetus of this trend has come from the growing realization that minute amounts of certain elements are essential to the metabolism of all living organisms. Accordingly the identification and measurement of trace elements have become indispensable aids to the understanding of many biological processes. The analysis of trace elements also plays an important role in such diverse disciplines as geology, medicine, archaeology, electronics, metallurgy, art history and criminology. Among the techniques devised for measuring the concentration of trace elements perhaps the most sensitive and versatile is neutron-activation analysis.

Reduced to its simplest terms, this method of analysis consists of the following main operations. First a sample of material is bombarded by an intense beam of neutrons. The neutrons interact with the nuclei of atoms in the sample, in many cases to form radioactive nuclei. The sample is then removed from the path of the neutron beam, whereupon the radioactivity of the sample can be measured. The radiation emitted by such "radionuclides" has a characteristic spectrum that can be analyzed to deduce both the elemental constituents of the sample and their respective concentrations. So far variations of this basic technique have been used to detect the presence of some 70 different elements, sometimes in amounts as small as a trillionth (10^{-12}) of a gram! In our laboratory at the Sterling Forest Research Center of the Union Carbide Corporation we have been working for the past few years to improve the sensitivity and extend the usefulness of this powerful analytic tool.

Neutron-activation analysis is one of the many unanticipated dividends of basic research into the nature of the atomic nucleus. The phenomenon of radioactivity—the spontaneous decay of a nucleus accompanied by the emission of radiation—was identified in some natural substances as early as 1898, but it was not until 1933 that Irène and Frédéric Joliot-Curie noted that when they placed pieces of aluminum next to a sample of naturally radioactive polonium, radiation was emitted that did not come from the polonium; moreover, the samples remained radioactive even after the polonium was removed. Chemical analysis showed that the "induced" radioactivity came from a radioisotope, or radioactive species, of phosphorus produced by the disintegration of the aluminum nuclei. The phosphorus decayed at a rate not previously observed for any naturally radioactive substance. This was the first reported observation of an artificial radioisotope.

A few years later the noted chemist Georg von Hevesy, "without having a special reason to do so," exposed a purified salt of the element dysprosium to a stream of neutrons emitted by a radioactive mixture of radium, radon and beryllium. He observed that the irradiated salt displayed "the most intense artificial radioactivity.... This observation induced me to determine the dysprosium content of an yttrium sample by exposing it to a neutron stream." Thus, on an impulse, von Hevesy discovered the principle of neutron-activation analysis.

The hiatus between the discovery of activation analysis and its routine application resulted from the lack of sufficiently intense neutron sources and the inability of early detection devices to resolve the various kinds of radiation produced by the activated samples. During World War II the development of the atomic bomb removed the first of these two obstacles. Essential to the making of the bomb were large nuclear reactors, which generate enormous quantities of neutrons. With the early reactors built at Oak Ridge and Hanford investigators were able to analyze at least 60 trace elements in amounts as small as a millionth (10^{-6}) of a gram.

Only a few workers were able to use these facilities for conducting neutron-activation analyses; radiation-detection equipment was still crude, and many hours were required for processing the huge volume of data needed to make a single analysis. As a result neutron-activation analysis remained for many years more of a demonstrated capability than a useful analytic tool. By the middle 1950's improvements in instrumentation had significantly reduced the time required for recording and processing large quantities of data. With this final obstacle removed neutron-activation analysis can now be employed for analyzing trace elements wherever an intense source of neutrons is available.

The first step in the technique, in which the sample is exposed to the neutron beam, is called the activation step. The instability of the "compound nuclei" produced in this step arises from the immense amount of energy that is transferred to a target nucleus whenever it absorbs a neutron. Almost immediately after a compound nucleus is formed it releases its excess energy by emitting "prompt radiation"; in the process it is transformed into a nucleus that can be

Scientific American
April 1967